TURKISH JOURNAL of ORTHODONTICS

DOI: 10.5152/TurkJOrthod.2020.19037

Original Article

Evaluation of Root Resorption, Tooth Inclination and Changes in Supporting Bone in Class II Malocclusion Patients Treated with Forsus Appliance

Amit Rekhawat, Sujala Ganapati Durgekar, Sumitra Reddy

Department of Orthodontics and Dentofacial Orthopedics, KLE Society's Institute of Dental Sciences and Hospital, Bangalore, Karnataka, India

Cite this article as: Rekhawat A, Durgekar SG, Reddy S. Evaluation of Root Resorption, Tooth Inclination and Changes in Supporting Bone in Class II Malocclusion Patients Treated with Forsus Appliance. Turk J Orthod 2020; 33(1): 21-30.

ABSTRACT

Objective: The aim of our study was to evaluate apical root resorption and changes in tooth inclinations, marginal bone height, and labio-lingual bone thickness at the mid-root and apical level in mandibular anterior teeth during the Forsus treatment using cone beam computed tomography (CBCT).

Methods: CBCT scans of 16 subjects (8 males and 8 females) with Class II malocclusion (age group: 13–29 years) taken before and 6 months after the Forsus treatment were evaluated for apical root resorption, tooth inclination, marginal bone height, and thickness of bone at the mid-root and apical level in mandibular anterior teeth.

Results: There was statistically significant root resorption of central incisors (0.39 mm) and canines (0.66 mm); a decrease in the angle of inclination for all teeth; an increase in the marginal bone measurement in labial (1.31 mm) and decrease in lingual (0.93 mm) aspect at the canine region; and an increase in bone width by 0.87 mm and 0.75 mm in central and lateral incisor regions, respectively, at the mid-root level lingually. At the apex level in the canine region, bone width increased by 1.4 mm labially, while it decreased by 2.18 mm lingually; it increased significantly for incisors in the lingual region.

Conclusion: The Forsus appliance therapy causes clinically insignificant root resorption and bone changes, and clinically significant proclination of mandibular anterior teeth. The findings of the present study aid clinicians in proper case selection and reinforce the prevention of incisor proclination while using the Forsus therapy to achieve better treatment results and stability.

Keywords: Forsus, root resorption, tooth inclination, bone

INTRODUCTION

One of the keys to a successful orthodontic treatment is a detailed evaluation of treatment outcomes. Orthodontically induced inflammatory root resorption (OIIRR) is a side effect of biological tissue response to tooth movement (1). Forsus fatigue resistance device (FRD) is a fixed functional appliance that provides effective correction of Class II malocclusion by combining skeletal and dentoalveolar effects (2). While attempting to camouflage a skeletal problem with moderate Class II malocclusion, there will be tipping of lower incisors, which might be detrimental to root length and bring about changes in the alveolar bone thickness around incisors (3).

There is literature available on root resorption following orthodontic therapy. However, most of studies use intraoral radiography, which misestimates the extent of resorption due to magnification errors (1, 3-5). The OIIRR affects every aspect of tooth in three dimensions, hence two-dimensional images mask the true extent of resorption. Cone beam computed tomography (CBCT) is a three-dimensional diagnostic modality capable of imaging complex craniofacial structures with a lower radiation dose compared to computed tomography (CT). The diagnostic value of CBCT in the diagnosis of OIIRR lies in its ability to obtain distortion-free reproducible images of roots with high sensitivity and specificity (3). It has the capability to collimate the primary beam to the area of interest, thus reducing the unnecessary patient exposure.

Address for Correspondence: Sujala Ganapati Durgekar, Department of Orthodontics and Dentofacial Orthopedics, KLE Society's Institute of Dental Sciences and Hospital, Bangalore, Karnataka, India
E-mail: sujala2003@yahoo.com

Received: April 1, 2019
Accepted: November 28, 2019

A systematic review and meta-analysis on randomized and non-randomized studies with three-dimensional images in linear and volumetric OIIRR during and after orthodontic treatment suggests that <1 mm of resorption is seen in an average tooth with CBCT (6). However, there were considerable differences in the amount of measured resorption seen according to tooth category, jaw, incorporation of extraction in treatment plan, and duration.

Another systematic review on Class II malocclusion states that the camouflage treatment mechanics subjects the teeth to large apical displacement, which may lead to mild-to-moderate root resorption (5). There is only one CBCT study on the assessment of resorption in Class II malocclusion treatment with a fixed functional appliance, to the best of our knowledge (7). Based on the results of this study, there was an evidence of statistically significant OIIRR affecting the tooth upon which the Herbst appliance was anchored (upper and lower first molars). In Forsus appliance therapy, the push rod is anchored anteriorly on a stainless steel archwire, just distal to the canine bracket. This has a more direct mesializing force on the lower anterior segment. There are studies for the assessment of apical root resorption and tooth inclination changes after orthodontic treatment in general (8-11). But, to the best of our knowledge, there are no studies that precisely measure the effects of Forsus appliance therapy concentrating on the lower anterior dento-alveolar segment. The aim of the present study was to evaluate the variations in root length, teeth inclination, and bone in the mandibular anterior teeth with regard to accuracy provided by the CBCT scanning technique.

METHODS

The Institutional Ethics Committee approved the study, and it was registered with Clinical Trials Registry-India (CTRI/2017/09/009865). Sample size determination revealed that for the two-tailed test on two groups, with an effect size of 0.75 for the root length, an alpha level of 0.05, and a power of 0.8, a minimum of 16 subjects in each group was required (G-Power software v. 3.1.9.2) (3, 12-14). The means used to get the effect size of 0.75 were 20.37 mm of root length before orthodontic treatment and 19.62 mm of root length after orthodontic treatment with the standard deviations of 1.06 and 0.96, respectively (13-14).

The methology is presented in the PICO format.

Population/Patient (P): Seventeen subjects were recruited for the study from the Department of Orthodontics and Dentofacial Orthopeadics, KLE Society's Institute of Dental Sciences, Bangalore, India. All of them belonged to south Indian population. The patients who fulfilled the following criteria were enrolled in the study: 1) Class II malocclusion; 2) with ANB ranging between 4 and 8°, and an overjet >4 mm; 3) decreased or optimal vertical facial height (FMA ranging from 17 to 34°); 4) lower incisors upright on the basal bone (IMPA ranging from 89 to 100°); 4) post-pubertal patients with cervical vertebral maturation index 6; 5) minimal crowding in the mandibular arch (<2 mm) and good periodontal status as assessed by panoramic radiograph; 6) the presence of fully erupted permanent teeth, including second molars with the exception of third molars; 7) none of the lower anteriors were malformed, carious, fractured, or attrited; and 8) non-syndromic patients. All patients and parents were informed about the orthodontic treatment procedures throughout the study, and signed informed consent was obtained. Table 1 shows the baseline data of the patients included in the study. The study group comprised of 17 post-pubertal patients (9 males, 8 females) in the age group 13-29 years.

Intervention (I): The treatment protocol was standardized using the MBT preadjusted appliance (3M Unitek Orthodontic Products, Monrovia, Calif) with 0.022-inch slots. After leveling and aligning of both the arches, 0.021X0.025-inch stainless steel archwires were placed. The transpalatal arch in the maxilla, second molar-to-second molar laceback and cinch-back of 0.021X0.025-inch stainless steel archwires enabled anchorage reinforcement. This archwire was left in both arches for a period of 4 weeks before placement of the Forsus appliance. Forsus FRD (3M Unitek Corp, Monrovia, CA, USA), that comes either in a three-piece (L-pin module) or two-piece (EZ2 module) system, was placed for a period of 6 months (mean, 6.23 months).

The patients were scanned in upright position using the CARESTREAM 9300 3D machine with a field of view of 5x5 cm (12), 90 kVp tube voltage, 6.3 mA tube current, and 9-micron isometric voxel to obtain the CBCT images of the mandibular anteriors region before (T0) and 6 months after the Forsus placement (T1).

Comparison (C): One patient dropped out of the study, as he did not report back for the treatment in the stipulated time frame of the study. A total of 32 scans 16 each of pre- and post-Forsus were analyzed to compare treatment effects on the lower anterior region. The untreated control group was not included as it is unethical to expose patient to radiation without proper indications.

Table 1. Baseline data of study subjects before the Forsus therapy

					95% CI	
	Mean	Standard Deviation	Minimum	Maximum	Lower	Upper
SNA	82.53	4.92	71.5	90.0	79.91	85.16
SNB	77.91	3.52	71.0	85.0	76.03	79.78
ANB	4.81	1.55	2.5	8.0	3.99	5.64
FMA	26.09	4.54	17.0	34.0	23.68	28.52
IMPA	98.59	6.15	89.0	111.0	95.32	101.87

Workstation: The CBCT data were exported in the DICOM format, and multiplanar reconstruction in axial, sagittal, and coronal reconstructions were done using the CS 3D Imaging Software v 3.5.7 on a workstation with Microsoft XP Professional SP-2 software (15). All measurements were made on the same system by the same observer.

Figure 1. Measurement of root length by means of axial guided navigation (AGN) method. Measured from root apex to intersection between CEJ and long axis of tooth.

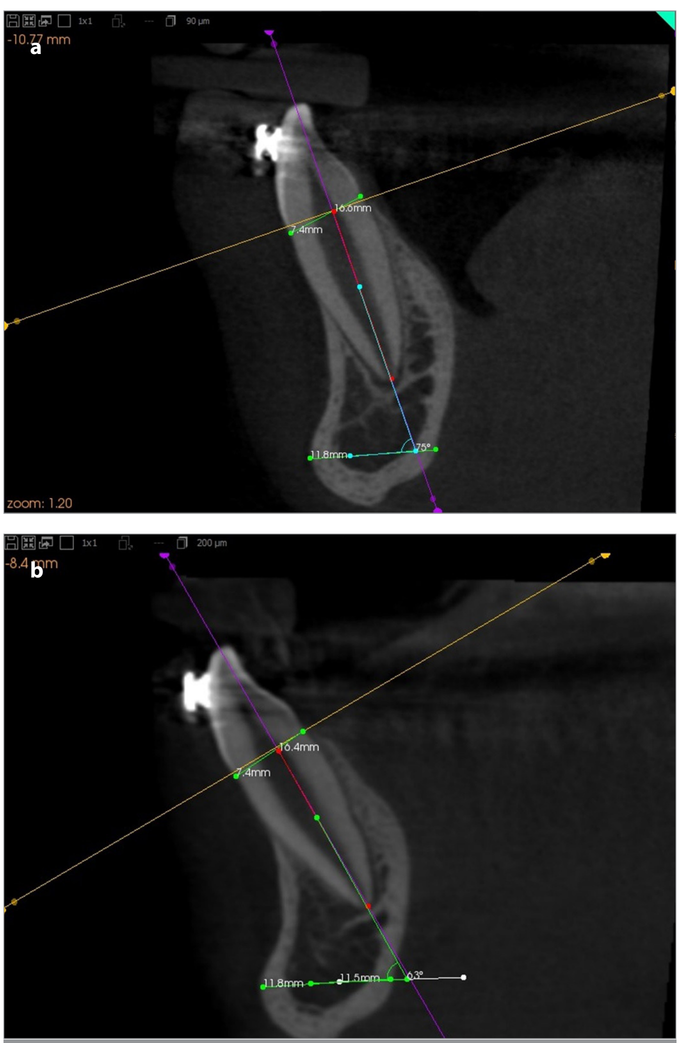

Figure 2. a, b. Tooth inclination is measured as an angle formed between the long axis of tooth and symphyseal base line at a) T0, b) T1. The base line length remains constant.

The following parameters were evaluated using these images:

1. Apical Root Resorption: All the mandibular anterior teeth were evaluated for root resorption. The axial guided navigation method was used (Figure 1). It makes use of the axial cursor movement three-dimensionally with axial and coronal multiplanar reconstruction (9, 11).

To make all the measurements of the apical resorption from standardized location for each tooth and to eliminate any bias due to the attrition of anteriors during the course of treatment, the cementoenamel junction (CEJ) width and crown height were measured before Forsus therapy (at T0) in the sagittal plane. These measurements were kept constant on the post-Forsus image (at T1) for standardization. The root length was measured along the long axis from CEJ to the root apex. The reduction in the values in post-Forsus therapy (i.e., at T1) showed the amount of apical root resorption.

2. Tooth Inclination: Tooth inclination was measured as an angle formed between the long axis of a tooth and the horizontal symphyseal baseline (11). The symphyseal baseline was drawn by a line passing along the most convex surface on the outer and inner margins in the symphyseal region in the sagittal plane (Figure 2a) (16). Any difference in the measured angle between pre- and post-Forsus therapy showed changes in the tooth inclination (Figure 2b).

3. Bone Variations:

a) Marginal bone height: This is a direct distance measured in the sagittal section from the CEJ to the coronal most aspect of labial and lingual marginal crestal bone (Figure 3) (9).

Figure 3. Marginal bone height (MBH) is measured from CEJ to coronal most portion of marginal bone crest on labial and lingual sides.

b) Bone thickness-"Simulated T0 tooth position": In post-treatment CBCT images (at T1), it was observed that the tooth moved counterclockwise due to proclination during the time frame of the study (Figure 2. a, b). The proclination changed the tooth long-axis orientation and gave a false-increased value of bone thickness labially, especially in the apex region at T1 (as the axial cursor marking is dependent on the long axis of the tooth). To reorient the cursor at T0 position of tooth long axis, a clockwise compensatory line was drawn in T1 image (Figure 4) at the CEJ long-axis intersection (at an angle equal to "the change in inclination of the tooth" from T0 to T1). This will be the new "simulated T0 tooth position" on T1 image. This was done for accurate measurement of bone thickness at the mid-root and apical root level at T1 CBCT images.

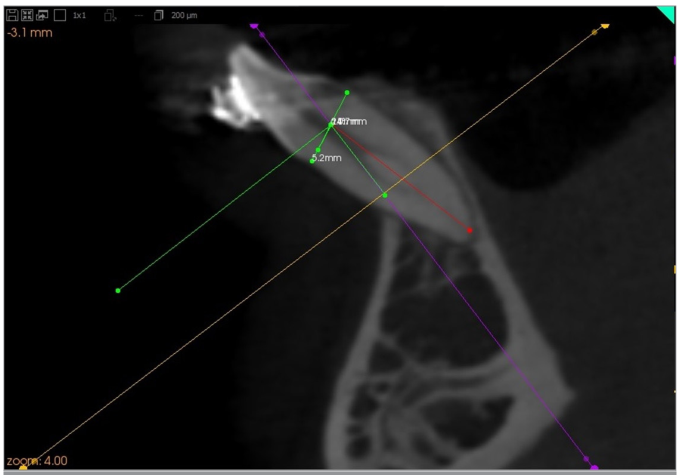

Figure 4. On T1 image, a compensatory line is drawn at CEJ-long axis intersection (at an angle equal to the change inclination of the tooth: refer Fig 2) in clockwise direction to simulate T0 position of tooth long axis.

A) At the mid-root level: First the mid-root was marked in sagittal view at half of the total root length, as seen in Figure 5a (3). The bone thickness at this level was measured in the corresponding axial plane as a distance between the tooth circumferences to the external cortical border both labially and lingually (Figure 5b). To evaluate bone thickness at the mid-root level in T1, the above-mentioned "simulated tooth T0 position" was drawn on T1 image (Figure 4) and the mid-root level was kept constant (as that of T0) for standardization. Then, bone thickness was measured in the corresponding axial view.

B) At the apical level: First, in the sagittal view (Figure 6a), the root apical level was marked at 2 mm short of root length, to eliminate any bias of root length loss during fixed functional therapy (3, 17). The bone thickness at this level was measured in the corresponding axial plane as a distance between the tooth circumferences to the external cortical border, both labially and lingually (Figure 6b). To evaluate bone thickness at the apical root level in T1, above-mentioned "simulated T0 tooth position" was drawn on T1 image (Figure 4), and the apical root level was kept constant (as that of T0) for standardization. Then, bone thickness was measured in the corresponding axial view.

The Forsus was activated to the same amount bilaterally. Hence, a single value obtained by the average of the right and left side for each tooth was considered in every patient, and the same was generated for the final statistical analysis.

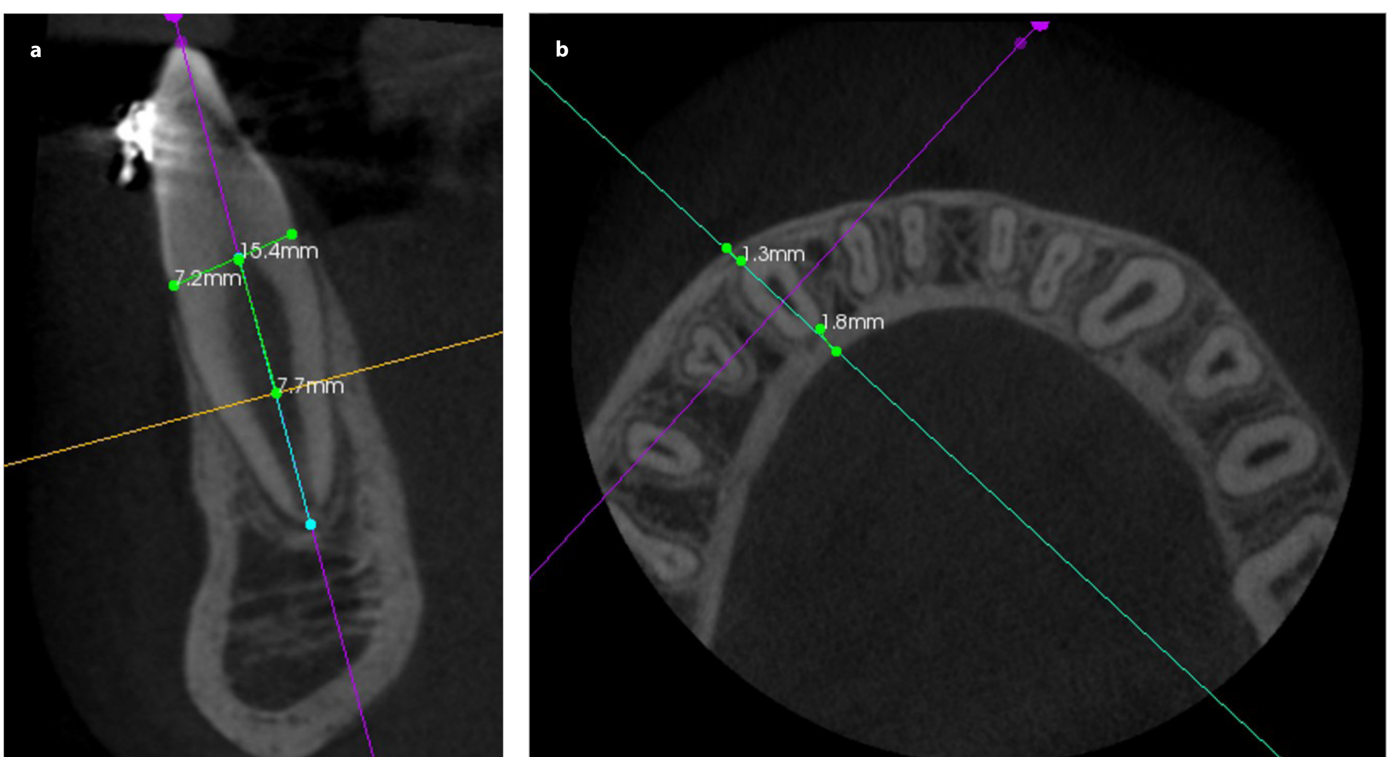

Figure 5. a, b. Measurement of bone at mid root level: a) In sagittal view, the mid-root level is marked at half of the total root length, b) Corresponding axial view used to measure bone thickness.

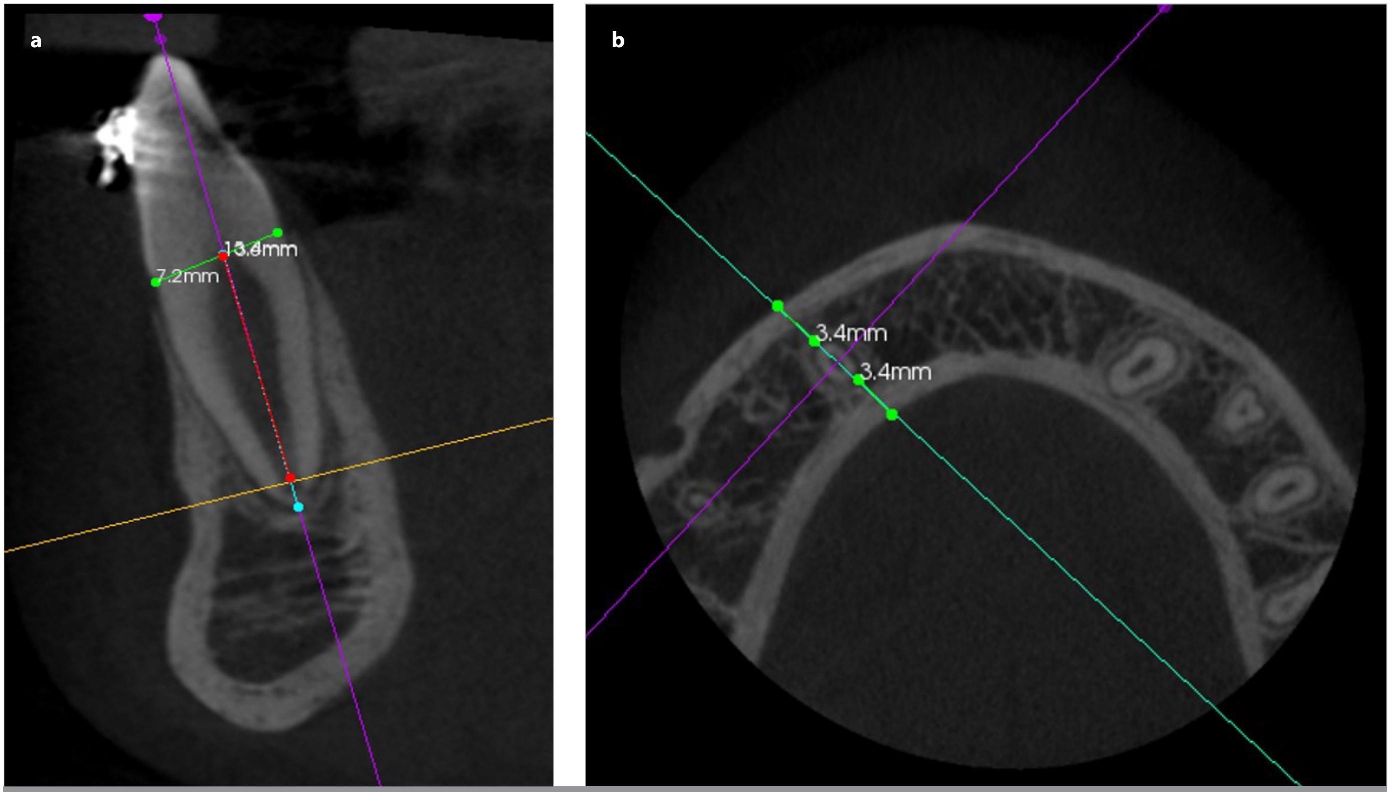

Figure 6. a, b. Measurement of bone at apical level: a) In sagittal view, the 2 mm short of root length is marked, b) Corresponding axial view used to measure bone thickness.

Statistical Analysis

Measurements were reevaluated randomly after a 2-week interval by the same-blinded examiner. Intraclass correlation coefficient (ICC) was used to evaluate the error of the method. ICC showed good-to-excellent reliability (ICC, 0.81–1.00), indicating high reproducibility of the method used for the study (Table 2). The Wilcoxon signed-rank test was used to compare parameters at T0 and T1. Spearman's correlation coefficient was used to analyze correlation between different parameters. The level of significance was set at $p<0.05$. Statistical Package for Social Sciences for Windows Version 22.0 (IBM Corp.; Armonk, NY, USA) was used to perform statistical analyses.

RESULTS

Outcome (O): The root length of central incisors and canines showed a statistically significant reduction by 0.039 mm and 0.66 mm, respectively, at T1 (Table 3). The angle of inclination was reduced for all teeth (central incisor, 6.47°; lateral incisor; 7.88°; canine, 8.69°).

A statistically significant increase by 1.31 mm and decrease by 0.93 mm in the marginal bone height measurement was seen in the canine region at both the labial and lingual aspect, respectively. A statistically significant decrease by 0.8 mm was also observed at the lingual aspect of central incisors (Table 4).

At the mid-root level of the lingual aspect, a statistically significant increase of bone width by 0.87 mm and 0.75 mm was found in the central and lateral incisor region, respectively (Table 4). Also, at the apical level in the lingual aspect, there was a statistically significant increase of bone width by 0.48 mm and 0.41 mm for the central incisor and the lateral incisor, respectively.

The bone width at apex in relation to canine showed a statistically significant increase by 1.40 mm on the labial aspect, whereas there was a decrease by 2.18 mm on the lingual aspect (Table 4).

However, there was a statistically insignificant weak correlation between the angle of inclination and other parameters (Table 5).

DISCUSSION

The incidence of OIIRR differs between various studies due to different techniques used to quantify it (4,5,8,17,18). A systematic review suggests that majority of incisors experienced mild to moderate OIIRR in treated Class II division 1 malocclusions (5). Samandara et al. (6) observed the greatest amount of OIIRR in central incisors (0.82 mm). Another study on root resorption that used panoramic radiographs showed 67.3% of moderate and 42.9% of severe root resorption of incisors (4).

Although the canine tooth has a good crown-to-root ratio and is capable of tolerating high occlusal forces, we found the highest (0.66 mm with $p=0.001$) root resorption of canines (Table 3), (19). One of the reasons for this observation could be because they are closer to the site where the rod of the Forsus FRD appliance is engaged on the lower arch, hence subjected directly to the push force compared to incisors. This is in accordance with a study on the Herbst appliance, where it was concluded that it delivers unphysiologic forces to immediate anchor teeth, thereby expos-

Table 2. Intra-examiner reliability assessment of parameters at pre- and post-Forsus therapy using intra-class correlation (ICC) statistic

		T0				T1		
		95% Conf. Interval				95% Conf. Interval		
Parameters	ICC	Lower	Upper	Reliability	ICC	Lower	Upper	Reliability
RL_CI	0.97	0.87	0.99	Excellent	0.99	0.98	1.00	Excellent
RL_LI	0.96	0.86	0.99	Excellent	0.95	0.91	0.98	Excellent
RL_CN	0.98	0.94	0.99	Excellent	0.99	0.98	0.99	Excellent
AI_CI	0.98	0.94	0.99	Excellent	0.95	0.86	0.99	Excellent
AI_LI	0.85	0.78	0.99	Good	0.98	0.95	1.00	Excellent
AI_CN	0.81	0.70	0.98	Good	0.84	0.33	0.97	Good
MBHL_CI	0.99	0.94	1.00	Excellent	0.97	0.94	0.99	Excellent
MBHL_LI	0.98	0.93	0.99	Excellent	0.98	0.96	0.99	Excellent
MBHL_CN	1.00	0.99	1.00	Excellent	0.98	0.97	1.00	Excellent
MBHLI_CI	0.96	0.86	0.99	Excellent	1.00	0.98	1.00	Excellent
MBHLI_LI	0.99	0.98	1.00	Excellent	0.97	0.95	0.99	Excellent
MBHLI_CN	0.95	0.91	0.98	Excellent	0.99	0.97	1.00	Excellent
MRBL_CI	0.91	0.81	0.98	Excellent	0.86	0.66	0.93	Good
MRBL_LI	0.90	0.64	0.94	Good	0.88	0.68	0.97	Good
MRBL_CN	0.86	0.52	0.96	Good	0.85	0.65	0.93	Good
MRBLI_CI	0.80	0.47	0.92	Good	0.88	0.57	0.99	Good
MRBLI_LI	0.93	0.90	0.96	Excellent	0.89	0.70	0.97	Good
MRBLI_CN	0.88	0.69	0.97	Good	0.94	0.84	0.98	Excellent
ABL_CI	0.89	0.70	0.97	Good	0.88	0.47	0.94	Good
ABL_LI	0.89	0.85	0.92	Good	0.94	0.84	0.98	Excellent
ABL_CN	0.98	0.97	1.00	Excellent	0.90	0.68	0.97	Good
ABLI_CI	0.93	0.90	0.96	Excellent	0.88	0.56	0.95	Good
ABLI_LI	0.83	0.55	0.95	Good	0.96	0.92	0.99	Excellent
ABLI_CN	0.92	0.88	0.96	Excellent	0.97	0.95	1.00	Excellent

ICC: intraclass correlation coefficient; CI: central incisor; CN: canine; LI: lateral incisor; RL: root length; AI: angle of inclination; MBHL: marginal bone height labial; MBHLI: marginal bone height lingual; MRBL: mid-root bone width labial; MRBLI: mid-root bone width lingual; ABL: apex bone width labial; ABLI: apex bone width lingual

Table 3. Comparison of mean, median, minimum and maximum values of root length (in mm) and angle of inclination (in °) for lower anterior teeth between pre- and post-Forsus phase by the Wilcoxon signed-rank test

		T0				T1				T1 – T0						
														95% Conf. Interval		
Variable	Tooth	Mean	Median	Min	Max	Mean	Median	Min	Max	Mean	Median	Min	Max	Lower	Upper	p-value
RL	CI	11.15	11.7	8.9	12.85	10.76	10.45	8.5	14.15	-0.39	-1.25	-0.4	- 1.3	-.11	-.68	0.01*
	LI	11.61	11.95	9.3	13.9	11.61	11.60	8.8	13.4	0.00	-0.35	-0.5	-0.5	1.30	-1.30	1.00
	CN	13.94	14.2	11.15	16.8	13.28	13.55	10.1	14.75	-0.66	-0.65	-1.05	- 2.05	-.53	-.79	0.001**
AI	CI	69.16	63.5	53	96.5	62.69	62.55	40.5	86.5	-6.47	-0.95	-12.5	-10	-3.79	-9.15	0.001**
	LI	71.00	72.2	53.5	99.5	63.13	65.5	42.5	87.5	-7.87	-6.7	-11	-12	-5.02	-10.7	0.001**
	CN	72.69	67.7	58.5	96	64.00	64.5	49.5	87	-8.69	-3.2	-9	-9	-6.25	-11.13	0.001**

RL: root length; AI: angle of inclination; CI: central incisor; CN: canine; LI: lateral incisor
*Statistically significant, **Highly significant

ing them to a higher risk of root resorption (20). However, in our study, we have not included the evaluation of teeth in posterior segment. Molars also being the anchor teeth would have shown significant resorption.

Narendran et al. (21) reported a prospective CBCT study on the effects of Class II malocclusion treatment with the Powerscope and Forsus FRD appliance. According to the results of this study, both the appliances lead to a statistically significant amount of linear and volumetric root resorption in all maxillary first molars and mandibular anteriors (p=0.001). The mandibular anteriors showed lesser extent of root resorption in subjects treated with a Forsus appliance than those treated with Powerscope, because the latter is secured to the archwire, and hence, stronger hori-

Table 4. Comparison of the mean median, minimum, and maximum values of marginal bone height, mid-root bone width, and apex bone width in labial and lingual regions (in mm) for lower anterior teeth between pre- and post-Forsus phase by the Wilcoxon signed-rank test

			T0				T1				T1 – T0						
															95% Conf. Interval		
Variable		Tooth	Mean	Median	Min	Max	Mean	Median	Min	Max	Mean	Median	Min	Max	LOWER	UPPER	p-value
MBH	CI	Labial	6.94	7.22	4.95	8.95	6.94	7.22	0	9.35	0.00	0	-4.95	0.4	.90	-.90	1.00
		Lingual	2.58	2.45	0.55	7.5	1.78	1.72	0.25	3.25	- 0.80	-0.73	-0.3	-4.25	.50	-1.80	0.01*
	LI	Labial	6.48	6.95	4.3	8.8	7.12	7.35	0.75	10.3	0.64	0.4	-3.55	1.5	1.63	-.355	0.14
		Lingual	2.28	2.15	0	7.4	1.93	1.65	0	7.55	- 0.35	-0.5	0	0.15	.70	-1.39	0.26
	CN	Labial	4.50	5.35	1.0	7.9	5.80	6.1	1.6	8.15	1.30	0.75	0.6	0.25	2.11	.51	0.006*
		Lingual	2.40	1.6	1	6.5	1.47	0.87	0.4	4.9	- 0.93	-0.73	-0.6	-1.6	.12	-1.99	0.01*
MRB	CI	Labial	0.02	0	0	0.3	0.01	0	0	0.1	- 0.01	0	0	-0.2	.03	-.06	0.66
		Lingual	1.20	1.7	0.1	2.95	2.07	2.10	0.1	4.0	0.87	0.4	0	1.05	1.17	.57	0.001**
	LI	Labial	0.15	0	0	1.1	0.14	0	0	0.75	- 0.01	0	0	-0.35	.09	-.11	0.94
		Lingual	0.98	0.82	0.2	2.0	1.73	1.62	0.65	3.65	0.75	0.80	0.45	1.65	1.04	.45	0.001**
	CN	Labial	0.67	0.32	0	3.8	0.77	0.37	0	3.45	0.10	0.05	0	-0.35	.77	-.56	0.21
		Lingual	1.57	1.57	0.15	3.25	1.65	1.5	0.2	3.45	0.08	-0.07	0.05	3.30	.28	-.12	0.86
AB	CI	Labial	0.97	0.92	0	2.15	1.29	1.32	0	3.8	0.32	0.4	0	1.65	.74	-.10	0.15
		Lingual	2.41	2.15	0	5.85	2.89	2.70	0.3	6.8	0.48	0.55	0.3	0.95	1.12	-.14	0.02*
	LI	Labial	2.00	1.47	0.45	4.05	2.28	1.97	0	6.7	0.28	0.5	-0.45	2.65	.65	-.10	0.19
		Lingual	1.63	1.47	0.45	4.05	2.04	1.62	0.6	5.8	0.41	0.5	0.15	1.75	.71	.12	0.008*
	CN	Labial	3.11	2.17	0.1	3.15	4.51	4.40	0.3	7.8	1.40	2.23	0.2	4.65	1.86	.95	0.001**
		Lingual	3.64	2.17	0.1	3.15	1.46	1.32	0	4.15	- 2.18	-0.85	-0.1	-1.0	.43	-4.80	0.002*

MBH: marginal bone height; MRB: mid-root bone width; AB: apex bone width; CI: central incisor; CN: canine; LI: lateral incisor
*Statistically significant, **Highly significant

Table 5. Spearman's correlation statistics to assess the relationship between the angle of inclination and other study parameters for different teeth

Angle of Inclination	Root Resorption		MBH Labial		MBH Lingual		MRB Labial		MRB Lingual		AB Labial		AB Lingual	
	Rho	P-Value	Rho	P-value	Rho	P-Value	Rho	P-Value	Rho	P-Value	Rho	P-value	Rho	p-Value
CI	0.27	0.31	-0.04	0.89	-0.05	0.85	-0.44	0.09	0.46	0.08	-0.36	0.18	0.05	0.86
LI	-0.25	0.35	0.04	0.89	0.22	0.41	0.29	0.27	-0.33	0.21	0.45	0.08	0.18	0.50
CN	0.17	0.53	-0.15	0.58	-0.03	0.93	-0.20	0.46	0.26	0.33	-0.09	0.74	0.31	0.24

CI: central incisor; CN: canine; LI: lateral incisor; MBH: marginal bone height; MRB: mid-root bone width; AB: apical bone width
The correlation coefficients are denoted by Rho.
Correlation coefficient range
0.0: No Correlation
0.01–0.40: Weak correlation
0.41–0.70: Moderate correlation
0.71–1.00: Strong correlation

zontal force vectors cause more resorption. The Forsus appliance is placed on 19X25 stainless steel lower arch wires with added 10° of labial root torque to minimize proclination (21). However, in our study, we make use of 21X25 stainless steel archwires to ensure a rigid anchorage unit before the engagement of Forsus appliance so as to minimize deleterious effects on anchor teeth.

In our study, canines showed maximum proclination compared to other teeth. Orthodontic camouflage of a Class II malocclusion with fixed functional appliance therapy often leads to proclination of the mandibular incisors (6-18). Our findings are in accordance with other studies, which show significant proclination post-Forsus ranging from 5.0° to 6.2° (2, 22). In a cephalometric study, Hansen et al. (23) reported 10.8° of proclination and anterior movement of the incisal edge by 3.2 mm with the Herbst appliance. In the present study, CBCT scans enabled us to evaluate the inclination change of individual anterior teeth, which is impossible with two-dimensional images.

The post-pubertal subjects in our study belonged to a wide-range age group, ranging from 13 to 29 years, which included both non-growing and younger patients with a residual growth potential. This would not have affected our study results, as the correction achieved in growing patients with post-pubertal maturation status is same as that in adults, that is, by mandibular dentoalveolar proclination (24). However, the growing patients may have unstable occlusion after the orthodontic treatment, unlike adults whose results would be retained better due to stable interdigitation, which prevents unfavorable occlusal changes post-debonding (25).

The substantial amount of proclination of anteriors is a concern in all age-group patients. The clinician must be cautions considering the initial inclination of lower anteriors before treatment initiation. We recommend the use of pre-torqued 0.021x0.028-inch stainless steel archwire in lower arch (which provides 6° lingual crown torque in the anterior segment)/use of –6° torque on mandibular anterior brackets or use of miniscrews to minimize the proclination post-therapy (2).

The marginal bone height and thickness of bone encapsulating the tooth are important factors to be considered to evaluate the response of tooth to the FRD force (26). In the present study, the marginal bone height measurement increased labially and decreased lingually at T1 for all the anteriors, indicating labial resorption and lingual deposition, respectively (Table 4). These findings indicate that the mandibular incisors proclination is associated with vertical bone loss (26, 27). However, statistically significant findings for marginal bone height were seen only with respect to canines (both labially and lingually) and in lingual aspect for central incisors, which is related to the proclination of teeth at T1, although they are clinically insignificant.

The thickness of bone where the tooth is embedded affects its response to force and visa-versa. We found a varied response to force by different tooth groups. If initially T0, the tooth was closer to the labial cortical bone, and labial marginal bone height was less; the bone thickness at the mid-root and apical level reduced in the labial aspect at T1 time frame. Also, the tooth translated labially at T1 due to least bony resistance but did not change the inclination much. On the other hand, if the tooth had a good cortical bone thickness labially and marginal bone height and at T0; experienced tipping (that is, inclination change causing proclination) along the bony fulcrum (located at the labial marginal bone height). So at T1, translation moved the tooth as a whole labially, and compensatory bone deposition occurred on the lingual aspect, increasing the lingual bone thickness, as observed in the incisors region (Table 4). However, tipping moved the coronal portion of the root labially, while pushing the root apex lingually, thereby increasing the bone thickness labially and decreasing it lingually, especially at the level of canine apex (Table 4), (27).

Considering the above explanation, it is now clearer that the lingual bone thickness both at the mid-root and apical regions for incisors increased significantly, showing that T0 incisors might not have had a good labial cortical bone thickness, which would have caused their bodily movement in the labial direction along with some proclination at T1, which is detrimental to periodontal support. In addition, a statistically significant decrease in the bone thickness on the lingual aspect at the apical region of canines shows that due to a good labial cortical bone thickness at T0, they have tipped more than incisors (by 8.69°, Table 3). These detailed findings highlight the importance of the labial cortical thickness as a crucial parameter to be considered for case selection prior to Forsus placement.

The standardization technique used in our study was predictable, stable and reconstructable anytime during our study. We could effectively achieve the individualized values for every tooth studied. The consideration was given to the proclination of teeth post-Forsus. To measure the bone thickness at the same level, "simulated T0 tooth position" was constructed, which was not done in the previous study (3). We have measured the root resorption from CEJ to root apex to prevent bias of any loss of the incisal edge in the study time frame (9).

The changes in bone are not inflammatory in nature as the bone height distal and mesial to tooth was within physiologic limits (28). It is has been documented that there is always some lag in the bone remodeling in response to tooth movement (29, 30). The alveolar bone has a bending capacity, and the orthodontic mechanotherapy induces alveolar bone distortion, which alters electric environment and initiates highly synchronized changes in the bone (29, 30). In this process, the alveolar bone retains its structural characteristic size through coordinated apposition and resorption. Hence, future CBCT studies on long-term changes induced by the Forsus appliance are recommended with a control group to evaluate the appositional bony repair and remodeling post-Forsus.

There was some weak positive correlation between the angle of inclination and root resorption of central incisors (Rho value, 0.27) and canines (Rho value, 0.17). Also, there was a weak correlation between the angle of inclination and bone changes, which was statistically insignificant (Table 5). This could have been because many factors such as periodontal environment, gingival type, and others influence alveolar bone changes (26). In a CT study by Garlock et al. (27), a similar weak positive correlation between the facial bone height and change in the apex position owing to the proclination of teeth was found.

An additional observation in the present study was surface root resorption, which led to a decrease in root thickness when viewed in the axial plane, especially in the apical region (31). This kind of resorption was more profound when the root surface was in close approximation to cortical bone at T0. The micro-CT scans enable volumetric evaluation of resorption craters, which can be a future scope of study (32).

Despite the excellent clinical relevance of the present study, we could not standardize the size of the Forsus FRD appliance as it varied according to the severity of patient's malocclusion. Although we took into consideration pubertal maturation, the age range of patients was wide, and the sample size was small (although it was minimal required to achieve clinically relevant results). The study also lacks a control group, but in that case, patients with skeletal Class II malocclusion would have to be left untreated, which would cause an ethical dilemma. The small focal of view reduced the availability of routinely used stable cranial anatomical structures needed for standardization.

We recommend a future randomized clinical trial using CBCT scans on Class II malocclusion patients with a narrower age group treated with the Forsus appliance with a larger sample size to evaluate long-term changes induced by the appliance. This will also provide additional information on appositional bony repair and remodeling in the lower anterior region post-Forsus.

CONCLUSION

- Forsus FRD appliance therapy showed statistically significant but clinically insignificant apical root resorption of mandibular canines.
- After Forsus FRD appliance therapy, statistically and clinically significant proclination of mandibular anterior teeth was observed.
- After Forsus FRD appliance therapy, clinically insignificant changes in the marginal bone height were observed.
- The teeth with good labial bone thickness are a pre-requisite for Forsus FRD therapy to prevent future bone and periodontal problems and to maintain a good long-term stability.

Ethics Committee Approval: Ethics committee approval was received for the study from the Ethics committee of KLE institute of Dental Sciences, Bangalore, India (IEC No.: KIDS/IEC/11-2016).

Informed Consent: Written informed consent was obtained from the volunteers who participated in the study.

Peer-review: Externally peer-reviewed.

Author Contributions: Concept - S.G.D.; Design - S.G.D., A.R.; Supervision - S.G.D, S.R.; Funding - A.R.; Material - A.R.; Data collection and processing - A.R.; Analysis and/or interpretation - A.R., S.G.D.; Literature review - A.R., S.G.D.; Writing Manuscript - A.R., S.G.D.; Critical review - A.R., S.G.D., S.R.

Conflict of Interest: The authors have no conflict of interest to declare.

Financial Disclosure: The authors declared that this study has received no financial support.

REFERENCES

1. Gegler A, Fontanella V. In vitro evaluation of a method for obtaining periapical radiographs for diagnosis of external apical root resorption. Eur J Orthod 2008; 30: 315-9. [CrossRef]
2. Cacciatore G, Alvetro L, Defraia E, Ghislanzoni LTH, Franchi L. Active-treatment effects of the Forsus fatigue resistant device during comprehensive Class II correction in growing patients. Korean J Orthod 2014; 44: 136-42. [CrossRef]
3. Schwartz JP, Raveli TB, Schwartz-Filho HO, Raveli DB. Changes in alveolar bone support induced by the Herbst appliance: a tomographic evaluation. Dental Press J Orthod 2016; 21: 95-101. [CrossRef]
4. Tieu L, Normando D, Toogood R, Flores-Mir C. External apical root resorption generated by Forsus simultaneously with brackets vs. Xbow followed by brackets to correct Class II malocclusions. J World Fed Orthod 2015; 4: 120-3. [CrossRef]
5. Tieu LD, Saltaji H, Normando D, Flores-Mir C. Radiologically determine orthodontically induced external apical root resorption in incisors after non-surgical orthodontic treatment of class II division 1 malocclusion: a systematic review. Prog Orthod 2014; 15: 48. doi: 10.1186/s40510-014-0048-7. [CrossRef]
6. Samandara A, Papageorgious SN, Ioannidou- Marathiotou I, Kavvadia Tsatala S, Papadopoulos MA. Evaluation of orthodontically induced external root resorption following orthodontic treatment using cone beam computed tomography (CBCT): a systematic review and meta- analysis. Eur J Orthod 2019; 41: 67-79. [CrossRef]
7. Schwartz JP, Raveli TB, Almeida KC, Schwartz-Filho HO, Raveli DB. Cone beam computed tomography study of apical root resorption induced by Herbst appliance. J Appl Oral Sci 2015; 23: 479-85. [CrossRef]
8. Dudic A, Giannopoulou C, Leuzinger M, Kiliaridis S. Detection of apical root resorption after orthodontic treatment by using panoramic radiography and cone-beam computed tomography of super-high resolution. Am J Orthod Dentofacial Orthop. 2009; 135:434-437. [CrossRef]
9. Lund H, Grondahl K, Grondahl HG. Cone Beam Computed Tomography for Assessment of Root Length and Marginal Bone Level during Orthodontic Treatment. Angle Orthod 2010; 80: 466-73. [CrossRef]
10. Castro IO, Alencar AH, Valladares-Neto J, Estrela C. Apical root resorption due to orthodontic treatment detected by cone beam computed tomography. Angle Orthod 2013; 83: 196-203. [CrossRef]
11. Gerszewski C, Topolski F, Correr GM, Gomes RAP, Morais ND, Moro A. Dentoalveolar evaluation of lower incisors by CBCT after treatment with Herbst appliance. Braz Dent J 2018; 29: 562-8. [CrossRef]
12. Suresh KP, Chandrashekara S. Sample size estimation and power analysis for clinical research studies. J Hum Reprod Sci 2012; 5: 6-14.
13. Ni M, Lei Y, Chen WJ, Wu GR. Cone beam computed tomography study on the apical root resorption after orthodontic treatment in root-filled teeth. Stomatologie 2016; 36: 233-6.
14. Deng Y, Sun Y, Xu T. Evaluation of root resorption after comprehensive orthodontic treatment using cone beam computed tomography (CBCT): a meta-analysis. BMC Oral Health 2018; 18: 2-14. [CrossRef]
15. Lund H, Gröndahl K, Hansen K, Gröndahl HG. Apical root resorption during orthodontic treatment A proscpective study using cone beam CT. Angle Orthod 2012; 82: 480-7. [CrossRef]
16. Nguyen T, Cevidanes L, Franchi L, Ruellas A, Jackson T. Three-dimensional mandibular regional superimposition in growing patients. Am J Orthod Dentofacial Orthop 2018; 153: 747-54. [CrossRef]
17. Nakada T, Motoyoshi M, Horinuki E, Shimizu N. Cone-beam computed tomography evaluation of the association of cortical plate proximity and apical root resorption after orthodontic treatment. J Oral Sci 2016; 58: 231-6. [CrossRef]
18. Brezniak N, Wasserstein A. Root resorption after orthodontic treatment: Part 2. Literature review. Am J Orthod Dentofacial Orthop 1993; 103: 138-46. [CrossRef]
19. Pasricha N, Sidana V, Bhasin S, Makkar M. Canine protected occlusion. Indian J Oral Sci 2012; 3:13-8. [CrossRef]
20. Kinzinger GS, Savvaidis S, Gross U, Gülden N, Ludwig B, Lisson J. Effects of Class II treatment with a banded herbst appliance on root lengths in the posterior dentition. Am J Orthod Dentofacial Orthop 2011; 139: 465-9. [CrossRef]
21. Narendran N, Batra P, Sonar S, Singla A. Effects of Class II treatment with hybrid fixed functional appliances on root length and root volume- a prospective study using CBCT. Int J Sci Res 2019; 8: 28-31.
22. Giuntini V, Vangelisti A, Masucci C, Defraia E, McNamara JA Jr, Franchi L. Treatment effects produced by the Twin-block appliance vs the Forsus Fatigue Resistant Device in growing Class II patients. Angle Orthod 2015; 85: 784-9. [CrossRef]

23. Hansen K, Koutsonas TG, Pancherz H. Long-term effects of Herbst treatment on the mandibular incisor segment: A cephalometric and biometric investigation. Am J Orthod Dentofac Orthop 1997; 112: 92-103. [CrossRef]
24. Mahamad IK, Neela PK, Mascarenhas R, Husain A. A comparison of Twin block and a Forsus (FRD) functional appliance-a cephalometric study. Int J Orthod Milwaukee 2012; 23: 49-58.
25. Ruf S, Pancherz H. Herbst/ multibracket appliance treatment of Class II Division 1 malocclusions in early and late adulthood: a prospective cephalometric study of consecutively treated subjects. Eur J Orthod 2006; 28: 352-60. [CrossRef]
26. Gracco A, Luca L, Bongiorno MC, Siciliani G. Computed tomography evaluation of mandibular incisor bony support in untreated patients. Am J Orthod Dentofacial Orthop 2010; 138: 179-87. [CrossRef]
27. Garlock DT, Buschang PH, Araujo EA, Behrents RG, Kim KB. Evaluation of marginal alveolar bone in the anterior mandible with pretreatment and posttreatment computed tomography in nonextraction patients. Am J Orthod Dentofacial Orthop 2016; 149: 192-201. [CrossRef]
28. Wehrbein H, Bauer W, Diedrich P. Mandibular incisors, alveolar bone, and symphysis after orthodontic treatment. A retrospective study. Am J Orthod Dentofacial Orthop 1996; 110: 239-46. [CrossRef]
29. De Angelis V. Observations on the response of alveolar bone to orthodontic force. Am J Orthod 1970; 58: 284-94. [CrossRef]
30. Yodthong N, Charoemratrote C, Leethanakul C. Factors related to alveolar bone thickness during upper incisor retraction. Angle Orthod 2013; 83: 394-401. [CrossRef]
31. Brezniak N, Wasserstein A. Orthodontically induced inflammatory root resorption. Part I: The basic science aspects. Angle Orthod 2002; 72: 175-9.
32. Dudic A, Giannopoulou C, Meda P, Montet X, Kiliaridis S. Orthodontically induced cervical root resorption in humans is associated with the amount of tooth movement. Eur J Orthod 2017; 39: 534-40. [CrossRef]