Original Article

Influence of Invisalign precision bite ramp utilization on deep bite correction and root length in adults

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ABSTRACT

Objectives: To assess the influence of Invisalign precision bite ramp use on skeletal deep overbite correction and root length and volume of maxillary anterior teeth.

Materials and Methods: This was a retrospective study of 60 adults with skeletal deep overbite. Patients were divided into three groups: Invisalign (Align Technology, San Jose, Calif) with precision bite ramps (Invisalign with Bite Ramps [IBR] = 12), Invisalign with no bite ramps (INBR = 22), and full-fixed appliances (FFA = 26). Cone beam computed tomography records at T1 (pretreatment) and T2 (posttreatment) were used to measure eight skeletal, nine dental, and three soft-tissue cephalometric variables. Maxillary anterior teeth root length (mm), root volume (mm^3), and percent root volume loss between T1 and T2 (%) were also recorded.

Results: Significant changes from T1 to T2 among the three groups were seen in ANB(^{o}), lower face height (%), ODI (overbite depth indicator) (^{o}), and U1–SN (^{o}). Reduction in root length was significantly less ($P < .001$) in the INBR and IBR groups compared to the FFA group. Reduction in root volume and percent volume loss were significantly higher in the INBR group compared to the IBR group ($P < .001$), but the difference between the two Invisalign groups and the FFA group was not significant.

Conclusions: Skeletal deep overbite correction using Invisalign with or without bite ramps is comparable to FFA. Reduction in root length was significantly less with Invisalign compared to FFA. Bite ramps influenced root volume and volume loss but not root length. (*Angle Orthod*. 0000;00:000–000.)

KEY WORDS: Clear aligner therapy; Deep bite; Root resorption

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INTRODUCTION

Deep overbite is a common malocclusion characteristic that is found in 15% to 20% of the U.S. population.[1] Correction of deep overbite can be achieved via pure intrusion of the maxillary and/or mandibular incisors, relative intrusion of the incisors, or extrusion of the posterior teeth.[2] Clear aligners (CAs) have been utilized for correcting deep overbite malocclusion.[3] Advantages in using CAs in such cases include eliminating the need to wait before leveling of the curve of Spee with mandibular incisor intrusion. This contrasts with fixed appliances, in which the clinician typically waits until some initial leveling and aligning is achieved before placing reverse curve arch wires. Bracket interferences with the opposing dentition can also cause delays in leveling of the curve of Spee with fixed appliances. Align Technology (San Jose, CA) initially introduced the G5 protocol with precision bite ramps to correct deep bites and recently introduced the G8 protocol for improved deep bite correction.[4,5]

Precision bite ramps (equivalent to bite turbos in fixed appliances) are prominences on the lingual surface of upper aligners. These bite ramps extend up to 3.0 mm in depth, creating contact in the anterior region, which leads to disocclusion of the posterior dentition.[4] Align Technology claims that the automatic placement of precision bite ramps in the G8 feature improves mandibular incisor intrusion by up to 30% compared to the mandibular incisor intrusion achieved in G5 cases with and without bite ramps.[5]

Orthodontic treatment may result in side effects, including orthodontically induced external apical root resorption (EARR). Evidence suggests a higher risk of EARR with intrusion mechanics,[6] particularly affecting the maxillary anterior teeth.[7] The prevalence and severity of EARR are reportedly lower with CAs than with fixed appliances.[8,9]

There is no evidence analyzing the effects of CAs with precision bite ramps on skeletal deep bite correction and EARR in comparison to CAs without bite ramps. The objectives of this study were to evaluate the influence of precision bite ramp utilization on skeletal deep overbite correction and maxillary anterior root length and volume in adults. It was hypothesized that the use of bite ramps does not influence the amount of skeletal deep overbite correction achieved and does not influence root length and volume of maxillary anterior teeth.

MATERIALS AND METHODS

This was a retrospective study of adults with skeletal deep bite who presented for treatment with Invisalign (Align Technology) or full-fixed orthodontic appliances (FFA). Subjects were divided into three groups according to treatment modality and precision bite ramp utilization: Invisalign with precision bite ramps included in the aligners (IBR); Invisalign with no precision bite ramps included (INBR); and FFA. The study was conducted in two private practices with data collected at two time points: at initial records prior to starting orthodontic treatment (T1), and at final records immediately after finishing orthodontic treatment (T2). Institutional Review Board approval was obtained from the University at Buffalo Institutional Review Board (#00005770).

Subjects were included if they met the following criteria: female and male adults $>$18 years at the start of treatment, overbite depth indicator (ODI) $\geq$ 80.5° indicating skeletal deep bite,[10] started and completed comprehensive orthodontic treatment using Invisalign (G5 generation or after), complete pre- and posttreatment records including cone beam computed tomography (CBCT), malocclusions of either Class I or Class II, mild to moderate crowding ($\leq$6 mm), treated without extractions, and full permanent dentition.

Subjects were excluded if they had systemic conditions predisposing them to root resorption, history of trauma or endodontic treatment to the anterior teeth, anterior teeth with large restorations, pretreatment apical root resorption of maxillary anterior teeth, treatment involving orthognathic surgery or single-arch Invisalign treatment, or history of orthodontic treatment.

Sample Size

An estimated sample of 22 subjects per group was determined to have an 80% power to detect a large effect size at a significance level of 5%. This estimation was based on analysis of variance with three groups and a Cohen's *f* effect size of 0.40.

Study Outcomes

The outcome measures were: (1) Skeletal deep overbite correction measured by changes in ODI° ([A-B Plane/MP) + (FH/PP]) on lateral cephalograms reconstructed from full head CBCTs at pre- and post-treatment phases; and (2) three-dimensional root changes: root length (mm), root volume (mm^3), and percent root volume loss (%). The percent root volume loss was calculated using the formula: (root volume at T1 minus root volume at T2/root volume at T1) * 100. Changes in root length and volume were measured for the maxillary anterior teeth (from right canine to left canine).

Study Procedures

The sample was selected from patients that presented for orthodontic treatment with Invisalign or FFA for the first time between 2014 and 2022. A total of 1237 cases were assessed for eligibility. Pre- and post-treatment CBCT (Dexis, Quakertown, Pennsylvania) images were acquired by calibrated technicians using an I-CAT Next Generation scanner (17 $\times$ 25 cm field of view, 120 kV, 5 mA, and 360° rotation, scan time: 26.9 seconds). Volumetric scans were de-identified using 3DSlicer software,[11] then exported in Digital Imaging and Communications in Medicine (DICOM) format into Dolphin Imaging software (Dolphin Imaging & Management Systems, Chatsworth, Calif) in which lateral cephalograms were reconstructed and measurements were made. Eight skeletal, nine dental, and three soft tissue variables were measured.

The volumetric scans were also converted from DICOM format to .stl files, then imported into Geomagic Control X (3D Systems, Rock Hill, SC, USA) for analysis of root length and volume of maxillary anterior teeth according to Puttaravuttiporn et al. and Baysal et al.[12,13]

Additional information was obtained from the Invisalign Treatment Overview Form regarding the protocol and mechanics used, total number of aligners used in

Table 1. Sample Characteristics at Baseline (T1)[a]

Variable	FFA N = 26	INBR N = 22	IBR N = 12	Total	*P* Value
Age (yr), mean (SD)	23.20 (6.46)	39.06 (15.62)	38.20 (13.74)	33.42 (11.94)	< .001*
Sex, N (%)					
F	17 (65)	17 (77)	9 (75)	43 (72)	.700
M	9 (35)	5 (23)	3 (25)	17 (28)	
Race, N (%)					
White	19 (73)	20 (91)	12 (100)	51 (85)	.070
Non-White	7 (27)	2 (9)	0 (0)	9 (15)	
ODI (°), median (IQR)	81.40 (3)	81.10 (1.33)	82.90 (2.60)	81.8 (2.31)	.076
OB (mm), median (IQR)	5.30 (2.48)	6.15 (3.13)	6.60 (3.75)	18.05 (3.12)	.646

* Kruskal-Wallis test; significance level set at 5%.

[a] F indicates female; IBR, Invisalign with bite ramps; INBR, Invisalign with no bite ramps; IIQR, interquartile ratio; M, male; OB indicates overbite; ODI, overbite depth indicator; SD, standard deviation.

the upper and lower arches, aligner number in which precision bite ramps were placed and removed, number and location of attachments, interproximal reduction plans, and information about elastic wear, if any. Information on oral hygiene and compliance was collected from electronic health records.

The treatment protocol for deep overbite correction in both private practices was dependent on several factors related to the smile line and incisal display. The protocol included gradually creating a reverse curve of Spee in lower aligners, adding precision bite ramps in variable locations, adding maxillary incisor palatal root torque, and creating hard posterior contacts. The FFA group was treated with preadjusted Damon 3MX or Damon Q2 System self-ligating brackets (Ormco, Glendora, CA). Bite opening mechanics involved using reverse curve of Spee wires in the mandibular arch with no bite turbos.

Intra-examiner Reliability

Measurements from 10 subjects were repeated by one investigator 2 weeks after the initial measurements. Intraclass correlation coefficients (ICC) were calculated and results indicated excellent reliability (ICC > 0.9).

Statistical Analysis

Nonparametric testing was performed on the continuous variables due to results of Shapiro-Wilks tests showing that the null of normality was rejected for at least one group. Demographic variables and treatment changes in cephalometric and CBCT measurements were evaluated by Kruskal-Wallis tests followed by Dunn's tests (Bonferroni multiple comparison adjusted) or by Fisher's exact test. The initial Kruskal-Wallis results for the CBCT measurements were adjusted to control the false discovery rate with the Benjamini-Hochberg method. Independent evaluations of the six anterior teeth were done by linear mixed-effect models (LMM). Analyses were performed at the 5% level using R Studio with R version 4.2.2.

RESULTS

Sixty records were included (FFA = 26, IBR = 12, and INBR = 22). Out of the 12 subjects treated with IBR, five had bite ramps on both maxillary central incisors, two had bite ramps on both maxillary central and lateral incisors, and five had bite ramps on maxillary canines. As shown in Table 1, there was a significant difference in the mean age among the three groups ($P < .001$). The pairwise Dunn's test showed that the INBR group was significantly older than the FFA group (FFA = 23.2 ± 6.46 years, INBR = 39.06 ± 15.62, adjusted $P = .009$).

The mean treatment duration with FFA was 2.31 ± 0.87 years, and it was 2.01 ± 1.25 and 1.43 ± 0.53 years for the INBR and IBR groups, respectively. The Kruskal-Wallis test indicated a statistical difference among the three groups ($P = .010$). Pairwise Dunn's Test showed that treatment duration was shorter in the IBR group than the FFA group ($P = .009$).

The mean number of maxillary and mandibular aligners used was 101 ± 35 and 100 ± 43 in the IBR and INBR groups, respectively. Most patients switched to the next aligner every 3 to 4 days, while the rest switched every 7 days. The IBR group was treated with the G8 protocol and received bite ramps starting on their first aligner. Class II elastics were used for anteroposterior correction by 77% of the patients in the FFA group, 25% in the IBR group, and 36% in the INBR group. Compliance with aligner wear and oral hygiene was reported to be high among the groups.

Cephalometric Changes

Comparing the median cephalometric changes between T1 and T2 among the three groups, the ANB°, lower face %, ODI°, and U1–SN° were significantly different

Table 2. Cephalometric Measurements at T1 and T2[a]

	T1							T2							
	FFA (n = 26)		INBR (n = 22)		IBR (n = 12)			FFA (n = 26)		INBR (n = 22)		IBR (n = 12)			T1 vs T2
Variable	Median	IQR	Median	IQR	Median	IQR	*P* Value*	Median	IQR	Median	IQR	Median	IQR	*P* Value*	*P* Value*
SNA (°)	84.40	8.13	84.25	4.48	82.35	3.43	.743	84.75	7.20	83.05	4.93	83.25	3.15	.598	.600
SNB (°)	79.35	5.70	79.95	5.88	79.70	3.83	.892	80.20	7.05	80.30	5.40	79.70	3.23	.765	.079
ANB (°)	5.10	2.80	4.05	3.40	2.30	3.30	.058	4.20	3.80	1.90	1.98	2.60	2.20	.107	**.004**
SN – GoGn (°)	27.75	9.38	29.35	7.48	27.60	4.33	.256	26.35	10.33	29.30	7.90	28.05	5.20	.193	.403
Occl Pl-GoGn (°)	15.60	4.85	15.65	6.18	14.65	6.45	.905	12.90	5.40	14.90	5.68	14.35	6.15	.871	.828
ODI (°)	81.40	3.00	81.10	1.33	82.90	2.60	.076	78.75	4.48	79.60	1.70	79.35	3.13	.234	**.040**
Lower Face %	49.95	2.68	50.90	4.23	52.05	5.18	.101	51.10	3.93	54.10	3.95	54.55	3.88	.004	**.006**
P-A Face Height (%)	68.80	7.38	65.55	5.43	66.80	3.30	.128	69.55	6.43	65.25	4.70	66.25	2.35	.09	.543
U1 – PP (°)	109.10	16.95	105.25	9.13	103.90	6.48	.150	107.55	8.58	107.95	4.33	105.70	4.95	.237	.193
U1 – SN (°)	107.80	20.83	99.00	11.10	100.20	10.23	.140	104.60	9.70	104.85	6.13	100.25	6.93	.072	**.046**
U6 – PP (mm)	19.35	3.33	36.95	12.93	39.75	10.98	**<.001**	19.70	4.28	37.05	12.45	39.55	13.68	**<.001**	.050
L6 – MP (mm)	27.35	5.60	56.70	16.40	52.70	19.20	**<.001**	28.10	5.10	57.05	16.83	52.30	21.73	**<.001**	.518
L1 – GoGn (°)	95.95	10.88	95.60	5.35	94.30	8.58	.617	103.80	15.73	100.55	7.13	101.10	13.40	.431	.927
IMPA (°)	93.85	10.50	93.85	5.35	92.30	7.43	.515	102.45	19.55	95.65	4.55	94.30	10.00	.119	.183
Interincisal Angle (°)	128.10	26.63	136.30	14.00	139.05	12.05	.174	125.85	23.85	130.15	9.68	132.80	12.35	.166	.524
Overbite (mm)	5.30	2.48	6.15	3.13	6.60	3.75	.646	2.20	1.40	2.35	0.78	3.60	1.90	.048	.254
Overjet (mm)	6.10	4.70	5.80	3.73	5.40	2.33	.777	4.20	2.30	2.05	0.88	2.70	2.63	**<.001**	.090
Nasolabial Angle (°)	106.40	19.40	111.75	11.30	110.15	11.18	.892	107.25	20.73	111.85	9.13	112.75	9.45	.265	.227
Lower Lip to E-Plane (mm)	−3.35	4.45	−6.90	7.28	−11.90	7.43	**<.001**	−1.65	5.50	−5.65	7.38	−10.60	6.50	.003	.458
Upper Lip to E-Plane (mm)	−4.05	5.28	−9.15	7.10	−14.90	7.83	**<.001**	−3.65	2.78	−7.75	6.50	−13.95	6.43	**<.001**	.130
Upper Lip to Incisor (mm)	4.40	2.95	6.40	5.20	7.75	2.88	<.001	4.70	1.83	6.10	3.88	6.60	6.50	.014	.546

* Kruskal-Wallis test; significance level set at 5%.
[a] FFA indicates full-fixed appliances; IBR, Invisalign with bite ramps: INBR, Invisalign with no bite ramps; IQR, interquartile ratio.

(Table 2). The pairwise comparisons showed that the change in ANB° was statistically significant when comparing FFA vs INBR ($P = 0.032$), and IBR vs INBR ($P = 0.005$). The change in lower face % was significant between the FFA vs INBR groups ($P = .007$). Finally, the change in U1-SN° and U6–PP was significant between IBR vs INBR groups ($P = .024$ and .020, respectively).

When the ODI° and overbite variables were modeled with LMM against treatment group, timepoint, and treatment duration, the duration of treatment was not significant.

3D Root Changes

There was a significant difference in root length changes among the three groups ($P < .001$) (Table 3). Pairwise comparisons showed a significant reduction in root length in the FFA group compared to the IBR and INBR groups in Table 4.

Detailed results of root volume are depicted in Table 5 and Figure 1. The Kruskal-Wallis test indicated a significant difference between groups. Pairwise Dunn's tests indicated that the difference was between the IBR vs INBR groups for all teeth ($P < .001$).

Greater root volume % loss was observed in the INBR group compared to IBR group, (Table 6). There was a significant difference in root volume % loss when comparing the two Invisalign groups; however, the difference between the FFA group and the two Invisalign groups was not significant.

DISCUSSION

The challenge in deep overbite correction with CAs arises from the fact that intrusive forces, arising from the patient's natural biting forces along with the thickness of the aligner material covering the occlusal surface of the teeth, could lead to intrusion of posterior teeth, thereby countering the force system needed to correct deep overbite. The orthodontic literature has previously reported the effectiveness of CA in treating deep overbite. Khosravi et al. and Fujyama et al. showed that CAs were effective in dental overbite correction,[3,14] while Henick et al.[15] concluded that the Invisalign G5 protocol was effective in bite opening in skeletal deep bite adults.

In the current study, overbite decreased from T1 to T2 by 3.1 mm, 3.8 mm, and 3 mm, for the FFA, INBR, and IBR groups, respectively. This finding, however, was not statistically significantly different among the groups, suggesting that Invisalign with or without bite ramps was comparable to fixed appliances in terms of bite opening. In a retrospective study done to assess overbite changes in patients treated with Invisalign, the median overbite opening

Table 3. Root Length by Timepoint, Treatment Group, and Tooth (mm)

Root Length by Timepoint, Group, and Tooth (mm)													
		UR1		UR2		UR3		UL1		UL2		UL3	
Group	Measure	T1	T2	T1	T2	T1	T2	T1	T2	T1	T2	T1	T2
FFA	Median	12.25	10.02	11.16	9.35	23.65	19.00	12.20	9.99	11.12	9.42	19.02	23.50
	IQR	0.72	0.53	0.41	0.59	3.99	1.59	0.72	0.59	0.49	0.59	1.82	4.06
	Mean	12.18	9.99	11.15	9.36	23.19	18.75	12.21	9.95	11.16	9.35	18.73	23.22
	SD	0.45	0.50	0.37	0.59	2.44	1.45	0.45	0.38	0.41	0.73	1.24	2.49
	P Value*	<.001		<.001		<.001		<.001		<.001		<.001	
INBR	Median	11.92	11.72	10.96	10.77	23.23	22.72	11.89	11.72	10.94	10.85	22.84	23.19
	IQR	0.52	0.60	0.67	0.74	2.11	1.91	0.51	0.59	0.72	0.79	1.89	2.34
	Mean	11.97	11.74	11.01	10.77	23.37	22.94	11.99	11.73	11.02	10.81	22.99	23.38
	SD	0.45	0.49	0.44	0.46	2.60	2.56	0.43	0.52	0.47	0.48	2.51	2.64
	P-value*	0.057		0.056		0.270		0.028		0.142		0.334	
IBR	Median	12.15	12.10	11.18	11.07	25.05	24.99	12.14	12.05	11.19	10.98	24.90	25.06
	IQR	0.52	0.48	0.86	1.18	4.49	4.99	0.64	0.76	0.89	1.25	4.55	4.26
	Mean	12.37	11.98	11.29	10.97	24.74	24.36	12.34	11.91	11.39	10.92	24.08	24.86
	SD	0.61	0.87	0.85	0.69	3.28	3.42	0.60	0.83	0.92	0.79	2.93	3.16
	P-value*	0.051		0.069		0.430		0.012		0.028		0.218	

* *P* values from estimated marginal means contrasts from linear mixed models; significance level set at 5%. All 18 *P* values adjusted by Benjamini-Hochberg method.

[a] FFA indicates full-fixed appliances; IBR, Invisalign with bite ramps; INBR, Invisalign with no bite ramps; IQR, interquartile ratio; SD, standard deviation.

was 1.5 mm, which was almost half the amount of overbite opening in the current study.[3] It is worth noting that the previous study was conducted before the introduction of the G5 and G8 features, thus explaining the lesser bite opening. On the other hand, the average total overbite reduction in severe deep overbite patients treated with Invisalign was 3.6 mm in a more recent study, similar to the findings of the current study.[14]

The change in ODI° from T1-T2 was 2.65°, 1.5°, and 3.55° for the FFA, INBR, and IBR groups, respectively. This change, however, was not significantly different among the groups at the pairwise comparison stage. This was different from the findings of Henick et al.[15] in which the change in ODI° between T1-T2 was statistically significant for both the Invisalign and fixed appliance groups. The difference between the results could have been due to the difference in treatment

Table 4. Kruskal-Wallis and Dunn tests for T1-T2 Changes Between Treatment Groups[a]

				Adjusted *P* Value***		
Variable	Tooth	*P* Value* All groups	Adj. *P* Value** All groups	FFA vs IBR	FFA vs INBR	IBR vs INBR
Root length (mm)	UR1	<.001	<.001	<.001	<.001	1
	UR2	<.001	<.001	<.001	<.001	1
	UR3	<.001	<.001	<.001	<.001	1
	UL1	<.001	<.001	<.001	<.001	1
	UL2	<.001	<.001	<.001	<.001	.759
	UL3	<.001	<.001	<.001	<.001	1
Root volume (mm^3)	UR1	.005	.007	.175	.256	.004
	UR2	.017	.021	.086	1	.015
	UR3	.024	.027	.034	1	.041
	UL1	.002	.004	.042	.537	.002
	UL2	.004	.007	.030	1	.003
	UL3	.002	.004	.003	1	.005
Root volume loss (%)	UR1	.005	.007	.133	.308	.003
	UR2	.132	.132	.510	1	.132
	UR3	.030	.032	.045	1	.051
	UL1	.002	.004	.030	.670	.001
	UL2	.011	.014	.072	.973	.008
	UL3	.002	.004	.003	1	.004

* Kruskal-Wallis test; significance level set at 5%.

** Multiple testing adjusted *P* values (Benjamini-Hochberg) across all variables and teeth.

*** Pairwise Dunn's tests. Bonferroni adjusted across pairs within tooth and variable.

[a] FFA indicates full-fixed appliances; IBR, Invisalign with bite ramps; INBR, Invisalign with no bite ramps; IQR, interquartile ratio.

Table 5. Root Volume by Timepoint, Treatment Group, and Tooth (mm^3)[a]

Root Volume by Timepoint, Group, and Tooth (mm^3)													
		UR1		UR2		UR3		UL1		UL2		UL3	
Group	Measure	T1	T2	T1	T2	T1	T2	T1	T2	T1	T2	T1	T2
FFA	Median	69.25	64.885	62.05	57.71	82.91	74.38	68.98	63.08	61.55	55.895	83.41	73.035
	IQR	6.248	8.037	8.752	10.675	9.918	8.572	6.115	8.395	9.502	11.962	11.657	7.757
	Mean	68.669	64.722	60.736	54.678	82.25	75.348	68.592	63.309	60.736	52.964	82.331	73.211
	SD	4.509	5.123	5.659	7.601	5.81	6.039	4.44	5.154	5.828	7.642	6.452	5.902
	P Value*	<.001		<.001		<.001		<.001		<.001		<.001	
INBR	Median	68.705	65.12	59.63	55.835	81.685	76.625	68.895	64.365	61.115	53.825	81.235	73.885
	IQR	5.675	7.373	8.743	8.15	10.523	11.055	6.065	7.058	9.243	8.017	9.788	10.822
	Mean	70.675	65.762	60.185	54.593	82.101	76.456	70.603	64.62	60.727	52.917	82.202	74.262
	SD	4.876	5.056	5.287	6.054	6.773	7.441	4.975	5.041	5.584	6.088	7.301	7.37
	P Value*	<.001		<.001		<.001		<.001		<.001		<.001	
IBR	Median	70.82	69.4	33.895	32.09	77.87	75.865	71.27	68.94	33.895	32.625	77.705	77.39
	IQR	11.525	10.257	27.333	23.477	9.598	8.013	11.525	9.062	28.083	21.56	9.877	7.728
	Mean	69.833	68.328	37.242	35.127	80.108	77.509	69.789	68.384	37.326	34.997	80.192	78.495
	SD	6.256	5.574	14.583	13.383	6.063	5.858	6.471	6.108	14.679	12.428	6.544	6.027
	P Value*	.318		.236		.233		.344		.236		.394	

* *P* values from estimated marginal means contrasts from linear mixed models; significance level set at 5%. All 18 *P* values adjusted by Benjamin-Hochberg method.

[a] FFA indicates full-fixed appliances; IBR, Invisalign with bite ramps; INBR, Invisalign with no bite ramps; IQR, interquartile ratio; SD, standard deviation.

mechanics related to the reverse-curve archwire use protocol and the method by which reverse-curve mechanics were programmed in the Invisalign ClinCheck.

According to the patient charts, deep overbite correction was achieved mostly by proclination of the anterior teeth in the FFA group, and by a combination of intrusion and proclination of anterior teeth in the IBR and INBR groups. Despite this, the cephalometric measurements showed that the T1-T2 change in upper incisor proclination was only significantly different between the two Invisalign groups. The median U1-SN in the INBR group changed from 99.00° at T1 to 104.85° at T2, while it changed minimally from to 100.20° to 100.25° in the IBR group. This could have been the result of the effects of bite ramp utilization on the torque of anterior teeth. As the patient bites on the bite ramps, the force vector leads to labial root torque, thus negating the lingual root torque added in the ClinCheck to allow for crown proclination. According to Kravitz et al.,[16] the presence of bite ramps reduces plastic in contact with the incisor cingulum, thus reducing the surface area available to apply the desired force vector for certain movements. Subsequently, this can limit torque expression, thus reducing upper incisor proclination.

The finding of reduced proclination was contradictory to findings of previous studies that showed that, in adults, true mandibular incisor intrusion with CAs when the G5 or G8 protocols were implemented was limited to 1 mm. Therefore, the primary method for overbite correction predominantly involved the extrusion of posterior teeth and proclination of anterior teeth. This could have happened because the mandibular incisors were significantly proclined at T1, thus warranting the need to avoid any further proclination in the planned treatment mechanics.[17]

Additionally, U6-PP increased significantly more in the IBR group than the INBR group. This may have been due to the disocclusion provided from the bite ramps, aiding in the extrusion of maxillary posterior teeth and, thus, promoting bite opening. Conversely, when there were no bite ramps, the intrusive effect of the aligner thickness, in combination with bite forces, negated the posterior extrusion, and even led to some posterior intrusion.

This study evaluated pre- and post-treatment root changes in the INBR, IBR, and FFA groups. Orthodontic treatment frequently results in some amount of root resorption.[18] This study, however, only assessed the maxillary anterior teeth because the purpose of the study was specifically to evaluate the effects of precision bite ramp placement on those teeth.

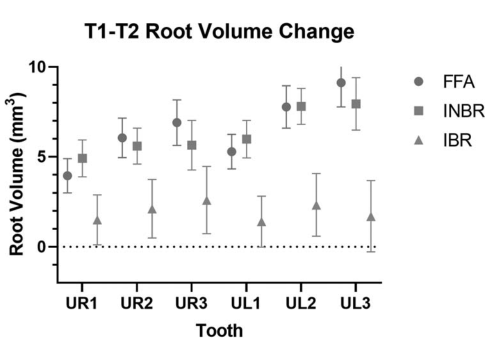

Figure 1. T1-T2 root volume change.

Table 6. Root Volume % loss (mm^3) by Treatment Group and Tooth[a]

	Root Volume % Loss												
	FFA				INBR				IBR				
Tooth	Median	IQR	Mean	SD	Median	IQR	Mean	SD	Median	IQR	Mean	SD	Adj. *P* Value*
UR1	4.61	13.85	5.33	9.89	7.01	4.75	6.97	2.64	1.97	1.55	2.09	1.19	.007
UR2	8.3	21.2	9.51	13.45	9.22	4.55	9.44	3.69	4.81	4.54	5.41	3.22	.132
UR3	10.35	18.62	7.79	11.44	6.64	3.51	6.96	2.59	3.7	1.83	3.23	1.5	.032
UL1	6.33	14.58	7.3	9.9	8.76	5.01	8.48	2.98	1.41	3.48	1.96	2.15	.004
UL2	11.16	23.15	12.24	14.05	12.92	4.49	12.99	4.26	3.8	8.46	4.88	5.02	.014
UL3	12.79	20.5	10.38	11.71	9.9	3.07	9.7	2.7	0	3.47	2.04	3.03	.004

* Kruskal-Wallis followed by Benjamini-Hochberg multiple testing adjustment.

[a] Adj. indicates adjusted; FFA indicates full-fixed appliances; IBR, Invisalign with bite ramps; INBR, Invisalign with no bite ramps; IQR, interquartile ratio; SD, standard deviation.

A statistically significant reduction in overall root volume of maxillary anterior teeth was noted in both the FFA and INBR groups. The amount of reduction varied among teeth. However, the change in root length of maxillary anterior teeth from T1 to T2 in the IBR group was not statistically significant. This may suggest that the force applied to maxillary teeth with bite ramps is low, thus resulting in less root resorption. Also, root length reduction in the fixed appliance group was significantly greater than that in both of the Invisalign groups ($P < .001$). This supports previous findings of a systematic review in which less root resorption was reported in patients treated with CAs.[19]

The change in root length was not significantly different between the two Invisalign groups. However, when root volume changes were compared, there was a difference between the IBR vs INBR groups, but not between the Invisalign groups and FFA group. Resorption may have occurred on root surfaces other than at the apex, which may explain these findings. Invisalign may be the preferred treatment for adult patients with a skeletal deep bite with pre-existing root resorption or those at risk of developing root resorption.

Results of this study also showed that treatment duration was significantly shorter in the IBR group compared to the FFA group, but there was no difference between the two Invisalign groups. In contrast, Fujiyama et al.[14] compared the clinical outcomes between fixed appliances and Invisalign after severe deep overbite correction in adult patients and reported that the average treatment duration did not differ significantly between the groups. The differences in findings can be explained by the Invisalign treatment protocols utilized. In the current study, most of the patients in both Invisalign groups switched to the next aligner every 3 to 4 days rather than every 7 days, mainly because the speed of tooth movement was cut in half per aligner.

The results of this study suggested that Invisalign, whether used with bite ramps or not, can produce bite opening in adults with skeletal deep bite, thus the hypothesis was not rejected. This study included patients with true skeletal deep overbite, which is often overlooked in orthodontic research. However, the small sample size, especially in the IBR group, made it difficult to detect small differences among the three groups. Since most orthodontists do not obtain CBCTs as part of their routine pre- and post-treatment records, this study is at risk of selection bias. Future studies may consider increasing the sample size and investigating the influence of precision bite ramps on root length of mandibular anterior teeth where the intrusion is claimed to happen, especially considering recent evidence suggesting that age influences mandibular anterior teeth intrusion.[19]

CONCLUSIONS

- Skeletal deep overbite correction with Invisalign, with or without precision bite ramps, is comparable to treatment with fixed appliances.
- Invisalign treatment resulted in significantly less reduction in root length compared to fixed appliances.

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