Original Article

Changes in mandibular incisor position and arch form resulting from Invisalign correction of the crowded dentition treated nonextraction

Laura O. Duncan[a]; Luis Piedade[b]; Milos Lekic[c]; Rodrigo S. Cunha[d]; William A. Wiltshire[e]

ABSTRACT

Objective: To investigate changes in mandibular incisor position resulting from Invisalign correction of the crowded dentition without extraction.

Materials and Methods: A retrospective chart review was completed on 61 adult White patients. Patients were categorized into three groups based on the value of pretreatment crowding of the lower dentition: 20 mild (2.0–3.9 mm), 22 moderate (4.0–5.9 mm), and 19 severe ($>$6.0 mm). Cephalometric radiographs were measured to determine lower incisor changes. Interproximal reduction and changes in arch width were also measured. Statistical evaluation of T_0 and T_1 values using paired *t*-tests and analysis of covariance were applied to evaluate mean value changes.

Results: Lower incisor position and angulation changes were statistically significant in the severe crowding group. There were no statistically significant differences in lower incisor position between the mild and moderate crowding groups. There was a statistically significant increase in buccal expansion in each of the three groups.

Conclusions: Invisalign® treatment can successfully resolve mandibular arch crowding using a combination of buccal arch expansion, interproximal reduction, and lower incisor proclination. When there is $<$6 mm of crowding, lower incisor position remained relatively stable. The lower incisors proclined and protruded in the more severely crowded dentitions ($>$6 mm). (*Angle Orthod.* 2016;86:577–583.)

KEY WORDS: Incisor proclination; Invisalign; Crowding

INTRODUCTION

Kesling[1] introduced the concept of tooth movement using sequential removable appliances in 1945. In 1998, Align Technology released Invisalign, which uses impressions or scans that are converted through stereolithographic technology (.stl) to a virtual study model. These.stl files are transported into the Align-Tech proprietary software, ClinCheck. This three-dimensional (3D) modeling program allows for virtual simulation of ideal tooth alignment. Each aligner is ideally worn for 14 days, moving the teeth at a maximum rate of 0.33 mm per aligner.

Anterior crowding is a key reason people seek orthodontic treatment.[2] Resolution of crowding requires either reduction in tooth mass with interproximal reduction (IPR), extraction, or an increase in arch perimeter with distalization, buccal arch expansion, or incisor protrusion. To date, two studies have investigated anterior tooth movement with Invisalign.[3,4] However, these studies focused on the position change of the lower incisors using superimposition of the 3D models. Our study used cephalometric analysis to determine the change in incisor position and angulation.

There are limited studies on the reliability of Invisalign in the treatment of crowding. Wax et al.[5]

[a] Graduate Orthodontic Resident, Department of Preventative Dentistry, School of Dentistry, University of Manitoba, Winnipeg, Manitoba, Canada.

[b] Assistant Orthodontic Professor, Department of Preventative Dentistry, School of Dentistry, University of Manitoba, Winnipeg, Manitoba, Canada.

[c] Private Practice, Winnipeg, Manitoba, Canada.

[d] Professor and Department Chair, Department of Restorative Dentistry, School of Dentistry, University of Manitoba, Winnipeg, Manitoba, Canada.

[e] Professor and Department Chair, Department of Preventative Dentistry, School of Dentistry, University of Manitoba, Winnipeg, Manitoba, Canada.

Corresponding author: Dr Laura O. Duncan, Graduate Orthodontic Resident, Department of Preventative Dentistry, School of Dentistry, University of Manitoba, 790 Bannatyne Avenue, Winnipeg, Manitoba, R3E 0W2, Canada (e-mail: laura.o.duncan@gmail.com)

Accepted: September 2015. Submitted: April 2015.
Published Online: December 4, 2015

found a 91.4% reduction in mandibular incisor crowding in a cohort of Invisalign-treated patients.

From a methodology perspective, Krieger et al.[4] found that, when assessing Invisalign treatment results, 48% of maxillary crowding was resolved using interproximal reduction, and 58% of the patients had their mandibular crowding resolved by IPR and incisor protrusion. The term *protrusion* refers to the anteroposterior position of an incisal edge of an incisor.[4] In this study, there was no discussion of incisor proclination. *Proclination* refers to the long axis angulation of an incisor, which is typically measured on a lateral cephalometric radiograph. Incisor proclination is a widely accepted treatment method, and consequence, when correcting anterior crowding.[4]

Kravitz et al.[3] looked at the predictability of the movement of anterior teeth comparing the 3D digital models of ClinCheck vs actual treatment results. The tooth movements studied included the expansion, constriction, intrusion, extrusion, mesiodistal tip, rotation, and labiolingual tip. They found that the mean accuracy of the anterior tooth movement with the Invisalign appliance was low at 41%.[3]

Through analysis of the literature we can conclude that lower incisor proclination and protrusion are critical treatment modalities in helping with crowding resolution. The lower incisor position can be measured with a reasonable means of accuracy from digital cephalometric radiographs. The initial incisor position should be a key diagnostic factor when planning treatment for Invisalign cases. If there is an intention to push the lower incisor forward in the basal bone of the mandibular symphysis, facial aesthetics, periodontal health, arch perimeter, intercanine width, and stability must be considered.

MATERIALS AND METHODS

A sample of 61 White, mixed-gender, nongrowing patients were selected from a single specialist's orthodontic practice. They were treated nonextraction with or without IPR using only Invisalign. Patients were excluded for poor compliance or if interarch elastics were used. This retrospective chart review received ethics approval from the University of Manitoba Bannatyne Campus research ethics board.

Patients were distributed into three groups depending on severity of mandibular crowding: mild (2–3.9 mm), moderate (4–5.9 mm), or severe ($>$6 mm). The degree of mandibular crowding was measured using Carey's analysis.[6,7] Gender was not equally distributed, with 44 women and 17 men. Patients were distributed into one of three groups as mild (20), moderate (22), or severe (19).

Data Collection

Pre- and posttreatment records were collected for each of the 61 participants and consisted of the following:

- digital study models created from.stl files of the dentition from iTero scans (iTero, software version 4.0, Cadent Inc., Carlstadt, N.J.),
- digital lateral cephalometric radiographs taken by the Planmeca Proline CC digital radiographic machine (Planmeca Inc., Helsinki, Finland), and
- digital study models of the dentition provided as.stl files from Align Technology and converted from polyvinyl siloxane (PVS) impressions (Align Technology, San Jose, Calif).

Reliability Testing

An intraclass correlation (ICC) test was completed on 20% of the sample to examine measurement reliability. Twelve digital study models and 12 digital cephalometric radiographs were randomly selected and measured by two independent investigators at a 4-week time interval to identify possible measurement error.

Data Measurement

The iTero scans taken pretreatment and posttreatment were uploaded into Geomagic Qualify software (Qualify, version 12:0, Geomagic, Rockhill, S.C.). The Geomagic digital software was used to measure tooth width, arch perimeter, and arch width. Digital measurement software has been shown to be more accurate, reproducible, and time efficient than measuring traditional plaster casts.[8]

Digitized Cephalometric Radiography

Each of the pre- and posttreatment lateral cephalometric radiographs were exported as Joint Photographic Experts Group (.jpg) digital files into Dolphin imaging software. Radiographic landmarks consistent with the measurement of lower incisor position and angulation were completed.[9,10] Landmark identification was undertaken by a single investigator to minimize measurement error.

SPSS software (SPSS, software version 20.0, IBM Corp, Armonk, NY) was used to analyze the data. An analysis of covariance (ANCOVA) test statistic was used to determine if there was a significant difference in the cephalometric variables for a change in lower incisor position and angulation following treatment with Invisalign. The *P* value was considered significant at $\alpha < .05$.

Arch Expansion

Intercanine width was measured from cusp tip to cusp tip, interpremolar width was measured from the palatal cusp of the first premolars, and intermolar width was measured from the mesiolingual cusp tip of the first molars.[11] In cases of attrition or restorative work the estimated cusp tip was used.[12]

An ANCOVA test statistic was used to determine if there was a statistically significant difference in the arch width following treatment with Invisalign. The *P* value was considered significant at $\alpha < .05$.

Interproximal Reduction

IPR was identified from the ClinCheck simulation for each of the samples of the total amount of tooth mass reduction that should have been completed for the entire treatment duration. This IPR value was assumed to be completed as prescribed by the software.

RESULTS

Reliability

To quantify the intrarater reliability an ICC was used. The ICC values for both the lateral cephalometric radiographs and iTero 3D models were in excess of 0.98, indicating extremely high reliability.

Treatment Time

The treatment time was determined by the total number of lower aligners worn by each patient for 2 weeks. The mean treatment time in weeks for each group was mild (53.6 $\pm$ 21.12), moderate (63.73 $\pm$ 20.69), and severe (71.68 $\pm$ 16.31).

Lower Incisor Changes

The cephalometric values were analyzed for each group using a paired *t*-test to determine if there was a statistically significant change between T_0 and T_1, and the means were calculated for each group. Differences in these means established if there was a statistically significant change between the outcomes from T_0 to T_1.

Differences Between T_0 and T_1

In the mild crowding group ($n = 20$), the only statistically significant change ($P < .05$) was overjet. In the moderate crowding group ($n = 22$), statistically significant differences were only seen in overbite and overjet ($P > .05$). This shows that the lower incisor position did not change with statistical significance if the crowding was between 2.0 mm and 5.9 mm (Table 1).

In the severe crowding group ($n = 19$), the majority of the dependent variables, excluding overbite, showed a statistically significant change between T_0 and T_1. Lower incisor angulation and anteroposterior position increased with a $P \leq .05$. The results indicate that when crowding was greater than 6.0 mm, the lower incisors proclined and protruded (Table 1).

Comparing the Lower Incisor Change From T_0 to T_1 in Mild, Moderate, and Severe Crowding Groups

An ANCOVA test was used to analyze differences between groups using a group *P* value to determine if the change in the lower incisor position was statistically significant between the three different groups. The groups were then paired together to determine if the different groups were statistically significant to each other. This is reflected in the pairwise *P* values ($P \leq .05$) (Table 2).

The mild and moderate groups had no statistical significance in lower incisor position or angulation between them ($P > .05$). The severe crowding group was statistically significant from both the mild and moderate crowding groups ($P < .05$). When there was a statistically significant difference in the lower incisor position between the groups (ie, when the group *P* value was $< .05$), the pairwise *P* values that included the severe crowding group were also statistically significant at $P < .05$.

Relationship Between Lower Incisor Position and Lower Incisor Angulation at T_0 and T_1

A Pearson correlation test was completed to compare the landmarks that used both linear and angular measurements; these included L1-NB and L1-APog. There is a statistically significant relationship between the position of the lower incisor in millimeters and the angulation in degrees for the two planes that have both of the descriptive analyses. The Pearson correlation test reported 0.887 for L1-NB and 0.897 for L1-APog. Thus, when there is a change in the anteroposterior position of the lower incisor there is also a change in its angulation.

Arch Width Changes

The difference from T_0 to T_1 showed a highly statistically significant change in the intercanine, interpremolar, and intermolar widths for all three groups. The arch width increase is greater in the premolar region for the moderate and severe crowding groups (Table 3).

Although there was a statistically significant increase in the buccal arch expansion in each of the groups, there were no statistically significant differences in the intercanine, intermolar, and intercanine widths between the groups at T_1. This shows that the change in arch width is correlated to the pretreatment arch form

Table 1. Sample Means Calculated at T_0 and T_1 for the Mild, Moderate, and Severe Crowding Groups and the Difference in These Means

Dependent Variable	T_0 Mean	T_1 Mean	Difference in Means	Difference Means, 95% CI[a]	*P* Value
Mild					
Overbite	2.195	1.585	0.610	–0.0970, 1.3170	.0868
Overjet	3.500	2.770	0.730	0.0307, 1.4293	.0416*
L1-NB (deg)	26.200	27.580	–1.380	–3.2255, 0.4655	.1341
L1-NB (mm)	5.260	5.645	–0.385	–0.0469, 0.2769	.2384
L1-MPA (deg)	95.760	96.805	–1.045	–2.8740, 0.7840	.2465
L1-APog (deg)	25.855	27.265	–1.410	–3.2992, 0.4792	.1348
L1-APog (mm)	2.225	2.510	–0.285	0.9359, 0.3659	.3709
Moderate					
Overbite	2.809	2.073	0.7364	0.1783, 1.2944	.0122*
Overjet	3.368	2.681	0.6864	0.4430, 0.9297	<.001*
L1-NB (deg)	26.073	26.268	–0.1955	–2.3126, 1.9217	.8496
L1-NB (mm)	5.136	5.414	–0.2773	–0.7749, 0.2204	.2596
L1-MPA (deg)	95.000	94.705	0.2955	–1.9048, 2.4957	.7828
L1-APog (deg)	25.750	26.109	–0.3591	–2.3176, 1.5994	.7068
L1-APog (mm)	2.537	2.768	–0.2318	–0.7524, 0.2887	.3649
Severe					
Overbite	2.532	2.137	0.3947	–0.6847, 1.4742	.4523
Overjet	4.290	2.963	1.3263	0.2495, 2.4031	.0186*
L1-NB (deg)	24.011	28.716	–4.7053	–7.0150, –2.3956	.005*
L1-NB (mm)	4.453	6.005	–1.5526	–2.2265, –0.8787	.001*
L1-MPA (deg)	94.532	98.479	–3.9474	–6.2254, –1.6693	.0019*
L1-APog (deg)	21.911	26.732	–4.8211	–7.2040, –2.4381	.0005*
L1-APog (mm)	0.958	2.700	–1.7421	–2.5213, –0.9629	.0002*

[a] CI indicates confidence interval.
* $P \leq .05$.

Table 2. ANCOVA Analysis of Cephalometric Changes Between Each Group Between T_1 and T_0

Dependent Variable	Group	Group *P* Value	Group Means	Pairwise *P* Values	
Overbite		.2346			
	Mild		1.667	Mild vs. Mod	.2249
	Moderate		2.001	Mod vs. Sev	.6272
	Severe		2.134	Mild vs. Sev	.1008
Overjet		.6934			
	Mild		2.787	Mild vs. Mod	.7340
	Moderate		2.710	Mod vs. Sev	.3954
	Severe		2.912	Mild vs. Sev	.6031
L1-NB (deg)		.0098*			
	Mild		27.179	Mild vs. Mod	.2690
	Moderate		25.937	Mod vs. Sev	.0026*
	Severe		29.520	Mild vs. Sev	.0494*
L1-NB (mm)		.0051*			
	Mild		5.432	Mild vs. Mod	.6708
	Moderate		5.289	Mod vs. Sev	.0023*
	Severe		6.374	Mild vs. Sev	.0090*
L1-MPA		.0099*			
	Mild		96.336	Mild vs. Mod	.2312
	Moderate		94.778	Mod vs. Sev	.0026*
	Severe		98.887	Mild vs. Sev	.0615*
L1-APog (deg)		.2856			
	Mild		26.848	Mild vs. Mod	.3167
	Moderate		25.727	Mod vs. Sev	.1252
	Severe		27.613	Mild vs. Sev	.5401
L1-APog (mm)		.0184*			
	Mild		2.336	Mild vs. Mod	.8463
	Moderate		2.403	Mod vs. Sev	.0155*
	Severe		3.305	Mild vs. Sev	.0101*

* $P \leq .05$.

Table 3. Arch Width Differences Between T_0 and T_1 in the Mild, Moderate, and Severe Crowding Groups for Canine, Premolar, and Molar Expansion

Outcome	T_0 Mean	T_1 Mean	Difference in Means	Difference Means, 95% CI[a]	*P* Value
Mild					
Canine	25.567	25.854	–1.2868	–1.8608, –0.7127	.0002*
Premolar	26.456	28.031	–1.5752	–2.3062, –0.8441	.0002*
Molar	32.577	34.231	–1.6537	–2.1326, –1.1748	<.0001*
Moderate					
Canine	23.556	25.331	–1.7742	–2.5553, –0.9931	.0001*
Premolar	24.943	27.465	–2.5223	–3.5381, –1.5064	<.0001*
Molar	32.741	34.606	–1.8653	–2.408, –1.3226	<.0001*
Severe					
Canine	24.077	25.816	–1.7391	–2.5470, –0.9312	.0003*
Premolar	24.973	28.168	–3.1952	–4.1464, –2.2440	<.0001*
Molar	31.334	33.986	–2.6526	–3.3550, –1.9521	<.0001*

[a] CI indicates confidence interval.
* $P \leq .05$.

because there is no statistically significant difference in arch width posttreatment (Table 4).

Prescribed vs Actual IPR

When the prescribed vs actual IPR are compared as a linear regression relationship ($r^2 = 0.44$), it shows a poor correlation (Figure 1).

DISCUSSION

There are very few studies investigating the relationship between Invisalign treatment and crowding resolution from both reliability and methodology perspectives. Wax et al.[5] reported a reliability index of 91.4% in the correction of mandibular incisor crowding. Krieger et al.[4] reported that 58% of patients had lower incisor crowding resolved with a combination of IPR and incisor protrusion, but they did not report on incisor proclination, with *protrusion* referring to the anterior movement of the incisal edge. Kravitz et al.[3] found that predictability of tooth movement when resolving <5 mm of crowding or spacing with incisor protrusion was only 41%. Cephalometric evaluation increases the accuracy of measuring the proclination and protrusion of incisors; however, consideration must be made when planning treatment for protrusion. The most accurate treatment methodology for crowding resolution is to increase the amount of IPR.

Our study showed that in the mild and moderate crowding groups, aside from overbite and overjet, there were no statistically significant changes between T_0 and T_1. In the severe crowding group, all of the variables, including lower incisor position and angulation, showed a statistically significant change from T_0 to T_1. Therefore, we can conclude that, in a more severely crowded dentition, the Invisalign treatment caused the lower incisor to procline and protrude.

Our study is the first to report on buccal arch expansion and its relationship to crowding resolution. The results revealed buccal arch expansion played a significant role in crowding management. The mean increase in intermolar width was 1.65 mm in the mild crowding group, 1.86 mm in the moderate group, and 2.65 mm in the severe group. Interpremolar widths increased 1.57 mm, 2.52 mm, and 3.19 mm, respectively, and intercanine widths increased 1.28 mm, 1.77 mm, and 1.74 mm, respectively. It was noted that there was no statistical difference between the three

Table 4. Analysis of Covariance to Compare the Buccal Arch Widths Between the Groups at T_1

Outcome	Group	Group *P* Value	Group Mean	Pairwise *P* Value	
Canine		.814			
	Mild		25.56	Mild vs Moderate	.9862
	Moderate		25.583	Mod vs Severe	.5693
	Severe		25.802	Mild vs Severe	.5892
Premolar		.1148			
	Mild		27.539	Mild vs Moderate	.6806
	Moderate		27.712	Moderate vs Severe	.1029
	Severe		28.401	Mild vs Severe	.0519
Molar		.1429			
	Mild		33.974	Mild vs Moderate	.4807
	Moderate		34.221	Mod vs Severe	.1874
	Severe		34.704	Mild vs Severe	.0520

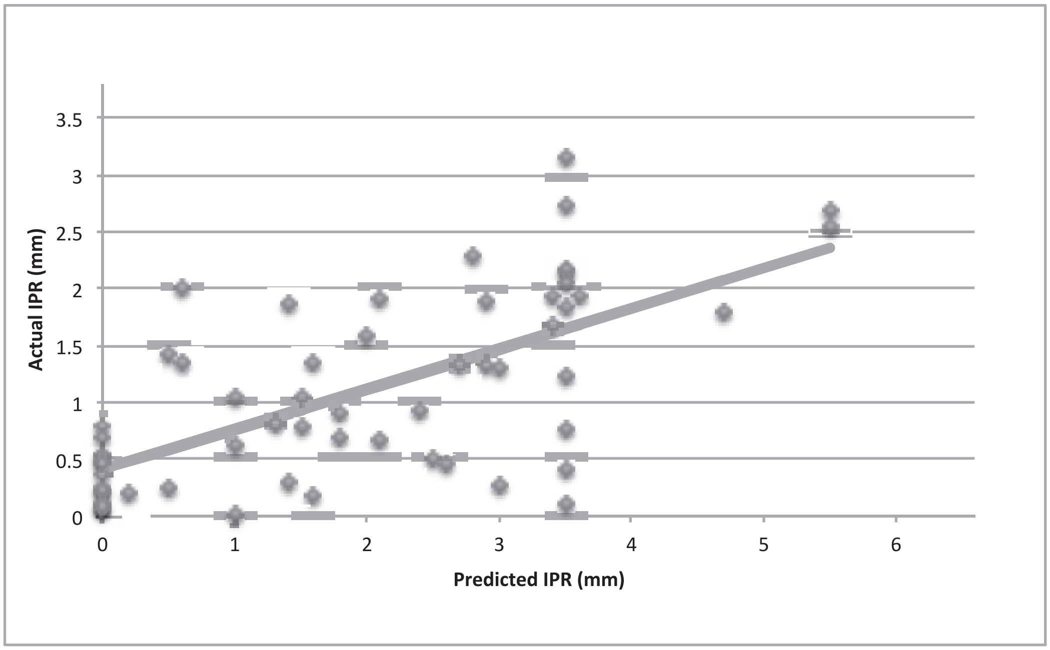

Figure 1. Graph showing the linear regression model for the amount of predicted interproximal reduction (IPR) from the ClinCheck prescription vs the amount of actual IPR completed.

groups in final arch width, suggesting there may be a correlation between crowding and pretreatment arch width. Ricketts et al.[13] calculated a formula between arch width and arch perimeter and reported that for every 1 mm of molar expansion, 0.25 mm of space is produced, and for every 1 mm of premolar expansion, 0.7 mm of space is created.

The inclusion criteria for our study required that IPR be done as programmed by the ClinCheck software. Studies have shown that, even when IPR is completed clinically as prescribed, it might not be accurate. Chudasama and Sheridan[14] and Johner et al.[15] highlighted that the amount of completed IPR achieved was consistently less than prescribed. In our study, when we compared the pretreatment with the post-treatment sum of the mesiodistal tooth widths, we found similar results. When removing the outliers, the percentage of crowding correction with IPR reduced to a mean of 35% between the three groups.

Of interest when considering IPR is the difference in mean values of IPR in the mild vs severe group of less than 1.0 mm. An increase in crowding did not correlate with a significant increase in IPR ($P > .05$). Our results clearly showed that buccal arch expansion and anterior proclination were the predominate contributors to crowding resolution in the severe crowding cohort. This indicates that if more IPR is prescribed, a reduction in proclination could be expected.

Reducing incisor proclination has benefits from a periodontal and stability perspective. Periodontally, moving roots through the thin labial bone increases the risk of bone dehiscence and recession that can occur in certain gingival phenotypes.[16] Maintaining lower incisors in their original position can reduce relapse.[17,18] Broadening contacts with IPR is still controversial in the literature but has shown that flattening the interproximal contacts through IPR may increase long-term stability.[19,20]

McNamara et al.[21] reported that patients with more than 6 mm of crowding in the mandibular arch typically require extraction. In cases treated with Invisalign, buccal arch expansion was insufficient to prevent lower incisor proclination. Due to the periodontal strain and increased relapse potential reported from lower incisor proclination, the clinician must consider the potential for extraction in crowded cases of greater than 6 mm or increase the amount of IPR in the treatment plan.[16]

CONCLUSIONS

- In mild to moderate lower anterior crowding cases, there is no change in the lower incisor position or angulation.
- Where crowding exceeds 6 mm treated nonextraction, lower incisors tend to procline and protrude.
- Buccal arch expansion and interproximal reduction have a statistically significant effect on the resolution of crowding in mild, moderate, and severe cases.
- When treating crowded dentitions, buccal expansion and IPR are important clinical tools to negate or minimize lower incisor proclination.
- Intercanine, interpremolar, and intermolar widths are not significant factors in the mild, moderate, and

severe cases. Thus, pretreatment crowded arches are narrower than noncrowded arches.

- Prescribed IPR is not accurately applied.

REFERENCES

1. Kesling HD. The philosophy of the tooth positioning appliance. *Am J Orthod Oral Surg*. 1945;31:297–304.
2. Meier B, Wiemer KB, Miethke RR. Invisalign®—patient profiling. Analysis of a prospective survey. *J Orofac Orthop*. 2003;64:352–358.
3. Kravitz ND, Kusnoto B, BeGole E, Obrez A, Agran B. How well does Invisalign work? A prospective clinical study evaluating the efficacy of tooth movement with Invisalign. *Am J Orthod Dentofacial Orthop*. 2009;135:27–35.
4. Krieger E, Seiferth J, Marinello I, et al. Invisalign® treatment in the anterior region: were the predicted tooth movements achieved? *J Orofac Orthop*. 2009;73:365–376.
5. Wax N, Beck FM, Firestone AR. Effectiveness of Invisalign® on correcting anterior crowding and spacing. Paper presented at: American Association for Dental Research (AADR) Annual Meeting; 2010; Washington, DC.)
6. Carey CW. Linear arch dimension and tooth size. *Am J Orthod*. 1949;35:762–775.
7. Weinberg M, Sadowsky C. Resolution of mandibular arch crowding in growing patients with Class I malocclusions treated nonextraction. *Am J Orthod Dentofacial Orthop*. 1996;110:369–364.
8. Grunheid T, Patel N, De Felippe NL, Wey A, Gaillard PR, Larson BE. Accuracy, reproducibility, and time efficiency of dental measurements using different technologies. *Am J Orthod Dentofacial Orthop*. 2014;145:157–164.
9. Ricketts RM. A foundation for cephalometric communication. *Am J Orthod*. 1960;46:330–357.
10. Steiner CC. Cephalometrics for you and me. *Am J Orthod*. 1953;39:720–755.
11. Prado GP, Furtado F, Aloise AC, Bilo JP, Masako Ferreira L, Pereira MD. Stability of surgically assisted rapid palatal expansion with and without retention analyzed by 3-dimensional imaging. *Am J Orthod Dentofacial Orthop*. 2014; 145:610–612.
12. Taner T, Ciğer S, El H, Germeç D, Es A. Evaluation of dental arch width and form changes after orthodontic treatment and retention with a new computerized method. *Am J Orthod Dentofacial Orthop*. 2004;126:463–474.
13. Ricketts RM, Roth RH, Chaconas SJ, Schulhof RJ, Engel GA. *Orthodontic Diagnosis and Planning: Their Roles in Preventive and Rehabilitative Dentistry*. Denver, CO:Rocky Mountain Orthodontics; 1982:194–200.
14. Chudasama D, Sheridan JJ. Guidelines for contemporary air-rotor stripping. *J Clin Orthod*. 2007;41:315–320.
15. Johner AM, Pandis N, Dudic A, Kiliaridis S. Quantitative comparison of 3 enamel-stripping devices in vitro: how precisely can we strip teeth? *Am J Orthod Dentofacial Orthop*. 2013;143(4 suppl):S168–S172.
16. Yared KF, Zenobio EG, Pacheco W. Periodontal status of mandibular central incisors after orthodontic proclination in adults. *Am J Orthod Dentofacial Orthop*. 2006;130: 6.e1–6.e8.
17. Little RM. Stability and relapse of mandibular anterior alignment: University of Washington studies. *Semin Orthod*. 1999;5:191–204.
18. Germec-Cakan D, Taner TU, Akan, S. Arch-width and perimeter changes in patients with borderline Class I malocclusion treated with extractions or without extractions with air-rotor stripping. *Am J Orthod Dentofacial Orthop*. 2010;137:734.e731–734.e737; discussion 734–735.
19. Aasen TO, Espeland L. An approach to maintain orthodontic alignment of lower incisors without the use of retainers. *Eur J Orthod*. 2005;27:209–214.
20. Singh G. *Textbook of Orthodontics (Second Edition)*. New Dehli, India: Jaypee Brothers Medical Publishers (P) Ltd; 2007;242.
21. Geran RG, McNamara JA Jr, Baccetti T, Franchi L, Shapiro LM. A prospective long-term study on the effects of rapid maxillary expansion in the early mixed dentition. *Am J Orthod Dentofacial Orthop*. 2006;129:631–640.