Original Article

Relationship between dental crowding and mandibular incisor proclination during orthodontic treatment without extraction of permanent mandibular teeth

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ABSTRACT

Objective: To examine changes in mandibular incisor proclination and protrusion resulting from alleviation of crowding.

Materials and Methods: Records of 96 patients from a private practice treated without extractions or interproximal enamel reduction in the mandibular arch were included. Pre- and post-treatment cephalograms and models were examined to determine changes in incisor proclination, protrusion and crowding.

Results: For every millimeter of crowding alleviation, increases in incisor proclination (ΔIMPA) and protrusion (ΔL1 to A-Pog) of 0.5° and 0.2 mm, respectively, were found, on average. High variability was calculated for both linear variables (that can be reduced by incorporating other variables by multilinear regression).

Conclusions: For every millimeter of crowding alleviated, 0.5° of proclination and 0.2 mm of protrusion are expected. Our results indicate that proclination is mulifactorial and cannot be explained solely by the amount of crowding alleviated during orthodontic treatment. These results may be a useful guiding principle rather than a prognostic tool. (*Angle Orthod.* 2016;86:727–733.)

KEY WORDS: Dental crowding; Orthognathic surgery; Dental VTO; Cephalometric analysis; Self-ligating brackets

INTRODUCTION

Dental crowding is the predominant malocclusion and the main reason people seek orthodontic treatment.[1,2] Crowding can be alleviated by tooth reduction (extraction or interproximal enamel reduction) or arch lengthening (expansion, proclination, or distalization). Distalizataion without active distal force application in the mandibular dental arch is minimally effective[3]; therefore, most crowding alleviation without extraction or interproximal enamel reduction results in transverse arch expansion and incisor proclination. Clinicians have claimed that a predictable linear relationship exists between the extent of uncrowding and the change in incisor proclination or protrusion.[4–7] Sadowsky[4] suggested that for each millimeter of crowding alleviation, mandibular incisor position will be advanced by 0.5 mm in relation to the cephalometric line connecting A-point to pogonion (ΔL1 to A-Pog). McLaughlin[6] claimed that alleviation of 1 mm of crowding should result in 1.25° of incisor proclination. Although this relationship is cited in the literature and taught at professional gatherings, it may be simplistic—never having been substantiated by clinical research. A reliable estimate of the relationship between crowding alleviation and the spatial position of the mandibular incisor can improve the dental visual treatment objective (dental VTO).[8] The dental VTO is important for all orthodontic patients, especially candidates for orthognathic surgery.[5,9] The presurgical position of the teeth dictates the surgical movement of the jaws. Reliable planning of tooth position will help determine whether extractions or adjunctive surgical procedures (eg,

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genioplasty) are necessary and will improve the monitoring of treatment progress and communication between the orthodontist and the maxillofacial surgeon.[9,10]

The position of the mandibular incisors in relation to the jaw bone is determined using cephalometric analysis. The incisor-mandibular plane angle has been used as a diagnostic measurement and a treatment goal for many decades.[11–13] A marked change in incisor angulation is clinically significant, as it influences the health of the supporting soft tissues, esthetic profile of the patient, and long-term treatment stability.[11–15]

The aim of this study was to examine the relationship between the degree of change in mandibular incisor proclination and protrusion as a result of crowding alleviation during orthodontic treatment and to examine other variables that might influence the resultant change.

MATERIALS AND METHODS

The Institutional Review Board of the Hadassah University Medical Centre approved the study protocol. A total of 111 patient clinical records were randomly selected from the private practice of one of the authors. Inclusion criteria: (1) nonextraction orthodontic treatment and no interproximal reduction of the mandibular dental arch, (2) fully erupted permanent mandibular dentition (not including second and third molars) before treatment, (3) good-quality lateral cephalograms and plaster models before and after treatment and (4) no missing or morphologically aberrant mandibular teeth. Treatment protocol included full orthodontic fixed appliances (Roth prescription, 0.022-inch slot, rectangular arch form wires). Both self-ligating brackets (InOvation R or InOvation C, GAC, Islandia, NY) and conventional brackets (Ovation, GAC) were used. Age, gender, type of appliance, and use of Class II elastics were recorded for all patients.

Lateral cephalograms were hand traced on tracing paper (3M Unitek, Monrovia, Calif) in a darkened room on a view box. The following cephalometric landmarks were marked with a fine pencil dot: (1) A-point, subspinale; (2) B-point, supramentale; (3) menton, the lowest point on the symphyseal shadow of the mandible; (4) Li, mandibular incisor tip; (5) La, mandibular incisor root apex; (6) L1, the most anteriorly placed point of the mandibular incisor crown; and (7) pogonion, the most anterior point of the chin. The following cephalometric measurements were made with a protractor (Ormco, Orange, Calif): (1) incisor-mandibular plane angle (IMPA), which is the angle between a plane tangent to the mandibular border of the mandible passing through menton (mandibular plane) and a line passing through points Li and La (incisor long axis) and (2) L1 to A-Pog, the distance between L1 and a line connecting A-point to pogonion (in mm).

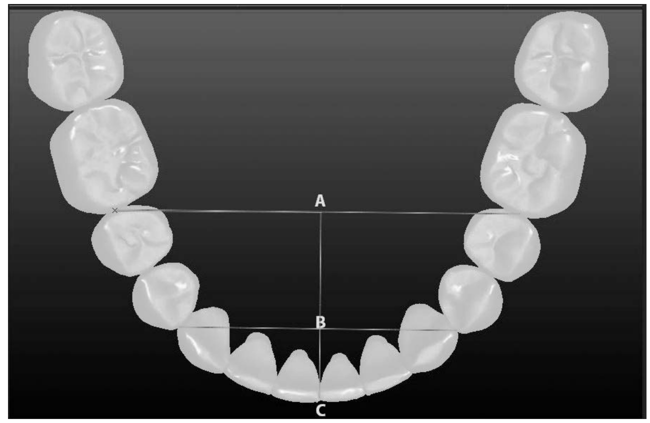

Figure 1. Arch depth from molars (depth 6-6) was measured as the distance A-C. Arch depth from canines (depth 3-3) was measured as the distance B-C.

Plaster models were measured using an electronic IP67 digital caliper (Tesa Technology, Bergdietikon, Switzerland). The tooth size–arch length discrepancy (TSALD) of each model was calculated by subtracting the combined mesiodistal widths of the teeth (mesial of first molar to first molar) from the arch perimeter. The arch perimeter was calculated as the sum of the four arch segments measured from the mesial contact point of the mandibular first molar to the distal contact point of the mandibular lateral incisor; distal contact point of the mandibular lateral incisor to the contact point between the central incisors; all measured at the level of the occlusal plane, both right and left. Arch width was measured at three locations on each model (before and after treatment): (1) intercanine width, distance between right and left canine tips; (2) interpremolar width, distance between right and left first premolar buccal cusp tips; and (3) intermolar width, distance between right and left first molar mesiobuccal cusp tips. The maximum depth of the curve of Spee (COS) was measured with a ruler as the greatest perpendicular distance between the buccal cusp tips of the mandibular teeth and a plane described by the central incisors and the distal cusp tip of the most posterior tooth in the mandibular arch. Arch depth from molars (depth 6-6) was measured as the perpendicular distance between the midpoint of a line that extends between the mesial contact point of the first mandibular molar and the incisal edges. Arch depth from the canines (depth 3-3) was measured as the perpendicular distance between the midpoint of a line that extends between the distal contact point of the mandibular canine and the incisal edges (Figure 1).

All measurements were completed by one experienced orthodontist (O.Y.). To examine intraexaminer reliability, 10 randomly selected records were measured again at least 2 weeks after preliminary data collection. Intraexaminer reliability and reproducibility were determined using the intraclass correlation coefficient (ICC) and Cronbach's α, with a range from 0 to 1. The ICC was found to range from 0.75 to 0.96; Cronbach's α, from 0.85 to 0.99, indicating good-to-excellent intraexaminer reliability for all parameters.

Statistical Analysis

The data was analyzed using SPSS 19.0 software (SPSS Inc, Chicago, Ill). Descriptive statistics were performed to calculate the change during treatment in each measurement (ΔTSALD, ΔIMPA, ΔL1 to A-Pog, ΔWidth Canine, ΔWidth Premolar, ΔWidth Molar, ΔCOS, ΔDepth 6-6, and ΔDepth 3-3).

Pearson correlations were calculated between each variable to change in proclination (ΔIMPA) and to ΔL1 to A-Pog. A *P* value of $<.05$ was considered statistically significant. A multiple linear (backward stepwise) regression analysis including the significantly correlated variables (ΔTSALD, ΔIMPA, ΔL1 to A-Pog, ΔWidth Canine, ΔWidth Premolar, ΔWidth Molar, ΔDepth 6-6, and ΔDepth 3-3) was applied.

A simple linear regression analysis was used to find the relationship between ΔTSALD and ΔIMPA and between ΔTSALD and ΔL1 to A-Pog. The regression equation ($y = bx + a$) was formulated to predict the change in incisor proclination and protrusion as a function of crowding alleviation (y = ΔIMPA or ΔL1 to A-Pog; x = ΔTSALD; a = y intercept; b = slope).

RESULTS

Ninety-six patients (47 females and 49 males) with an average age of 13.4 ± 1.6 years (range, 10.5 to 19.3 years) were included in the study. Fifteen (14.8%) patients were excluded because of unsatisfactory records. Thirty-six (37.5%) used class II elastics during treatment. In 41 (42.7%) patients, self-ligating brackets were used and the remaining 55 (57.3%) were treated with conventional brackets.

Table 1 presents the mean, SD, and range for each measurement. Significant correlations to ΔL1 to A-Pog and/or to ΔIMPA were found with ΔCrowding, ΔDepth 6-6, ΔDepth 3-3, ΔWidth canine, ΔWidth premolar, and ΔWidth molar.

Table 2 presents the first and last steps of the stepwise process for ΔL1 to A-Pog multilinear analysis. In the last step, a significant linear relationship between ΔTSALD and ΔDepth 6-6, to ΔL1 to A-Pog with the adjusted coefficient of determination, $R^2 = 0.27$, was found. The regression equation is ΔL1 to A-Pog = −0.15(ΔTSALD) + 0.13(ΔDepth 6-6) + 1.08.

Table 3 presents the first and last steps of the stepwise process for ΔIMPA multilinear analysis. In the last step (step 5), results showed a significant linear relationship between ΔTSALD and ΔDepth 6-6, to change in proclination (ΔIMPA), with adjusted $R^2 = 0.16$. The regression equation is ΔIMPA = −0.41(ΔTSALD) + 0.41(ΔDepth 6-6) + 2.14.

The results of the linear regression analysis showed a negative linear relationship between ΔTSALD and ΔL1 to A-Pog, with adjusted $R^2 = 0.17$. The regression equation ($y = bx + a$) is ΔL1 to A-Pog = −0.19 ΔTSALD + 1.01 (Figure 2). For every millimeter of ΔTSALD, incisor protrusion was increased (ΔL1 to A-Pog) by 0.19 mm.

The analysis also showed a negative linear relationship between ΔTSALD and ΔIMPA, with adjusted $R^2 = 0.08$. A negative change in ΔTSALD indicates

Table 1. Mean, SD, and Range Measurements of Highly Correlated Variables

		Mean	SD	Minimum	Maximum
IMPA (°)	Before	93.9	6.6	74.0	110.0
	After	96.7	6.1	73.0	112.0
	ΔIMPA[a]	2.7	4.5	−8.0	13.0
L1 to A-Pog (mm)	Before	2.9	1.6	−1.0	7.5
	After	4.2	1.6	1.0	8.0
	ΔL1 to A-Pog[b]	1.3	1.2	−1.5	3.5
TSALD (mm)	Before	1.2	3.2	−10.9	9.1
	After	0.2	0.9	−1.6	1.8
	ΔTSALD[c]	−1.0	3.1	−8.1	12.7
Curve of Spee (mm)	Before	2.2	1.1	0.0	5.5
	After	0.3	0.5	0.0	2.0
	ΔCOS	−1.9	1.1	−5.5	0.0
Width Canine (mm)	Before	26.3	1.8	21.4	30.0
	After	26.6	1.4	22.4	30.1
			1.6	−4.1	3.9
Width Premolar (mm)	Before	33.6	2.3	28.7	39.2
	After	36.0	1.8	26.4	39.3
	ΔWidth canine	2.4	2.4	−6.5	8.1
	0.3				
	ΔWidth premolar				
	ΔWidth molar				
Width Molar (mm)	Before	43.3	2.5	37.6	50.2
	After	44.7	1.6	41.8	49.1
		1.4	2.0	−5.9	5.3
Depth 6-6 (mm)	Before	23.4	2.3	9.2	27.1
	After	23.7	1.6	19.9	27.1
	ΔDepth 6-6	0.3	2.2	−6.6	13.4
Depth 3-3 (mm)	Before	9.5	1.4	6.0	12.4
	After	9.8	1.8	7.6	24.3
	ΔDepth 3-3	0.3	2.1	−3.1	14.5

[a] indicates change over the course of treatment; negative TSALD change score represents crowding alleviation.
[b] indicates change over the course of treatment; negative IMPA change score represents incisor retroclination.
[c] indicates change over the course of treatment; negative L1 to A-Pog change score represents incisor retrusion.

Table 2. Results of First and Last Steps of Stepwise Process for ΔL1 to A-Pog Multilinear Regression

Model	ΔL1APOG	Unstandardized Coefficients		Standardized Coefficients			95.0% Confidence Interval for B	
		Beta	Std Error	Beta	*t*-test	Level of Significance	Mandibular Bound	Maxillary Bound
1*	(Constant)	0.987	0.161		6.143	<.001	0.668	1.307
	ΔCrowding	−0.117	0.051	−0.0297	−2.307	.023	−0.218	−0.016
	ΔWidth premolar	0.057	0.063	0.110	0.906	.367	−0.068	0.183
	ΔWidth molar	0.005	0.069	0.008	0.067	.946	−0.132	0.142
	ΔDepth 3-3	−0.098	0.118	−0.163	−0.832	.408	−0.332	0.136
	ΔDepth 6-6	0.217	0.122	0.0384	1.782	.078	−0.025	0.460
4**	(Constant)	1.083	0.117		9.283	<.001	0.851	1.315
	ΔCrowding	−0.155	0.040	−0.0393	−3.901	<.001	−0.234	−0.076
	ΔDepth 6-6	0.126	0.057	0.223	2.207	.030	0.013	0.239

* Adjusted $R^2 = 0.259$.
** Adjusted $R^2 = 0.271$.

that the crowding was reduced, and a positive change in DTSALD indicate that spaces were close/crowding increases. The regression equation ($y = bx + a$) is $\Delta\text{IMPA} = -0.52\ \Delta\text{TSALD} + 2.23$ (Figure 3). For every millimeter of ΔTSALD, ΔIMPA was increased by 0.52°.

DISCUSSION

Crowding alleviation and proclination are interrelated. In order to alleviate crowding, the arch perimeter can be expanded, usually causing incisor proclination. Reducing incisor proclination requires space and, therefore, increases crowding.[1] Furthermore, a marked increase in incisor proclination from orthodontic treatment is considered unstable and can result in side effects such as labiogingival recession.[14–16]

Our results confirm the significant correlation between crowding alleviation and the change in mandibular incisor proclination and protrusion during orthodontic treatment. However, the magnitude of incisor proclination and protrusion change caused by a given amount of crowding alleviation was lower than that previously published.[4–6] Sadowsky[4] suggested that for each millimeter of crowding alleviation, the mandibular incisor position will be advanced by 0.5 mm in relation to the cephalometric line ΔL1 to A-Pog. In our sample, linear regression analysis showed that for every millimeter of ΔTSALD, incisor protrusion increased by only 0.2 mm. McLaughlin[6] claimed that alleviation of 1 mm of crowding should result in 1.25° of incisor proclination. In our sample, for every millimeter of ΔTSALD, ΔIMPA was increased by only 0.5°. Neither Sadowsky nor McLaughlin substantiated their data empirically.

Our results imply that less incisor proclination is expected when crowding is alleviated by nonextraction orthodontic treatment than previously suggested. It is important to note that all the patients in our sample were treated with rectangular arch form wires. These wires tend to expand arches transversally and may cause less protrusion of mandibular incisors. Different treatment protocols (eg, ovoid or tapered arch form) might result in more pronounced proclination. Based on our results, it is not unreasonable to claim that the marked incisor proclination/protrusion previously reported[4–6] could not be measured even using a differ-

Table 3. Results of First and Last Steps of Stepwise Process for ΔIMPA Multilinear Regression

Model	ΔIMPA	Unstandardized Coefficients		Standardized Coefficients			95.0% Confidence Interval for Beta	
		Beta	Std Error	Beta	*t*-test	Level of Significance	Mandibular Bound	Maxillary Bound
1*	(Constant)	1.459	0.631		2.311	.023	0.204	2.713
	ΔCrowding	−0.274	0.197	−0.194	−1.388	.169	−0.667	0.118
	ΔWidth premolar	0.374	0.255	0.199	1.469	.145	−0.132	0.880
	ΔWidth molar	−0.053	0.267	−0.024	−0.200	.842	−0.583	0.477
	ΔDepth 3-3	−0.092	0.489	−0.043	−0.189	.851	−1.065	0.880
	ΔDepth 6-6	0.504	0.494	0.248	1.022	.310	−0.477	1.486
	ΔWidth canine	−0.033	0.356	−0.012	−0.094	.926	−0.742	0.675
5**	(Constant)	2.136	0.449		4.756	<.001	1.244	3.028
	ΔCrowding	−0.407	0.153	−0.288	−2.667	.009	−0.711	−0.104
	ΔDepth 6-6	0.413	0.220	0.203	1.880	.063	−0.023	0.849

* Adjusted $R^2 = 0.149$.
** Adjusted $R^2 = 0.161$.

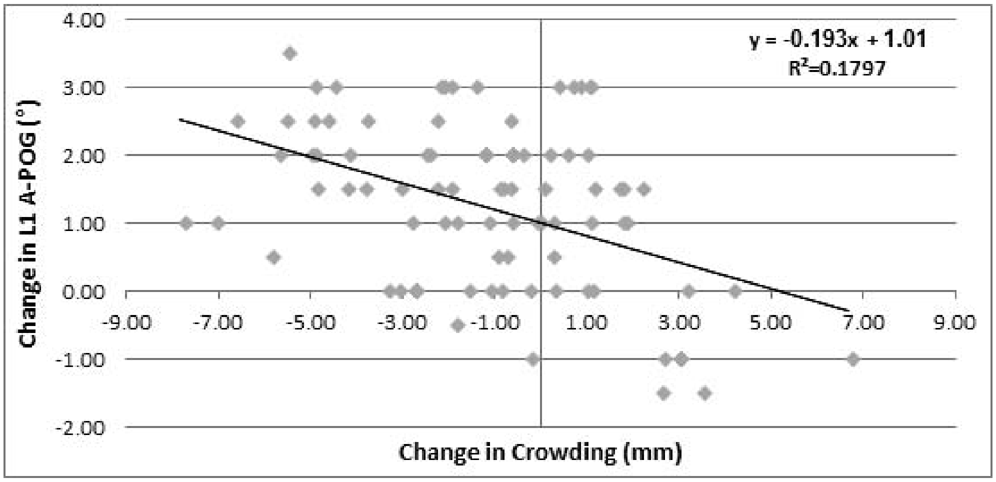

Figure 2. Scatter plot of the change in incisor protrusion (y-axis–ΔL1 to A-Pog) as a result of crowding alleviation (x-axis–ΔTSALD). For every millimeter of ΔTSALD, ΔL1 to A-Pog will increase by 0.19 mm.

ent form of archwire. The forces that expand the mandibular arch in orthodontic treatment and move the incisors to a more protruded location are probably not the only significant forces involved. Other forces that tend to stabilize teeth and diminish orthodontic movement include bone resilience, perioral muscle contraction, and others. Furthermore, the perioral muscles (orbicularis oris and mentalis) produce forces that limit the amount of incisor proclination, have a marked effect during retention, and play a role determining long-term stability.[14] Our results may imply that these forces have a more significant effect during treatment than previously considered. The lip muscles might resist the tendency of the incisors to procline, and this effect has been named the "lip-bumper effect."[17,18] According to some studies, the lip bumper effect may be attributed to the light forces produced by self-ligating brackets.[17] In our study, 41 patients were treated with self-ligating brackets and 55 with conventional brackets. A multiple regression analysis showed that appliance type did not significantly change the relationship between crowding alleviation and incisor proclination. The claim that self-ligating brackets tend to procline mandibular incisors less is not supported by our results.

There was a great deal of variability in the relationship between incisor proclination or protrusion and the amount of crowding alleviation ($R^2 = 0.09$ and $R^2 = 0.18$, respectively), making predicting the amount of proclination anticipated as a result of treatment difficult. A better predictive value was attained using a backward multilinear analysis. The ΔDepth 6-6 variable was found to be an additional significant parameter, strengthening the relationship and meaningfully

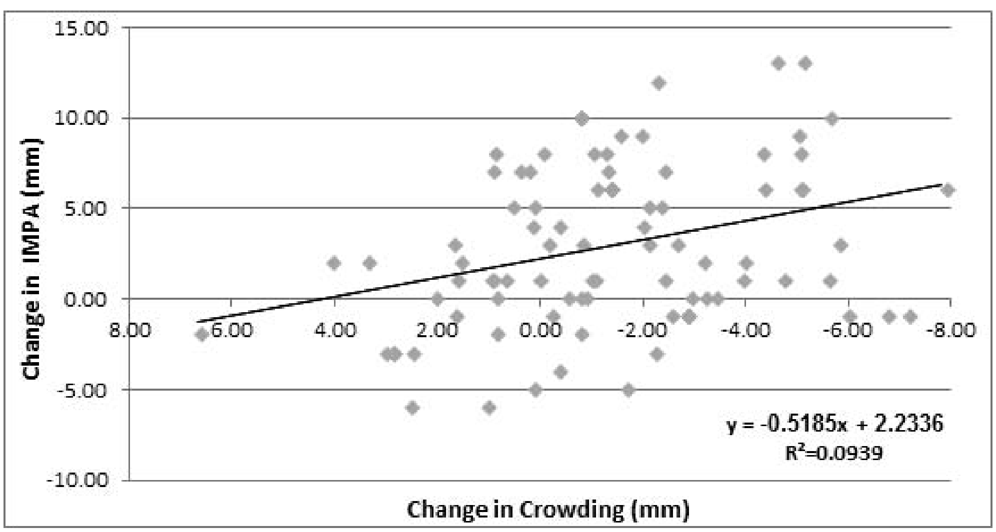

Figure 3. Scatter plot of the change in incisor angulation (y-axis–ΔIMPA) as a result of x-axis–ΔTSALD. For every millimeter of ΔTSALD, ΔIMPA will increase by 0.52°.

upgrading adjusted R^2 to 0.16 and 0.27, respectively. This result is logical, since the change in proclination and protrusion is equivalent to a forward movement of the mandibular incisors, which increases mandibular arch depth. Class II elastics were also found to be significant in the protrusion relationship (with a moderate contribution to the adjusted R^2).

The results are based on the main effects identified during stepwise analysis. When the possible interactions between independent variables are considered, we improve adjusted R^2 to 0.31 and 0.47, respectively. Some of these interactions are interesting, for example, that between arch depth and intercanine width and between intercanine width and Class II elastics should be investigated further.

Abdulaziz et al. examined the change of mandibular incisor proclination as a result of different types of mechanics. The research included 28 patients, divided into two groups by the mechanics used for COS leveling (rectangular vs round archwires).[19] They concluded that a comparable amount of proclination is expected using both types of mechanics for leveling the COS. They also examined the influence of different variables (arch depth, intercanine width, etc) on the amount of incisor proclination (by using a multiple regression analysis) and came to a conclusion very similar to ours, that only about a third of the variance in incisor proclination can be explained by changes in width and crowding. Compared with the present study, their sample was smaller and included only patients with mild or no crowding,[19] yet we wrongly expected to find a stronger correlation in our research. Pandis et al. studied the relationship between several arch variables and the change in COS and concluded that for every 1 mm of COS leveling, a 4° incisal proclination is expected in the mandibular arch.[20] The regression equation and the amount of variability were not presented, but the backward regression analysis also highlighted the problems of predicting changes in the COS from other arch dimensions. We can therefore conclude that attempting to associate any two parameters of arch dimension is simplistic and must be treated suspiciously, having only limited clinical application.

The phenomena of incisor angulation change and arch leveling are complicated, so all arch dimensions, growth changes, soft tissue influences, and treatment mechanics must be considered. More research is needed to offer an applicable and practical formula to clinicians with a fair R^2, both for protrusion and proclination based on a multidimensional model. Mathematical models might help explain some of clinical observations.[21–23] For example, Germane et al. found that incisor expansion (which may represent incisor protrusion) contributes more to arch perimeter than intermolar or intercanine width change.[21] We found that incisor protrusion is better predicted by crowding alleviation (represented by arch perimeter lengthening) than by change in arch width. However, the mathematical models might be difficult to apply clinically.

The methods used to determine arch crowding and incisor proclination in the current study are the most prevalent in clinical practice, yet one must consider that they might contribute to the variability of the results. Even though intraexaminer reliability showed high consistency of measurements, it is important to remember that cephalometry has built-in inaccuracies, which are especially high for measurements that depend on accurate identification of the mandibular incisor apex.[24,25] Measuring longitudinal change in incisor position in relation to the mandibular basal bone requires superimposition of stable mandibular structures (ie, mandibular canal, symphysis) from the before-and-after-treatment cephalomteric tracings.[3,26] This method might reduce variability since the reference lines are not influenced by surface remodeling of the jaw. The downside of this method is that it does not reflect the cephalometric appraisal that clinicians encounter in everyday practice.

We aimed to address a claim that a predictable linear relationship exists between the extent of crowding alleviation and the change in incisor proclination or protrusion, as measured in everyday practice.[4–6] It is important to mention that these claims referred to all orthodontic patients, without differentiation on the basis of skeletal or dental malocclusion classification; for that reason, we included a random sample of patients. A future study that refers to a specific patient cohort (such as Angle Class II patients) might reduce the variability found in our results. It is important to emphasize that our research does not support the conclusion that every patient with dental crowding can be treated using arch expansion without extraction; the clinical decision to extract is justified by different reasons. Our results suggest that the expected incisor proclination due to crowding alleviation might be less pronounced than previously suggested.

CONCLUSION

Clinicians can expect a 0.5° proclination and 0.2-mm protrusion for every millimeter of crowding alleviated by incisor proclination, but the relatively low R^2 means that these results cannot be used as a prognostic tool for individual cases, but rather as a general guiding principle.

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