

Prediction of lower incisor proclination during Xbow treatment based on initial cephalometric variables

Tehnia Aziz^a; Usama Nassar^b; Carlos Flores-Mir^c

ABSTRACT

Objective: To predict lower incisor proclination from initial cephalometric values in Class II division 1 patients treated in phase I with the Xbow appliance.

Materials and Methods: Two hundred forty-nine mild to moderate Class II division 1 patients treated with the Xbow appliance as a phase I treatment were considered. Patients were in late mixed dentition or early permanent dentition. Commonly used cephalometric variables at T1 (before treatment) were used to predict lower incisor proclination after Xbow treatment (T2). A principal component analysis (PCA) was performed. The four extracted PCA components were skeletal component, incisal distance, anterior facial projection, and maxillo-mandibular relation. Thereafter, a multiple linear regression analysis (MLRA) was performed using the four extracted PCA components at T1 as predictor variables, and lower incisor inclination relative to the mandibular plane (L1-MP) at T2 as the dependent variable.

Results: The mean L1-MP at T1 was 95.46 degrees and the mean L1-MP at T2 was 98.51 degrees, resulting in a mean difference of 3.04 degrees. Only incisal distance and maxillo-mandibular relation PCA components had significance ($P < .05$) according to the MLRA. The overall model gave an adjusted R2 value (coefficient of determination) of 0.091.

Conclusion: The best prediction model could account for only 9% of the total variability. Using common cephalometric variables at T1, average lower incisor proclination from Xbow treatment cannot be predicted in a clinically meaningful way. (*Angle Orthod.* 0000;00:000–000.)

KEY WORDS: Cephalometrics; Principal component analysis; Xbow; Class II treatment

INTRODUCTION

Class II malocclusion is a common orthodontic concern that requires comprehensive treatment planning.¹ Treatment of Class II malocclusion is frequently initiated in mid to late mixed dentition, wherein crowding and/or an increased overjet becomes of greater

concern to patients and parents. Earlier correction of Class II abnormalities could be suggested in patients with significant occlusal discrepancies, increased risk of trauma to protruding upper incisors, and impaired masticatory functions.²

Class II correctors are appliances specifically designed to improve a combination of skeletal and dental components found among Class II division 1 malocclusions. Among the available Class II correctors, fixed options are gaining popularity. Systematic reviews^{3,4} have shed some light on what fixed Class II correction devices appear to produce during treatment of mild to moderate Class II malocclusion. Short-term changes include a combination of skeletal and dental modifications. Skeletal modifications include both maxillary restriction and mandibular repositioning, and dental effects consist of mandibular incisor proclination and maxillary molar distalization.

Cephalometric analysis is a valuable tool used for diagnosis and treatment planning of dental malocclusion and underlying skeletal discrepancies. In view of the fact that malocclusion is the product of an interaction between the alignment of erupting teeth in

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their basal bone and the skeletal position of the basal bone itself, cephalometric analysis can be used to evaluate dentoalveolar proportions and to elucidate the anatomic basis for jaw- and tooth-related abnormalities in the sagittal plane.¹

The Xbow (pronounced "crossbow") appliance is an orthodontic device that is used in late mixed or early permanent dentition before full fixed orthodontic treatment is initiated. It consists of a maxillary (Hyrax type) and a mandibular (lingual and labial arches) rigid frame linked together through a resilient fixed spring (FRD, Unitek, Monrovia, Calif). In comparison with the Herbst, bands are used instead of crowns in the first molars. Also, instead of a telescopic spring, which forces the mandible permanently forward (as in a Herbst), the Xbow springs allow the condyles to settle back if the patient forces the springs. Its main goal is to rapidly correct the occlusion in mild to moderate Class II malocclusions.⁵ Since the time of its introduction, only two published studies have reported on the Xbow appliance. One study⁶ focused on the evaluation of short-term skeletal and dental effects from lateral cephalograms; the other⁷ discussed treatment-originated lower incisor proclination according to vertical facial types. Both reported mild mandibular incisor proclination with significant variability after Xbow use. Facial type did not appear to significantly affect the amount of lower incisor inclination.

Because large variability has been observed in the magnitude of lower incisor proclination during Xbow treatment,^{6,7} it would be clinically beneficial to know whether initial values of 20 commonly used cephalometric variables could predict the final lower incisor proclination. This would potentially allow clinicians to treatment plan preventive measures or even discard use of the Xbow for specific patients. Therefore the objective of this study was to evaluate which cephalometric variables, or combination, can predict lower incisor inclination in mild to moderate Class II patients treated with the Xbow appliance.

MATERIALS AND METHODS

Materials

The Xbow appliance consists of a maxillary expander, a mandibular labial and lingual bow, and a Forsus Fatigue Resistance Device (FRD, Unitek) with springs that can be inserted unilaterally or bilaterally. The Xbow is not considered a protrusive Class II corrector because the FRD springs do not position the mandible forward. The treatment protocol and other details on appliance design and construction have been previously reported.⁵ After insertion, the Xbow appliance is followed up every 4 weeks until a half to a full cusp overcorrection of the Class II dental component is achieved. Once this has occurred, the springs are

removed. If the physiologic recovery is deemed acceptable after 1 month, then the maxillary expander and labial/lingual bows are removed. It is customary to follow this with a 3- to 4-month period with no active or passive orthodontic appliances to allow for any further physiologic relapse, if it happens. Only after this period has passed, it is suggested that full braces treatment should be started to fine-tune the occlusion. If deemed clinically necessary, maxillary expansion can be carried out before or after Xbow activation.

Methods

The sample was obtained from the private practice of two clinicians, both with significant experience in treating patients with the Xbow appliance. It consisted of 249 patients significantly treated with this appliance as part of phase I orthodontic treatment. All patients had both pretreatment and posttreatment lateral cephalograms taken between September 2002 and September 2009. As part of the coding required to send patients' radiographs between Canadian provincial boundaries, all identifiers, including age and gender, were removed. Based on a previous publication,⁶ the mean age of the patients was assumed to be around 11 years 11 months at T1 (Time 1, radiograph taken before appliance insertion) and 13 years 2 months at T2 (Time 2, radiograph taken 6.4 months after Xbow treatment). The mean time that the Xbow appliance was activated in the mouth was 4.5 months. The remaining difference corresponded to the time elapsed between T1 and actual insertion of the appliance. Some of the patient records used in the current study were also utilized in previous publications.^{6,7}

All radiographs were taken with Orthoceph (model OC100D, General Electric, Tuusula, Finland). The cephalometric radiographs were scanned using an Epson Expression digital scanner (model 1680, Epson America, Long Beach, Calif) at a resolution of 300 dpi with no magnification of the radiographs. They were then printed and numbered randomly for blinding purposes. One individual not involved in the research had the codes. The 498 radiographs (T1 and T2 radiographs of 249 patients) were randomly assigned, and no information was given to the evaluator regarding the age of the patients or whether the radiographs were taken before or after treatment. As explained before, these x-rays were not taken with any orthodontic appliance in the mouth.

Commonly used cephalometric landmarks, reference planes, and measurements were used. Definitions for each landmark (S, N, A, B, Pg, Gn, Go, Ar, Me, ANS, PNS, Po) and plane (MP, SN, OP, FH, Np) are included in Table 1. A list of all cephalometric

Table 1. Definitions of Landmarks and Reference Planes Used

Landmarks	
Sella (S)	Center of the pituitary fossa (sella turcica)
Nasion (N)	The most anterior point of the frontonasal suture, or the most posterior point on the curvature of the bridge of the nose
Point A	Point on the anterior innermost curvature between the anterior nasal spine and the crest of the maxillary alveolar process
Point B	Point on the anterior innermost curvature between the mandibular alveolar crest and the chin
Pogonion (Pg)	Most anterior point on the contour of the chin
Menton (Me)	Lowest point on the mandibular symphysis
Gnathion (Gn)	Most outward and everted point on the profile curvature of the symphysis of the mandible
Gonion (Go)	Point midway between the points representing the middle of the curvature at the left and right angles of the mandible (if each side of the mandible was clearly visible on the cephalogram, the midpoint between the left and right Gonion was used)
Articulare (Ar)	Point midway between the two posterior borders of the left and right mandibular rami at the intersection with the basilar portion of the occipital bone
Orbitale (Or)	Point midway between the lowest point on the inferior bony margin of the two orbits
Porion (Po)	Superior-most point on the external auditory meatus
ANS	Anterior nasal spine, tip of the bony anterior nasal spine in the median plane
PNS	Posterior nasal spine, intersection of the continuation of the anterior wall of the pterygopalatine fossa and the floor of the nose
L1	Tip of the most prominent lower incisor as seen on lateral cephalogram
U1	Tip of the most prominent upper incisor as seen on lateral cephalogram
Upper lip (UL)	Used lower-most point on the border of the upper lip
Subnasale (Sn)	Point at which the nasal septum joins the upper cutaneous lip in the midsagittal plane
Planes	
SN	Line connecting S and N
Frankfort horizontal	Line connecting Or and Po
Np	Line perpendicular to Frankfort horizontal passing through N
OP (Functional)	Line through intercuspation of upper and lower premolars and molars
MP	Line connecting Go and Me represents mandibular plane.
PP	Line connecting ANS and PNS represents palatal plane.

variables measured with their descriptions is provided in Table 2. All angles and linear variables were measured and rounded off to full degree and millimeter, respectively. All variables were measured at T1 and T2. Measurements for each variable at T1 were utilized in the statistical analysis; however, only lower incisor proclination (ie, L1-MP) was used at T2. For the purpose of consistency, each variable was measured consecutively on all (498) radiographs before quantification of the next variable. One evaluator placed all the landmarks, and the locations of the landmarks were verified by a second evaluator by randomly selecting 40 radiographs. Landmarks were placed on 50 lateral cephalograms per day at the beginning of the study; later only 100 measurements were taken per day to reduce operator fatigue. To assess intrarater reliability, 10 randomly selected radiographs were landmarked and measured three times with 2 days apart between sets. Intraclass correlation coefficients (ICCs) for each variable were above 0.8, suggesting good reliability (Table 3).

Statistical Tests and Analysis

The Statistical Package for the Social Sciences (SPSS) for MAC (version 18, SPSS Inc, Chicago, Ill)

was used to run all statistical tests. Data reduction was employed using principal component analysis (PCA), a statistical procedure that groups correlated variables into sets of uncorrelated variables called principal components. In addition, the first principal component accounts for as much variability in the data as possible. Every additional principal component helps explain a portion of the remaining variability.

RESULTS

Several predictor variables in this study measured similar relationships, meaning they were correlated with one another. Tolerance values were close to zero and the variance inflation factor was greater than 2 for most variables when stepwise regression was run using all cephalometric variables at T1. This confirmed a multicollinearity problem, which would result in exaggerated standard errors of the regression coefficients, making it less likely that the influence of predictor variables on lower incisor proclination could be assessed. With the use of PCA, the 20 predictor variables were grouped into a few uncorrelated components, whereby each component was a linear combination of the original variables. Principal components were then used as predictor variables and lower

Table 2. List of the Cephalometric Variables Measured and Their Descriptions

Cephalometric Variable	Description
SNA, degrees	Angle between the Sella, Nasion, and Point A (signifies: position of the maxilla to the skull base)
SNB, degrees	Angle between the Sella, Nasion, and Point B (position of the mandible to the skull base)
ANB, degrees	Angle between Point A, Nasion, and Point B (relation of maxilla and mandible to each other)
ANp, mm	Distance of Point A in relation to the Np (perpendicular to Frankfort horizontal) line (anterior-posterior relationship of maxilla to a reference plane)
PgNp, mm	Distance of Pg in relation to the Np line (anterior-posterior relationship of mandible to a reference plane)
Wits, mm	Distance between AO and BO (which are points on the occlusal plane formed by perpendiculars dropped from Points A and B) on the occlusal plane (relation of maxilla and mandible to each other)
SN-SGn, degrees	Angle between Sella-Nasion line and Sella-Gnathion line (chin positioning in relation to the skull base)
SN-PP, degrees	Angle between Sella-Nasion line and Palatal Plane (line through anterior and posterior nasal spine) (signifies: tilt of the maxilla to the skull base)
SN-MP, degrees	Angle between Sella-Nasion line and Mandibular Plane (line through the Menton and Gonion) (tilt of the lower border of the mandible to the skull base)
SN-OP, degrees	Angle between Sella-Nasion line and Occlusal plane (line through the cuspatation of upper and lower molars and premolars) (tilt of occlusal plane to the skull base)
Ar-Go-Me, degrees	Angle between Articulare, Gonion, and Menton (tilt of the ramus to the body of the mandible, related to vertical facial height)
SGo- NMe, ratio	Ratio of distance from Sella to Gonion and from Nasion to Menton (ratio of posterior to anterior facial height)
NSn- SnMe, ratio	Ratio of distance from Sunbasale to Nasion and from Subnasale to Menton (ratio of upper to lower facial height)
L1-MP, degrees	Angle between the long axis of the most prominent mandibular incisor and the mandibular plane (axial inclination of the lower incisor to the mandibular plane)
U1-PP, degrees	Angle between the long axis of the most prominent maxillary incisor and palatal plane (axial inclination of the upper incisor to the palatal plane)
L1-U1, degrees	Angle between the long axes of the most prominent upper and lower incisors (axial inclination of the upper incisor and lower incisor to each other)
L1-APg, mm	Distance of the incisor tip of the most prominent lower incisor to the APg line (through Point A and Pg) (position of the lower incisor relative to the anterior border of the maxilla and mandible)
OB, mm	Vertical distance between the most prominent upper and lower incisors (vertical overlap of incisors)
OJ, mm	Horizontal distance between the most prominent upper and lower incisors (horizontal overlap of incisors)
U1-UL, mm	Vertical distance between the most prominent upper incisor tip and the lower border of the upper lip (maxillary incisor display)

incisor proclination as a response variable in a multiple linear regression (MLR) model. MLR was chosen because the purpose of the study was to predict the mean lower incisor proclination after Xbow treatment from numerous cephalometric variables/components.

Principal Component Analysis

Extraction communalities were high for most variables (0.9 to 0.7 for all, except Ar-Go-Me [0.64], OB [0.4], U1-UL [0.39]) (Table 4). This proposed that the extracted components represented the original variables favorably. Six components were extracted based on eigenvalue greater than one, accounting for 78% of the cumulative variance (Table 5). Scree plot demonstrated the first four components on the steep part of the slope and then a significant drop in eigenvalue from component four to five (Figure 1). Therefore only four components were retained, explaining 60% of the variance of the original 20 variables based on the scree plot. The critical value for loading was $2 \times 0.163 = 0.33$, based on the sample size of 249 patients. Therefore, the factors extracted consisted of variables with factor loadings greater than 0.33. Components from varimax rotation were used for easier interpreta-

tion (Table 6). All components were combinations of linear and angular measurements; they represent the vertical and anterior-posterior (AP) distance/relationships of craniofacial structures.

- Component 1, skeletal component: positive correlation with original variables when vertical orientation is considered (SN-SGn, SN-PP, SN-MP, SN-OP, Ar-Go-Me), and negative correlation with AP relationships (SNA, SNB, PgNp, and SGo:NMe ratio, which is measured anteroposteriorly)
- Component 2, incisal distance: positively correlated with AP measurements (OJ, U1-PP) and negatively correlated with vertical length (OB, L1-U1)
- Component 3, anterior skeletal projection: positively correlated with all AP relationships (SNA, SNB, ANB, PgNp, and ANp)
- Component 4, maxillo-mandibular relation: positively correlated with original variables for ANB, Wits (AP), and OB (vertical)

Multiple Linear Regression

MLR was used with L1-MP at T2 as the response variable and the four principal components as predictor

Table 3. Intrarater Reliability (ICC) Values for All Variables

Variable	ICC Values
SNA	.89
SNB	.91
ANB	.81
ANp	.89
PgNp	.96
Wits	.85
OB	.97
OJ	.99
U1-UL	.99
U1-PP	.82
L1-MP	.91
L1-U1	.87
L1-APg	.92
SN-SGn	.90
SN-PP	.86
SN-MP	.93
SN-OP	.92
Ar-Go-Me	.98
SGo-NMe	.93
NSn-SnMe	.98

variables. Model assumptions of constant variance, normality, linearity, and independence were reasonably met. Component 3 (anterior skeletal projection) yielded a nonsignificant *P* value of .929 and therefore was removed and the model rerun. Both incisal and maxillo-mandibular relations (Components 2 and 4) were significant (Table 7), whereas the skeletal component (Component 1) was not significant (*P* = .071). It was still retained because it accounted for the greatest variability. *P* values of coefficients were β_0 (< .001), β_1 (= .071), β_2 (= .004), and β_3 (< .001) (significance level, alpha = .05). The skeletal coefficient in the linear regression

Table 4. Extraction From PCA

Variable	Communalities	
	Extraction	
SNA	.884	
SNB	.917	
ANB	.893	
ANP	.919	
PGNP	.805	
WITTS	.819	
OB	.402	
OJ	.771	
U1-UL	.388	
U1-PP	.872	
L1-MP	.849	
L1-U1	.943	
L1-APG	.774	
SN-SGN	.840	
SN-PP	.777	
SN-MP	.946	
SN-OP	.791	
AR-GO-ME	.637	
SGO:NME	.859	
NSn:SnMe	.711	

Table 5. Variance Explained by the Six Extracted Components^a

Component	Total Variance Explained			
	Dimension	Rotation Sums of Squared Loadings		
		Total	% Variance	Cumulative %
1	4.841	24.203	24.203	
2	2.870	14.348	38.551	
3	2.382	11.912	50.463	
4	1.970	9.849	60.312	
5	1.900	9.501	69.813	
6	1.836	9.179	78.992	

^a Extraction method: principal component analysis.

equation was negative, suggesting a decrease of 0.78 degrees in the lower incisor inclination for each unit increase in skeletal distance (Figure 2), with constant values for other components. However, L1-MP at T2 would increase by 1.26 degrees for each unit increase in incisal distance (Figure 3) and by 1.52 degrees per unit increment of maxillo-mandibular distance (Figure 4). The regression coefficients were β_0 (intercept = 98.51), β_1 (= -0.78), β_2 (= 1.26), and β_3 (= 1.52) (Table 7). The R squared statistic from regression was 0.091, which means that only 9% of variability in the response variable L1-MP at T2 could be explained by the skeletal, incisal, and maxillo-mandibular components. This would leave 91% of variability unaccounted for.

The estimated regression equation was as follows:

$$L1-MP2 = 98.51 - 0.78 \text{ Skeletal Component} + 1.26 \text{ Incisal Distance} + 1.52 \text{ Maxillo-mandibular Relation}$$

DISCUSSION

In this study, we assessed anterior-posterior (SNA, SNB, ANB, ANp, PgNp, and Wits), vertical basal

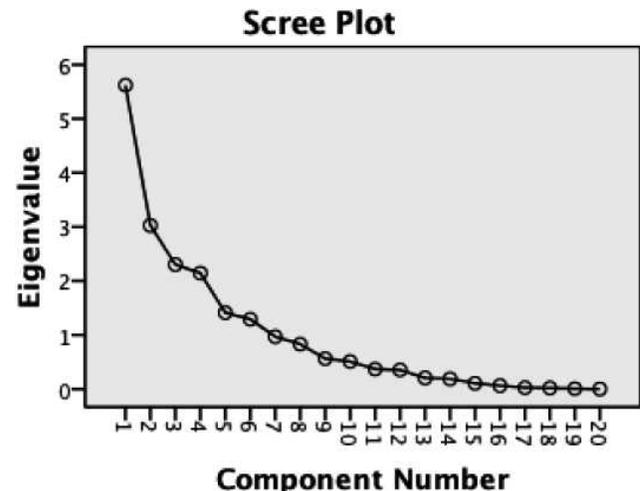


Figure 1. Scree plot from PCA.

Table 6. Components Extracted From PCA Using Varimax Rotation

	Rotated Component Matrix			
	Component			
	1	2	3	4
SNA	-.533		.680	
SNB	-.776		.504	
ANB			.425	.754
ANP			.933	
PGNP	-.417		.706	
WITS				.851
OB		-.407		.440
OJ		.811		
U1-UL				
U1-PP		.907		
L1-MP				
L1-U1		-.928		
L1-APG				
SN-SGN	.871			
SN-PP	.699			
SN-MP	.858			
SN-OP	.852			
AR-GO-ME	.354			
SGO:NME	-.799			
NSn:SnMe				

(SN-SGn, SN-PP, SN-OP, SN-MP, Ar-Go- Me, SGo:NMe, and NSn:SnMe), and dentoalveolar (L1-MP, L1-PP, L1-U1, L1-APg, OB, OJ, U1-UL) cephalometric relationships. Although initially the cephalometric variables were grouped into six principal components, only four were finally utilized as described in the Results. At the end of the selection process, the incisal and maxillo-mandibular components were statistically significant in predicting lower incisor proclination, but the obtained correlation value was of little clinical significance. In fact, the magnitude of proclination was more dependent on variation in individual patient factors. This is especially true in a sample of patients in which different degrees of initial dental and skeletal discrepancies affect the progress of each treatment effect. It should be noted that the size of this sample is large enough that it would depict a large spectrum of mild to moderate Class II division 1 clinical scenarios.

Table 7. Multiple Linear Regression

Regression Model ^a	Regression Coefficients		95.0% Confidence Interval
	Coefficients	P Value	
Intercept (β_0)	98.506	.000	(97.67, 99.35)
Skeletal component (β_1)	-.776	.071	(-1.62, 0.067)
Incisal distance (β_2)	1.255	.004	(0.41, 2.10)
Maxillo-mandibular distance (β_3)	1.515	.000	(0.67, 2.36)

^a R square = 0.091.

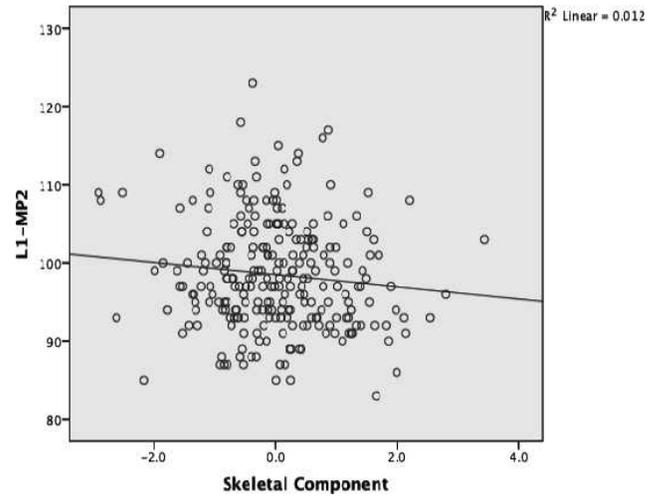


Figure 2. Plots of response variable (L1-MP T2) versus predictors (skeletal component).

The skeletal component was a combination of vertical (positive correlation) and horizontal distances (negative correlation). This could be interpreted as larger vertical cephalometric measurements (longer faces/vertical growth pattern), which would be associated with less incisor proclination. This will be inverted in horizontal growers. Reduced proclination after Xbow treatment in long faces was reported in a previous study⁷ when compared with patients with short or normal facial height. Alternatively, lower incisor inclination post Xbow treatment could be more likely to occur in individuals who have a greater horizontal distance between anterior teeth as opposed to vertical overlap. This is expected as larger lower incisor proclination will be required to attain incisal contact. This hypothesis will have to be explored in the future.

For the maxillo-mandibular component, AP variables (ANB and Wits) had higher loadings and component coefficients when compared with OB variables (verti-

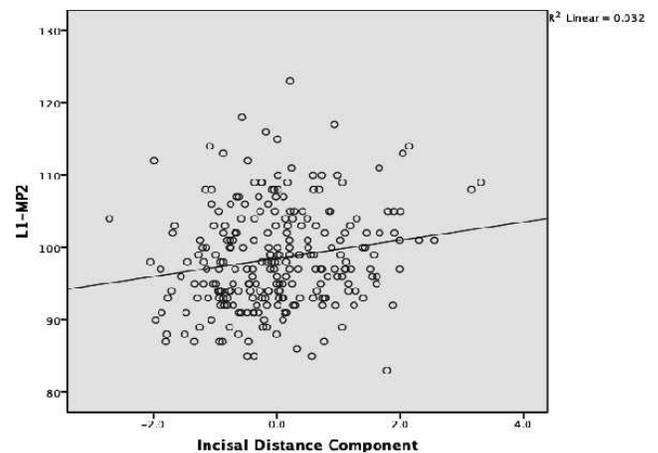


Figure 3. Plots of response variable (L1-MP T2) versus predictors (incisal distance component).

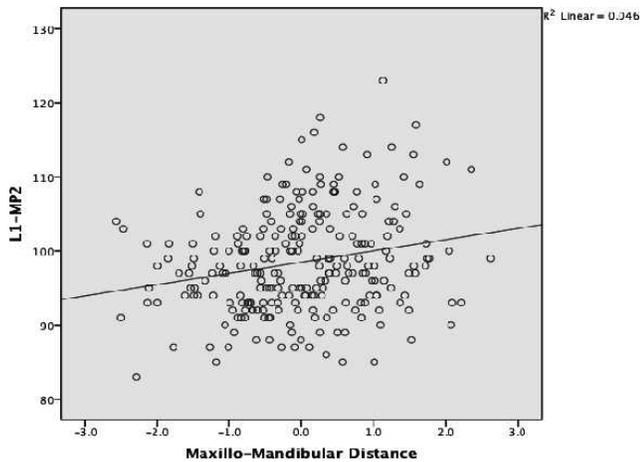


Figure 4. Plots of response variable (L1-MP T2) versus predictors (maxillo-mandibular distance).

cal). Therefore, it could be hypothesized that the greater the horizontal distance as opposed to vertical length between the jaws, the larger is the treatment-generated lower incisor proclination.

One potential limitation of our study could be the lack of cephalograms taken immediately after appliance removal. However, we do not perceive this as a drawback because physiologic recovery was allowed to take place before the T2 radiographs were taken. By using this approach, a clinician would know the amount of proclination after relapse and before full fixed appliances are used. Although radiographs taken immediately after removal of the springs could give some extra information, this was not an established protocol at the practice from which the radiographs were retrieved. In fact, most Class II treatment studies⁸⁻¹² report T2 radiographs taken immediately after completion of treatment without allowing time for any muscle-splinting effect or physiologic relapse to occur.¹³

Other drawbacks include lack of quantification of appliance breakage, which would affect treatment time and simultaneous maxillary expansion in some patients. Additionally, a few patients received an upper 2×4 to create an overjet in cases of retroclined upper laterals. Information about these two factors was not readily available, but they could have been considered confounders. Finally, because of the fact that a previous study⁶ discussed cephalometric and dental changes rendering from Xbow treatment, we believed that there was no need to describe again the changes that occur in each cephalometric landmark during the course of this type of treatment.

Clinically, the Xbow appliance can be considered an efficient treatment alternative for mild to moderate Class II malocclusion^{6,7}; however, the large variability in final proclination needs to be gauged during treatment

planning. We were unable to identify cephalometric factors that could have predicted early identification of clinical cases that would result in significant lower incisor proclination during Xbow treatment. Clinicians have to monitor this treatment effect closely because of the unknown predictability of the magnitude of incisor proclination from the Xbow appliance.

Factors such as reduced thickness of the free gingival margin and the presence of gingival inflammation should also be considered before any orthodontic appliance that would procline incisors is used, as was shown in two recent systematic reviews.^{14,15} It needs to be emphasized that the amount of initial crowding was not considered in the analysis. Crowding is a key factor in considering whether a nonextraction class II correction is feasible. The clinician in these cases decided to go ahead with Xbow treatment after careful analysis of the malocclusion, including crowding. In some cases, extractions may be required before or after Xbow treatment based on the expected amount of incisor flaring.

CONCLUSION

- The best prediction model could account for only 9% of the total variability. Therefore, the average lower incisor proclination from Xbow treatment cannot be predicted, in a clinically meaningful way, with the use of common cephalometric variables at T1.

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