ORIGINAL ARTICLE

Short-term skeletal and dental effects of the Xbow appliance as measured on lateral cephalograms

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Introduction: Our objective was to determine the short-term skeletal and dental effects of the Xbow appliance when compared with an equivalent untreated control group as measured on lateral cephalograms. **Methods:** A prospective sample of 69 consecutive Class II patients treated with only the Xbow appliance was compared with 30 historical Class II untreated controls. Standardized lateral cephalograms were used. **Results:** Two patients from the treatment group did not complete treatment. The 2 groups appeared similar at pretreatment with the exception of the positions of the maxillary central incisor (2.9 mm more protruded in Xbow group), the mandibular incisor (1.7 mm more protruded with the Xbow group), and Point A (2.8 mm forward restriction in Xbow group). There were statistically significant differences for 9 of the 14 evaluated cephalometric variables when normal growth changes were factored out. Those differences favoring the Xbow for changes in the direction of Class II correction include SNA, ANB, L1-MP, L1 minus Pg, overjet, U6 minus A, L6 minus Pg, and A-OLp. Meanwhile, the control group showed a statistically significant decrease in the mandibular plane angle compared with the Xbow group. **Conclusions:** Skeletally, a diminution of maxillary protrusion without mandibular advancement and an increase of the vertical dimension were found. Dentally, overjet correction was accomplished by an increase in mandibular incisor protrusion without maxillary incisor movement. The maxillary molars were distalized whereas the mandibular molars were mesialized. (Am J Orthod Dentofacial Orthop 2009;136:822-32)

Correction of Class II malocclusion is a common orthodontic treatment objective, with many approaches used in contemporary clinical practice. Lately, the use of Class II springs has been gaining popularity in the treatment of both noncompliant and compliant patients.[1] Springs have an advantage over headgear and mandibular protrusive appliances in that they can be used bilaterally or unilaterally. Until recently, these springs have only been used with a full edgewise appliance.

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The Xbow appliance design is patented. Duncan W. Higgins has a commercial interest in Xbow appliances. He receives royalties when Xbows are fabricated in licensed dental laboratories. The other authors have no commercial interest in the Xbow or any other conflict of interest.
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Submitted, November 2007; revised and accepted, January 2008.
0889-5406/$36.00

doi:10.1016/j.ajodo.2008.01.021

The Xbow (pronounced crossbow, Xbow is a patented appliance design by D.W.H.) uses Class II springs as a phase 1 appliance for treatment in the late mixed dentition or early permanent dentition. With published randomized control trials[2,3] having shed some doubt on the ability of functional appliances and headgear to truly alter skeletal growth significantly in the long term, the Xbow could be an alternative. No published studies have demonstrated the skeletal and dental treatment effects or the time required to achieve Class II correction with the Xbow appliance.

The objective of this study was to determine the short-term skeletal and dental effects of the Xbow appliance when compared with an equivalent untreated control group as measured on lateral cephalograms.

MATERIAL AND METHODS

The treatment sample was obtained from the private practice of the inventor of the Xbow appliance (D.W.H.) and included all patients started with the appliance having both pretreatment (T1) and posttreatment (T2) lateral cephalograms taken between September 26, 2002, and September 30, 2006. This resulted in a sample of 69 (30 boys, 39 girls) consecutively started patients. Two patients (1 boy, 1 girl) did not complete treatment

Table I. Summary statistics for the Xbow group

Parameter	*Mean*	*Minimum*	*Maximum*	*SD*
Age at T1 (y, mo)	11, 11	9, 6	14, 9	1, 3
Age at T2 (y, mo)	13, 2	10, 4	16, 2	1, 3
Total time between cephalograms, T1-T2 (mo)	14.67	6	37	5.27
Time between cephalogram at T1 and Xbow placement (mo)	3.73	0	25	4.19
Xbow use (mo)	4.54	2	11	1.56
Time between Xbow removal and cephalogram at T2 (mo)	6.43	0	14	3.12

Table II. Summary statistics for the control group

Parameter	*Mean*	*Minimum*	*Maximum*	*SD*
Age at T1 (y, mo)	11, 9	10, 0	13, 0	0, 9
Age at T2 (y, mo)	12, 7	12, 0	14, 4	0, 10
Total time between cephalograms T1-T2 (mo)	21.90	11	28	4.65

because they could not tolerate the Xbow due to soft-tissue sores; the appliance was removed soon after spring placement. An analysis of these 2 patients showed that, at the start, they were not cephalometrically different from the other treated patients. A summary of the treatment sample characteristics is given in Table I.

To factor out the effects of growth over the treatment period, an untreated, age-matched Class II control group with skeletal and dental characteristics as similar as possible was obtained from the Burlington Growth Centre, Faculty of Dentistry, University of Toronto, in Ontario, Canada. All available patients with cephalometric radiographs at similar time intervals as those of the Xbow sample were included. This yielded a control group of 30 patients (20 boys, 10 girls), who are summarized in Table II.

The Xbow is a fixed Class II corrector that consists of 3 main components: a maxillary hyrax expander, a mandibular labial and lingual bow, and Forsus fatigue resistant device (FRD) springs (3M Unitek, Monrovia, Calif) connecting the 2 bilaterally or unilaterally. The maxillary hyrax included bands on the first molars and first premolars. The Forsus spring is placed in the headgear tube of the maxillary first molar band and hooked around the labial bow near the mandibular canine-first premolar area, contained anteriorly by a Gurin lock (3M Unitek). This lock allows for reactivation of the Forsus device without the need for a longer push rod or split tubing shims. The mandibular labial and lingual bows are in passive contact with the mandibular incisors and are retained in the mouth by bands on the first molars and occlusal rests bonded to the first premolars. Forsus FRD springs do not rigidly hold the mandible forward and allow the patient to function in centric occlusion. It could thus be categorized as a nonprotrusive interarch Class II corrector (Fig 1).

The ends of the springs can be protected by spring caps (Comfort Solutions, Langley, British Columbia, Canada). The hyrax jackscrew allows posterior expansion for constricted arches or compensatory maxillary expansion. Maxillary incisor teeth can be bracketed and aligned in a 2 × 4 arrangement. In this case, the archwire is segmented from lateral incisor to lateral incisor while the Forsus springs are active. The mandibular labial bow precludes the placement of orthodontic brackets on mandibular anterior teeth.

The treatment protocol begins with the Forsus springs inserted bilaterally, even if 1 side is Class I. The springs are completely compressed every 6 weeks until the maxillary first premolars are in an overcorrected Class III relationship where they are end on with the mandibular second premolars. The spring is left on 1 side longer in a patient with an asymmetric Class II relationship. This was common in our study. Once the springs are removed, the hyrax screw is activated if compensatory maxillary expansion is required. The expansion is retained for 5 months, while the physiologic recovery of the Class II overcorrection is monitored once springs have been removed. If too much relapse occurs, the spring is replaced on 1 side or both sides, as necessary. This happened in only a few patients in the study. The Xbow framework is left in place for the entire treatment period to allow for replacement of the springs. As noted in Table I, a mean of almost 6.5 months elapsed between spring removal and the T2 cephalograph. No retention appliances were used during this time to help hold the Class II correction.

All radiographs of the treatment group were taken with an Orthoceph (model OC100D, General Electric, Tuusula, Finland), a horizontally scanning direct digital unit. All radiographs of the control group were taken on a film-based unit manufactured by Keleket (Covington, Ky). Because that machine is no longer in use, verification of the magnification was not possible. The magnification of 9.84% stated by the manufacturer was used. The conventional radiographs were scanned by using an Epson Expression digital scanner (model 1680, Epson America, Long Beach, Calif) at 300 dpi

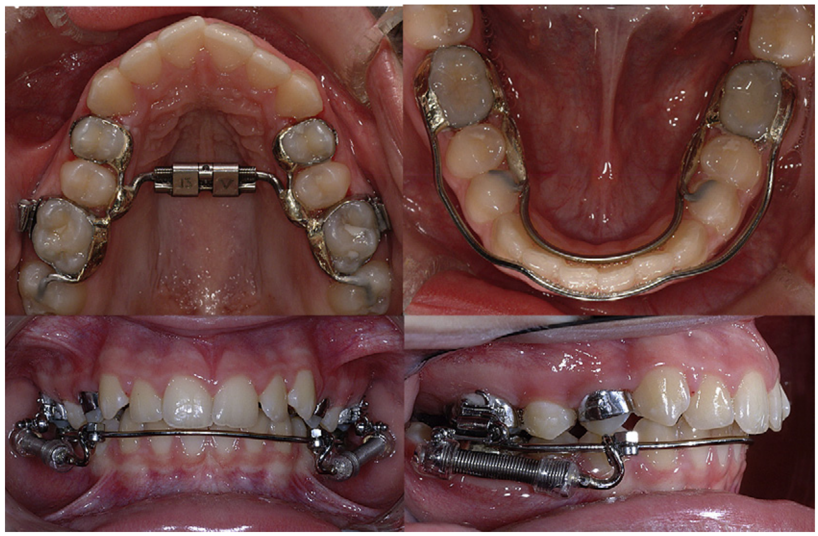

Fig 1. Xbow appliance: various views.

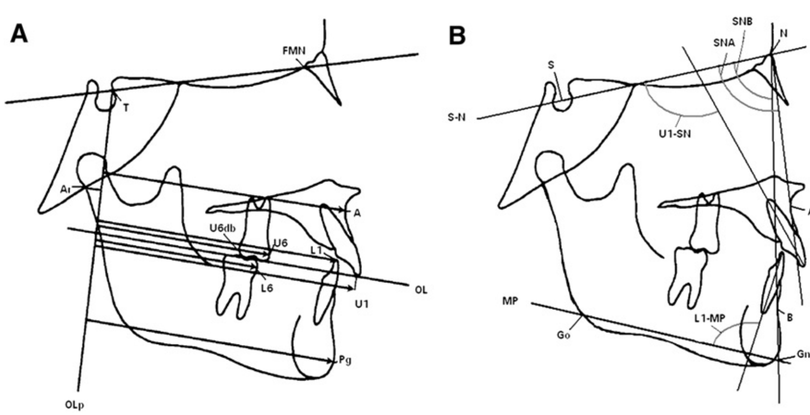

Fig 2. A, Landmarks and linear measurements (modified Pancherz analysis[4]); **B,** reference planes and angular measurements.

with a 100-mm marking system incorporated into the scan. No ruler was visible in the control sample radiographs, but one was included in the scan, and thus it was unmagnified with respect to the patient image. Correction was calculated and set as a scale of 91.04 mm when the analysis was being carried out. Traditional x-ray units such as this use a pyramid-shaped beam applied in a static manner, and thus magnification should theoretically be equal in both the horizontal and vertical aspects at equal distances from the center of the central ray.

All radiographs of both groups were then loaded into Viewbox 3 (dHAL Orthodontic Software, Athens, Greece), landmarked and measured. All cephalometric landmark measurements were made with the proper magnification accounted for, in that the value recorded was "true patient size," and not what one would necessarily measure directly on the radiograph itself.

This was done by setting the scale magnification to the nosepiece ruler in the Xbow sample. Validity of using this ruler for the measurements was previously addressed through an acrylic plastic box with markers incorporated at known distances. Based on this, no allowances for differential magnification or distortion were needed for this sample.

A modified Pancherz analysis[4] was used. The landmarks, reference planes, and measurements used are shown in Table III and Figure 2; 14 variables (6 angular,

Table III. Landmark definitions and reference planes used

Landmarks
Sella (S): center of the roughly circular hypophyseal fossa (sella turcica)
Nasion (N): junction of the nasal and frontal bones at the most posterior point on the curvature of the bridge of the nose
A-point (A): point of greatest concavity on the anterior surface of the maxilla between the anterior nasal spine and the crest of the maxillary alveolar process
B-point (B): point of greatest concavity on the anterior bony curvature of the mandible between the chin and the mandibular alveolar crest
Pogonion (Pg): most anterior point on the contour of the chin
Gnathion (Gn): most outward and everted point on the profile curvature of the symphysis of the mandible
Gonion (Go): point midway between the point representing the middle of the curvature at the left and right angles of the mandible; if each side of the mandible was distinctly visible on the radiograph, the midpoint between the right and left Go was used
Articulare (Ar): point midway between the 2 posterior borders of the left and right mandibular rami at the inter section with the basilar portion of the occipital bone
T-point (T): most superior point of the anterior wall of sella turcica, at the junction with tuberculum sellae
Frontomaxillary-nasal suture (FMN): the posterior junction of the nasal bone with the frontomaxillary bones
U1: incisal tip of most prominent maxillary central incisor
Root apex of same maxillary incisor used for U1
L1: incisal tip of most prominent mandibular central incisor
Root apex of same mandibular incisor used for L1
U6: most mesial surface of the crown of the maxillary first permanent molars; if the right and left molars were visible separately, the midpoint between their respective mesial surfaces was used
L6: most mesial surface of the crown of the mandibular first permanent molars; if the right and left molars were visible separately, the midpoint between their respective mesial surfaces was used
U6db: distobuccal cusp tip of the maxillary first permanent molars; if the right and left molars were visible sepa rately, the midpoint between their respective cusp tips was used
Reference planes
OL: the occlusal line as constructed by connecting U1 and U6db
OLp: a line constructed perpendicular to OL that passes through T-point; the OLp line from the T1 cephalographs was transferred to the T2 cephalographs to avoid any influence of occlusal plane inclination during treatment on the posttreatment measurements
Mandibular plane (MP): line connecting Go and Gn
S-N: line connecting S and N
T-FMN line: used for orientation of all cephalographs to properly transfer OLp from T1 to T2 radiographs

8 linear) were measured. Measurements from the Pancherz analysis were kept to a relevant minimum.

FMN and T-point have been used previously as substitutes for nasion and sella, respectively, since stable reference points are needed to correctly transfer the OLp when using the Pancherz analysis.[5,6] Melsen[7] reported that sella can be displaced by remodeling the floor and posterior wall of the hypophyseal fossa, whereas the anterior area around the junction with tuberculum sellae remained unchanged. Similarly, nasion can be displaced by enlargement of the frontal sinus. FMN is not affected by this enlargement. Thus, the line connecting T-point and FMN should be unchanged by remodeling between successive radiographs. The angle between the T-FMN line and OLp is kept constant between radiographs, ensuring that no effect on the actual OL in the T2 radiograph alters the measurements. Viewbox 3 has a feature in which the 2 radiographic images can be overlaid, with the landmarks and analysis lines displayed. During superimposition of the T2 image, the T-FMN line from T1 is kept visible, and the T2 image is aligned to it. The T2 image is then landmarked normally, with exception of the distobuccal cusp tip of the maxillary first permanent molar, which is placed in a manner that recreates the same OLp line visible from T1. By

Table IV. Descriptive statistics: error test of 15 T1 radiographs (absolute differences)

Variable	*Mean (T1 only/T1-T2)*	*SD (T1 only/T1-T2)*	*Dahlberg's error (T1 only/T1-T2)*	*ICC (T1 only/T1-T2)*
SNA (°)	0.5/0.4	0.3/0.3	0.44/0.33	0.985/0.989
SNB (°)	0.3/0.4	0.2/0.3	0.24/0.35	0.992/0.985
ANB (°)	0.3/0.2	0.3/0.1	0.28/0.16	0.965/0.986
MP-SN (°)	0.7/0.6	0.6/0.5	0.65/0.56	0.977/0.988
U1-SN (°)	1.6/1.5	1.0/1.1	1.29/1.31	0.982/0.962
L1-MP (°)	1.7/1.8	1.0/1.6	1.36/1.66	0.971/0.958
U1-OLp (mm)	0.5/1.1	0.3/1.0	0.39/1.01	0.993/0.952
L1-OLp (mm)	0.5/1.1	0.3/0.8	0.37/0.93	0.993/0.944
Overjet (mm)	0.4/0.4	0.3/0.2	0.31/0.31	0.976/0.938
U6-OLp (mm)	0.7/0.8	0.7/0.5	0.66/0.64	0.964/0.951
L6-OLp (mm)	0.5/0.9	0.4/0.7	0.41/0.76	0.986/0.950
A-OLp (mm)	0.4/0.8	0.3/0.8	0.34/0.82	0.992/0.943
Pg-OLp (mm)	0.8/0.9	0.5/0.6	0.65/0.76	0.979/0.975
Ar-OLp (mm)	0.5/0.6	0.4/0.4	0.47/0.53	0.972/0.973

keeping the superimposition angle between the T-FMN line and OLp constant between radiographs, orientation as a source of measurement error was minimized. The sella-nasion line was still used for the angular measurements (rather than the T-FMN line) for ease of communication and comparison with previous studies. Distances anterior to the OLp line were given positive values, and those posterior to it were given negative values.

Two sets of 15 cephalograms were chosen randomly and remeasured at least 4 weeks after the original measurements. One group was taken entirely from the T1 set, and the second from both the T1 and T2 sets. One set was taken entirely from the T1 sample and was used to determine landmark identification error. The second set included pairs of T1 and T2 radiographs and was used to determine error associated with superimposition. Intraclass correlation coefficients[8] and Dahlberg's error of the method[9] were both used to assess any landmark errors, and the means of errors were calculated.

On confirmation that the distribution of the sample could be assumed to be normal, multivariate analysis of variance (MANOVA) tests were applied to analyze the data interactions. All statistical tests were run with SPSS for Windows (version 14.0, SPSS, Chicago, Ill).

RESULTS

Measurement error analysis results are shown in Table IV. For both the T1 and the T1-T2 sets, the greatest angular variations were with U1-SN and L1-MP. The greatest linear variations for the T1 set were with U6-OLp and Pg-OLp. For the T1-T2 set, the incisor measurements (U1-Olp, L1-OLp) had the greatest variations.

Dahlberg's error of the method yielded results between 0.31 and 0.66 for linear measurements in the T1 set and between 0.31 and 1.0 for the T1-T2 set. For angular measurements, both sets had similar ranges, from 0.16 to 1.66. The ICC values showed high agreement between the sets of measurements, between 0.964 (U6-OLp) and 0.993 (U1-OLp and L1-OLp) for the T1 set. The T1-T2 set showed slightly lower ICC values, between 0.938 (overjet) and 0.989 (SNA).

A composite superimposition tracing of the experimental and control groups at T1 is shown in Figure 3. The statistical comparison of the Xbow and control groups at T1 is given in Table V. On cursory examination, the 2 groups appear similar at T1, with the exception of the positions of the maxillary central incisor (2.9 mm greater in Xbow group) and Point A (2.8 mm greater in Xbow group). These contribute to a larger overjet in the Xbow group (1.7 mm). The mandibular incisor in the Xbow group was also more protrusive, with L1-OLp 1.2 mm greater than in the control group.

To determine whether there were any significant differences between the Xbow and control groups at T1, a MANOVA considering group and sex was performed. The interaction term was not significant (P = 0.3). A MANOVA without the interaction term showed significant differences between both sex and group (P <0.001 for both). The MANOVA P values at T1 for group and sex are shown in Table V. For group, there were significant differences at α = 0.05 for U1-OLp, L1-OLp, overjet, and A-OLp. For sex, there were significant differences at α = 0.05 for age at T1, MP-SN, U1-OLp, L1-OLp, U6-OLp, L6-OLp, A-OLp, and Pg-OLp.

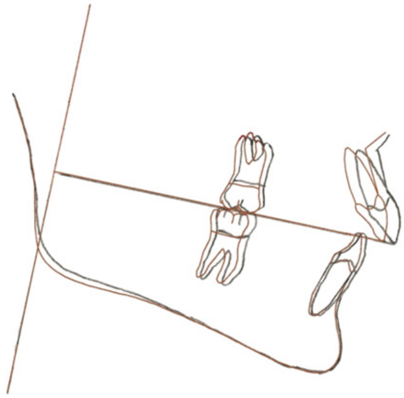

Fig 3. Composite tracings at T1, aligned on OL. Xbow group composite is *black*; control group composite is *red*.

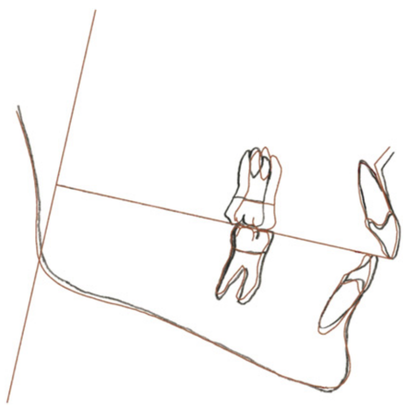

Fig 4. Composite tracings at T2, aligned on OL. Xbow group composite is *black*; control group composite is *red.*

A composite superimposition tracing at T2 is shown in Figure 4. Differences between T2 and T1 measurements for the Xbow and control groups are provided in Table VI. All variables except Ar-OLp were significant at the $\alpha = 0.05$ level based on MANOVA with only 1 factor—group.

An independent samples *t* test was conducted with months between cephalograms treated as the variable. This was found to be significantly different between the 2 groups, with means of 21.9 months for the control group and 14.7 months for the Xbow group ($P < 0.001$). The variable of months between cephalograms of T1-T2 was then included as a covariate in the analysis; this allowed for the difference in time spans between the 2 groups to be accounted for in the statistical analysis. The MANOVA was again run for comparison of the groups, first with the interaction for group and sex. The interaction term was not significant, so it was omitted and the MANOVA run again. Sex was considered not significant at the $\alpha = 0.05$ level, so it was removed. The MANOVA was run a final time with group as a factor and months between cephalograms remaining as a covariate. Estimated marginal means (EMM) were calculated for the 2 treatment groups based on the analysis with the months between cephalograms as a covariate, and the group differences for this is shown in the column labeled "EMM group difference" in Table VI. The *P* values obtained for this analysis are shown in the column labeled "*P* value for EMM group difference."

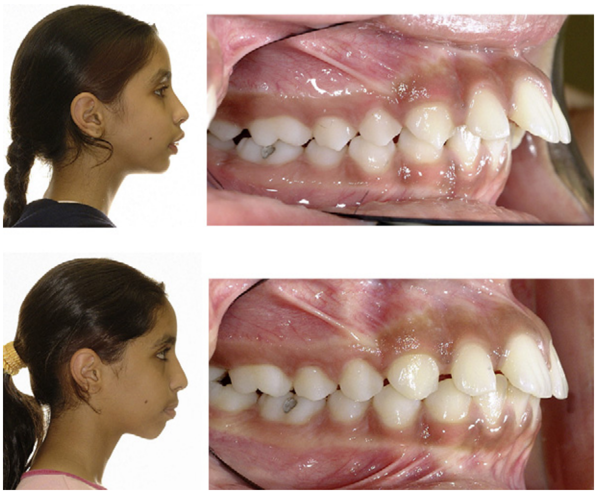

Fig 5. Changes after 6 months of Xbow use and 9 months of physiological recover allowed with no retainer.

One subject in the Xbow group was identified as a possible outlier with regard to months between cephalograms (37 months). The next longest time span in the Xbow group was 27 months. The statistical analysis was run with and without this subject, and no significant changes in the results were observed, so it was left in analysis.

There were statistically significant differences over the observation period for 9 of the 14 variables at the $\alpha = 0.05$ level when the difference in observation period (months between cephalograms) was taken into account. The differences favoring the Xbow for changes in the direction of Class II correction included SNA, ANB, L1-MP, L1 minus Pg, overjet, U6 minus A, L6 minus Pg, and A-OLp. Meanwhile, the control group showed a statistically significant decrease in mandibular plane angle compared with the Xbow group, as measured by MP-SN (–1.3° for control, –0.1° for Xbow). Neither group showed a significant difference in SNB,

Table V. MANOVA results by variable as tested by group (Xbow vs control) and sex (male vs female) at T1

Factor	Variable	Xbow (mean/SD)	Control (mean/SD)	P value
Group	Age (y)	11.9/1.2	11.8/0.8	0.162
	SNA (°)	81.1/3.2	80.6/4.1	0.344
	SNB (°)	75.8/2.7	76.0/3.8	0.924
	ANB (°)	5.3/1.6	4.6/1.5	0.054
	MP-SN (°)	31.9/5.1	32.5/4.6	0.348
	U1-SN (°)	103.7/8.1	100.9/8.8	0.206
	L1-MP (°)	99.5/7.2	99.0/6.7	0.878
	U1-OLp (mm)*	77.5/4.4*	74.6/4.2*	<0.001*
	L1-OLp (mm)*	70.4/4.3*	69.2/4.1*	0.032*
	Overjet (mm)*	7.1/1.8*	5.4/1.8*	<0.001*
	U6-OLp (mm)	47.4/3.7	46.5/3.9	0.080
	L6-OLp (mm)	46.5/3.9	45.6/4.1	0.091
	A-OLp (mm)*	69.4/4.1*	66.6/3.7*	<0.001*
	Pg-OLp (mm)	70.8/5.1	70.2/4.8	0.119
	Ar-OLp (mm)	–12.5/3.0	–11.8/3.3	0.315
Factor	**Variable**	**Male (mean/SD)**	**Female (mean /SD)**	**P value**
Sex	Age (y)*	12.2/1.1*	11.6/1.0*	0.002*
	SNA (°)	81.3/3.1	80.6/3.8	0.235
	SNB (°)	76.4/2.8	75.4/3.3	0.116
	ANB (°)	4.9/1.5	5.2/1.7	0.643
	MP-SN (°)*	31.2/4.5*	33.0/5.2*	0.044*
	U1-SN (°)	101.7/8.5	104.0/8.2	0.296
	L1-MP (°)	98.6/6.1	100.1/7.9	0.354
	U1-OLp (mm)*	77.7/5.0*	75.5/3.7*	0.001*
	L1-OLp (mm)*	71.3/4.5*	68.7/3.5*	<0.001*
	Overjet (mm)	6.4/1.8	6.78/2.1	0.870
	U6-OLp (mm)*	48.1/4.4*	46.1/2.8*	0.004*
	L6-OLp (mm)*	47.3/4.3*	45.2/3.3*	0.003*
	A-OLp (mm)*	69.9/4.6*	67.1/3.1*	<0.001*
	Pg-OLp (mm)*	72.7/5.6*	68.5/3.3*	<0.001*
	Ar-OLp (mm)	–12.2/3.5	–12.4/2.6	0.977

*Statistical significance at the $\alpha = 0.05$ level.

U1-SN, U1 minus A, Pg-OLp, or Ar-OLp. Examples of the clinical changes obtained with Xbow appliance can be found in Figure 5.

DISCUSSION

The purpose of comparing the T1 craniofacial forms of the Xbow and control groups was to evaluate the equivalency of the samples. The comparison of the T1 forms showed statistically significant differences for the variables U1-OLp, L1-OLp, overjet, and A-OLp. These starting differences were taken into account during the statistical analysis. Furthermore, differences in sex and length of time of the T1 and T2 records were also considered in the analysis.

This was a mixed study (treatment group of consecutively started patients and control group of a retrospective historical sample), and randomization was not possible. The purpose of including an untreated control group for comparison is that it can serve as an estimate for what should have happened to the patients with no intervention, and thus the true effect of the intervention (in this case, use of the Xbow appliance) can be appreciated. It was therefore desirable to have a control group with growth potential (magnitude and direction) similar to the Xbow group. It could have introduced bias if the control was a Class I or Class III skeletal group, because the growth over the observation period would not necessarily represent those in the (Class II) Xbow group. The angular variables SNA, SNB, ANB, and MP-SN gave the best indication of skeletal pattern and potential growth pattern; none showed significant differences between the 2 groups.

One drawback of using historical untreated subjects as controls, such as those from the Burlington Growth Study or similar databases, is that the time frames for record taking might not fit the cohort under investigation. This was evident in this study, since the mean times between the T1 and T2 cephalograms were 14.7 months for the Xbow group and 21.9 months for the control group. Records for the Burlington Growth Study were taken at ages 9, 12, and 14 for most patients. The T1-T2 time difference between groups was just over 7 months. This extra time and the growth that would occur between T1 and T2 for the control group could account for the counterintuitive finding that the Xbow group had a trend for smaller increases in the Pg-OLp and SNB measurements. The mandible is typically catching up to the maxilla about the time the subjects in this study were examined (control group ages were mainly 11-12.5 years at T1 and 12.5-14.5 years at T2).[1,10,11] By using months between cephalograms as a covariate in the MANOVA, this was taken into account when determining P values, and thus these 2 variables showed no statistically significant differences between the 2 groups once the effect of time was factored out.-The EMMs were calculated for the patients, who had the same months between cephalograms. The measurement and superimposition errors in this study were comparable with or better than those in other similar studies.[2,3,5,12-15]

Since the Forsus FRD springs do not posture the mandible forward out of the glenoid fossa, acceleration in mandibular growth would not necessarily be expected. This was reported in several other studies involving nonprotrusive interarch Class II correctors.[16-18] We found that the Xbow not only restricted maxillary skeletal anterior movement (determined by Point A), but also actually displaced it posteriorly. Again, this headgear effect was noted in other studies

Table VI. MANOVA results for differences between treatment groups at T2-T1

Variable	Xbow (mean/SD)	Control (mean/SD)	Group difference (mean)	P value for group difference*	EMM group difference	P value for EMM group difference†
SNA (°)	–0.4/0.9	0.9/0.8	–1.3‡	<0.001‡	–1.0‡	<0.001‡
SNB (°)	0.5/1.0	1.0/0.9	–0.5‡	0.013‡	–0.3	0.234
ANB (°)	–0.8/0.8	–0.2/0.7	–0.6‡	<0.001‡	–0.8‡	<0.001‡
MP-SN (°)	–0.1/1.3	–1.3/1.3	1.2‡	<0.001‡	1.0‡	0.005‡
U1-SN (°)	–3.5/5.3	–0.4/3.6	–3.1‡	0.004‡	–1.8	0.148
L1-MP (°)	4.7/4.1	1.1/2.5	3.6‡	<0.001‡	3.8‡	<0.001‡
U1 minus A (mm)	–0.9/1.4	0.2/1.2	–1.1‡	0.001‡	–0.5	0.111
L1 minus Pg (mm)	0.9/1.2	–0.5/0.8	1.4‡	<0.001‡	1.2‡	<0.001‡
Overjet (mm)	–3.0/1.4	–0.4/1.2	–2.6‡	<0.001‡	–2.4‡	<0.001‡
U6 minus A (mm)	–0.9/1.2	1.2/1.1	–2.1‡	<0.001‡	–2.0‡	<0.001‡
L6 minus Pg (mm)	1.1/1.3	0.5/1.0	0.6‡	0.015‡	0.6‡	0.045‡
A-OLp (mm)	0.7/1.1	1.9/1.0	–1.2‡	<0.001‡	–0.5‡	0.047‡
Pg-OLp (mm)	2.0/1.8	3.0/1.7	–1.0‡	<0.001‡	0.0	0.913
Ar-OLp (mm)	–0.2/1.0	–0.5/1.0	0.3	0.313	0.1	0.691

EMM, Estimated marginal means.
*Group as a factor; †Group as a factor and months betweeen cephalograms as a covariable; ‡Statistically significant between groups at the $\alpha = 0.05$ level.

of nonprotrusive interarch Class II correctors[18-22] and also in previous related systematic reviews.[23,24]

The Xbow group showed a statistically significant increase in MP-SN angle by 1.0° relative to the control group. This also could account for the SNB and Pg-OLp findings. This change is relative, since the Xbow group's mean MP-SN was virtually unchanged (measured mean, –0.1° change), whereas the control group showed a –1.3° change. If the mandible is rotating in a counterclockwise direction, as was seen in the control group, both the SNB angle and the Pg-OLp distance will tend to be larger. Even if the mandible grew forward in both groups by the same amounts over the treatment period, the relative clockwise rotation could partially negate some of that expressed change in the Xbow group. Another point to consider is that some treated patients had maxillary expansion concurrent with the anteroposterior correction. A previous systematic review in this regard showed no long-term effect of expansion on vertical and anteroposterior changes.[25]

When the short duration of Xbow treatment (mean, 4.54 months) and the fact that most dental and musculo-skeletal relapse occurred before the measurements were taken (T2 radiographs taken a mean of 6.43 months after appliance removal), the Xbow treatment results compare quite favorably with those of other appliances as reported in the literature.[26] This is in contrast to some studies in which posttreatment records were taken relatively soon after appliance removal.[5,13,14,27,28] Without allowing time for dental and skeletal rebound, the true lasting treatment effects are possibly overstated.

Direct comparison of this study with other published studies is difficult. Studies vary in landmarks and measurements used, time from appliance removal to the posttreatment cephalographs, and use of active retainers between appliance removal and posttreatment cephalographs. The authors of a recent systematic review including only crown or banded Herbst studies that had similar Class II Division 1 untreated control groups and no adjunctive appliances, similar to the Xbow group in this study, selected 3 articles for the review.[24] All 3 studies used posttreatment cephalographs taken immediately at appliance removal, so the results are not as comparable in that regard.[4,28,29] A summary of the findings of this systematic review and a comparison with our results are shown in Table VII. Our study included all consecutively treated patients as did also the studies selected for the banded Herbst systematic review.[24] In general, a significant number of the Class II treatment studies included samples for successfully treated patients that would significantly bias the results.

Both the Herbst and the Xbow appliances show such dental changes as proclination and anterior movement of the mandibular incisors, retroclination and posterior movement of the maxillary incisors (although not with statistical significance for the Xbow group), overjet reduction, small anterior movement of the mandibular first molars, and greater posterior movement of the maxillary first molars. Regarding mandibular molar mesial movement, use of the mandibular lingual arch while the appliances are in the mouth could reduce natural mesial migration of the molars compared with

Table VII. Selected results of crown/banded Herbst systematic review[24]

Measurement	*de Almeida et al*[28]	*Pancherz*[29]	*Pancherz*[4]	*This study (EMM)*
Herbst/Xbow (n)	30	22	22	67
Control (n)	30	20	20	30
Mean treatment time (mo)	12	6	6	4.5
Maxillary skeletal sagittal				
SNA (°)	–0.4			–1.0*
Nperp-A (mm)	–0.7			
Co-A (mm)	–0.5			
Nperp-ANS (mm)	–0.8			
OLperp-A (mm)			–0.4	–0.5*
U1 angulation				
U1-NA (°)	–5.7*			–1.8 (to SN)
U1 sagittal				
U1-NA (mm)	–1.5			
OLperp-U1 minus OLperp-A (mm)			–0.5	–0.5
U6 sagittal				
OLperp-ms minus OLperp-A (mm)			–2.8*	–2.0*
Mandibular skeletal sagittal				
SNB (°)	0.6*			–0.3
Co-Gn (mm)	1.6*			
OLperp-Pg (mm)			2.5*	0.0
Mandibular angulations				
NSL/ML (MP-SN) (°)	0.4	0.2		1.0*
L1 angulations				
IMPA (°)	4*			3.8*
L1-NB (°)	5.4*			
L1 sagittal				
L1-NB (mm)	1.0*			
OLperp-L1 minus OLperp-Pg (mm)			1.8*	1.2*
L6 sagittal				
OLperp-L6 minus OLperp-Pg (mm)			1.0*	0.6*
Interincisor relationship				
Overjet (mm)			–5.2*	–2.4*
Profile skeletal				
ANB (°)	–1.0*			–0.8*

Only results comparable with the variables we used are shown.
EMM, Estimated marginal means.
*Significant difference relative to the control group used in each study.

what would be normally expected. Skeletally, the ANB angle is reduced, but the mandibular measurements are the significant contributors with the Herbst, whereas maxillary measurements are significant only for the Xbow. This might not be surprising because the Herbst appliance postures the mandible forward so that the patient cannot close in centric occlusion, whereas, with the Xbow, patients can overcome the forces produced by the Forsus springs (reportedly about 200 g) and seat the condyles as they would normally. Thus, the remodeling of the glenoid fossa or the increased condylar growth to reach back to the glenoid fossa may not occur with the Xbow.

Furthermore, with radiographs taken immediately after Herbst removal, any muscle-splinting effect or other physiologic recovery was yet to occur. The mandibular position reported in these Herbst studies was in a somewhat falsely protruded position when the radiographs were taken, making it appear that pogonion and B-point were more anterior than they would be after relapse. Pancherz[26] stated that approximately 30% of overjet correction and 25% of molar correction relapses, and that 90% of that occurs during the first 6 months after appliance removal. Pancherz and Hansen[30] examined 40 Herbst-treated patients. Treatment time had been 7 months. Patients had lateral cephalographs taken before Herbst placement, at Herbst removal, and again at 6 and 12 month intervals. Fifteen patients had no retention, 19 had activators, and the remaining 6 had a combination of maxillary plate and mandibular holding arch. They found only dental relapse in 58% of the patients, and, in the 42% who had some "unfavourable maxillary-mandibular growth relationship," it "contributes only to a minor degree."

A problem with the Herbst postremoval x-ray sample is that it includes different retention protocols. In reality, the only group that is comparable with our study would be the nonretention 6-month group.

The Xbow accomplished its overjet reduction primarily by dental movement. Overjet was reduced by 3.0 mm; 0.9 mm of this was from maxillary incisor posterior movement (U1 minus A) and 0.9 mm from mandibular incisor anterior movement (L1 minus Pg). This totals 1.8 mm, or 60% of the total overjet reduction. The remaining 1.2 mm (40%) was attributed to the mandible's outgrowth of the maxilla (shown by changes in Pg-OLp and A-OLp) over the observation period. These figures do not account for normal growth changes. Due to the different times over the observation period, direct comparison was impossible. Although growth does not occur in a purely linear fashion, if the changes are viewed as the average amount of mandibular growth above maxillary growth per month, an approximation of the contributions of normal growth and the effects of the Xbow appliance can be done.

The Xbow group showed a mean of 0.088 mm per month of growth of the mandible, and the control group had 0.050 mm per month. By using these mean growth values, the mandible would have outgrown the maxilla in the control group by 0.74 mm over 14.7 months. This attributes (1.2 – 0.74 mm) 0.47 mm to the Xbow; 0.47 mm is approximately 15% of the total overjet correction; the remaining 25% of the change was due to normal growth. A problem with this method of comparison does not delineate which jaw is responsible for the skeletal changes.

Weiland et al[31] reported that the dental component of functional appliance Class II correction treatment is from 23% to 80% of the total correction. Regarding spring-type Class II correctors, jasper jumpers (American Orthodontics, Sheboygan, Wis) have had varying results in studies; some showed maxillary skeletal restraint,[16,17] and others showed mandibular skeletal change as the predominant component of skeletal correction.[20,31-33] Dental correction is frequently the main means of correction with the Jasper jumper[16-18,21,34] and the Eureka spring (Eureka Spring, San Luis Obispo, Calif).[35]

CONCLUSIONS

1. Treatment with the Xbow appliance in Class II patients resulted in favorable dental and skeletal changes in the direction of Class II correction.
2. Skeletally, a diminution of maxillary protrusion without mandibular advancement and an increase of the vertical dimension were found.
3. Dentally, overjet correction was accomplished by an increase in mandibular incisor protrusion without maxillary incisor movement. The maxillary molars were distalized, and the mandibular molars were mesialized.
4. Although some of these changes were statistically significant, the magnitude of the differences may not likely have clinical significance in some patients.
5. From the samples used in this investigation, Xbow treatment appears to be equally effective for both male and female patients.

We thank Lesley Williams (private practitioner in Delta, British Columbia, Canada) for providing some treated patients.

REFERENCES

1. Proffit W, Fields H. Contemporary orthodontics. St Louis: Mosby; 2007.
2. O'Brien K, Wright J, Conboy F, Sanjie Y, Mandall N, Chadwick S, et al. Effectiveness of treatment for Class II malocclusion with the Herbst or Twin-block appliances: a randomized, controlled trial. Am J Orthod Dentofacial Orthop 2003;124:128-37.
3. Tulloch JF, Proffit WR, Phillips C. Outcomes in a 2-phase randomized clinical trial of early Class II treatment. Am J Orthod Dentofacial Orthop 2004;125:657-67.
4. Pancherz H. The mechanism of Class II correction in Herbst appliance treatment. A cephalometric investigation. Am J Orthod 1982;82:104-13.
5. Franchi L, Baccetti T, McNamara JA Jr. Treatment and posttreatment effects of acrylic splint Herbst appliance therapy. Am J Orthod Dentofacial Orthop 1999;115:429-38.
6. Leonardi M, Armi P, Baccetti T, Franchi L, Caltabiano M. Mandibular growth in subjects with infraoccluded deciduous molars: a superimposition study. Angle Orthod 2005;75: 927-34.
7. Melsen B. The cranial base. Acta Odontol Scand 1974;32:1-126.
8. Lin L, Hedayat A, Sinha B, Yang M. Statistical methods in assessment agreement: models, issues, and tools. J Am Stat Assoc 2002; 97:257-70.
9. Dahlberg G. Statistical methods for medical and biological students. London, United Kingdom: George Allen & Unwin; 1940.
10. Bishara SE, Fahl JA, Peterson LC. Longitudinal changes in the ANB angle and Wits appraisal: clinical implications. Am J Orthod 1983;84:133-9.
11. Ochoa BK, Nanda RS. Comparison of maxillary and mandibular growth. Am J Orthod Dentofacial Orthop 2004;125: 148-59.
12. Mills CM, McCulloch KJ. Treatment effects of the twin block appliance: a cephalometric study. Am J Orthod Dentofacial Orthop 1998;114:15-24.
13. Pancherz H, Ruf S, Kohlhas P. "Effective condylar growth" and chin position changes in Herbst treatment: a cephalometric roentgenographic long-term study. Am J Orthod Dentofacial Orthop 1998;114:437-46.
14. Berger JL, Pangrazio-Kulbersh V, George C, Kaczynski R. Long-term comparison of treatment outcome and stability of Class II patients treated with functional appliances versus bilateral sagittal

split ramus osteotomy. Am J Orthod Dentofacial Orthop 2005; 127:451-64.
15. Ruf S, Pancherz H. Herbst/multibracket appliance treatment of Class II division 1 malocclusions in early and late adulthood. A prospective cephalometric study of consecutively treated subjects. Eur J Orthod 2006;28:352-60.
16. Cope JB, Buschang PH, Cope DD, Parker J, Blackwood HO 3rd. Quantitative evaluation of craniofacial changes with Jasper jumper therapy. Angle Orthod 1994;64:113-22.
17. Covell DA Jr, Trammell DW, Boero RP, West R. A cephalometric study of Class II Division 1 malocclusions treated with the Jasper jumper appliance. Angle Orthod 1999;69:311-20.
18. Nalbantgil D, Arun T, Sayinsu K, Fulya I. Skeletal, dental and soft-tissue changes induced by the Jasper jumper appliance in late adolescence. Angle Orthod 2005;75:426-36.
19. Jasper JJ, McNamara JA Jr. The correction of interarch malocclusions using a fixed force module. Am J Orthod Dentofacial Orthop 1995;108:641-50.
20. Weiland FJ, Bantleon HP. Treatment of Class II malocclusions with the Jasper jumper appliance—a preliminary report. Am J Orthod Dentofacial Orthop 1995;108:341-50.
21. Mills CM, McCulloch KJ. Case report: modified use of the Jasper jumper appliance in a skeletal Class II mixed dentition case requiring palatal expansion. Angle Orthod 1997;67: 277-82.
22. Karacay S, Akin E, Olmez H, Gurton AU, Sagdic D. Forsus nitinol flat spring and Jasper jumper corrections of Class II division 1 malocclusions. Angle Orthod 2006;76:666-72.
23. Flores-Mir C, Ayeh A, Goswani A, Charkhandeh S. Skeletal and dental changes in Class II division 1 malocclusions treated with splint-type Herbst appliances: a systematic review. Angle Orthod 2007;77:376-81.
24. Barnett G, Higgins D, Major P, Flores-Mir C. Immediate skeletal and dentoalveolar effects of the Herbst appliance on Class II division 1 malocclusions: a systematic review. Angle Orthod 2008;78: 361-9.
25. Lagravere M, Major P, Flores-Mir C. Long-term skeletal changes with rapid maxillary expansion: a systematic review. Angle Orthod 2005;75:1046-52.
26. Pancherz H. The effects, limitations, and long-term dentofacial adaptations to treatment with the Herbst appliance. Semin Orthod 1997;3:232-43.
27. Du X, Hägg U, Rabie AB. Effects of headgear Herbst and mandibular step-by-step advancement versus conventional Herbst appliance and maximal jumping of the mandible. Eur J Orthod 2002; 24:167-74.
28. de Almeida MR, Henriques JF, de Almeida RR, Weber U, McNamara JA Jr. Short-term treatment effects produced by the Herbst appliance in the mixed dentition. Angle Orthod 2005;75: 540-7.
29. Pancherz H. Vertical dentofacial changes during Herbst appliance treatment. A cephalometric investigation. Swed Dent J Suppl 1982;15:189-96.
30. Pancherz H, Hansen K. Occlusal changes during and after Herbst treatment: a cephalometric investigation. Eur J Orthod 1986;8: 215-28.
31. Weiland FJ, Ingervall B, Bantleon HP, Droacht H. Initial effects of treatment of Class II malocclusion with the Herren activator, activator-headgear combination, and Jasper jumper. Am J Orthod Dentofacial Orthop 1997;112:19-27.
32. Stucki N, Ingervall B. The use of the Jasper jumper for the correction of Class II malocclusion in the young permanent dentition. Eur J Orthod 1998;20:271-81.
33. Heinig N, Goz G. Clinical application and effects of the Forsus spring. A study of a new Herbst hybrid. J Orofac Orthop 2001; 62:436-50.
34. Kucukkeles N, Ilhan I, Orgun A. Treatment efficiency in skeletal Class II patients treated with the Jasper jumper. Angle Orthod 2007;77:449-56.
35. Stromeyer EL, Caruso JM, DeVincenzo JP. A cephalometric study of the Class II correction effects of the Eureka Spring. Angle Orthod 2002;72:203-10.