ORIGINAL ARTICLE

Treatment effects of the edgewise Herbst appliance: A cephalometric and tomographic investigation

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Introduction: The crown Herbst appliance was introduced in the late 1980s because of shortcomings of the banded Herbst. In edgewise Herbst treatment, a fixed appliance is used with the crown Herbst to maximize the skeletal effects of treatment. Treatment response to the edgewise Herbst appliance has not been reported in the literature. Our objective was to investigate skeletal and dental changes in patients with Class II malocclusions treated with the edgewise Herbst appliance. **Methods:** Fifty-two consecutive patients were treated with the edgewise Herbst appliance; 32 (18 girls, 14 boys) met the criterion of 16 months out of Herbst treatment and were included in the study. Mean treatment time with this appliance was 8.0 $\pm$ 1.8 months. Patients in the mixed dentition received additional treatment with 2 $\times$ 4 appliances until proper overbite, overjet, and torque on the incisors and permanent first molars were achieved. Patients in the permanent dentition were treated with full appliances to finalize the occlusion. Cephalometric measurements were taken at pretreatment, posttreatment, and 16 months after removal of the Herbst appliance, and the results were compared with 32 untreated Class II subjects from the Bolton Brush Study, matched for sex, age, and cephalometric dentofacial morphology. Data were analyzed with ANOVA, Tukey-Kramer multiple comparison tests, and 2-tailed *t* tests. **Results:** After 8 months of Herbst treatment, incisal relationship was overcorrected to an end-to-end incisal relationship and improved 8.4 mm, compared with the control group. The maxilla moved backward 1.4 mm at Point A, and the mandible moved forward 1.7 mm. The maxillary incisors moved lingually 1.7 mm, and the mandibular incisors were proclined 3.6 mm. The molars were corrected to a Class III relationship with a change of 7.2 mm compared with the control group. The mandible moved downward and forward. However, the condyle showed only 0.2 mm forward movement in the fossa. Sixteen months after appliance removal, the molars had relapsed into a Class I relationship, for a net change of 2.4 mm compared with the control group. Net overjet gain was 2.7 mm. Net restraint of maxillary growth was 1.3 mm, and net forward movement of the mandible was 1.0 mm. The maxillary incisors had no net movement, and the mandibular incisors had a net forward movement of 0.3 mm. Overall, skeletal change contributed 85% of the net overjet correction. **Conclusions:** Class II treatment with the edgewise Herbst appliance is accompanied by both skeletal and dental changes. The changes are stable, with significant skeletal differences remaining 16 months after appliance removal. The forward and downward movement of the mandible with minimal changes in the position of the condyles in the fossae suggests a combination of condylar growth and remodeling of the glenoid fossa with treatment. (Am J Orthod Dentofacial Orthop 2006;130:582-93)

The Herbst appliance was introduced in the early 1900s by Emil Herbst as a fixed bite-jumping device for Class II treatment.[1] Pancherz[2,3] reintroduced the Herbst in the 1970s as a banded appliance and called attention to the possibilities of stimulating mandibular condylar growth. The crown Herbst was introduced in the late 1980s in response to breakage problems and shortcomings of the banded Herbst appliance.[4-7] The crown Herbst is worn full time, unlike a removable functional appliance. The active treatment time is relatively short and requires little or no patient cooperation, and the appliance is streamlined, making hygiene simple. Research showed that the Herbst appliance can correct Class II skeletal problems by

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Table I. Comparison of starting craniofacial morphology of treated and control subjects

	Treated group		Control group			
Variables	Mean	SD	Mean	SD	P value	Significance
SNA angle (°)	82.8	0.6	82.5	0.6	.7195	NS
SNB angle (°)	77.3	0.5	77.6	0.5	.6284	NS
ANB angle (°)	1.5	0.4	4.9	0.4	.5144	NS
PP angle (°)	6.0	0.3	6.5	0.4	.3639	NS
MP angle (°)	33.2	0.8	32.3	0.9	.4445	NS
ANS-Me (mm)	65.2	0.7	61.4	0.8	.0005	*
OP angle (°)	16.3	0.6	15.4	0.6	.2769	NS
U1/SN (°)	99.5	1.2	101.2	1.3	.3427	NS
L1/MP (°)	93.5	1.1	93.3	1.2	.9082	NS
U1/L1 (°)	133.8	1.7	132.6	1.8	.6330	NS
Co-A (mm)	89.2	0.8	84.2	0.8	.0001	*
Co-Gn (mm)	110.3	1.0	105.0	1.1	.0006	*
Co-A-Co-Gn (mm)	21.1	0.6	20.8	0.6	.7524	NS
Wits (mm)	3.5	0.4	3.1	0.4	.4499	NS

NS, Not significant.
*Significant at $P < .05$.

encouraging mandibular growth[2,3,5,7-10] and elicit glenoid fossa remodeling.[11,12] Several investigators reported the long-term skeletal and dental changes with banded Herbst treatment.[13,14] The edgewise Herbst uses a fixed appliance with the stainless steel crown Herbst appliance to maximize the skeletal changes of the treatment.[4,5] The literature contains few reports on the follow-up of patients after fixed appliance treatment. In addition, there are conflicting reports on the effect of the Herbst appliance on temporomandibular joint morphology.[15-17] Recent animal studies showed condyle-fossa adaptations during Herbst treatment.[12] Treatment with the Herbst appliance might even inhibit normal downward and backward growth of the fossa, which may give the clinically observed super Class I molar relationship. Our objectives were to investigate the short-term and follow-up skeletal and dental changes of 32 patients treated consecutively with the edgewise Herbst appliance, and the position of the condyle relative to the glenoid fossa by using horizontally corrected axis tomograms.

MATERIAL AND METHODS

Fifty-two patients were treated consecutively by an author (T.D.) with the edgewise Herbst appliance. Thirty-two patients (14 boys, 18 girls) who met the criterion of 16 months out of Herbst treatment were included in the treatment group. The mean ages were 10 years 6 months ± 1 year 7 months for the girls and 9 years 9 months ± 1 year 5 months for the boys. The stages of dental development varied from early mixed to early permanent dentition. The mean treatment time with the Herbst appliance was 8 years 0 months ± 1.8 months. Lateral cephalograms were taken at pretreatment (T1), immediately after Herbst treatment (T2), and 16 months after removal of the Herbst appliance (T3). Horizontally corrected tomograms were taken at T1 and T2 to determine the position of the condyle in the glenoid fossa.

The control group consisted of serial cephalometric radiographs of 32 subjects (16 boys, 16 girls) with no history of orthodontic treatment from the Bolton-Brush Study. The control subjects were closely matched in sex, age, and craniofacial morphology with the experimental subjects (Table I). Because the Bolton-Brush cephalograms were taken at either 6- or 12-month intervals, attempts were made to match the treatment radiographs by annualizing the time periods of the control group from T1-T2 and T2-T3 to correspond with the matched subjects in the treated group.

The edgewise Herbst appliance consisted of stainless steel crowns on the maxillary and mandibular first molars. A −10° torque was built into the mandibular incisor brackets to prevent unnecessary forward tipping of the incisors. Double buccal tubes were placed on the maxillary stainless steel crowns to facilitate the use of auxiliary wires got for intruding the maxillary incisors. If there was sufficient root on the deciduous second molars, the crowns were placed on them, making it easier to place and remove the crowns after Herbst treatment in the mixed-dentition patients. Also, the axle of the maxillary molars would not distalize or impinge on the ascending ramus. The maxillary arch was tied back to the molar tubes to prevent space from opening between the molars and the second premolars. This procedure prevented the distal movement of the max-

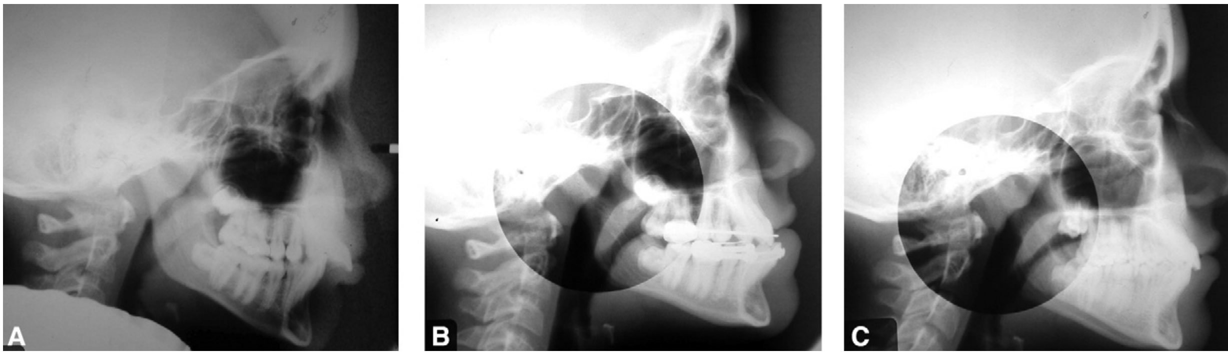

Fig 1. Lateral cephalograms of typical subject: **A,** T1; **B,** T2; **C,** T3.

illary molars and the subsequent distalization of the mandible and seating of the condyle, thus decreasing the orthopedic effect because the condyle was not unloaded in the joint to allow the maximum orthopedic effect. A 2-mm half-round Remenium cantilever was placed between the first molar and the interproximal area of the canine and the first premolar in the mandibular arch. An axle was placed at the mesial end of the cantilever, and a .022 × 028-in archwire tube was placed below the axle. Most Class II subjects had deep bites, and the archwire tubes were positioned below the axle. Positioning the archwire tube below the axle was important in controlling tooth movement and leveling the mandibular arch because of the reciprocal force of intrusion of the mandibular incisors that resulted in a tip-back force to the mandibular first molar due to the cantilever construction. This tip-back controlled the movement of the mandibular molar. If the patient had an open-bite tendency, the archwire tube was placed above the axle to aid in the eruption of the mandibular incisors and the closing of the open bite. A transpalatal arch was not incorporated in the appliance to allow the maxillary first molars to rotate as the Class II relationship was corrected. A mandibular lingual arch was not part of the appliance to allow easier placement of the appliance and ease of recementation of the crown if it loosens. However, a stop off the crown on the mandibular molar in the permanent dentition to the second premolar and in the mixed dentition to the deciduous first molar was placed and bonded to the teeth to prevent tipping of the cantilever arm or rotation of the molar lingually. If the second premolar was not present or the deciduous first molar would be lost during mixed-dentition treatment, a lingual arch was placed until the brackets could be placed with an edgewise archwire to support the cantilever arm. The mandible was advanced initially to an end-to-end position and reactivated 3 mm every 10 weeks until an overcorrected Class III canine relationship was achieved with the maxillary canines in an end-to-end relationship with the mandibular first premolar. In more severe cases, the maxillary canine was in a full-tooth Class III in relationship to the mandibular first premolar and the incisors in an anterior crossbite.

Cephalometric analysis

Figure 1 shows the lateral cephalometric radiographs of a typical subject taken at T1, T2, and T3. The cephalometric systems described by Pancherz[18,19] were used to analyze the treatment and posttreatment changes. The landmarks used are shown in Figure 2. The magnification factor of the lateral cephalograms was found to be similar for the treated and control groups (6% for both). Therefore, no standardization was needed. Registration of the lateral cephalograms was performed on a 0.003-in matte cephalometric acetate tracing film. For all cephalometric landmarks with right and left images, the midpoint bisecting the 2 images was used. The measurement for each variable was made with a cephalometric protractor or an electronic caliper. Angular measurements were evaluated to the nearest 0.5° by using a cephalometric protractor. Sagittal and vertical measurements were evaluated to the nearest 0.1 mm. Analysis of the sagittal, skeletal, and dental changes were recorded along the occlusal plane (OLs) and to the occlusal plane perpendicular (OLp) from the first cephalogram; this formed the reference grid. The grid was then transferred to subsequent cephalograms by superimposing the tracings on the midsagittal cranial structure.

Figure 3 shows the pretreatment and posttreatment tomograms of a typical subject. The tomographic measurements were determined as described by Croft et al[20] (Table II, Fig 4). Each tomogram (right and left)

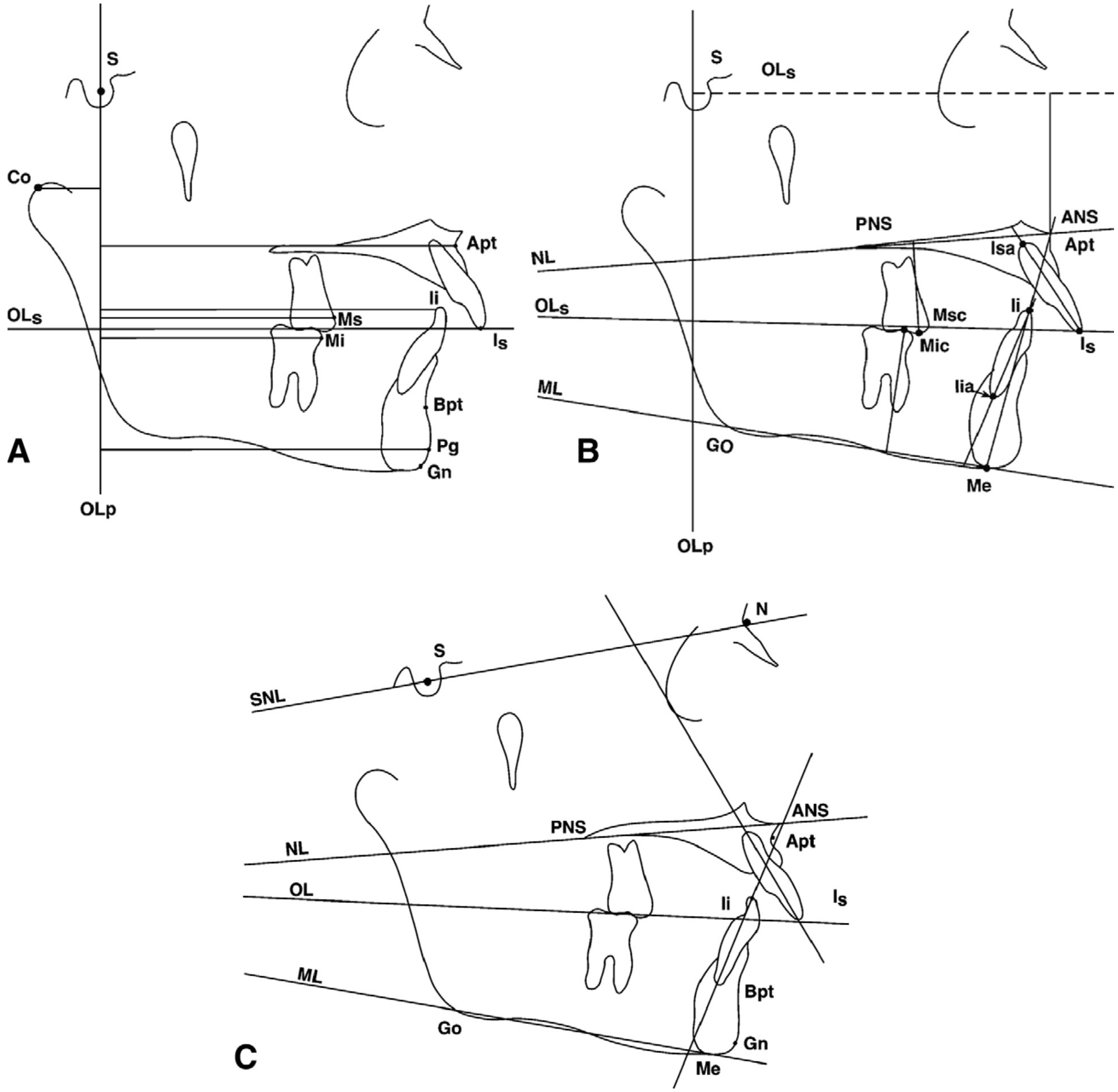

Fig 2. Cephalometric landmarks and construction lines: **A,** horizontal measurements; **B,** vertical measurements; **C,** angular measurements.

was traced, and joint spaces were analyzed by using a modification of the protractor overlay method of Pullinger and Hollender.[21] This method determines the joint space by tracing the surface of the condylar head and the inferior surface of the glenoid fossa. The distances between these 3 spaces were measured along 3 planes. The first plane measured the superior joint space. The other 2 planes determined anterior and posterior joint spaces. The first plane represented the long axis of the condyle and was constructed by using the midpoint at the narrowest part of the condylar neck and the concentric center of the condylar head. The other 2 planes were constructed at 45° angles to the first plane through the concentric center of the condylar head.

Data analysis

The dentofacial morphologies of the subjects in the experimental group at T1, T2, and T3 were compared with 1-way analysis of variance (ANOVA) and Tukey-

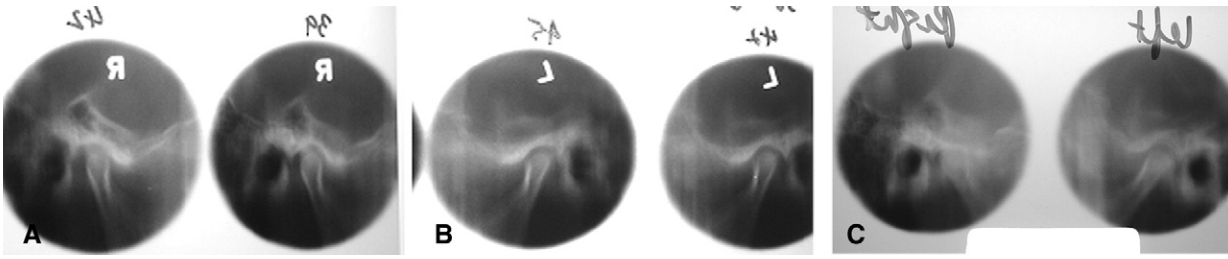

Fig 3. Tomograms: **A,** T1 right; **B,** T1 left; **C,** T2.

Table II. Tomographic measurements of variables

Name	*Symbol*	*Definition*
Right posterior joint space	RP	Position of right condyle in relation to superior wall of the eminence
Right superior joint space	RS	Position of right condyle in relation to anterior wall of eminence
Right anterior joint space	RA	Position of right condyle in relation to the posterior wall of eminence
Left posterior joint space	LP	Position of left condyle in relation to posterior wall of eminence
Left superior joint space	LS	Position of left condyle in relation to superior wall of eminence
Left anterior joint space	LA	Position of left condyle in relation to anterior wall of eminence

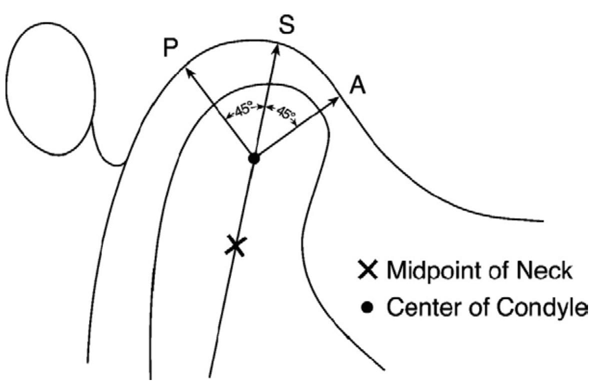

Fig 4. Landmarks and construction lines for tomogram measurements.

Kramer multiple comparison tests. The starting forms of the treated and control samples were compared with a 2-tailed *t* test. The skeletal and dental changes between the treated and control samples at the various times were compared with a 2-tailed *t* test. The tomograms were compared with the Student *t* test to determine whether there was a change in condylar position from T1 to T2.

Error measurements

The errors in locating, superimposing, and measuring the changes of the landmarks by 1 examiner were measured on the cephalograms of 10 subjects. All cephalograms were measured twice with 3 weeks between sessions. For all the cephalometric variables, differences between the independent repeated measurements of each subject at T1, T2, and T3 and superimposition errors were calculated. The error of measurement and location of anatomical landmarks were calculated by the Dahlberg formula[22]

$$ME = \frac{\sum d^2}{2h}$$

where *d* is the difference between 2 registrations of a pair and *h* is the number of double registrations. The greatest mean error for all linear measurements did not exceed 0.7 mm. The greatest mean error for angular measurements did not exceed 1.5°. In the combined errors in tracing and superimposition of landmarks at T2-T1, T3-T2, and T3-T1, the greatest mean error did not exceed 0.6 mm. The error in tomographic measurements at T1 and T2 did not exceed 0.2 mm.

RESULTS

Sagittal changes

Changes in subjects in the treatment and control groups from T2-T1, T3-T2, and T3-T1 are compared in Tables III through V. Compared with the control group, treatment induced backward movement of the maxillary base (OLp-A pt) from T1 to T2 (1.4 mm) and forward movement (0.1 mm) during the follow-up period (T2-T3), with a net restraint of forward growth of 1.3 mm (T1-T3). The position of the condyle (OLp-Co) was found to move forward 0.1 mm with treatment, but there was no change during the follow-up period, with

Table III. Comparison of treated and control groups at T2-T1

Variables	Treated Mean	Treated SD	Control Mean	Control SD	Significance
Sagittal (mm)					
1. OLp-A pt	−0.2	0.78	1.2	0.76	*
2. OLp-Pg	3.4	1.54	1.7	1.24	*
3. OLp-Co	0.2	0.50	0.3	0.35	NS
4. Co-A pt	0.0	1.53	1.9	0.99	*
5. Co-Gn	4.6	1.38	2.7	1.50	*
6. Co-Gn minus Co-A pt	4.6	2.04	0.8	1.28	*
7. Wits	−6.9	2.36	0.0	0.86	*
8. Is/OLp	−1.7	2.10	1.4	1.03	*
9. Ii/OLp	6.6	2.16	1.3	1.08	*
10. Overjet	−8.3	2.95	0.1	1.35	*
11. Ms/OLp	−2.1	1.87	1.3	1.01	*
12. Mi/OLp	5.4	2.29	1.6	1.00	*
13. Molar Rel.	−7.5	2.99	−0.3	0.59	*
Vertical (mm)					
14. OLs-A pt	1.5	0.93	1.0	0.60	NS
15. ANS-Me	1.4	1.15	1.1	0.98	NS
16 Is-NL	0.4	1.25	0.8	0.94	NS
17. Ii-ML	−0.9	1.04	0.8	0.77	*
18. Overbite	−3.5	2.00	0.3	0.56	*
19. Msc-NL	−0.4	1.01	0.7	0.66	NS
20 Mic-ML	1.7	0.88	0.7	0.60	*
Angular (°)					
21. SNA	−1.0	0.97	0.3	0.60	*
22. SNB	1.6	1.31	0.1	0.60	*
23. ANB	−2.7	1.21	0.1	0.52	*
24. SNL-NL	2.7	2.97	0.1	1.31	*
25. SNL-ML	0.1	0.44	0.1	0.57	NS
26. SNL-OLs	5.2	2.20	0.3	1.02	*
27. Is/SNL	−2.6	6.10	0.2	2.34	NS
28. Ii/ML	11.4	4.70	1.0	2.34	*
29. Is/Ii	−9.8	8.60	−0.7	3.70	*

NS, Not significant.
*Significant at $P < .05$.

a net movement of 0.1 mm. The effective maxillary length (Co-A pt) was restrained 1.9 mm compared with the control group during treatment; there was an increase of 0.3 mm during the follow-up period, for a net restraint of 1.6 mm. Effective mandibular length (Co-Gn) increased 1.9 mm during treatment and decreased 0.9 mm during follow-up, for a net increase of 1.0 mm compared with the control group. The position of the maxilla relative to the mandible (Wits) decreased 6.9 mm during treatment and increased 2.8 mm during observation, for a net decrease of 4.1 mm. For the angular measurements, the position of the maxilla relative to the cranial base (SNA) had a decrease during treatment (1.3°) compared with the control group and an increase of 0.2° during the follow-up period, for a net decrease of 1.1°. The treatment induced forward movement of the mandible (1.5°) relative to the cranial base (SNB). This increase was maintained during the follow-up period, for a net increase of 1.5°. ANB angle had a decrease of 2.8° from T1 to T2 and an increase of 0.4° during the follow-up period, for a net decrease of 2.4°.

Dentally, the maxillary incisor (Is/OLp) showed backward movement of 3.1 mm after treatment compared with the control group and forward movement of 1.8 mm during the follow-up period, for a net forward movement of 1.3 mm. Treatment effects on the position of the mandibular incisor (Ii/OLp) showed forward movement of 5.3 mm with treatment and backward movement of 4.0 mm during follow-up, for a net forward movement of 1.3 mm. Overjet improved significantly, showing a decrease of 8.4 mm during treatment. There was a return of 5.8 mm of overjet during the follow-up period, with an overall decrease of 2.6 mm. The maxillary molars moved backward 3.4 mm compared with the control group during treatment and

Table IV. Treated subjects vs control subjects at T3-T2

	Treated		Control		
Variables	*Mean*	*SD*	*Mean*	*SD*	*Significance*
Sagittal (mm)					
1. OLp-A pt	1.4	0.89	1.3	0.91	NS
2. OLp-Pg	0.9	1.84	1.6	1.42	NS
3. OLp-Co	0.3	0.42	0.3	0.44	NS
4. Co-A pt	1.8	1.46	1.5	1.59	NS
5. Co-Gn	1.5	2.17	2.4	2.34	*
6. Co-Gn minus Co-A pt	−0.3	2.32	0.9	1.19	NS
7. Wits	2.7	1.31	−0.1	0.84	*
8. Is/OLp	3.5	2.22	1.7	1.06	*
9. Ii/OLp	−2.3	1.91	1.7	1.10	*
10. Overjet	5.8	2.53	0.0	0.59	*
11. Ms/OLp	3.7	2.16	1.5	1.23	*
12. Mi/OLp	−0.9	2.21	2.1	1.60	*
13. Molar Rel.	4.6	2.42	−0.6	1.73	*
Vertical (mm)					
14. OLs-A pt	1.2	0.88	1.0	0.84	NS
15. ANS-Me	1.1	1.31	1.6	1.59	*
16 Is-NL	1.1	1.43	0.4	0.67	NS
17. Ii-ML	0.6	1.14	0.5	1.80	NS
18. Overbite	1.6	1.41	0.2	0.46	*
19. Msc-NL	1.1	1.07	0.9	0.79	NS
20 Mic-ML	0.5	1.20	0.8	0.90	NS
Angular (°)					
21. SNA	0.3	0.65	0.1	0.55	NS
22. SNB	0.0	1.05	0.0	0.48	NS
23. ANB	0.4	1.04	0.0	0.52	NS
24. SNL-NL	−0.6	1.50	0.1	1.12	NS
25. SNL-ML	0.0	0.51	0.1	0.68	NS
26. SNL-OLs	−3.4	2.39	−0.2	1.04	*
27. Is/SNL	7.9	5.97	−0.3	1.78	*
28. Ii/ML	−7.8	3.20	0.2	2.39	*
29. Is/Ii	1.0	6.41	−0.2	3.02	NS

NS, Not significant.
*Significant at $P < .05$.

moved forward 2.2 mm during follow-up, for a net backward movement of 1.2 mm. The mandibular molars moved forward 3.8 mm and backward 3.0 mm during the follow-up, for a net forward movement of 0.8 mm. The molar relationship was altered significantly, with a change of 7.2 mm during treatment resulting from forward movement of the mandibular molars and backward movement of the maxillary molars. During the follow-up period, the molar relationship relapsed 4.7 mm, giving a net change of 2.0 mm. The maxillary incisor angle (Is/SNL) moved lingually 2.8° during treatment and moved labially 8.2° during follow-up, for a net labial movement of 5.4°. The mandibular incisor angle (Ii/ML) proclined 10.4° during treatment and moved back 8.0° during follow-up, for a net proclination of 2.4°. The interincisal angle decreased 9.1° during treatment and increased 1.2° during follow-up, for a net decrease of 7.9°.

Vertical changes

The vertical position of the maxilla (OLs-A pt.) showed downward movements of 2.5 mm compared with the controls during treatment and 0.2 mm during follow-up, for a net downward movement of 2.7 mm. The lower facial height (ANS-Me) increased 0.3 mm during treatment and decreased 0.5 mm during follow-up, for a net decrease of 0.2 mm. The palatal plane (SNL/NL) exhibited downward movement of 2.6° with treatment and upward movement of 0.7° during follow-up, for a net downward movement of 1.9°. The occlusal plane (SNL/OLs) had clockwise tipping of 4.9° during treatment and counterclockwise tipping of 3.2° during follow-up, for a net clockwise tipping of 1.7°.

Dentally, the maxillary incisor (Is/NL) was intruded 0.4 mm during treatment and extruded 0.7 mm during follow-up, for a net extrusive movement of 0.3 mm.

Table V. Treated subjects vs control subjects at T3-T1

	Treated		Control		
Variables	*Mean*	*SD*	*Mean*	*SD*	*Significance*
Sagittal (mm)					
1. OLp-A pt	1.2	1.07	2.5	1.15	*
2. OLp-Pg	4.3	2.05	3.3	1.89	*
3. OLp-Co	0.5	0.64	0.6	0.50	NS
4. Co-A pt	1.8	1.62	3.4	1.88	*
5. Co-Gn	6.1	2.10	5.1	2.49	*
6. Co-Gn minus Co-A pt	4.3	2.07	1.7	1.71	*
7. Wits	−4.1	2.10	0.0	1.17	*
8. Is/OLp	1.8	2.26	3.3	1.53	*
9. Ii/OLp	4.2	2.29	3.0	1.65	NS
10. Overjet	−2.4	1.78	0.3	1.06	*
11. Ms/OLp	1.6	1.90	3.3	1.69	*
12. Mi/OLp	4.4	2.01	3.7	1.92	NS
13. Molar Rel.	−2.8	1.18	−0.4	0.93	*
Vertical (mm)					
14. OLs-A pt	2.7	1.27	2.0	1.00	NS
15. ANS-Me	2.6	1.89	2.3	1.55	*
16 Is-NL	1.5	1.89	1.1	1.06	NS
17. Ii-ML	−0.3	1.20	1.3	1.83	*
18. Overbite	−1.9	1.76	0.6	0.79	*
19. Msc-NL	0.7	1.28	1.6	0.90	NS
20. Mic-ML	2.2	1.17	1.5	1.05	NS
Angular (°)					
21. SNA	−0.7	1.2	0.4	0.57	NS
22. SNB	1.6	1.36	0.1	0.83	*
23. ANB	−2.3	1.40	0.2	0.73	*
24. SNL-NL	2.1	2.73	0.2	1.10	*
25. SNL-ML	0.1	0.50	0.0	0.65	NS
26. SNL-OLs	1.8	2.61	0.1	0.75	*
27. Is/SNL	5.3	6.61	−0.1	2.27	*
28. Ii/ML	3.6	2.84	1.2	2.43	*
29. Is/Ii	−4.5	9.66	−0.9	3.40	*

NS, Not significant.
*Significant at $P < .05$.

The mandibular incisor (Ii/ML) exhibited intrusive movement of 1.7 mm during treatment and extrusive movement of 0.1 mm during follow-up, for a net intrusive movement of 1.6 mm. Overbite decreased 3.8 mm compared with the controls during treatment and increased 1.4 mm during follow-up, for a net decrease of 2.4 mm. The maxillary molar (Msc/NL) was intruded 1.1 mm during treatment and extruded 0.2 mm during follow-up, for a net intrusion of 0.9 mm. The mandibular molar (Mic/NL) was extruded 1.0 mm during treatment and intruded 0.3 mm during follow-up, for a net extrusive movement of 0.7 mm.

Sex differences

During treatment, only 3 of the 29 variables showed significant differences between the sexes (data not shown). Compared with the controls, the maxilla moved down 0.2 mm in the girls and 0.9 mm in the boys. Lower facial height increased 0.7 mm in the girls and decreased 0.2 mm in the boys. The mandibular molars erupted 1.2 mm in female group and 0.7 mm in the male group For the follow-up period, 6 variables had significant differences between the sexes. Compared with the controls, the effective length of the maxilla increased 0.7 mm in girls and decreased 0.1 mm in boys. SNA angle increased 0.3° in girls and 0.2° in boys. For the vertical variables, lower facial height decreased 0.9 mm in girls, with no change in boys. The maxillary incisors erupted 1.0 mm in girls and 0.4 mm in boys. For the net changes, 5 variables showed significant differences between the sexes. Compared with the control group, the net forward movements of the mandibular incisors were 4.6 mm in the female group and 1.8 mm in the male group. The net downward movements of the maxilla were 1.1 mm in the male group and 0.7 mm in the female group. Lower

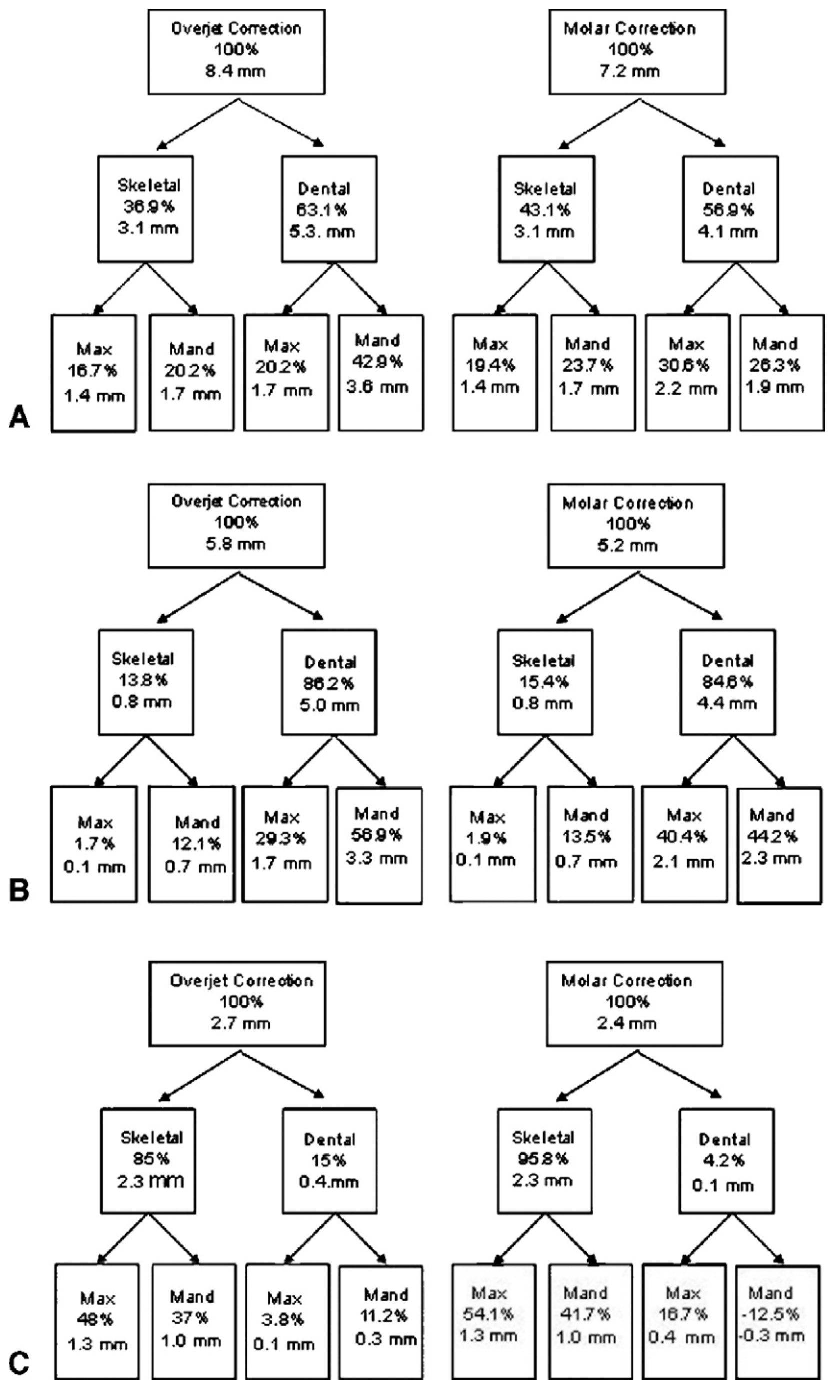

Fig 5. Skeletal and dental contributions to overjet and molar corrections: **A,** T2-T1 (treatment vs control); **B,** T3-T2 (treatment vs control); **C,** T3-T2 (treatment vs control).

facial height increased 0.3 mm in the female group and decreased 0.1 mm in the male group. The vertical intrusion of maxillary molars was 1.6 mm in the male group compared with 0.6 mm in the female group. Vertical eruptions of the mandibular molars were 0.9 mm in the male group and 0.5 mm in the female group.

Skeletal and dental contributions of overjet and molar correction

Figure 5 shows the skeletal and dental contributions to overjet and molar correction. During Herbst treatment, overjet correction was 8.4 mm compared with the

Table VI. Tomographic measurements and differences from T2-T1

	T1		*T2*		*T2-T1*		
Variables (mm)	*Mean*	*SD*	*Mean*	*SD*	*Difference*	*SD*	*Significance*
Tomograms							
1. RS	2.33	0.38	2.57	0.40	0.24	0.07	*
2. RP	2.07	0.25	2.40	0.20	0.33	0.03	*
3. RA	1.90	0.10	1.63	0.08	−0.27	0.09	*
4. LS	2.39	0.22	2.61	0.24	0.23	0.07	NS
5. LP	2.23	0.41	2.52	0.39	0.29	0.03	*
6. LA	2.02	0.07	1.79	0.04	−0.23	0.04	*

NS, Not significant.
*Significant at $P < .05$.

control group; 36.9% of this was due to skeletal changes and 63.1% to dental changes. During the follow-up, overjet increased by 5.8 mm; 13.8% was due to skeletal changes and 86.2% to dental changes. The net change in overjet was 2.7 mm; 85% was due to skeletal changes and 15% to dental changes. During Herbst treatment, the molars were corrected 7.2 mm to a super Class I or Class III relationship compared with the control group; 43.1% was due to skeletal changes and 56.9% to dental changes. During follow-up, the molar relationship relapsed to a Class I relationship with a change of 5.2 mm; 15.4% was due to skeletal changes and 84.6% to dental changes. The net change in molar relationship was 2.4 mm, with 95.8% due to skeletal changes and 4.2% to dental changes.

Tomographic measurement changes

Tomographic measurement changes for T1 to T2 are shown in Table VI. Five variables had significant differences. The right and left superior joint spaces showed increases of 0.24 and 0.23 mm, respectively, indicating downward displacement of the condyle in the fossa during treatment. The right and left posterior joint spaces had increases of 0.33 and 0.29 mm, respectively, and the right and left anterior joint spaces had decreases of 0.27 and 0.23 mm, respectively, indicating anterior positioning of the condyle in the fossa during treatment. No sex differences were found for the tomographic measurements.

DISCUSSION

This retrospective study was performed with 32 young patients with skeletal Class II malocclusions treated consecutively with edgewise crown Herbst appliances. The average treatment time was about 8 months. The patients were followed for another 16 months after removal of the Herbst appliances. During the observation period, the mixed-dentition patients were treated with 2 × 4 appliances until proper torque on the incisors and proper overbite and overjet were achieved. In the permanent-dentition patients, full appliances were placed to complete the treatment. All patients were in retention at T3. The effect of the edgewise Herbst treatment could be estimated by deducting the growth changes obtained from a matched control sample in Tables III through V.

With 8 months of Herbst treatment, all treatment subjects developed super Class I or Class III malocclusions, the result of many factors including posterior movement of the maxilla, increased horizontal component of condylar growth, anterior displacement of the mandible, and most likely remodeling of the glenoid fossa. The position of the maxilla did not change significantly. This means that its normal forward growth was significantly restrained. Similar headgear effects were reported by Pancherz,[3] Burkhardt et al,[7] and Hägg et al.[10] This effect was enhanced by edgewise treatment in which the incisors were tied back to the molars. Mandibular growth was stimulated beyond what normally occurs in Class II Division 1 growing children. Paulsen[23] reported newly formed bone on the posterior part of the condyle as a response to hypertophic chondrocytes, and on the posterior part of the ramus as a response to mechanically induced changes in the condyle. In our study, the appliance was advanced to an end-to-end incisal relationship and eventually overcorrected to a negative overjet. Omblus et al[24] reported improvement in jaw-base relationships with the step-by-step advancement of the mandible using removable functional appliance. Rabie et al[25] reported similar results using the headgear-Herbst appliance. The forward growth of the mandible with step-by-step advancement of the mandible was 3.1 mm in 6 months compared with 3.4 mm per year in our study.

In this study, we also showed downward and forward displacement of the mandible along with accelerated horizontal growth. However, the supracondylar position of the condyle in the glenoid fossa was similar to normal growth at the end of Herbst treatment.

That means that the anteroinferior translation of the mandible was most likely accompanied by appositional growth in the glenoid fossa. The glenoid fossa must have relocated to a more downward and forward position after Herbst treatment. This is supported by recent animal studies that show that, in condyle-fossa modifications during Herbst treatment, growth modification in the glenoid fossa was in an inferior and anterior direction.[11,12,26] Those authors suggested that Herbst treatment might even inhibit normal downward and backward growth of the fossa; this can result in the clinically observed super Class I molar relationship. In our study, we also found that the position of the condyle in the fossa after Herbst treatment did not change more than 0.2 mm in any direction of the joint space. This agrees with other tomogram and magnetic resonance imaging studies that reported only minor condyle position changes.[12,17]

The combination of restraining maxillary growth and enhancing mandibular growth with Herbst treatment resulted in significant improvements in overjet, molar, and jaw-base relationships. Of the 8.4 mm of overjet change, 37% was contributed by skeletal changes and 63% by dental changes. Of 7.2 mm of molar correction, 43% was contributed by skeletal changes and 56% by dental changes. This agrees with most other studies that reported about 50% of the changes from skeletal changes.[7,10,16]

Vertically, average overbite increased by 2 mm. This could be because the maxilla (A-pt) moved inferiorly more than normal growth, and the maxillary molars were temporary intruded. However, the mandibular molars erupted more than normal growth. The mandibular plane was maintained during treatment.

During the 16 months of follow-up, the maxilla resumed forward and downward growth similar to the control group. The mandibular horizontal growth was less than normal growth. Wieslander[9] stated that, without retention devices, initial skeletal effects were difficult to maintain. Hägg et al[10] reported the use of headgear and removable activators after Herbst treatment to maintain positive growth pattern. They suggested that increasing the length of treatment enhances successful outcomes. No orthopedic retention device was used in this study. In the mixed-dentition patients, maxillary and mandibular lingual arches with clasps on the maxillary lateral teeth were used as retainers. Lingual arches are important for stability of the orthopedic correction. Overbite correction was maintained by the lingual wires to prevent relapse of the Class II treatment. The torque on the maxillary incisors was also maintained to prevent Class II relapse. The arch form was maintained, and the "e" space was preserved. In the permanent dentition, maxillary and mandibular vacuum-formed retainers were used.

Significant dental changes were found with the edgewise Herbst treatment including retraction of the maxillary incisors and proclination of the mandibular incisors. These changes were found to return to T1 levels during the observation period. We believe that the use of super-torque brackets on the maxillary incisors and negative-torque brackets on the mandibular incisors aids in this recovery of incisors to pretreatment levels. Paulsen[23] reported that 80% of the anchorage loss was recovered after removal of the appliance. The maxillary molars were significantly distalized and intruded. Some changes relapsed during the observation period. The net amount of molar distalization was 1.7 mm more than normal growth. The net amount of molar intrusion was 0.9 mm more than normal growth.

The net effect of the edgewise Herbst treatment is primarily skeletal (85% of the overjet correction and 96% of the molar correction). This contrasts with 70% reported by Hagg et al.[10] The increase in skeletal effect might be related to the osseous adaptive changes in the glenoid fossa that are presumed to be more stable than mandibular positional changes as in the case of removable functional appliances.

CONCLUSIONS

1. Correction of overjet and molar relationship by edgewise Herbst treatment was a combination of posterior movement of the maxilla and the maxillary teeth, increased horizontal component of condylar growth, anterior displacement of the mandible, and possibly remodeling of the glenoid fossa.
2. During the 16 months of post-Herbst treatment, part of the initial skeletal correction was lost without retention. However, the net effects of the treatment were found to be mostly skeletal, suggesting the advantage of edgewise treatment combined with Herbst treatment to maximize the skeletal outcome.

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