Stability of Class II treatment with an edgewise crowned Herbst appliance in the early mixed dentition: Skeletal and dental changes

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Introduction: The objectives of this research were to assess skeletal and dental changes in patients with Class II malocclusion treated with the edgewise crowned Herbst appliance in the early mixed dentition and to measure the stability of treatment after a second phase of fixed appliance therapy. **Methods:** Twenty-two patients (ages, 8.4 ± 1.0 years) with Class II Division 1 malocclusion treated consecutively with the edgewise crowned Herbst appliance in the early mixed dentition were studied. Lateral cephalograms were taken before Herbst treatment, immediately after Herbst treatment, and after a second phase of fixed appliance therapy. The results were compared with a control group of untreated Class II subjects selected from the Bolton-Brush study, matched by age, sex, and craniofacial morphology. A total of 37 sagittal, vertical, and angular cephalometric variables were evaluated. Changes in overjet and molar relationship were calculated. Changes due to growth were subtracted to obtain the net changes due to treatment. The data were analyzed by using analysis of variance (ANOVA) and the *t* tests. **Results:** Overcorrection with the Herbst appliance resulted in an average reduction in overjet of 7.0 mm and a change in molar relationship of 6.6 mm. Several factors contributed to the change in overjet: restraint of the forward movement of the maxilla (0.4 mm), forward movement of the mandible (2.0 mm), backward movement of the maxillary incisors (3.7 mm), and forward movement of the mandibular incisors (0.9 mm). Skeletal changes together with a 3.1-mm backward movement of the maxillary molars and a 1.1-mm forward movement of the mandibular molars contributed to the changes in molar relationship. After the second phase of fixed appliance therapy, the change in overjet was reduced to 2.8 mm. Most of the remaining overjet corrections were contributed by the restraint of maxillary growth (2.8 mm). The mandible moved posteriorly by 1.6 mm, and the mandibular incisors moved forward by 0.2 mm. Change in molar relationship was reduced to 2.2 mm. The maxillary molars moved backward by 0.2 mm, and the mandibular molars moved forward by 0.8 mm. **Conclusions:** Overcorrection of Class II malocclusion with the edgewise crowned Herbst appliance in the early mixed dentition resulted in a significant reduction in overjet and correction of the molar relationship. A portion of the correction was maintained after a second phase of fixed appliance therapy because of the continuous restraint of maxillary growth and the dentoalveolar adaptations. (Am J Orthod Dentofacial Orthop 2011;140:210-23)

Class II skeletal malocclusions are commonly treated in 1 phase of fixed appliance therapy or with a functional appliance followed by a fixed appliance. The Herbst appliance can be used with a fixed appliance, and the treatment time is shorter. Patient cooperation is minimal, with a high success rate of treatment.[1,2] Recent studies suggested that fixed functional appliances can be effective in correcting Class II skeletal abnormalities by promoting growth of the mandible and remodeling of the glenoid fossa.[3-5] The timing of orthopedic intervention with functional appliances is also a subject of intense controversy. When determining the optimal time to initiate Class II treatment, factors such as the ability to use all potential growth, the likelihood of incisor trauma, the development of improper swallowing patterns, incomplete lip function, effects on the

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temporomandibular joint, and psychosocial concerns need to be considered. Successful treatments of Class II malocclusions in the early mixed dentition have been reported.[6,7] However, data from randomized controlled clinical trials have shown that effective skeletal changes were better achieved in the late mixed dentition and early permanent dentition with more stable results.[8,9] Other studies suggest that supplementary mandibular growth with functional appliance therapy appears to be greater if the functional treatment is performed during the pubertal growth period.[10] The purpose of this study was to investigate the skeletal and dental changes of Class II patients treated in the early mixed dentition with the crowned Herbst appliance and the stability of these changes after a second phase of fixed appliance therapy. The null hypotheses were that there will be no significant differences in skeletal or dental changes with Herbst treatment in the early mixed dentition and after a second phase of fixed appliance therapy compared with the control group.

MATERIAL AND METHODS

The experimental group included 56 Class II patients treated consecutively by an author (T.D.) with the edgewise crowned Herbst appliance in the early mixed dentition followed by fixed appliance therapy. The criteria for selection included (1) no previous orthodontic treatment, (2) Class II malocclusion in the mixed dentition with an ANB greater than 4°, and (3) completion of both phases of treatment (patients who did not require a second phase of treatment or did not complete the second phase of treatment were excluded), and (4) no craniofacial anomalies. The final sample that met the inclusion and exclusion criteria included 22 subjects.

Serial cephalometric radiographs of 22 untreated subjects with Class II malocclusion were obtained from the Case Western University's Bolton-Brush study, Cleveland, Ohio, as the control group. They were matched in sex, age, and craniofacial morphology with the experimental subjects.

The Herbst appliance uses a bilateral telescope mechanism consisting of a tube, a plunger, 2 pivots, and 2 locking screws that function to keep the mandible in a continuously anterior jumped position (Fig 1).[11] The pivot for the tube was located on the maxillary second deciduous molar or the permanent first molar, and the pivot for the plunger was attached to the mandibular second deciduous molar or the permanent first molar. The length of the tube determined the amount of anterior displacement of the mandible. The appliance was designed to incorporate edgewise brackets and mechanics into the correction of Class II malocclusions.

The mandibular incisor brackets incorporated a $-10°$ inclination to minimize the proclination of the incisors during the Herbst treatment. Stainless steel crowns on the maxillary and mandibular second deciduous molars or the permanent first molar, anchored the Herbst appliance to the dentition. Double buccal tubes were placed on the molar crowns to permit an auxiliary archwire to intrude the maxillary or mandibular incisors as necessary. The maxillary arch was tied back to hooks on the molar tubes to prevent space from opening in the maxillary arch and the maxillary molars from distalizing. In addition, consolidation of the maxillary arch distributed the load applied to all teeth in an attempt to elicit the maximum orthopedic effect. In the mandibular arch, a 2-mm half-round cantilever was placed between the second deciduous molar and the interproximal area between the first deciduous molar and the canine. The axle was placed at the mesial end of the cantilever, and a 0.022 × 0.028-in archwire tube was placed above and below the axle.

A transpalatal arch was not included in the appliance to allow the first molars to rotate as the Class II relationship was corrected. A lingual arch was not included to allow easier placement of the appliance and prevent possible tipping of the mandibular anterior incisors. Both arches were free to accommodate expansion during treatment, if necessary. An occlusal stop off the cantilever arm or directly soldered to the stainless steel crowns extended into and rested on the distal central fossa of the first deciduous molar to prevent tipping of the cantilever arm and impingement into the buccal mucosa and to minimize tipping and rotation of the mandibular second deciduous molar.

The Herbst appliance was activated initially to an edge-to-edge incisor relationship with the skeletal midlines in alignment. Brackets were bonded to the maxillary and mandibular incisors and deciduous canines as needed. Heat-treated copper-nickel-titanium archwires were used to control incisor inclination and mandibular molar movement. The archwire sequence began with a 0.014-in copper-nickel-titanium wire. Then a 0.016 × 0.025-in copper-nickel-titanium wire was used with the maxillary wire tied back to the hook on the maxillary molar, and the mandibular wire was annealed and cinched to prevent anterior movement. Next, a mandibular 0.019 × 0.025-in reverse curve nickel-titanium archwire was placed when more leveling was necessary, and a maxillary 0.019 × 0.025-in beta-titanium alloy wire was placed if more leveling or torque was desired.

To achieve the maximum orthopedic effect, the maxillary archwire was tied back to prevent distalization of the maxillary molars. The appliance was activated in a step-by-step fashion at a distance of 4 mm every 12 weeks until the maxillary canine achieved an end-to-

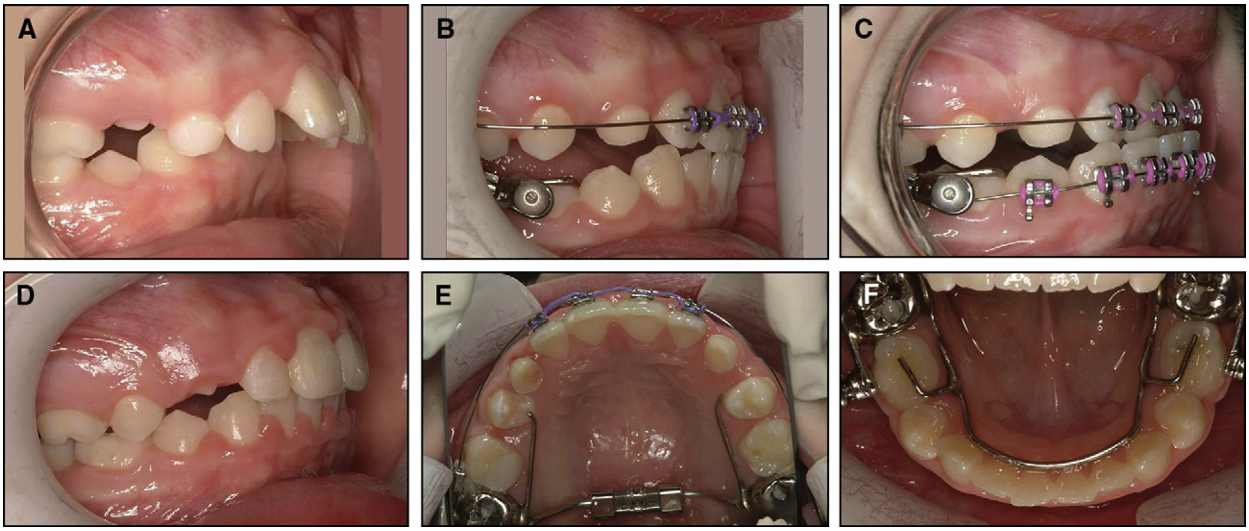

Fig 1. **A,** Pretreatment lateral view of a patient; **B,** initial advancement of the mandible; **C,** advancement of the mandible until the canines were in Class III position; **D,** settling of the occlusion after removal of the Herbst appliance; **E,** maxillary occlusal view of the appliance; **F,** mandibular occlusal view of the appliance.

end or full-tooth overcorrected relationship with the mandibular first premolar or first deciduous molar. The overcorrected position was held for 12 weeks. Corrected sagittal tomograms were taken before placement of the Herbst appliance and before its removal to confirm the condylar position. If the condyles were reasonably centered in the glenoid fossa, then a lateral cephalogram was taken, and the patient was scheduled for Herbst removal as soon as possible.

In the mixed dentition treatment after Herbst removal, the first permanent molars were banded, and 2 × 4 appliance treatment continued until the anterior occlusion was corrected, overbite was corrected, and there was proper torque on the incisors. Also, the maxillary and mandibular first permanent molar width was coordinated. If more arch length was necessary, molar bands with 0.022 × 0.028-in extension tubes soldered in the archwire slots were placed, and open-coil springs were used to create more arch length. Appliance removal occurred in 2 appointments. At the first appointment, maxillary and mandibular alginate impressions were taken, and sectional archwires were placed. At the second appointment, the incisor brackets were removed, and maxillary and mandibular lingual holding arches were placed. The lingual arches helped to prevent overbite relapse, saved leeway space, and maintained the arch form. The patients were instructed that the holding arches would remain in place until all permanent teeth had erupted. At that time, the patients were reevaluated for comprehensive orthodontic treatment to finalize the occlusion.

Institutional review board approval was obtained from West Virginia University before the study. Approval was also obtained from the author's office (T.D.) and the Bolton-Brush Center for the use of the orthodontic records and radiographs, respectively.

Lateral cephalograms were scanned into digital format with a scanner (Expression 1680, Epson America, Long Beach, Calif) and printed on a printer (C510, Lexmark International, Lexington, Ky). Each printout was superimposed on the original radiograph to ensure a 1:1 conversion with no distortion. Digital radiographs obtained from the Bolton-Brush study were scanned at 12-bit gray-scale resolution with a spatial resolution of 0.1 mm per pixel and stored in uncompressed TIFF format. The images were converted to JPEG format with software (Irfan View, version 4.0; http://www.irfanview.com/) and loaded into Photoshop (version 6.0, Adobe Systems, San Jose, Calif) for size analysis. All original radiographs from the Bolton-Brush study were indexed with 4 corner fiduciary points by using a template according to the method described by Baumrind and Miller.[12] In Photoshop, the resolutions of the images were verified (600 dpi), and the images were resized to the original dimensions of the unscanned radiographs. Printouts were then made, and the fiduciary points were measured with an electronic digital calipers to ensure a 1:1 conversion with no distortion from the original radiographs.

Tracings were made by an operator (T.G.W.) using a #2 HB mechanical lead pencil (Pentel 0.5 mm lead; Torrance, Calif), an orthodontic protractor, and 0.003-in matte cephalometric acetate tracing film (3M Unitek, Monrovia, Calif). A custom cephalometric analysis was performed by using landmarks described by published cephalometric systems.[13-16] The data were normalized to account for magnification differences between the cephalometric machine used for the Bolton-Brush study (5.6%) and the cephalometric machine at the author's office (10%).

Each angular variable was measured with a cephalometric protractor and evaluated to the nearest 0.5°. Each sagittal and vertical measurement was made with electronic digital calipers and evaluated to the nearest 0.1 mm.

The reliability of the cephalometric measurements was tested by investigating the errors in locating, superimposing, and measuring the changes of all landmarks. Pretreatment and posttreatment lateral cephalograms of 10 randomly selected patients were retraced at least 2 weeks after the initial tracing and analyzed to evaluate errors. For all cephalometric variables, differences between the measurements recorded at the first and second tracings were compared for each subject before treatment (T1), immediately after treatment (T2), and after the second phase of fixed appliance therapy (T3). A matched-pairs *t* test was performed to compare the 2 registrations. A correlation coefficient was established for each variable at each time point to determine the reliability. Overall, the method of cephalometric analysis used in this study, including landmark identification, superimposition of radiographs, and measurements, was determined to be reliable, with most correlation coefficients above 0.9.

Analyses of the sagittal skeletal and dental changes were performed by constructing a reference grid based on the occlusal line (OL) and the occlusal line perpendicular (OLp), obtained from the T1 lateral cephalogram (Fig 2). This reference grid was used for all sagittal measurements between OLp and the cephalometric landmarks. The reference grid from T1 was transferred to the T2 and T3 radiographs by superimposition on the anterior cranial base.

The reference lines that were used for the vertical measurements included OLs, NL, and ML, and OL. OLs was obtained from the T1 radiograph and transferred by superimposition on the anterior cranial base to the T2 and T3 radiographs. A measurement from ANS to Me (ANS-Me) was also included (Fig 3).

Angular measurements were used to identify changes in the dentofacial complex. Cephalometric landmarks and reference lines for the angular measurements are illustrated in Figure 4.

To determine the amounts of skeletal and dental contributions to the overjet and molar relationship corrections, the dental changes in the maxilla and the mandible were calculated according to the method described by Pancherz.[14]

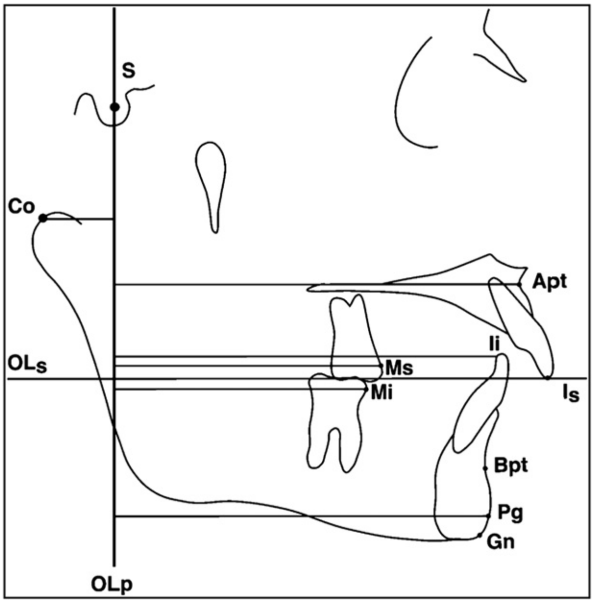

Fig 2. Cephalometric landmarks and reference lines for the sagittal measurements.

Statistical analysis

A matched-pairs *t* test was used to compare the starting forms between the treatment and control subjects at T1. The differences between the treatment and control subjects for each variable across the 3 time periods (T1-T3) were analyzed for each sex and the pooled subjects. A repeated-measures analysis of variance (ANOVA) was performed to determine whether the differences between the treatment and control subjects were the same across the 3 time periods. A matched-pairs *t* test was performed for each variable to identify the treatment effects of the Herbst appliance (changes in the treatment group T2-T1) minus (changes in the control group t2-t1), and combined phase 1 and phase 2 treatment (T3-T1) minus (t3-t1). A significance level of $P < 0.05$ was used.

RESULTS

The final sample size consisted of 22 subjects (7 boys, 15 girls). The mean ages of the treatment and control groups at T1 of the pooled subjects were 8.4 ± 1.0 and 8.4 ± 1.1 years, respectively. The mean ages of the treatment and control groups at T2 were 9.3 ± 0.9 and 9.4 ± 0.8 years, respectively. The mean ages of the treatment and control groups at T3 were 14.6 ± 1.4 and 14.7 ± 1.5 years, respectively. No significant

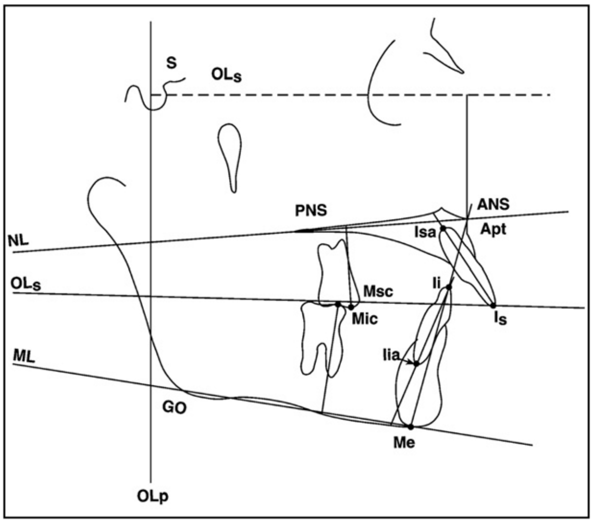

Fig 3. Cephalometric landmarks and reference lines for the vertical measurements.

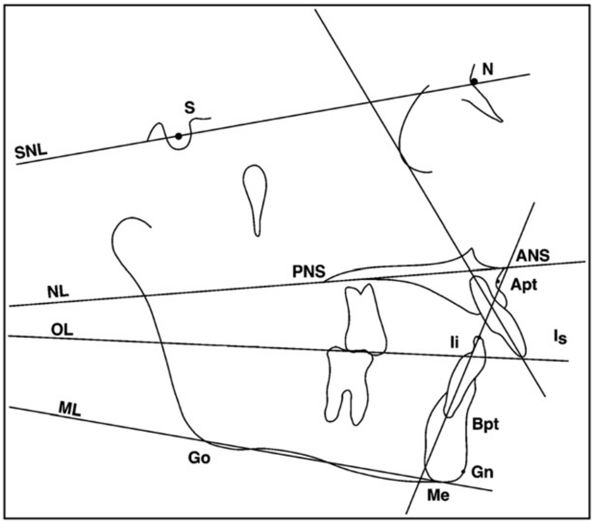

Fig 4. Cephalometric landmarks and reference lines for the angular measurements.

differences were found between the treatment and control groups at any time period.

Sex differences were analyzed for pretreatment craniofacial morphology and treatment changes. Because of the large quantity of data generated, only pooled data were reported.

Table I shows the pretreatment craniofacial morphology of the 2 groups. For the pooled subjects, significant differences were found in 4 of the 37 variables at T1. The variables OLp–A-point, Is-OLp, and ANB were greater in the treatment group than in the control group, and OLs–A-point was less in the treatment group than in the control group.

Table II compares the skeletal and dental changes (T2-T1) between the treatment and control groups for the pooled subjects.

All sagittal variables showed a significant difference between the treatment and control group except for OLp–A-point, OLp-Pg, and Co-Gn. The position of the maxillary base (OLp–A-point) moved backward 0.4 mm compared with the control group. The position of the mandibular base (OLp-Pg) moved forward 2.0 mm compared with the control group. The position of the condyle (OLp-Co) moved anteriorly 1.5 mm relative to the control group. The effective maxillary length (Co–A-point) and mandibular length (Co-Gn) showed differences of −2.6 and 0.7 mm from the control group, respectively. The position of the maxilla relative to the mandible along the functional occlusal plane (Wits appraisal) showed a difference of −3.7 mm compared with the control group. The position of the maxillary incisor (Is-OLp) moved backwards 4.1 mm compared with the control group. The mandibular incisors (Ii-OLp) moved forward 2.9 mm compared with the control group. The maxillary molars (Ms-OLp) moved posteriorly 3.5 mm compared with the control group.

All vertical variables showed no significant differences between the treatment and control groups from T2 to T1, except for Ii-ML and Msc-NL. The mandibular incisor (Ii-ML) was intruded 1.8 mm compared with the control group. The maxillary molar was intruded 2.6 mm compared with the control group.

Significant differences in the angular variables between the control and treatment groups were found in the variables ANB, SNL-NL, SNL-OL, Is/NL, and Ii/ML. A net decrease in ANB of 2.0° was found in the treatment group relative to the control group. Net increases of 1.7° and 2.8° were found in the palatal plane angle (SNL-NL) and the functional occlusal plane angle (SNL-OL), respectively. The inclination of the maxillary incisor (Is/NL) decreased by 7.0° compared with the control group, but the mandibular incisor angle (Ii/ML) had a net increase of 7.6° compared with the control group.

Figures 5 and 6 show the calculation of net overjet and molar relationship corrections. The amount of skeletal and dental contributions to the changes in overjet and molar relationship are shown in Figure 7. The net overjet reduction in the treatment group was 7.0 mm, with 2.4 mm (34%) of the correction contributed by skeletal change and 4.6 mm (67%) by dental change. The net molar correction was 6.6 mm, with 2.4 mm (36%) of the correction contributed by skeletal change and 4.2 mm (64%) by dental change.

Table III compares the skeletal and dental changes between the treatment and control groups for the pooled subjects from T3 to T1.

Table I. Comparison of pretreatment craniofacial morphology in the pooled subjects

	Control		*Treated*				
Variable	*Mean*	*SD*	*Mean*	*SD*	P *value*	*Difference*	*Significance*
Sagittal (mm)							
Olp–A-point	68.3	4.2	70.6	3.3	0.0479	2.3	*
Olp-Pg	71.0	5.5	71.9	4.5	0.5437	0.9	NS
Olp-Co	9.6	2.1	8.2	2.9	0.0738	1.4	NS
Co–A-point	78.3	4.3	79.7	4.9	0.3255	1.4	NS
Co-Gn	95.5	5.0	95.1	4.9	0.8154	0.4	NS
Co-Gn minus Co–A-point	17.1	2.9	15.8	3.8	0.2072	1.3	NS
Wits	1.1	1.6	1.1	1.9	0.983	0.0	NS
Is-Olp	73.5	5.6	76.6	4.3	0.0403	3.1	*
Ii-Olp	68.8	4.4	71.0	3.5	0.0782	2.2	NS
Overjet	4.7	2.1	5.6	2.6	0.1694	0.9	NS
Ms-Olp	46.0	3.7	47.9	2.7	0.0524	1.9	NS
Mi-Olp	45.7	4.3	47.1	2.9	0.1894	1.4	NS
Molar relationship	0.3	0.9	0.8	2.0	0.3244	0.5	NS
Vertical (mm)							
OLs–A-point	25.2	2.2	22.8	4.1	0.0215	2.4	*
ANS-Me	57.0	4.6	56.9	3.2	0.9324	0.1	NS
Is-NL	23.7	4.1	23.6	2.8	0.9635	0.1	NS
Ii-ML	34.1	3.2	33.2	2.4	0.3418	0.9	NS
Overbite	1.6	3.0	1.4	3.4	0.8021	0.2	NS
Msc-NL	16.7	3.0	17.0	1.9	0.7502	0.3	NS
Mic-ML	25.7	1.9	25.6	2.1	0.8807	0.1	NS
Angular (°)							
SNA	79.9	3.2	81.4	3.9	0.1633	1.5	NS
SNB	75.3	3.0	75.0	3.6	0.8058	0.3	NS
ANB	4.6	1.3	6.4	2.1	0.0018	1.8	*
SNL-NL	7.5	3.2	8.3	3.6	0.459	0.8	NS
SNL-ML	34.1	4.6	34.4	7.9	0.8803	0.3	NS
SNL-OL	20.3	3.5	22.3	4.2	0.1057	2.0	NS
Is/NL	111.0	5.9	109.6	6.0	0.4226	1.4	NS
Ii/ML	94.6	5.7	96.0	9.3	0.5413	1.4	NS
Interincisal angle	127.6	7.9	126.7	10.3	0.7386	0.9	NS

NS, Not significant.
**P* <0.05 level of significance.

Seven sagittal variables showed significant differences between the treatment and control groups: OLp–A-point, Co–A-point, Wits appraisal, Is-OLp, overjet, Ms-OLp, and molar relationship. The position of the maxillary base (OLp–A-point) moved backward 2.8 mm compared with the control group. The effective maxillary length (Co–A-point) showed a −3.8 mm difference from the control group. The position of the maxilla relative to the mandible along the functional occlusal plane (Wits appraisal) showed a difference of −1.6 mm compared with the control group. The position of the maxillary incisor (Is-OLp) moved backward 4.2 mm compared with the control group. The maxillary molars (Ms-OLp) moved backward 3.0 mm compared with the control group.

All vertical variables showed no significant differences between the treatment and control groups from T3 to T1.

All angular variables showed no significant differences between the treatment and control groups from T3 to T1, except for SNA and ANB. A decrease in SNA of 2.6° was found relative to the control group. A decrease in ANB of 2.1° was found compared with the control group.

Figures 8 and 9 show the calculation of net overjet and molar relationship corrections from T3 to T1. The skeletal and dental contributions to the net overjet and molar corrections are shown in Figure 10. The net overjet correction in the treatment group was 2.8 mm, with 1.2 mm (43%) of the correction contributed by skeletal change and 1.6 mm (57%) by dental change. The net molar relationship correction was 2.2 mm, with 1.2 mm (55%) of the correction contributed by skeletal change and 1.0 mm (45%) by dental change.

DISCUSSION

Overcorrection with the crowned Herbst appliance resulted in significant skeletal changes compared with the control group. The forward movement of the maxilla

Table II. Comparison of skeletal and dental changes between the treatment (T2-T1) and control (t2-t1) groups for the pooled subjects

	Control (t2-t1)		*Treated (T2-T1)*				
Variable	*Mean*	*SD*	*Mean*	*SD*	*Difference*	*P value*	*Significance*
Age (y)	13.5	6.9	12.2	6.8	−1.3	0.6304	NS
Sagittal (mm)							
Olp–A-point	1.4	0.6	1.0	1.9	−0.4	0.4206	NS
Olp-Pg	0.8	2.8	2.8	3.5	2.0	0.1221	NS
Olp-Co	0.7	1.6	−0.8	1.9	−1.5	0.0396	*
Co–A-point	2.1	1.7	−0.5	3.4	−2.6	0.0205	*
Co-Gn	2.7	2.5	3.4	2.3	0.7	0.4778	NS
Co-Gn minus Co–A-point	0.6	2.1	3.2	2.9	2.6	0.0159	*
Wits	−0.7	1.6	−4.4	3.0	−3.7	0.0009	*
Is-Olp	2.5	1.9	−1.6	4.5	−4.0	0.0065	*
Ii-Olp	1.9	1.5	4.8	3.0	3.0	0.0041	*
Overjet	0.6	1.6	−6.4	3.9	−6.9	0.0001	*
Ms-Olp	1.6	1.3	−1.9	2.2	−3.4	0.0001	*
Mi-Olp	1.7	1.4	4.8	1.9	3.1	0.0001	*
Molar relationship	−0.2	0.9	−6.6	2.8	−6.4	0.0001	*
Vertical (mm)							
OLs–A-point	1.4	1.2	2.0	1.6	0.6	0.3174	NS
ANS-Me	1.7	1.4	1.3	1.7	−0.4	0.5006	NS
Is-NL	1.8	3.1	0.9	3.0	−0.9	0.4766	NS
Ii-ML	1.0	0.8	−0.8	2.5	−1.8	0.0175	*
Overbite	1.3	2.9	−1.1	3.6	−2.4	0.0821	NS
Msc-NL	1.3	2.0	−1.3	1.2	−2.7	0.0005	*
Mic-ML	0.6	1.0	1.2	1.3	0.7	0.1517	NS
Angular (°)							
SNA	0.6	1.4	−0.3	2.4	−1.0	0.2269	NS
SNB	0.6	1.6	1.6	2.1	1.0	0.1745	NS
ANB	0.0	1.2	−2.0	2.4	−2.0	0.0141	*
SNL-NL	−0.7	2.0	1.0	1.8	1.7	0.0283	*
SNL-ML	−0.1	1.8	0.1	1.6	0.2	0.7347	NS
SNL-OL	0.6	2.1	3.4	3.8	2.8	0.0306	*
Is/NL	−0.3	3.4	−7.3	7.3	−7.0	0.0043	*
Ii/ML	−0.5	2.8	7.1	6.9	7.6	0.0012	*
Interincisal angle	−0.8	6.0	1.4	9.4	2.2	0.4922	NS

NS, Not significant.
**P* <0.05 level of significance.

was restrained by 0.4 mm compared with the control group. This is consistent with previous studies reporting 0.2 to 1.2 mm less forward movement with Herbst treatment compared with the control group.[1,7,17] In other studies, A-point moved backward as much as 0.5 to 1.0 mm.[6,18-21] The Herbst appliance exerts a posterior and upward force on the maxilla via the maxillary dentition similar to high-pull headgear.[2,7,22-24] During the second phase of fixed appliance therapy, the amount of forward A-point movement was restrained by 2.8 mm, indicating that the headgear effect of the Herbst appliance is stable after fixed appliance therapy. This is consistent with reports by other investigators that the maxillary base moved forward 0.8 to 1.4 mm[5,19,25,26] in the short term and 1.3 to 5.1 mm[1,23,26-30] in the long-term posttreatment period.

Another indicator of maxillary restraint during Herbst treatment was the change in the SNA angle. In our study, initial treatment with the Herbst appliance resulted in a 0.9° decrease in the SNA angle relative to the control group. Other studies reported a decrease of 0.4° to 1.2° during treatment.[1,7,17-19,21,22,25-27,29,31-36] After phase 2 treatment, a further decrease in SNA angle (−2.6°) was found, supporting a continuous headgear effect of treatment.

The position of the mandibular base was moved forward with Herbst appliance treatment an average of 2.0 mm relative to the control group. This is consistent with other studies reporting forward movement of the mandibular jaw base of 0.9 to 5.0 mm.[1,17-21,24-26,28,29,32,33,35-43] However, after fixed appliance therapy, the mandible moved backward 1.6 mm

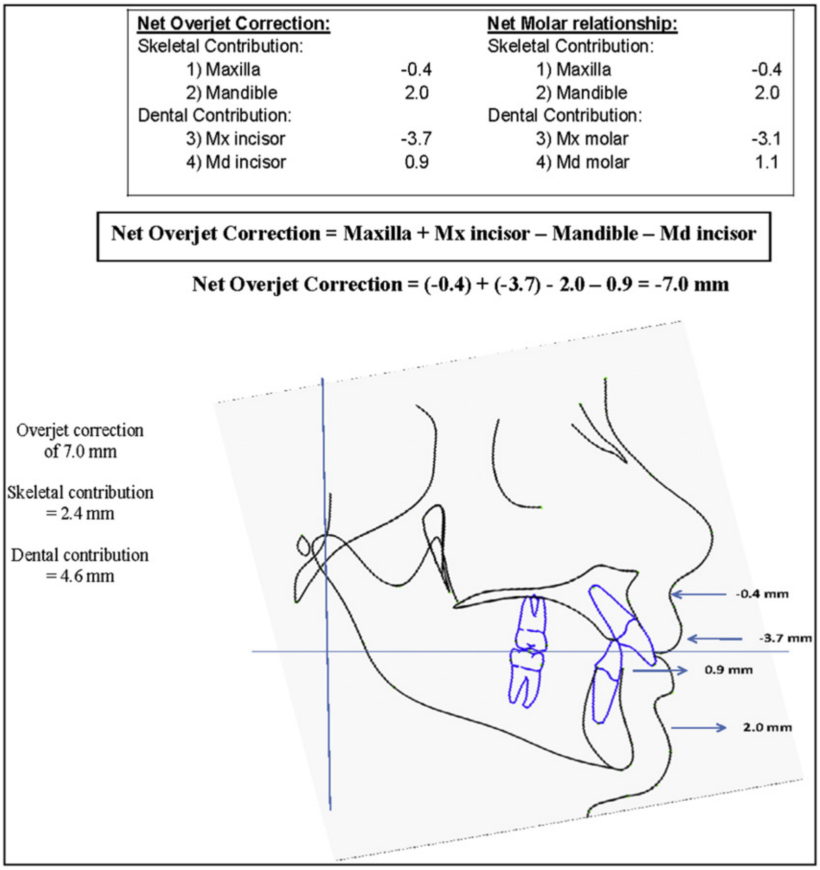

Fig 5. Components of net overjet correction after Herbst treatment (changes in treatment group [T1 to T2] minus changes in control group [t1 to t2]).

compared with the control group, suggesting that the forward positioning of the mandibular base was not maintained after phase 2 treatment. Similarly, a net increase in SNB of 1.0° was observed with Herbst treatment; this is consistent with other studies that reported increases ranging from 0.2° to 2.6°.[1,5,7,15,18,21,22,24-26,28,32-36,42,44,45] After fixed appliance therapy, there was a net decrease of 0.5° compared with the controls. Wieslander[30] made similar conclusions when he found no significant long-term effect of Herbst treatment in the early mixed dentition on the mandibular structures and positions in comparison with changes in the control group. Another study found greater effects on mandibular growth if treatment was started during the pubertal growth period.[10]

An initial increase in mandibular length of 0.7 mm, as measured by Co-Gn, was observed with Herbst treatment compared with the controls. This was less than reported by other studies, ranging from 1.4 to 4.4 mm.[6,21,32,46] After the second phase of fixed appliance therapy, the mandibular length was 1.9 mm shorter than in the control group. A possible explanation is that the patients in this study were started in the early mixed dentition, long before the pubertal growth period. In addition, mandibular growth in the second phase of fixed appliance treatment might be "restricted" by the headgear effect on the maxilla.

Overall, the sagittal intermaxillary jaw relationships were improved with Herbst treatment. The Wits appraisal showed a net decrease of 3.7 mm, which was slightly greater than the 2.4 to 3.0 mm reported by other investigators.[24,25,32-34] However, it is consistent with the decrease in the Wits appraisal of 3.0 to 5.1 mm reported on Class II Division 2 patients.[33,47] After fixed appliance therapy, the net decrease in the Wits appraisal was maintained at 1.6 mm relative to the control group. Similar results were found with the ANB angle. The ANB angle showed a decrease of 2.0°, which is consistent with other studies reporting decreases of 1.1° to 3.9°.[1,6,7,15,18,21,22,24-28,32-36,42,44,46] After fixed appliance treatment, the decrease in ANB stayed at 2.1° relative to the control group, indicating that the skeletal correction after Herbst treatment was maintained.

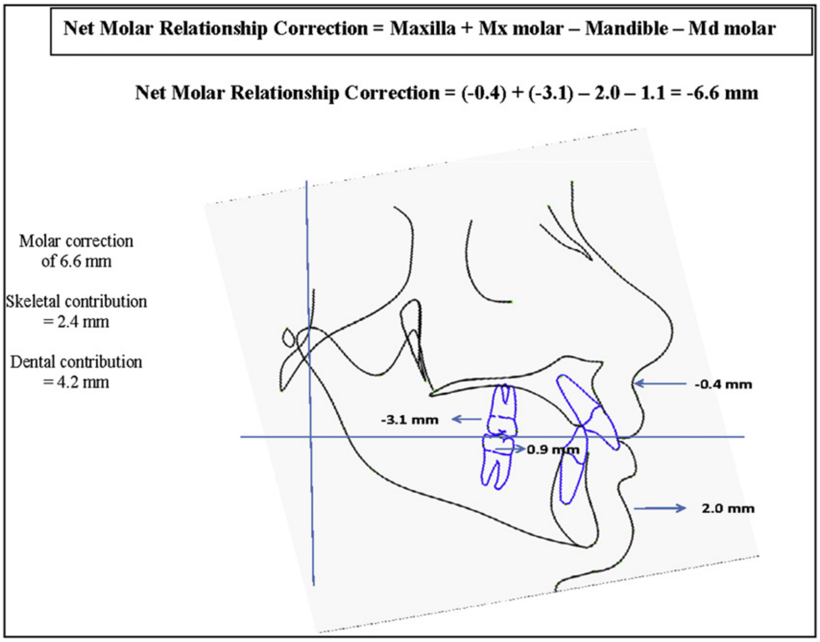

Fig 6. Components of net molar correction after Herbst treatment (changes in treatment group [T1 to T2] minus changes in control group [t1 to t2]).

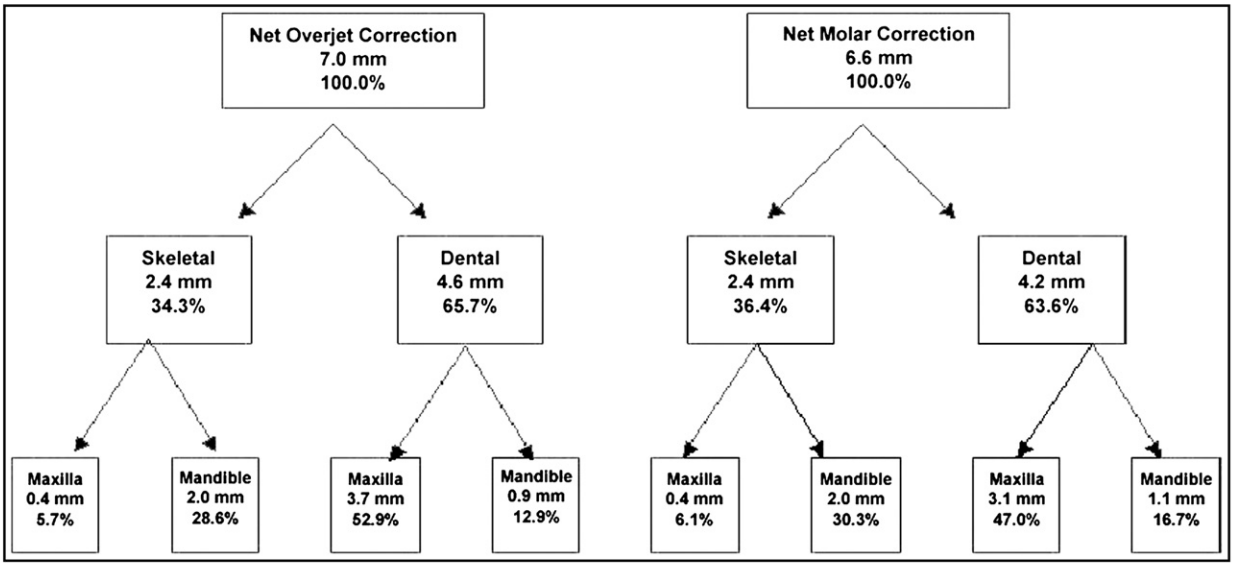

Fig 7. Pitchfork analysis of net overjet and molar corrections after Herbst treatment (changes in treatment group [T1 to T2] minus changes in control group [t1 to t2]).

The Herbst appliance exerts a posterior superior force on the maxillary dentition and an anterior inferior force on the mandibular dentition[8,33,35,38,44,45]; these forces generally result in distalization of the maxillary molars, retroclination of the maxillary incisors, mesial movement of the mandibular molars, and proclination of the mandibular incisors.[8,35,42,46] In our study, a net distal molar movement of 3.1 mm was observed with Herbst treatment compared with the control group. This is consistent with the 0.6 to 3.0 mm of distal

Table III. Comparison of skeletal and dental changes between the treatment (T3-T1) and control (t3-t1) groups for the pooled subjects

	Control (t3-t1)		Treated (T3-T1)				
Variable	*Mean*	*SD*	*Mean*	*SD*	*Difference*	P *value*	*Significance*
Age (y)	75.1	15.3	73.8	15.5	−1.3	0.7628	NS
Sagittal (mm)							
Olp–A-point	7.1	2.3	4.3	2.5	−2.8	0.0005	*
Olp-Pg	9.5	2.8	7.9	3.8	−1.6	0.1248	NS
Olp-Co	1.4	2.3	0.8	2.5	−0.6	0.3788	NS
Co–A-point	8.6	3.1	4.8	3.7	−3.8	0.0006	*
Co-Gn	13.5	3.3	11.6	4.3	−1.9	0.0967	NS
Co-Gn minus Co–A-point	5.0	2.6	6.4	3.5	1.4	0.1261	NS
Wits	0.0	1.7	−1.6	2.0	−1.6	0.0091	*
Is-Olp	9.3	2.7	5.1	4.5	−4.2	0.0004	*
Ii-Olp	8.7	2.2	7.3	3.9	−1.4	0.1735	NS
Overjet	0.7	1.6	−2.3	2.8	−3.0	0.0001	*
Ms-Olp	9.6	2.9	6.6	2.7	−3.0	0.0008	*
Mi-Olp	10.3	3.1	9.5	2.8	−0.8	0.3965	NS
Molar relationship	−0.7	1.1	−2.9	2.0	−2.2	0.0001	*
Vertical (mm)							
OLs–A-point	4.8	2.2	5.2	2.5	0.4	0.6137	NS
ANS-Me	6.8	2.4	5.8	3.0	−1.0	0.2234	NS
Is-NL	3.9	3.0	3.0	3.4	−0.9	0.3716	NS
Ii-ML	4.5	1.9	3.6	2.3	−0.9	0.1547	NS
Overbite	1.7	3.2	0.3	3.2	−1.4	0.1695	NS
Msc-NL	4.7	2.0	3.6	2.3	−1.1	0.0834	NS
Mic-ML	3.9	2.2	4.1	1.6	0.2	0.7349	NS
Angular (°)							
SNA	1.8	2.3	−0.8	2.9	−2.6	0.0016	*
SNB	1.9	2.0	1.4	2.4	−0.5	0.3924	NS
ANB	−0.1	1.3	−2.2	1.6	−2.1	0.0001	*
SNL-NL	−0.9	2.7	0.3	3.3	1.2	0.1957	NS
SNL-ML	−1.3	2.3	−1.1	2.6	0.2	0.7839	NS
SNL-OL	−2.4	3.2	−0.9	3.2	1.5	0.1317	NS
Is/NL	−1.0	5.6	0.5	6.4	1.5	0.4359	NS
Ii/ML	0.0	4.9	3.0	7.7	3.0	0.1102	NS
Interincisal angle	1.6	7.4	−0.3	13.4	−1.9	0.5704	NS

NS, Not significant.
*P <0.05 level of significance.

molar movement reported in other studies.[1,17-20,22-25,28,29,32,35,36,38,39,45,46] A few studies reported mesial movement of the maxillary molars of 0.2 to 0.6 mm.[7,21,37] At the completion of fixed appliance therapy, only 0.2 mm of the distal movement remained, suggesting that the mechanics during comprehensive orthodontic treatment might have led to the recovery of the forward movement of the maxillary molars.

In this study, 1.1 mm of forward movement of the mandibular molar was found with Herbst treatment. This agrees with the range of 0.9 to 5.5 mm reported in other studies.[5,7,8,17-22,25,28,29,31-40,42,46] After fixed appliance therapy, only 0.8 mm of forward mandibular movement remained, suggesting that treatment mechanics during phase 2 treatment might have caused the recovery of the mandibular molars.

In this study, the maxillary incisors moved backward 3.7 mm or retroclined by 7.0° during Herbst treatment; these values are consistent with the ranges of 0.5 to 3.6 mm and 3.2° to 8.2° reported by others.[5,19-21,24,25,28,29,32,33,35-40,45,46] In a few studies, no significant differences in maxillary incisor position[18,22,44] or mesial movement of 0.8 mm were found.[7] After fixed appliance therapy, a net posterior movement of 1.4 mm or 1.5° remained, contributing to the reduction in overjet. The mandibular incisor moved forward by 0.9 mm or proclined by 7.6°; this is consistent with the ranges of 0.2 to 4.0 mm and 5.4° to 10.8° reported by others.[1,5,8,17-22,24-29,33-39,42,44-49] After fixed appliance therapy, a net forward

Net Overjet Correction:		Net Molar relationship:	
Skeletal Contribution:		Skeletal Contribution:	
1) Maxilla	-2.8	1) Maxilla	-2.8
2) Mandible	-1.6	2) Mandible	-1.6
Dental Contribution:		Dental Contribution:	
3) Mx incisor	-1.4	3) Mx molar	-0.2
4) Md incisor	0.2	4) Md molar	0.8

Net Overjet Correction = Maxilla + Mx incisor – Mandible – Md incisor

Net Overjet Correction = (-2.8) + (-1.4) – (-1.6) – 0.2 = -2.8 mm

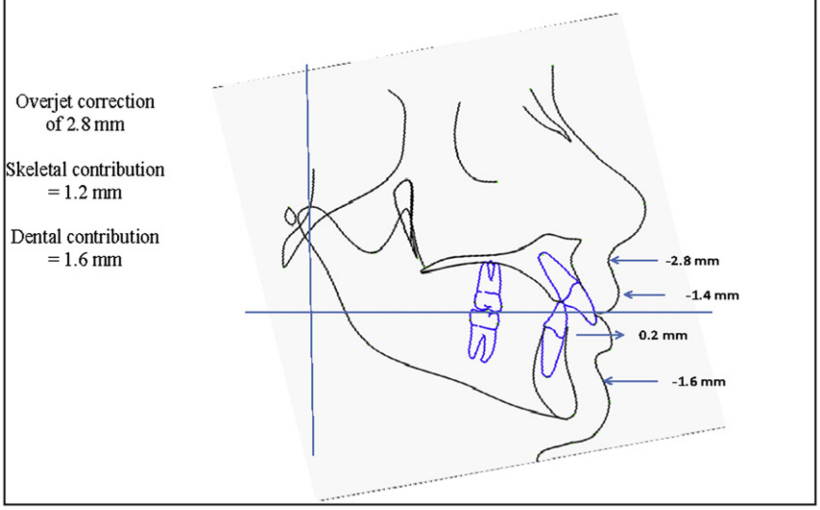

Fig 8. Components of net overjet correction after fixed appliance treatment (changes in treatment group [T1 to T2] minus changes in control group [t1 to t2]).

movement of 0.2 mm or incisor proclination of 3.0° remained, suggesting that most of the forward movement of the mandibular incisors during Herbst treatment can be recovered during comprehensive orthodontic treatment.[29]

Overcorrection with the Herbst appliance resulted in a net overjet correction of 7.0 mm relative to the control group. The skeletal contribution to the net overjet correction was 2.4 mm, or 34%. At the end of fixed appliance therapy, the overjet reduction decreased to 2.8 mm relative to the controls, and the skeletal contribution was 43%. This is in contrast to a study on treatment with the Herbst appliance in the late mixed dentition, with a skeletal contribution of 84% after 16 months of follow-up observation.[16] In our study, mandibular length after fixed appliance therapy was less than in the control group. Most of the remaining skeletal contributions to overjet reduction were from restriction of forward maxillary growth. The dental contribution to the net overjet correction was 4.6 mm, or 66%, after Herbst treatment. The contribution at the end of fixed appliance therapy was 57%. The maxillary incisors were moved posteriorly in response to Herbst treatment. A net posterior movement remained after fixed appliance therapy, contributing to the net overjet correction over the long term. The mandibular incisors were initially moved forward and proclined in response to Herbst treatment; they remained proclined to compensate for the change in the intermaxillary skeletal relationship.

Overcorrection with the Herbst appliance resulted in a net molar correction of 6.6 mm relative to the control group. The skeletal contribution was 2.4 mm, or 36%. At the end of fixed appliance therapy, the molar correction decreased to 2.2 mm relative to the controls, and the skeletal contribution was 56%. The dental contribution to correction in the molar relationship was 4.2 mm, or 64%, after Herbst treatment and remained stable after fixed appliance therapy, compensating for the relapse in skeletal correction. The maxillary molars moved posteriorly during Herbst treatment and maintained a net posterior movement after phase 2 treatment. The mandibular molars were moved forward in response to Herbst treatment and maintained that during phase 2

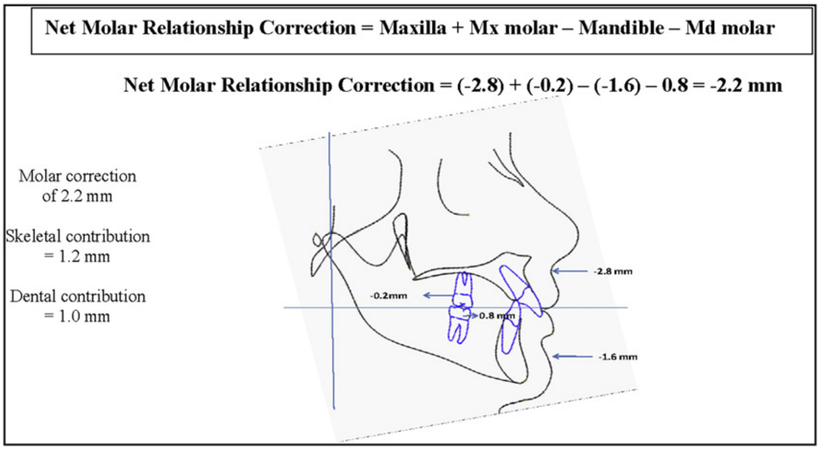

Fig 9. Components of net molar correction after fixed appliance treatment (changes in treatment group [T1 to T2] minus changes in control group [t1 to t2]).

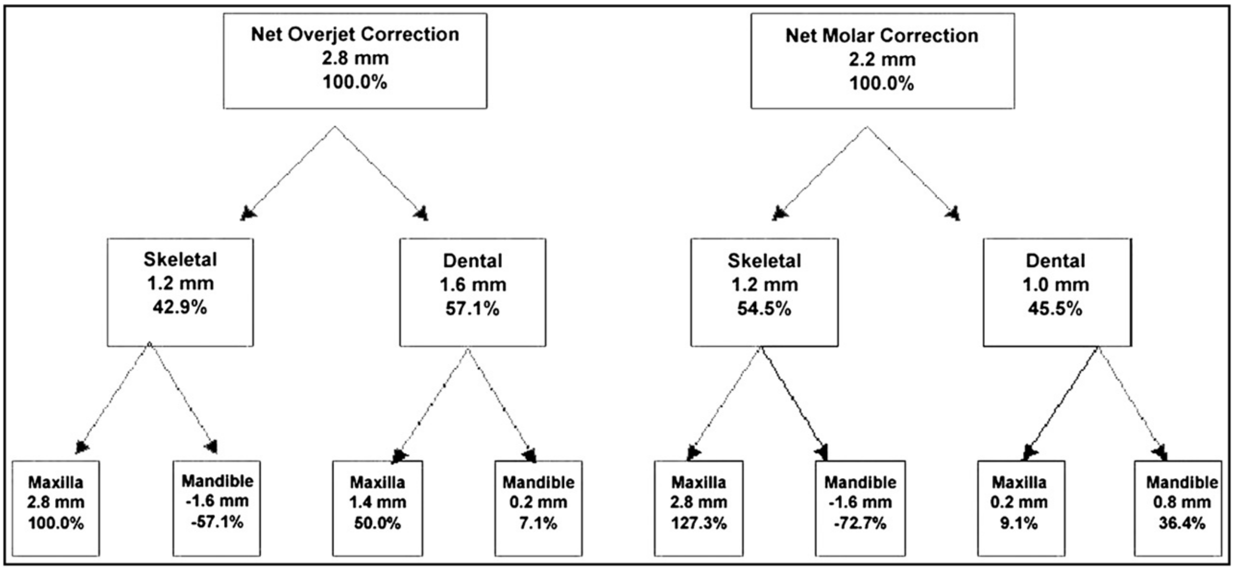

Fig 10. Pitchfork analysis of net overjet and molar corrections after fixed appliance treatment (changes in treatment group [T1 to T2] minus changes in control group [t1 to t2]).

of comprehensive orthodontic treatment, contributing to the improvement in the molar relationship.

In this study, the palatal plane tipped counterclockwise by 1.7° relative to the control group; this was slightly higher than the range of 0.2° to 1.0° reported by other investigators.[1,22,26-29,32,36,44-46] After phase 2 treatment, the palatal plane returned to its pretreatment position. Other studies reported either a 1.0° increase in the palatal plane angle,[23,28], a 0.5° to 0.6° decrease,[29,45] or no change in the palatal plane angle.[25]

The occlusal plane angle tipped clockwise by 3.4° in response to Herbst treatment and returned to its pretreatment position after phase 2 treatment. This is consistent with the range of 1.1° to 5.1° of clockwise tipping reported by other investigators[5,18,23-25,28,32,33,35,36,45,46] and the counterclockwise tipping after fixed appliance therapy during the long-term posttreatment period.[5,27,45]

No significant differences were found in the mandibular plane angle. Other investigators found increases in the mandibular plane angle during Herbst treatment,[5,18,20,22,24-28,33-36,44,45,50] decreases in the mandibular plane angle of 0.1° to 2.0° during treatment,[19-21,29,46,50] or no change.[1,41,44] In the long-term posttreatment period, Ruf and Pancherz[49] found no significant effect on the mandibular plane angle.

No significant differences in anterior lower facial height (ANS-Me) were found with Herbst treatment and in the long term after fixed appliance treatment relative to the controls. Other investigators reported increases of 0.4 to 4.1 mm in response to Herbst treatment.[18,20,21,32,42,44,46,51] However, long-term studies found no differences relative to the controls.[15,18]

Significant differences were found in the vertical positions of the maxillary molars and the mandibular incisors. The maxillary molars were intruded 1.3 mm with Herbst treatment compared with eruption of 1.3 mm in the control group. This is consistent with others reporting maxillary molar intrusions of 0.5 to 1.1 mm in response to Herbst treatment.[18,19,23,46,47] A few studies reported extrusions of 1.4 to 1.5 mm.[21,47] After fixed appliance therapy, the maxillary molars erupted 3.6 mm compared with 4.7 mm in the control group. This is consistent with the eruption of 3.5 mm reported in other long-term studies.[19,23]

The mandibular molars (Mic-ML) extruded 1.2 mm with Herbst treatment compared with 0.6 mm in the control group. After fixed appliances, no differences were found between the treatment group (4.1 mm) compared with the control group (3.9 mm). Previous studies reported molar extrusions of 1.3 to 2.8 mm after treatment,[18-20,42,45,46] followed by additional extrusion of 0.6 mm after fixed appliance therapy.[19]

The mandibular incisors were initially intruded by 0.8 mm with Herbst treatment compared with 1.0 mm in the control group. This was probably related to the proclination of the mandibular incisors. No significant changes in the vertical position of the mandibular incisors were found after fixed appliance treatment. Previous studies reported mandibular incisor intrusions of 0.4 to 2.4 mm in response to Herbst treatment,[18-20,42,46,47] followed by extrusion of 0.6 mm with fixed appliance treatment.[19]

Overbite was reduced by 1.1 mm with Herbst treatment compared with an increase of 1.3 mm in the control group. A relative decrease in overbite was maintained over the long term. Previous studies reported reductions in overbite of 1.9 to 5.6 mm after Herbst treatment,[1,5,15,18,21,41,42,44,45,47,51] followed by increases of 0.5 to 1.1 mm after fixed appliance treatment.[1,45,51]

CONCLUSIONS

Treatment of Class II patients with the Herbst appliance in the early mixed dentition resulted in Class II correction that was stable after fixed appliance treatment. Net corrections of 2.8 mm in overjet and 2.2 mm in the molars were maintained after fixed appliance therapy. The continuous restraint in the forward growth of the maxilla contributed toward maintaining these changes. The forward movement of the mandibular base returned to the pretreatment position after fixed appliance therapy. Backward movement of the maxillary incisors and forward movement of the mandibular molars were maintained after fixed appliance therapy, contributing to the changes in overjet and molar relationship. Distalization of the maxillary molars and forward movement of the mandibular incisors returned to pretreatment positions after fixed appliance therapy. No long-term vertical changes were found with Herbst treatment after fixed appliance therapy.

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