An Evaluation of Two-Phase Treatment With the Herbst Appliance and Preadjusted Edgewise Therapy

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The purpose of this study was to evaluate the skeletal and dentoalveolar changes occurring during two-phase orthodontic treatment. A cephalometric study of Class II correction was carried out in 40 subjects (20 females, 20 males) who had been treated with the acrylic-splint Herbst appliance immediately followed by a second phase of preadjusted edgewise therapy. The average age at the start of Herbst therapy was 12.5 ± 0.8 years for females and 13.6 ± 1.2 years for males. Descriptive cephalometric data were compared with the normative values derived from the University of Michigan Elementary and Secondary School Growth Study. Control values were generated for each of the 40 Herbst patients based on gender, initial age, and duration of treatment. The results of this study indicate that the Class II correction achieved during Phase I treatment with Herbst appliance was due mainly to an increase in mandibular length, as well as distal movement of the maxillary molars and mesial movement of the mandibular molars and incisors. The accelerated mandibular growth rate observed during Herbst therapy was followed by a diminished growth rate during the edgewise phase that was less than control values. The overall increase in mandibular length was slight (~1 mm), but significantly greater than control data for the whole group and the male subgroup; however, it was not significantly different between the treatment group and control data in the female subgroup. There were no significant treatment effects on lower anterior facial height and the mandibular plane angle at the end of either phase of treatment. The skeletal changes contributed to 55% of the molar correction during the Herbst therapy, whereas at the end of the second phase of treatment, skeletal change accounted for 80%. Significant anteroposterior dentoalveolar rebound was seen during the edgewise phase. (Semin Orthod 1998;4:46-58.) *Copyright © 1998 by W.B. Saunders Company*

A contemporary strategy for the treatment of Class II malocclusion features an initial phase of functional appliance therapy followed by a subsequent phase of fixed appliance treatment. Supposedly, the underlying skeletal discrepancy is corrected during the first phase of treatment, and detailed tooth alignments are performed during the later fixed appliance phase.

Among the various types of functional appliances available today, the Herbst appliance is thought to be an effective device to correct Class II malocclusions. The Herbst appliance, developed by Emil Herbst[1,2] in 1905, is a bite-jumping device that features a bilateral telescoping mechanism that keeps the mandible in a continuously protruded position. This appliance is designed to be worn 24 hours a day, and the treatment effect can be achieved in a relatively short period of time (6 to 12 months).[3]

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During the last 20 years, a number of clinical studies have evaluated the effects of the various types of Herbst appliances on the craniofacial skeleton. Both skeletal and dentoalveolar effects have been documented, regardless of the method of attachment of the Herbst mechanism to the dental arches (eg, banded,[3,4] cast splint,[5] acrylic splint,[6,7] and stainless steel crowns[8,9]).

Most previous investigators have reported only limited effects of the Herbst appliance on the maxillary complex. When change in maxillary position (SNA) was evaluated, the forward growth of maxilla relative to nasion was slightly less in the treatment groups in comparison with controls.[3,4,7,10,11] In contrast, the measures of maxillary size (Co-ANS and Co-Point A) indicated that the Herbst appliance did not affect the growth of the maxilla significantly.[6,7,12]

Increases in the length of the mandible, ranging from 1.3 mm to 3.5 mm, have been documented in previous clinical studies of the Herbst appliance in comparison with untreated controls. Pancherz[3,13] found that the average increase in mandibular length of 10 growing patients exceeded that of 10 untreated subjects by 2.2 mm over a 6-month period. A subsequent study by Pancherz[4] also showed an additional 2.0 mm of length increase. In an investigation of headgear-Herbst treatment on a group of patients with severe Class II malocclusions in the early mixed dentition, Wieslander[5] reported that within a 5-month interval, mandibular length increased 2.0 mm more in a treated group than in an untreated control group. Additional mandibular growth of 1.3 mm was reported by Valant and Sinclair[11] in a 10-month treatment period. McNamara et al[6] reported an average of 2.7 mm more growth in patients wearing the acrylic-splint Herbst than in an untreated group, whereas Windmiller[7] reported an additional 3.5 mm of mandibular length increase.

Previous studies have shown that Herbst appliance treatment typically has a bite opening effect. Pancherz[3,4] observed an increase in lower anterior facial height produced by the banded Herbst appliance. In the investigation of treatment effects with the acrylic-splint Herbst, both McNamara et al[6] and Windmiller[7] reported a significant increase in lower anterior facial height in the treatment groups. These studies did not show significant treatment effect on the mandibular plane, presumably because of an increase in ramus height posteriorly.[6,7] In a study of vertical changes produced by different types of Herbst appliances, Schiavoni et al[14] found the banded type as used by Pancherz did not modify the vertical growth pattern significantly, whereas the acrylic-splint type allowed an upward and forward rotation of the mandible.

In the dentoalveolar region, the Herbst bite-jumping mechanism produces a posteriorly-directed force on the upper posterior teeth and an anteriorly-directed force on the lower anterior teeth, resulting in distal tooth movements in the maxillary buccal segments and mesial tooth movements in the mandible. The mandibular incisors have been shown to procline during Herbst treatment.[3,4,11,15] An analysis of vertical dentoalveolar changes revealed that the upper first molars and lower incisors are inhibited from erupting during treatment,[4,6,11] whereas the eruption of lower first molars is not affected significantly.[6,7,11]

The treatment effects produced by the Herbst appliance have been well documented in the literature; however, the treatment changes occurring during two-phase treatment have not been described previously. The purpose of this study was to evaluate the skeletal and dental changes during two-phase treatment: the acrylic-splint Herbst followed by a preadjusted edgewise appliance. In particular, this study emphasized the posttreatment impact of the acrylic Herbst appliance on subsequent mandibular growth, vertical control, and dentoalveolar movement.

Subjects and Methods

Sample Selection

The cephalometric records of Class II, division 1 subjects who underwent treatment with a Herbst appliance immediately followed by a preadjusted edgewise appliance were analyzed. The Herbst appliance used was of the acrylic-splint type[16,17] that had occlusal coverage from the canines to the first molars in the maxillary arch and full occlusal and incisal coverage in the mandibular arch. About 75% of the maxillary splints were removable, with the remainder bonded, whereas the mandibular splint always was removable. In about half of the appliances, a midpalatal expansion screw was incorporated into the appliance and activated one quarter turn once per week until appropriate expansion of the maxilla was achieved.

The samples were selected from an original group of 135 consecutively-treated patients who underwent Herbst appliance therapy in one of two faculty practices[i] or in the Graduate Orthodontic Program at the University of Michigan.[ii] To be included in this study, subjects had to meet the following criteria:

1. a pretreatment Angle Class II, division 1 malocclusion defined by at least an end-to-end molar relationship;

[i]Drs James A. McNamara, Jr. and Patrick J. Nolan (N = 120) and Dr Richard A. Johnson (N = 5).

[ii]Subjects were treated under the supervision of Dr J.A. McNamara, Jr (N = 10).

2. no permanent teeth extracted before or during treatment;
3. two-phase treatment—Herbst therapy immediately followed by preadjusted edgewise appliance treatment;
4. three consecutive cephalograms, pre-Herbst (T_1), immediate post-Herbst (T_2), and postedgewise (T_3).

No subject was excluded from the study on the basis of cooperation. Ninety-five of the 135 subjects were eliminated from further consideration according to the exclusionary criteria outlined in Table 1, leaving a sample of 40 patients for further analysis. This sample consisted of 20 females and 20 males. For females, the average age at the start of Herbst therapy was 12.5 ± 0.8 years, with a range from 11.2 years to 13.8 years; for males, 13.6 ± 1.2 years, with a range from 11.8 years to 15.8 years. The average ages at T_1, T_2, and T_3, as well as the mean treatment intervals for the whole sample and its two subgroups are summarized in Tables 2 and 3, respectively.

Control Standards

To compare the treatment changes with the growth changes that would have occurred without treatment, normative values derived from The University of Michigan Elementary and Secondary School Growth Study (UMGS)[18] were used. These values are population norms in that the untreated subjects were selected solely on the basis of attendance at the University School, a laboratory school on the Ann Arbor campus. All malocclusion types are represented in this sample, although there is a bias toward Class II malocclusion and increased lower anterior facial height. The current digitized UMGS sample size now is nearly double the original number of subjects (N = 83) described in the atlas of Riolo et al[18] that was published in 1974.

Norms for initial values and expected change during treatment were calculated for each of the 40

Table 1. Summary of Sample Selection

Parent Sample	*135*
Exclusionary Criteria	
In active treatment at the time records were reviewed	17
No fixed appliance after Herbst therapy	13
Relocation during active treatment	6
Other treatment between Herbst therapy and fixed appliance treatment	14
Surgical cases	5
Molar relation less than 1/2 cusp Class II	5
Extraction of teeth	3
Incomplete cephalograms	29
Poor film quality	2
Cephalogram with Herbst appliance in place	1
Sample Satisfying the Criteria	40

Table 2. Average Starting Age

Group	*N*	T_1	T_2	T_3
Total	40	13y 0m ± 13m	14y 0m ± 13m	15y 6m ± 15m
Female	20	12y 6m ± 10m	13y 6m ± 11m	14y 9m ± 12m
Male	20	13y 7m ± 14m	14y 7m ± 13m	16y 2m ± 13m

Herbst patients, based on gender, age, and duration of treatment.[19] The normative values provided in the UMGS data are reported in yearly increments (11 to 12, 12 to 13, etc.). Control data were calculated for each individual, based on the ages at which the cephalograms were taken. To estimate a mean growth increment specific to each subject's exact age, it was necessary to interpolate by proportional parts.

The UMGS cephalograms have a standardized 12.92% enlargement. For the current study, all linear measurements were converted to 8%.

Normative data were not available for the measures that used the Frankfort Horizontal because, as originally digitized in the UMGS sample, Anatomical Porion was not used. Porion was defined as "the midpoint of the line connecting the most superior point of the radiopacity generated by each of the two ear rods of the cephalostat."[18] Normative data were also not available for the measures of Class II correction.[20]

Cephalometric Analysis

Serial lateral cephalograms initially were hand-traced, with the films of a given series analyzed at a single sitting by the same investigator (M.L.). The tracings were verified by another investigator (J.A.M.), and any disparities in landmark location were resolved by mutual agreement. The landmarks were digitized, and 39 variables were generated, 26 linear and 13 angular. The Herbst group was divided into two groups according to gender to evaluate the amount of mandibular growth, represented by the measure Condylion-Gnathion. The change in the horizontal and vertical positions of the molars and incisors was determined according to the method described previously by McNamara et al.[6,21]

The method for determining skeletal and dental contributions to Class II correction was a modified version of Johnston's pitchfork analysis.[20] Regional superimpositions were used to quantify the source of correction at the level of the functional occlusal plane: displacement of maxillary and mandibular basal bone relative to the cranial base, displacement of the

Table 3. Average Treatment Time

Group	*N*	T_1-T_2	T_2-T_3	T_1-T_3
Total	40	12m ± 4m	17m ± 6m	29m ± 8m
Female	20	12m ± 4m	15m ± 4m	27m ± 6m
Male	20	12m ± 4m	19m ± 7m	31m ± 9m

mandible relative to the maxilla (apical base change or ABCH), and dental movement relative to maxillary and mandibular basal bone. The functional occlusal plane was used because it is less affected by treatment changes in incisor position.[20,22]

The skeletal and dental components of Class II molar and overjet correction were measured along a mean functional occlusal plane (MFOP),[20] the average of the pre-Herbst (T_1) and post-edgewise (T_3) functional occlusal planes, when the tracings were superimposed in the maxilla.[22] The MFOP then was transferred to each tracing based on superimposition on maxillary structures. The tracings were digitized, and all measurements were calculated parallel to the MFOP based on the protocols of Johnston.[20,22]

Statistical Analysis

Means and standard deviations were calculated for age, duration of treatment, and all cephalometric variables for the Herbst group and the control data, as well as for the measurements of treatment changes taken along the MFOP for the treatment group.

To evaluate the between-group differences in pretreatment morphology and change during each interval, paired t-tests were used to test the null hypothesis (H_o): $\mu_1 = \mu_2$. Treatment changes executed along MFOP were analyzed by completely randomized t-tests, Ho: $\delta_1 = \delta_2$, for each phase (Herbst phase, edgewise phase, and overall change).

Results

Comparison of Starting Forms

Means and standard deviations for selected cephalometric variables before treatment (T_1) are presented in Table 4. Significant between-group differences were noted for some measures. The Herbst group was more Class II than the controls at the onset of treatment, as indicated by a significantly greater ANB angle ($P < .001$) and a significantly smaller maxillomandibular differential[23] ($P < .001$) in comparison with the population norms. The size of the maxilla was larger than the normative values (Co-ANS and Co-Pt A; $P < .001$). In the vertical dimension, the treatment subjects had a greater posterior facial height and ramal height, as measured by S-Go and Co-Go ($P < .05$ and $P < .01$, respectively), and a flatter mandibular plane angle (SN-MP, $P < .05$).

Dentoalveolar measures showed the lower dentition to be in a more anterior position relative to the mandibular basal bone, as indicated by the shorter L1 horizontal and L6 horizontal ($P < .05$). In addition, the lower incisor was more proclined in the treatment sample (98.7°) than in the controls (95.5°; $P < .01$).

Analysis of Treatment Effects

Descriptive and inferential statistics for changes during each interval (T_1-T_2, T_2-T_3, and T_1-T_3) are summarized in Tables 5, 6, and 7. The differences between the mean changes in the two groups constitute the treatment effects.

Maxillomandibular relationship. In the treatment group, significant improvements in the sagittal skeletal relationship were evident at the end of Herbst therapy, as indicated by a significant decrease in the ANB angle and a significant increase in the maxillomandibular differential ($P < .001$; Table 5). Although the treatment group had a lesser increase ($P < .05$; Table 6) in the latter measure during the second phase, the treatment effects still were significant at the end of total treatment ($P < .001$; Table 7).

Maxillary effects. A significant decrease in the SNA angle was observed during both phases when compared with the controls ($P < .01$ and $P < .001$, respectively). With respect to the change in the size of the midface, represented by the measures Condylion-Point A and Condylion-Anterior Nasal Spine, no significant between-group difference was found, except for the distance Co-Pt A, which increased less in the treatment group than could be inferred from the control data for T_2 to T_3 ($P < .01$).

Mandibular effects. A significant increase in the SNB angle was evident during Herbst treatment ($P < .001$). The reverse was noted in the fixed appliance phase ($P < .001$), resulting in no significant difference between the two groups for the overall change in the SNB angle. A greater increase in mandibular length, as represented by Co-Gn, was noted during Herbst treatment (4.7 mm *v* 2.5 mm, $P < .001$). The reverse again was seen in the increments of mandibular length during the fixed appliance phase, with greater growth increments observed in the controls (3.1 mm) than in the treated group (1.9 mm; $P < .001$). A significant difference between the two groups, however, still was noted for the overall change in the mandibular length (6.6 mm *v* 5.6 mm, $P < .01$). The same trend was noted for the Articulare-Anatomical Gnathion measure.

The whole group was divided into two groups according to gender. The amount of mandibular growth, as measured by Co-Gn, in each of the resulting groups was compared with the control standards. An increased growth rate during Herbst therapy followed by a slower growth rate in comparison with control norms was obvious for both subgroups. The overall change was not significant in the female group, whereas this overall increase was significant in the male group ($P < .05$).

Vertical effects. Significant treatment-related changes

Table 4. Comparison of Starting Forms†

Measure	Herbst Group (N = 40)		Control Data (N = 40)		Significance
	Mean	S.D.	Mean	S.D.	
Sagittal Skeletal Measures					
S-N	73.4	3.3	74.1	2.1	ns
M/M differential	23.0	3.6	25.6	1.7	***
ANB (°)	4.9	1.5	3.6	0.2	***
Maxillary Skeletal Measures					
Co-ANS	97.2	5.4	92.8	3.0	***
Co-Pt A	93.9	5.4	89.7	2.8	***
Pt A-Nasion Perp	0.2	2.5	–	–	–
SNA (°)	81.7	3.3	80.6	0.2	ns
Mandibular Skeletal Measures					
Co-Gn	116.8	6.7	115.0	4.3	ns
Ar-Gn	108.3	6.7	108.8	3.8	ns
Pog-Nasion Perp	−6.8	4.9	–	–	–
SNB (°)	76.7	3.4	77.1	0.3	ns
Vertical Skeletal Measures					
N-Me	118.2	7.5	118.7	4.5	ns
N-ANS	53.6	3.2	53.6	1.5	ns
ANS-Me	67.0	5.8	67.1	3.0	ns
S-Go	76.6	5.8	74.5	3.6	*
Co-Go	56.9	4.7	54.9	2.8	**
SN-Occlusal plane (°)	17.4	4.6	16.2	0.7	ns
SN-Mand plane (°)	31.8	5.4	33.9	0.4	*
FMA (°)	23.2	5.2	–	–	–
Facial axis (°)	−0.6	3.8	−2.0	0.2	*
Maxillary Dentition					
U6 horizontal	28.4	2.7	–	–	–
U1 horizontal	59.2	3.5	–	–	–
U1-Pt A Perp	5.8	2.1	–	–	–
U1-SN (°)	106.1	7.2	103.4	0.7	*
U6-PP	22.7	2.5	22.1	1.5	ns
U1-PP	28.6	2.4	28.6	1.3	ns
Mandibular Dentition					
IMPA (°)	98.7	6.3	95.5	0.9	**
L6 horizontal	31.5	2.7	32.4	0.3	*
L1 horizontal	8.3	3.0	9.4	0.6	*
L1 to A-Pog	0.7	1.9	1.7	0.2	**
L6 vertical	32.2	2.7	31.7	1.7	ns
L1 vertical	41.8	3.2	41.2	1.9	ns

NOTE. † = in mm unless otherwise noted; – = not available; ns = not significant.
*$P < .05$.
**$P < .01$.
***$P < .001$.

in vertical measures also were noted. Total anterior facial height (N-Me), upper anterior facial height (N-ANS), total posterior facial height (S-Go), and lower posterior facial height (Co-Go) increased significantly more during the Herbst treatment ($P < .001$). These measures were larger still in the Herbst group at the end of fixed appliance treatment. In contrast, neither the Herbst appliance nor fixed-appliance therapy had any significant effect on lower anterior facial height (ANS-Me).

The palatal plane angle increased when compared with control values ($P < .01$) during the first treatment phase. During the second phase, however, the palatal plane angle decreased ($P < .05$), resulting in no overall between-group differences. The same tendency also was true for the occlusal plane. The occlusal plane in the treatment group, however, was steeper after fixed appliance therapy ($P < .05$) in comparison with the controls. The overall effect on facial axis angle was not significant, although there

Table 5. Comparison of Change During the Herbst Phase ($T_1 - T_2$)

Measure	*Herbst Group (N = 40)*		*Control Data (N = 40)*		*Significance*
	Mean	*S.D.*	*Mean*	*S.D.*	
Sagittal Skeletal Measures					
M/M difference	3.6	1.4	1.4	0.7	***
ANB (°)	−1.5	0.9	−0.2	0.2	***
Maxillary Skeletal Measures					
Co-Pt A	1.1	1.5	1.1	0.5	ns
Co-ANS	1.1	1.6	1.2	0.5	ns
Pt A-Nasion Perp	−0.5	0.8	–	–	–
SNA (°)	−0.3	0.8	0.1	0.3	**
Mandibular Skeletal Measures					
Co-Gn	4.7	1.7	2.5	1.0	***
Ar-Gn	4.6	1.7	2.3	1.0	***
Pog-Nasion Perp	1.8	1.6	–	–	–
SNB (°)	1.2	0.8	0.3	0.3	***
Vertical Skeletal Measures					
N-Me	4.0	1.90	2.5	1.3	***
N-ANS	1.6	1.0	0.8	0.4	***
ANS-Me	2.0	1.5	1.6	0.9	ns
S-Go	4.0	1.3	2.0	0.9	***
Co-Go	3.5	1.4	1.7	0.6	***
SN-Palatal plane (°)	0.4	0.8	−0.1	0.2	**
SN-Occlusal plane (°)	2.1	2.5	−0.5	0.5	***
SN-Mand plane (°)	−0.6	1.2	−0.3	0.5	ns
FMA (°)	−0.5	1.0	–	–	–
Facial axis (°)	0.6	1.0	0.0	0.4	**
Maxillary Dentition					
U6 horizontal	−0.9	1.4	–	–	–
U1 horizontal	−0.2	2.1	–	–	–
U1-Pt A Perp	−0.6	1.7	–	–	–
U6-PP	−0.2	0.9	1.0	0.6	***
U1-PP	0.8	1.2	0.5	0.3	ns
Mandibular Dentition					
IMPA (°)	5.1	4.0	−0.5	1.1	***
L6 horizontal	1.5	1.0	0.1	0.2	***
L1 horizontal	1.6	1.4	−0.5	0.4	***
L1 to A-Pog	2.8	1.3	0.0	0.2	***
L6 vertical	1.5	0.8	0.9	0.3	***
L1 vertical	0.2	1.2	0.8	0.5	***

NOTE. – = not available; ns = not significant.
*$P < .05$.
**$P < .01$.
***$P < .001$.

was a significant mean change in this angle during the first phase. There was no significant treatment effect on the mandibular plane.

Dentoalveolar effects. When the dentoalveolar changes in the Herbst group were compared with those inferred from the Michigan controls, the mandibular teeth of the Herbst group moved forward (L6 horizontal and L1 horizontal, $P < .001$; Table 5) and the mandibular incisors flared an average 5.5° more during the first phase ($P < .001$). Although there was opposite tooth movement thereafter (Table 6), the lower dentition still was located in a more anterior position at the end of treatment (L6 horizontal, $P < .01$; L1 horizontal and IMPA, $P < .001$).

In the vertical dimension, the Herbst appliance prevented the upper molars and the lower incisors from erupting ($P < .001$), but allowed the lower molars to erupt more ($P < .001$). The upper incisors were not affected by the Herbst appliance. During the fixed appliance phase, upper posterior vertical alveolar change was not significantly different between the two groups. Therefore, the overall changes featured less of an increase in upper posterior alveolar height (U6-PP, $P < .001$) and a greater increase in lower

Table 6. Comparison of Change During the Fixed Appliance Phase ($T_2 - T_3$)

	Herbst Group (N = 40)		*Control Data (N = 40)*		
Measure	*Mean*	*S.D.*	*Mean*	*S.D.*	*Significance*
Sagittal Skeletal Measures					
M/M difference	1.1	1.5	1.8	1.1	*
ANB (°)	−0.2	0.9	−0.2	0.3	ns
Maxillary Skeletal Measures					
Co-Pt A	0.7	1.4	1.3	0.7	**
Co-ANS	1.1	1.6	1.5	0.8	ns
Pt A-Nasion Perp	−0.5	0.8	–	–	–
SNA (°)	−0.3	0.7	0.4	0.2	***
Mandibular Skeletal Measures					
Co-Gn	1.9	1.8	3.1	1.8	***
Ar-Gn	1.7	1.8	3.0	1.8	***
Pog-Nasion Perp	−0.5	2.0	–	–	–
SNB (°)	−0.1	0.9	0.5	0.3	***
Vertical Skeletal Measures					
N-Me	2.5	2.5	2.7	2.1	ns
N-ANS	0.7	1.0	0.8	0.6	ns
ANS-Me	1.7	1.9	2.0	1.7	ns
S-Go	1.9	1.8	2.5	1.6	**
Co-Go	1.2	1.3	2.3	1.2	***
SN-Palatal plane (°)	−0.3	0.7	0.0	0.2	*
SN-Occlusal plane (°)	−1.7	2.6	−0.1	0.5	***
SN-Mand plane (°)	−0.3	1.5	−0.6	0.7	ns
FMA (°)	−0.1	1.4	–	–	–
Facial axis (°)	−0.4	1.2	0.4	0.6	**
Maxillary Dentition					
U6 horizontal	1.9	1.5	–	–	–
U1 horizontal	−0.3	1.5	–	–	–
U1-Pt A Perp	−0.6	1.3	–	–	–
U6-PP	1.6	1.1	1.3	0.8	ns
U1-PP	0.2	1.1	0.6	0.4	*
Mandibular Dentition					
IMPA (°)	−2.8	5.5	−0.3	0.9	**
L6 horizontal	−0.7	1.1	0.0	0.4	***
L1 horizontal	−1.2	1.5	−0.5	0.5	*
L1 to A-Pog	−0.7	1.4	0.1	0.4	**
L6 vertical	1.6	1.2	1.2	0.8	**
L1 vertical	1.4	1.4	1.1	1.1	ns

NOTE. – = not available; ns = not significant.
*$P < .05$.
**$P < .01$.
***$P < .001$.

posterior alveolar height (L6 Vertical, $P < .001$) when compared with the controls.

Class II correction. Linear changes measured along the MFOP during each phase for the treatment are depicted diagrammatically in Figure 1. At the start of Herbst treatment, the Class II molar and overjet were 1.2 mm and 7.2 mm, respectively, as measured along the MFOP.

An improvement in sagittal occlusal relationship was observed at the end of Herbst therapy. The 5.7 mm molar correction was accomplished by 3.1 mm apical base change, 1.3 mm distal movement of the maxillary molars, and 1.3 mm mesial movement of the mandibular molars (Fig 1A). Overjet correction also was largely a result of apical base change in combination with 1.1 mm mesial movement of the lower incisors. During the second phase of treatment, the sagittal molar relationship rebounded by an average of 1.9 mm (Fig 1B), leading to a reduced Class II correction by the end of total treatment (3.8 mm; Fig 1C). The results were due to significant opposite tooth movements for the upper and lower molars (1.4 mm and 0.4 mm, respectively). The upper and lower incisors were retracted 0.9 mm. At the end of two-phase treatment, therefore, the Class II molar correction was a result of the apical base change and mesial

Table 7. Comparison of Overall Change, Including Phase I and Phase II Treatment ($T_1 - T_3$)

Measure	Herbst Group (N = 40) Mean	Herbst Group S.D.	Control Data (N = 40) Mean	Control Data S.D.	Significance
Sagittal Skeletal Measures					
M/M difference	4.8	1.8	3.2	1.5	***
ANB (°)	−1.7	1.1	−0.3	0.2	***
Maxillary Skeletal Measures					
Co-Pt A	1.8	2.1	2.4	1.0	*
Co-ANS	2.2	2.3	2.7	1.0	ns
Pt A-Nasion Perp	−1.0	1.0	–	–	–
SNA (°)	−0.6	1.0	0.5	0.3	***
Mandibular Skeletal Measures					
Co-Gn	6.6	3.0	5.6	2.3	**
Ar-Gn	6.3	2.9	5.3	2.3	**
Pog-Nasion Perp	1.3	2.5	–	–	–
SNB (°)	1.1	1.0	0.8	0.4	ns
Vertical Skeletal Measures					
N-Me	6.5	3.5	5.2	2.9	**
N-ANS	2.3	1.5	1.6	0.9	***
ANS-Me	3.7	2.4	3.6	2.2	ns
S-Go	5.9	2.4	4.6	1.9	***
Co-Go	4.7	1.9	4.0	1.4	**
SN-Palatal plane (°)	0.1	0.8	−0.1	0.2	ns
SN-Occlusal plane (°)	0.4	2.7	−0.6	0.8	*
SN-Mand plane (°)	−0.8	1.7	−0.8	0.9	ns
FMA (°)	−0.6	1.7	–	–	–
Facial axis (°)	0.2	1.5	0.4	0.7	ns
Maxillary Dentition					
U6 horizontal	1.0	1.5	–	–	–
U1 horizontal	−0.4	2.4	–	–	–
U1-Pt A Perp	−1.2	1.9	–	–	–
U6-PP	1.4	1.3	2.2	1.0	***
U1-PP	1.0	1.8	1.1	0.5	ns
Mandibular Dentition					
IMPA (°)	2.3	3.9	−0.7	0.8	***
L6 horizontal	0.7	1.3	0.1	0.4	**
L1 horizontal	0.4	1.8	−1.0	0.6	***
L1 to A-Pog	2.1	1.2	0.1	0.5	***
L6 vertical	3.1	1.4	2.1	1.0	***
L1 vertical	1.6	1.5	1.9	1.4	ns

NOTE. – = not available; ns = not significant.
*$P < .05$.
**$P < .01$.
***$P < .001$.

tooth movements of the lower molars, whereas overjet correction was due to the apical base change and retraction of the upper incisors (Fig 1C).

Discussion

This retrospective clinical study compared a sample of 40 patients, derived from an original sample of 135 consecutively-treated patients undergoing Herbst therapy, to population norms derived from untreated individuals of mixed malocclusion type. Because changes during treatment contain both normal growth and changes due to treatment, the normal growth process that contributes to the correction must be factored out to evaluate the effects of appliances. In general, the pattern of growth that accompanies the development of Class II malocclusion often may be relatively short-lived.[20] Subsequently, there appears to be little obvious difference between Class II individuals and the general population in terms of the growth that can be expected during a period of observation or treatment.[24-27] Despite the fact that the treatment group of this study had larger maxillae and more protrusive lower dentitions at the time of initial records, there is little reason to expect that subsequent growth will differ from the changes given by the

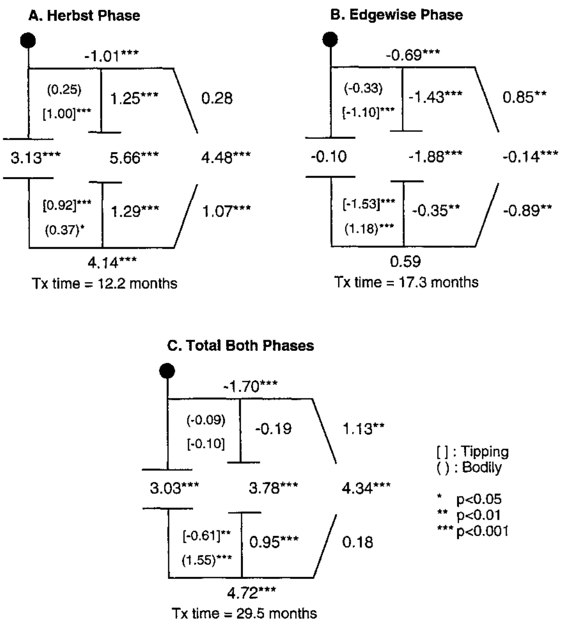

Figure 1. Skeletal and dentoalveolar treatment changes along the mean functional occlusal plane (MFOP) by phases: (A) Herbst Phase, (B) Edgewise phase, (C) Total treatment.

UMGS Standards.[18] Therefore, normative values derived from the Michigan Growth Study were used to provide a baseline against which the effects of the appliances could be assessed.

Maxillomandibular Relationship

At the end of Herbst therapy, the significant decrease in the ANB angle was accomplished both by a significant reduction in the SNA angle and a significant increase in the SNB angle. In contrast, the significant increase in the maxillomandibular differential was accomplished primarily by a significant increase in mandibular length. The changes observed in the treatment group were in agreement with the Herbst results published by Pancherz,[3,4,13] Valant and Sinclair,[11] McNamara et al,[6] and Windmiller.[7]

During the fixed appliance treatment, the basal jaw relationship continued to improve in both groups. The improvement, however, was larger in the control group. Mandibular growth exceeded maxillary growth by 1.8 mm in control group and by 1.1 mm in the Herbst group.

Mandibular Effects

During the Herbst phase, mandibular length, represented by Co-Gn, increased significantly more than that inferred from the Michigan Standards. Relative to control data, a 2.2 mm increase over a 12-month period was observed. This observation could be interpreted as a stimulation of growth in the condyle. This finding is in agreement with those of several authors,[3-7,10,11,19,21,22,28,29] all of whom have suggested that functional appliances are capable of inducing additional mandibular growth. The greater increase in mandibular length, however, contradicts the findings of other investigators who have failed to document significant differences between functional appliance treatment and controls.[30-32]

The increase in mandibular length during functional appliance treatment can be interpreted in two ways. The first possibility is that the increase may indicate a true stimulation of the growth of the condyle. An increase in both the rate and amount of condylar growth might take place during functional appliance treatment, followed by a normal growth rate thereafter, leading to a mandible that is larger than it would have been without treatment.[33] Secondly, the increase could be a transient phenomenon. The increased growth rate during functional appliance treatment would be followed by a subnormal growth rate, resulting in no permanent increase in the final length of the mandible (Fig 2).

In the present study, the mandible increased 4.7 mm during an average 12-month interval during the first phase. This rate, however, was not maintained during the second phase. Instead, it dropped to an average of 1.9 mm over a 17-month period. This finding may be interpreted as a deceleration in the rate of increase in mandibular length during the

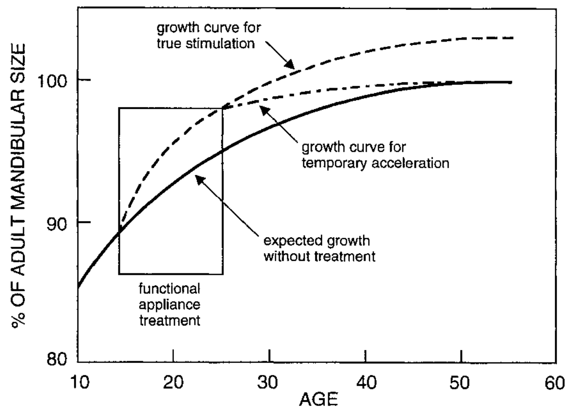

Figure 2. An illustration of true stimulation and temporary stimulation of mandibular growth. True stimulation indicates that growth occurs at a faster-than-expected rate during functional appliance therapy, then continues at the expected rate thereafter, so that the ultimate size of the mandible is larger. Temporary acceleration means that faster growth occurs during functional therapy, but slower growth thereafter ultimately brings the mandible back to the size that would be expected without treatment. (Modified and reprinted with permission from Proffit WR, Fields HW Jr. Contemporary Orthodontics (2nd ed). St Louis, MO, Mosby-Year Book, Inc, 1993.[33])

edgewise phase. This finding agrees with Pancherz,[13] Wieslander[5] and Pancherz and Fackel,[34] who showed a reduction in the mandibular growth rate after Herbst appliances were removed.

Furthermore, Pancherz[13] and Wieslander[5] have reported that an acceleration of mandibular growth during Herbst therapy is followed by a return to a normal growth rate during the period after treatment. By the end of the 10 to 12 month follow-up period, mandibular length was significantly longer in comparison with the controls. In the present study, mean mandibular length (Co-Gn) in the control group increased an average of 3.1 mm during the second treatment period, whereas in the Herbst patients the measure increased by 1.9 mm. Significantly less growth was noted ($P < .001$) in the treatment group. The same trend was noted for both female and male subgroups. Accordingly, the present results do not support the findings of Pancherz[13] and Wieslander[5] that mandibular growth continues to the same extent in the treated group as in the control group during the period after Herbst treatment.

When the changes during the second period were added to the changes during the first period, there was great individual variation. The overall increase in mandibular length was significantly different between the treatment group and control data for the whole group and the male subgroup; however, it was not significantly different between the treatment group and control data in the female subgroup. The possible reason for this difference between these two subgroups could be due to the fact that females already had completed most of their mandibular growth by the conclusion of Phase II. Given that the T_3 films were taken at age 14.8 years for females, one might assume that at the end of the edgewise treatment the female individuals in the Herbst sample were close to or at the end of their growth.[35,36] It also should be remembered that the UMGS cephalograms were gathered in the 1950s and 1960s, a time during which the onset of menarche may have been delayed in comparison with adolescents today.[37]

The present data support the studies of Pancherz and Littmann[38] and Wieslander,[15] who found no significant increase in the mandibular length after growth was completed. These results do not corroborate the findings of Petrovic et al[39] on young male rats or the long-term study of McNamara and Bryan[40] on *Macaca mulatta,* who concluded that, when experimental mandibular protrusion was performed throughout the growth period, the final length of the mandible could be increased. Therefore, the present study shows that, in a clinical situation, an acceleration of mandibular growth during functional appliance treatment was followed by a growth rate lesser than normal, resulting in a limited increase in mandibular length in males and no permanent increase in the final length of the mandible for the female.

Effects on the Vertical Dimension

The acrylic-splint Herbst has occlusal coverage and thus is thought to be better than the banded type in terms of vertical control. The occlusal coverage presumably inhibits dental eruption, helps control the vertical dimension and thereby allows the growth of the mandible to express itself more horizontally than vertically. In the present study, total anterior facial height (N-Me) increased significantly (1.2 mm) more than control values, as did posterior facial height (S-Go; 1.3 mm). These findings explain the observation that the mandibular plane angle did not deviate significantly from the control value. It seemed that the Herbst appliances, either the banded type or the acrylic-splint type, has little effect on the mandibular plane.[3,5-7,11,15]

Interestingly, the present study did not demonstrate an increase in lower anterior facial height (ANS-Me) after either phase of treatment. This finding contradicts other Herbst studies in which the authors found a significant increase in this dimension.[3,4,6,7] In addition, the finding that upper anterior facial height increased significantly contradicts Pancherz[3] and Wieslander,[5] who found no difference between treatment and control groups. The present findings could be ascribed to the location of attachment of the piston and sleeve assemblies on the appliance. This telescope system exerted a posterosuperior force on the maxillary posterior region, resulting in a clockwise rotation of the palatal plane. The telescope mechanism also might cause the increase in occlusal plane angulation. The maxillary molars and mandibular incisors were prevented from erupting because of the proximity of the piston and sleeve assembly. In contrast, more vertical eruption was observed in the lower molar region, producing an increase in mandibular alveolar height that was significantly more than expected. As a result of dental changes, the angulation of the occlusal plane increased. This observation is consistent with the findings of Harvold[41] who showed that the transformation from a Class II occlusion to a normal molar occlusion was intimately related to an increase in lower facial height that resulted from an increased vertical development of alveolar height in the region of the lower molars. Harvold and Vargervik[31] concluded that mandibular teeth are encouraged to erupt vertically and mesially, while the maxillary molars are prevented from vertical eruption and are even moved posteriorly, transforming the Class II molar relationship into a Class I molar relationship.

Anteroposterior Effects in the Dentoalveolar Region

Force exerted from the telescope mechanism induced distal tooth movements in the maxillary buccal segments and mesial tooth movement in the mandible. In contrast to activator therapy, which has been shown to produce a significant amount of maxillary retraction,[42-45] this study showed essentially no treatment effect on maxillary incisor position during Phase I treatment. This observation perhaps derives from the fact that the acrylic splint did not cover the maxillary incisors. Considerable flaring of mandibular incisors with functional therapy and with the Herbst appliance was noted in most of the studies. This study showed 5.1° of incisor flaring during an average 12-month treatment period.

After the Herbst appliance was removed, the dental changes rebounded to a considerable extent. The upper molars moved anteriorly and the lower teeth moved posteriorly. Even though rebound was observed during the Phase II, the dentoalveolar effects of the Herbst appliance seem to be maintained at the end of two-phase treatment, but to a lesser extent, ie, more anteriorly positioned mandibular teeth (~1.5 mm), and more proclined lower incisors (3.0°).

Class II Correction

An average molar correction of 5.7 mm and overjet correction of 4.5 mm were achieved during Herbst therapy (Table 8 and Fig 1A). Similar Class II molar and overjet corrections have been reported for other Herbst samples. Pancherz and Hansen[46] reported, on average, a molar correction of 6.3 mm and an overjet correction of 6.9 mm. Windmiller[7] reported 5.4 mm molar correction and 5.3 mm overjet correction. The greater overjet correction seen in Pancherz and Hansen's study could be due to the fact that the upper incisors were incorporated within the appliance in most of the treated subjects, whereas in the present study the acrylic splint did not cover these teeth.

It appeared that Class II correction came from a combination of factors, including skeletal changes, distal movement of the maxillary teeth and mesial movement of the mandibular teeth. In particular, mandibular skeletal changes dominated. In the present study, 55% of the total molar correction was due to apical base change. This finding was larger than Pancherz's determination of 35% in banded Herbst treatment. Similar skeletal change with the acrylic Herbst appliance was reported by Windmiller.[7] Apical base change is, by definition, the change in the maxillomandibular relationship observed at the level of the functional occlusal plane. This change may be a reflection of growth or treatment effects or both. Furthermore, apical base change would be expected to be a function of differential jaw growth and treatment time until growth is completed.[10,20,47] It must be emphasized that the skeletal change is not linear over time. The average treatment duration in Pancherz and Hansen's study[46] was 6 months, whereas it was 12 months in both Windmiller's[7] and the present study. The difference in treatment time may account for the observation that skeletal changes contributed more to the Class II correction in acrylic Herbst studies.

Mandibular length, as measured by Co-Gn, increased 2.2 mm more than controls during the Herbst phase (Table 5). To estimate how much of this extra growth contributes to Class II correction, this change

Table 8. Treatment Change Along the Mean Functional Occlusal Plane by Phases: Skeletal and Dental Components of Molar and Overjet Correction

	Herbst Phase (N = 40)		*Fixed Phase (N = 40)*		*Two Phases (N = 40)*	
Measure	*Mean*	*S.D.*	*Mean*	*S.D.*	*Mean*	*S.D.*
Time (months)	12.2	4.0	17.3	5.8	29.5	7.9
Skeletal Measures						
Maxilla	−1.0	0.9	−0.7	1.1	−1.7	1.5
Mandible	4.1	2.0	0.6	2.1	4.7	2.69
ABCH	3.1	1.6	−0.1	1.7	3.0	2.02
Dentoalveolar Measures						
Upper molar to maxilla						
Tipping	1.0	1.2	−1.1	1.4	−0.1	1.3
Bodily	0.3	1.0	−0.3	1.3	−0.1	1.4
Total	1.3	1.1	−1.4	1.2	−0.2	1.2
Lower molar to mandible						
Tipping	0.9	1.1	−1.5	1.1	−0.6	1.1
Bodily	0.4	1.1	1.2	1.0	1.6	1.1
Total	1.3	0.9	−0.4	0.8	1.0	1.1
Upper incisor to maxilla	0.3	1.8	0.9	1.5	1.1	2.0
Lower incisor to mandible	1.1	1.3	−0.9	1.5	0.2	2.0
Total Correction						
Molar (6/6)	5.7	2.2	−1.9	1.8	3.8	1.4
Incisor (1/1)	4.5	2.0	−0.1	1.3	4.3	1.9

was projected on the mean functional occlusal plane. An average angle of 37.4° was found between Co-Gn line and the mean functional occlusal plane. The 2.2 mm of extra growth was multiplied by the cosine of 37.4°. Based on this calculation, 1.9 mm of extra mandibular growth (reflected as additional apical base change) was seen at the mean functional occlusal plane during the Herbst phase of treatment.

At the end of edgewise treatment, the molar correction averaged 3.8 mm. The relapse of correction was due primarily to the movement of maxillary molars and mandibular dentition during fixed appliance therapy (Fig 1B, Table 8). These findings are in agreement with those of Pancherz and Hansen,[46] who found that relapse of the sagittal molar relationship was almost exclusively a result of tooth movement during the follow-up period of 12 months. After 29 months of treatment, skeletal changes and mesial tooth movement of mandibular molars contributed to molar correction. The overjet correction was the result of skeletal changes and distal tooth movement of upper incisors. It was found that apical basal change contributed to 80% of molar correction and 70% of overjet correction, with the mandibular component dominating.

Summary and Conclusions

The purpose of this study was to evaluate the skeletal and dental changes that occur during two-phase treatment: an acrylic-splint Herbst followed by a preadjusted edgewise appliance. The authors examined 40 subjects (20 females, 20 males) who began Herbst therapy at an average age of 12.5 ± 0.8 years for females, and 13.6 ± 1.2 years for males. Descriptive cephalometric data were compared with normative values derived from the University of Michigan Elementary and Secondary School Growth Study. Normative values were generated for each of the 40 individuals based on gender, initial age, and duration of treatment. The following conclusions can be reached:

1. An acceleration of mandibular growth during Herbst therapy was followed by a reduced rate of mandibular growth during the edgewise phase. The overall increase in mandibular length was significantly greater than control data for both the whole group and for the male subgroup; however, it was not significantly greater in the female subgroup.
2. There was no significant treatment effect on lower anterior facial height and on the mandibular plane angle, either at the end of Herbst therapy or at the end of two-phase treatment.
3. Class II correction achieved by the Herbst appliance was mainly due to mandibular growth, distal movement of the maxillary molars, and mesial movement of the mandibular molars and incisors.
4. Significant rebound was seen during the edgewise phase. At the end of two-phase treatment, the Class II molar correction had been accomplished by mandibular skeletal change, as well as mesial movement of the mandibular molars, whereas the overjet correction was due to mandibular growth and retraction of the maxillary incisors.
5. Skeletal changes contributed to 55% of the molar correction during the Herbst therapy, whereas at the end of two-phase treatment it accounted for 80%.

The present results suggest that the acrylic Herbst appliance may have a modest stimulatory effect on mandibular growth that diminishes with time and does not significantly affect the vertical growth of the face. Anteroposterior dentoalveolar rebound during the edgewise phase is significant.

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