

Initial and late treatment effects of headgear-Herbst appliance with mandibular step-by-step advancement

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The aim of this study was to investigate the effects of the headgear-Herbst appliance with mandibular step-by-step advancement followed by retention with the headgear activator. The sample comprised 22 consecutively treated patients (13.2 ± 1.5 years old) and 31 matched controls (12.6 ± 1.3 years old). Lateral cephalograms were obtained at the beginning of treatment, after 6 months (at completion of the initial phase), after 12 months of active treatment (at the end of the late phase), and after 18 months (at the end of retention). The results showed that the skeletal effects over 12 months of treatment were restrained maxillary growth, enhanced mandibular growth, and reduced increase in lower facial height. The restraint effect on the maxilla was significant in both the initial and late phases; the enhanced growth of the mandible was significant during the initial phase only; and the height of the lower face was affected during the late phase only. During retention with the headgear activator, the jaw base relationship was maintained, and the effect on the lower facial height was reinforced. A small relapse of the overjet and molar relationship was the result of dental changes only. During 18 months of active treatment and retention, the overjet correction was the result of 70% skeletal changes. The headgear-Herbst appliance is an effective orthopedic device, and the effect on the maxilla seems to increase with the length of treatment, but the pattern was reversed for the mandible. (Am J Orthod Dentofacial Orthop 2002;122:477-85)

Over the years, growth modification with various orthodontic devices (eg, headgear, activators, headgear-activators, Twin-block, Herbst appliance, headgear-Herbst appliance) has often been claimed to correct skeletal Class II malocclusion.^{1,2} The appliances were thought to restrain maxillary growth and enhance mandibular growth,¹ but a review of the studies showed great variations in the results.² In fact, it has been questioned whether the effect of functional appliance therapy is anything but a modest skeletal effect.³ Untreated Class II Division 1 occlusions showed small improvements and large individual

variations. Some patients improved, some remained unchanged, and others got worse.⁴

Most published studies of functional appliances state that it is impossible to correctly evaluate treatment effects or to compare treatment outcomes of various appliances because of a lack of sound study designs.^{6,7} Although the situation has improved somewhat over the last 10 years, clinical study designs of prospective and randomized trials still need improvement. In 2 recent randomized clinical trials,^{4,8} it was shown that headgear significantly restrained maxillary forward growth but also seemed to negatively affect mandibular growth. Mandibular growth of the treated sample was less than that during normal growth. Evaluation of the effects of treatment with the Fränkel II appliance (FR II)⁸ made it clear that the FR II produced no significant skeletal effects, only dental effects. Tulloch et al⁴ showed that there was a small but statistically significant enhancement of mandibular growth with the Bionator. In a recent prospective study⁹ of the headgear activator, it was shown that the skeletal effect was limited to the maxilla and that mandibular growth was not significantly affected. However, it has been shown that the Bass appliance¹⁰ (headgear-activator concept)

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Table I. Patient ages and treatment duration

	T_1/T_1-T_2			T_2/T_2-T_3			T_3/T_3-T_4			T_4/T_1-T_4		
	<i>n</i>	Mean	<i>SD</i>									
Patient age (y)	22	13.2	1.47	21	13.7	1.48	18	14.3	1.56	18	14.8	1.57
Treatment duration (mo)	22	6.0	0.12	21	6.2	0.18	18	6.1	0.11			
Control age (y)	31	12.6	1.33	30	13.1	1.39						
Examination period (mo)	31	6.2	0.10									

T_1 , Start of treatment; T_2 , 6 months of treatment; T_3 , 12 months of treatment; T_4 , 6 months of follow-up treatment.

with step-by-step advancement of the mandible improved the jaw base relationship when compared with that of matched patients treated with the Herbst appliance.^{11,12} In a recent study,¹³ it was reported that the jaw base relationship was unchanged in patients treated with the Bass appliance, somewhat improved in patients treated with the Bionator, and more significantly improved in those treated with Twin-block only. Studies of the Herbst appliance have consistently shown that mandibular growth was enhanced during the short treatment, usually for 5 to 7 months only.¹⁴⁻¹⁷ When 6-month posttreatment skeletal changes in the Herbst patients were compared with the changes in untreated controls, the maxilla showed a period of catch-up growth, whereas the mandible showed a period of minor reduction in growth.¹⁸⁻²⁰ Wieslander¹⁶ used high-pull headgear Herbst appliance and reported that maxillary growth was restrained significantly after only 5 months of treatment. In a follow-up study,¹⁷ it was indicated that the restraint effect on the maxilla achieved with the Herbst appliance and a series of activators used as retainers over many years remained significant. It has been shown that maxillary and mandibular growth was affected during Herbst treatment only, with a similar growth pattern before and after treatment.²¹

It has been indicated in an animal experiment²² and in a clinical study^{11,12} that step-by-step advancement of the mandible might enhance mandibular growth more than maximal jumping only. In a previous comparison of treatment results over 12 months, it was shown that the improvement in the jaw base relationship produced by the headgear-Herbst appliance with step-by-step advancement of the mandible was twice as large as that of the conventional Herbst appliance with maximum jumping of the mandible.²³

In this study, we present an experimental investigation of the effects of treatment with the headgear-Herbst appliance and step-by-step mandibular advancement and the changes and effects that occur during active retention with the headgear activator.

MATERIAL AND METHODS

The sample consisted of 22 consecutive young patients (12 boys and 10 girls) with skeletal Class II Division 1 malocclusions who were treated with the headgear-Herbst appliance with step-by-step advancement of the mandible (Table I). Before treatment, all patients had a full unit Class II molar relationship and an increased ANB angle (larger than 5°). All 22 subjects had cephalometric records taken before treatment and after 6 months of treatment, 21 had cephalometric records taken at the end of treatment, and 18 had records taken 6 months after retention with the headgear activator.²¹ The control group comprised 31 subjects (16 boys and 15 girls) with the same malocclusion and skeletal morphology as the treated sample. Cephalometric records were obtained at the beginning and the end of the 6-month examination period (Table I). The effects of the active treatment with the Herbst appliance and retention with the headgear activator were estimated by deducting the growth changes from the treatment changes. Interpolations and extrapolations of the growth changes were not made to match the exact length of the various observation intervals of the treated sample because they were very close (Table I).

The splinted headgear-Herbst appliance consisted of 1 upper and 1 lower framework cast in silver.²⁴ The upper framework had an expansion screw and 2 buccal tubes at the side of the first premolar region that were used for attaching the high-pull headgear, which was worn for 12 hours a day and had a force of 400 to 500 g on each side. The mandible was initially advanced 2 mm, then another 2 mm every 2 months thereafter by soldering a 2-mm section of fitting metal tube to the pivot ends of the plungers. This procedure was repeated until a Class III incisal relationship was achieved. All patients used a headgear activator²⁵ as the retainer during the 6-month retention period. Sagittal and vertical changes during the examination period were recorded with lateral cephalograms taken in centric occlusion and 1 taken with the mouth wide open; we used the analysis (Table II; Figs 1 through 3) described by

Table II. Cephalometric variables²⁶⁻²⁸ as shown in Figures 1, 2, and 3

Variables	Abbreviations
Sagittal measurements (Figs 1 and 3)	
Overjet	is/OLp – ii/OLp
Molar relation	ms/OLp – mi/OLp
Jaw base relation	ss/OLp – pg/OLp
Sagittal condyle	OLp-Cop
Position of maxillary base	ss/OLp
Position of mandibular base	pg/OL
Position of maxillary central incisor	is/OLp
Position of mandibular central incisor	ii/OLp
Position of maxillary permanent first molar	ms/OLp
Position of mandibular permanent first molar	mi/OLp
Lower facial height (distance from ANS-Me perpendicular to OL)	ANS-Me
Vertical condyle	Cos-OLs
Vertical measurements (Figs 2 and 3)	
Position of maxillary central incisor	is/NL
Position of mandibular central incisor	ii/ML
Position of maxillary permanent first molar	ms/NL
Position of mandibular permanent first molar	mi/ML
Angular measurements (Figs 2 and 3)	
Maxillary plane angle	NL/NSL
Mandibular plane angle	ML/NSL
Lower incisor angulation	Ili/ML

Pancherz.²⁶⁻²⁸ The dentofacial morphology of the patients did not differ from that of the controls (Table III).

The arithmetic mean and SD were calculated for each cephalometric variable. Student *t* tests were performed, and the levels of significance used were $P < .001$, $P < .01$, and $P < .05$. The combined method error did not exceed 0.8 mm or 0.5° for any of the variables measured.

RESULTS

Results of the current study describe the changes that occur with (1) normal growth, (2) treatment with the use of the headgear-Herbst appliance with step-by-step advancement of the mandible, and (3) active retention with the headgear activator. Finally, the overall changes and effects are described (Tables IV and V).

Mandible

Mandibular changes during the 6 months of growth are shown in Table IV and Figure 4. The mandibular base came forward 1.4 mm ($P < .001$), and there was significant growth of the condyle in the sagittal and vertical dimension. Both molars and incisors erupted significantly.

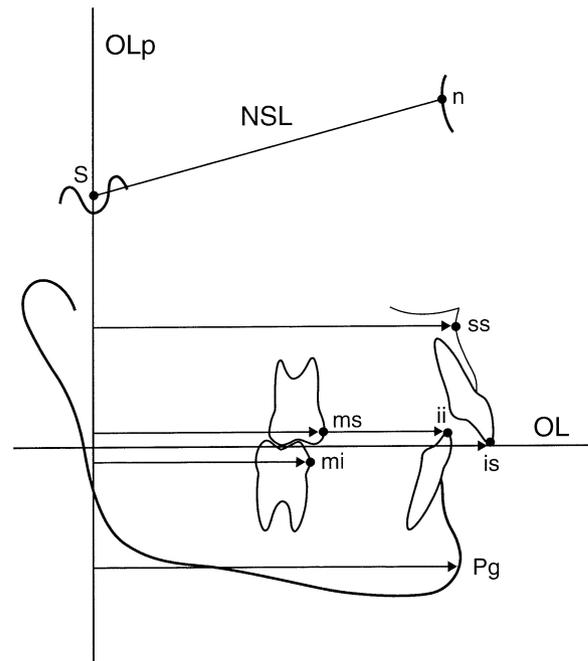


Fig 1. Registration line (NSL), reference grid (OL and OLp), and measuring points used in sagittal cephalometric analysis (Table II).²⁶

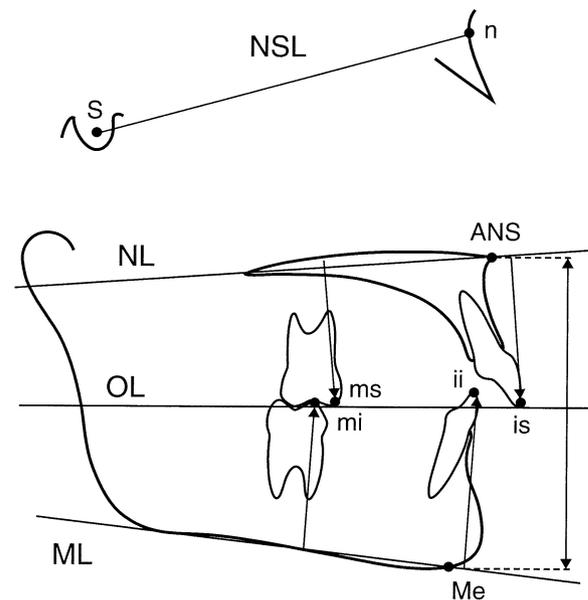


Fig 2. Registration line (NSL), sella (S), measuring points, and reference planes used in vertical cephalometric analysis (Table II).²⁷

Treatment changes in the initial and the late periods are summarized in Table IV and Figure 4. The mandibular base came forward 3.1 mm ($P < .001$) during

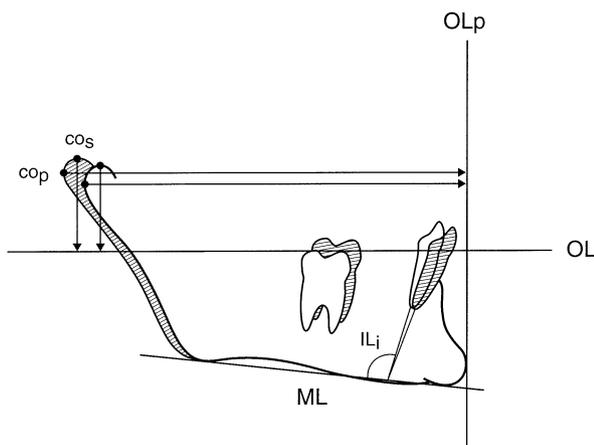


Fig 3. Measures of changes of mandibular condylar and mandibular incisor angulation. Mandibular tracings of mouth-open cephalograms superimposed on anterior and inferior mandibular bone contours (Table II).²⁸

the initial treatment period and 1.9 mm ($P < .01$) during the late treatment period; the difference between the 2 periods was statistically significant ($P < .05$). The condylar vertical change was significantly larger ($P < .05$) during the initial treatment period than during the late period, but there was no significant difference for sagittal condylar growth between these periods. The changes of most dental parameters in both sagittal and vertical planes were statistically significant. The mandibular incisors were intruded in both periods but were significantly more intruded and proclined during the late treatment period (Fig 5).

Treatment effects during the initial and the late period are summarized in Table V. The treatment resulted in forward movement of the mandibular base by 1.7 mm ($P < .001$) during the initial period and only 0.5 mm (not significant) during the late period. The difference between the 2 periods was statistically significant ($P < .05$). The vertical condylar effect was significantly less in the late period ($P < .05$) compared with the initial period, whereas the sagittal condylar effect was similar in both periods. The mandibular incisors were more protruded during the initial period ($P < .05$) and more intruded ($P < .05$) during the late period. There was no significant vertical effect on the mandibular molars, and the effect in the sagittal plane was statistically significant ($P < .001$) for both periods.

Maxilla

Maxillary changes during 6 months of growth are summarized in Table IV. The maxillary base moved forward 1.1 mm ($P < .001$). The maxillary molars erupted and moved forward significantly.

There was no change in the sagittal position of the maxilla during the initial period, and the maxilla moved posteriorly ($P < .05$) during the late period; the difference was statistically significant ($P < .05$). There was a significant distal movement and intrusion of the molars during both periods.

Treatment effects during the initial and the late periods are summarized in Table V. The restraint effect on the maxillary base in the sagittal plane was statistically significant during both periods but was significantly more pronounced during the late period ($P < .05$). A similar pattern was seen for the distalization of the molars. The molars were also significantly ($P < .001$) and similarly intruded during both periods.

Lower facial height

During 6 months of growth (Table IV), the lower facial height increased by 1.8 mm ($P < .001$). The lower facial height increased by 2.2 mm ($P < .001$) during the initial period and 0.5 mm (not significant) during the late period; the difference between the 2 periods was statistically significant ($P < .01$). The lower facial height was unaffected (0.4 mm; not significant) during the initial period but was significantly restrained during the late period ($P < .01$); the difference between the 2 periods was statistically significant ($P < .01$). There was no effect on the maxillary plane, and the mandibular plane closed significantly ($P < .01$) during the late period only.

Intermaxillary changes

Intermaxillary changes during 6 months of growth are summarized in Table IV. There was no improvement of the overjet-molar relationship, and the jaw base relationship showed an insignificant improvement. The changes in the overjet, the molar relationship, and the jaw base relationship were statistically significant in both periods ($P < .001$). Treatment effects during initial and late periods are summarized in Table V. The overjet reduction and improvement of the jaw base relationship were significantly greater during the initial period ($P < .05$), and the effect on the molar relationship was similar in both periods.

Active retention

Changes that occurred during the 6 months of retention are summarized in Table IV. The overjet increased, the molar relationship relapsed, but the jaw base improved, although the changes were not statistically significant. The maxillary and mandibular bases came forward significantly. The lower facial height and maxillary plane were unchanged, whereas the mandibular plane closed insignificantly. The maxillary molars

Table III. Facial morphology²⁶⁻²⁸ before treatment in headgear-Herbst with step-by-step advancement group and controls

Variables	HHSSA (n = 22)		Controls (n = 31)		Difference*
	Mean	SD	Mean	SD	
Sagittal (mm)					
Overjet	9.6	2.2	10.1	2.1	-0.5
Molar relation	1.7	2.0	1.7	1.9	0.0
Jaw base relationship	1.8	3.2	1.5	3.4	0.3
Maxillary base	80.7	3.6	78.3	3.7	2.4
Mandibular base	78.9	6.0	76.8	6.5	2.1
Maxillary incisor	93.2	4.0	91.0	4.0	2.2
Mandibular incisor	83.7	4.0	80.8	4.4	2.9
Maxillary molar	58.2	3.2	55.6	3.4	2.6
Mandibular molar	56.5	4.0	53.8	4.3	2.7
Vertical (mm)					
Maxillary incisor	31.2	2.3	30.8	2.5	0.4
Maxillary molar	21.9	2.3	21.2	2.6	0.7
Mandibular incisor	47.4	4.4	46.8	4.6	0.6
Mandibular molar	33.1	3.0	32.6	3.2	0.5
Lower facial height	70.2	5.0	68.8	5.4	1.4
Angles (°)					
Maxillary plane angle	9.5	3.9	9.5	3.4	0.0
Mandibular plane angle	38.3	4.4	38.9	5.2	-0.6
Mandibular incisor angle	98.5	5.6	98.1	5.9	0.4

*No difference statistically significant.

HHSSA, headgear-Herbst with step-by-step advancement group.

moved mesially ($P < .05$), and the mandibular molars moved distally ($P < .05$). Both the maxillary and mandibular molars erupted significantly ($P < .001$). The mandibular incisors erupted, retruded (Fig 5), and significantly uprighted ($P < .001$).

The effects of 6 months of active retention are summarized in Table V. The overjet increased, and the molar relationship relapsed significantly ($P < .05$), but the jaw base relationship improved insignificantly. The lower facial height was significantly reduced ($P < .001$) compared with normal growth. The molars were extruded ($P < .05$). The mandibular molars moved distally, and the maxillary molars moved mesially ($P < .01$). The mandibular incisors erupted, retruded, and uprighted ($P < .001$).

The combined changes and effects after 18 months of growth, treatment, and retention are summarized in Table IV.

All investigated parameters other than the maxillary base, maxillary plane angle, and position of the maxillary molars in the vertical dimension underwent statistically significant changes during treatment. Only 2 parameters, the maxillary plane and the sagittal position of the incisal edge of the mandibular incisors, were not affected by the treatment and retention.

Relationship of treatment changes

Condylar changes versus those in the mandibular position during the observation periods are shown in Figure 4; the change in the position of the mandibular incisal edge during the growth period and initial treatment, late treatment, and retention are shown in Figure 5.

DISCUSSION

The present prospective study was made on the basis of consecutive young patients with skeletal Class II malocclusions who were observed over 18 months. The patients were treated with the headgear-Herbst appliance and step-by-step advancement of the mandible for 12 months, and then with retention with a headgear activator²⁵ for 6 months. The effects caused by the orthodontic devices used in this study could be estimated by deducting the growth changes obtained from a matched control sample (Tables I and III) from the treatment changes recorded for the patient sample (Tables IV and V). Three patients (13%) dropped out, but this was unlikely to affect the overall results (Table I). The design of the present study allowed the comparison of the skeletal and dental changes among the 6-month observation periods: the initial period of treat-

Table IV. Skeletal and dental changes²⁶⁻²⁸ with headgear-Herbst appliance and step-by-step advancement of mandible and retention with headgear activator: differences between initial and late treatment

Variables	Growth 6 mo (n = 31)		Initial treatment 6 mo (n = 22)		Late treatment 6 mo (n = 21)		Initial-late Difference	Total treatment 12 mo		Retention 6 mo		Combined 18 mo	
	Mean	SD	Mean	SD	Mean	SD		Mean	SD	Mean	SD	Mean	SD
Sagittal (mm)													
Overjet	-0.3	1.4	-6.1***	2.6	-4.5***	3.5	-1.6*	-10.6***	3.1	1.6	3.4	-9.0***	3.2
Molar relationship	0.0	0.3	-5.4***	2.1	-5.5***	3.4	0.1	-10.9***	2.8	1.1	3.3	-9.8***	3.0
Jaw base relationship	-0.3**	0.6	-3.1***	1.4	-2.5***	1.1	-0.6	-5.6***	1.3	-0.7	2.0	-6.3***	1.7
Sagittal condyle	0.7***	0.5	2.0***	1.5	1.8***	1.3	0.2	3.8***	1.4	0.3*	0.5	4.1***	1.1
Maxillary base	1.1***	0.8	0.0	0.6	-0.6*	1.0	0.6*	-0.6**	0.8	0.9**	1.3	0.3	1.1
Mandibular base	1.4***	1.0	3.1***	1.5	1.9**	3.0	1.2*	5.0***	2.4	1.6*	2.4	6.6***	2.4
Maxillary incisor	0.2	0.8	-1.0***	1.0	-0.8	1.9	-0.2	-1.8***	1.5	0.2	1.4	-1.6***	1.5
Mandibular incisor	0.2	0.9	2.0***	1.3	1.2**	1.6	0.8	3.2***	1.5	-2.1***	1.2	1.1**	1.4
Maxillary molar	0.3**	0.6	-1.1***	0.9	-1.7***	1.3	0.6	-2.8***	1.1	1.1*	1.7	-1.7***	1.4
Mandibular molar	0.0	0.7	1.2***	1.0	1.3***	1.1	-0.1	2.5***	1.0	-0.7*	1.0	1.8***	1.0
Vertical (mm)													
Lower facial height	1.8***	1.9	2.2***	1.5	0.5	1.7	1.7**	2.7***	1.6	0.0	1.7	2.7***	1.6
Vertical condyle	0.9***	0.8	2.2***	0.8	1.6***	0.9	0.6*	3.8***	0.9	0.5*	0.8	4.3***	0.9
Maxillary incisor	0.3**	0.4	0.8***	0.8	1.4***	0.9	-0.6*	2.2***	0.9	-0.1	1.2	2.1***	1.0
Mandibular incisor	0.6***	0.6	-0.6**	0.9	-1.7***	2.0	1.1*	-2.3***	1.5	1.2**	1.4	-1.1**	1.5
Maxillary molar	0.8***	0.8	-0.7***	0.6	-0.4*	0.8	-0.3	-1.1***	0.7	1.4***	0.8	0.3	0.7
Mandibular molar	0.7***	0.6	1.0***	0.8	1.0***	1.1	0.0	2.0***	1.0	1.3***	1.2	3.3***	1.1
Angles (°)													
Maxillary plane angle	0.0	0.6	0.2	0.6	-0.2	0.8	0.4	0.0	0.7	0.0	0.8	0.0	0.7
Mand. plane angle	0.0	0.8	0.1	1.0	-0.7*	1.1	0.8*	-0.6*	1.0	-0.5	1.0	-1.1*	1.0
Mand. incisor angle	0.9**	1.5	5.1***	3.6	7.4***	6.5	-2.3*	12.5***	5.2	-6.6***	4.8	5.9***	5.0

Unpaired *t* test with Welch correction **P* < .05; ***P* < .01; ****P* < .001.

ment, the later period of active treatment, and the retention period. The design also allowed us to study the effects of a standardized treatment on all patients during the first 6 months of treatment with the Herbst appliance (ie, all patients used high-pull headgear with the same amount of force; likewise, all patients had their mandibles advanced gradually with the same amount of force). During the second 6-month period, the amount of mandibular advancement varied with the severity of the malocclusions. During the 6 months of retention, all patients used the headgear activator with the same amount of force and type of adjustments (eg, to allow the protruded mandibular incisors to upright and to allow eruption of the mandibular premolars to improve the curve of Spee). It would have been ideal to have followed the controls for 18 months, instead of only 6, and to have interpolated the growth data for comparisons over 6 and 12 months.

The initial treatment response on 6-mm advancement of the mandible was a reduction of the overjet by 6 mm, which was equally the result of dental and skeletal changes (Table IV). The maxilla did not change; this means that its normal forward growth was significantly restrained, and the mandible grew forward

significantly more than expected from normal growth only (Table V). As a result, the jaw base relationship improved significantly (Table IV and V). The mandible came forward and downward more than did the condyle (Figure 4); this indicated that apposition of bone in the glenoid fossa has an essential role in the forward positioning of the mandible. It seemed that standardized gradual forward positioning of the mandible with 6 mm advancement resulted in a forward positioning of the mandible with an average of about 3 mm, but the individual treatment response varied considerably. This might reflect the individual variations of the normal condylar growth rate and responses to the mechanical stimuli on the temporomandibular joint caused by the gradual advancement of the mandible. Half of the forward positioning of the mandible during the initial treatment period was the result of normal growth changes (Table IV). During the late treatment period of 6 months (Table I), the average gradual advancement of the mandible was again 6 mm, but it varied considerably among the subjects. The average amount of forward positioning of the mandible during the late part of the treatment was no more than that expected from normal growth only (Tables IV and V). During the

Table V. Skeletal and dental effects²⁶⁻²⁸ during treatment with headgear-Herbst appliance and step-by-step advancement of the mandible, retention with headgear activator, and overall during active treatment and retention and differences between initial and late treatment

Variables	Initial treatment 6 mo (n = 22)		Late treatment 6 mo (n = 21)		Initial-late difference	Total treatment 12 mo		Retention 6 mo (n = 18)		Combined 18 mo (n = 18)	
	Mean	SD	Mean	SD		Mean	SD	Mean	SD	Mean	SD
Sagittal (mm)											
Overjet	-5.8***	2.0	-4.2***	2.5	-1.6*	-10.0***	2.3	1.9**	2.3	-8.1***	2.1
Molar relationship	-5.4***	1.4	-5.5***	2.2	0.1	-10.9***	1.8	1.1*	2.0	-9.8***	1.6
Jaw base relationship	-2.8***	1.0	-2.2***	0.8	-0.6*	-5.0***	0.9	-0.4	1.3	-5.4***	0.9
Sagittal condyle	1.3***	1.0	1.1***	0.9	0.2	2.4***	1.0	-0.4*	0.5	2.0***	0.4
Maxillary base	-1.1***	0.7	-1.7***	0.9	0.6*	-2.8***	0.8	-0.2	1.0	-3.0***	0.7
Mandibular base	1.7***	1.2	0.5	2.1	1.2*	2.2***	1.7	0.2	1.6	2.4***	1.1
Maxillary incisor	-1.2***	0.9	-1.0**	1.4	-0.2	-2.2***	1.2	0.0	1.1	-2.2***	0.7
Mandibular incisor	1.8***	1.1	1.0**	1.2	0.8*	2.8***	1.1	-2.3***	1.0	0.5	1.8
Maxillary molar	-1.4***	0.7	-2.0***	1.0	0.6*	-3.4***	0.9	0.8**	1.1	-2.6***	0.9
Mandibular molar	1.2***	0.8	1.3***	0.9	-0.1	2.5***	0.9	-0.7**	0.8	1.8***	0.7
Vertical (mm)											
Lower facial height	0.4	1.7	-1.3**	1.8	1.7**	-0.9*	1.7	-1.8***	1.8	-2.7***	1.8
Vertical condyle	1.3***	0.8	0.7**	0.8	0.6*	2.0***	0.8	-0.4	0.8	1.6***	0.6
Maxillary incisor	0.5***	0.6	1.1***	0.7	-0.6*	1.6***	0.7	-0.4	0.8	1.2***	0.6
Mandibular incisor	-1.2***	0.7	-2.3***	1.4	1.1*	-3.5***	1.1	0.6*	1.0	-2.9***	0.8
Maxillary molar	-1.5***	0.7	-1.2***	0.8	-0.3	-2.7***	0.8	0.6*	0.8	-2.1***	0.7
Mandibular molar	0.3	0.7	0.3	0.8	0.0	0.6**	0.8	0.6*	0.9	1.2***	0.8
Angles (°)											
Maxillary plane angle	0.2	0.6	-0.2	0.7	0.4	0.0	0.7	0.0	0.7	0.0	0.5
Mandibular plane angle	0.1	0.9	-0.7**	0.9	0.8*	-0.6**	0.9	-0.5*	0.9	-1.1***	0.7
Mandibular incisor angle	4.2***	2.6	6.5***	4.3	-2.3*	10.7***	3.5	-7.5***	3.1	3.2**	5.9

Unpaired *t* test with Welch correction **P* < .05; ***P* < .01; ****P* < .001.

retention period, the mandible continued to be positioned forward the same amount as expected from growth only. Subsequently, enhancement of mandibular growth seemed to occur only during the initial period of treatment. Nevertheless, the mandible was further advanced during the late period of treatment and was held in a forward position at night during the retention period; no further enhancement of the mandibular positioning was observed.

The sagittal treatment effect on the maxilla was significant during both treatment periods and was enhanced during the late period (Table V). In effect, there was an average of no forward maxillary growth during treatment, and this effect was maintained during retention. There was no vertical effect during the initial period, but there was significant effect during the late treatment and retention periods (Table V). This would allow for an increased amount of anterior rotation of the mandible during those periods as indicated by the closure of the mandibular plane angle (Tables IV and V). The lower facial height might have been influenced by the insertion of the Herbst appliance during the initial phase of treatment and by its removal during the retention period. However, it seemed that the increase

of the lower facial height was reduced compared with that of normal growth during the 18-month period. The treatment effect on the jaw base relationship during the initial treatment period was more the result of forward positioning of the mandible than of restraint of maxillary forward growth. During the late treatment period, the pattern was reversed; and during the entire observation, the effects on the jaw base relationship were the same as the effects on the maxilla and mandible. During the 18 months of observation, the jaw base relationship improved on average 7 times more than expected from normal growth only (Table IV).

Direct comparison with previous studies regarding the effects of functional appliance therapy must be conducted with caution because of differences in sampling procedures and methodology. Some previous studies of the Herbst appliance had prefixed treatment lengths but unstandardized amounts of activation because activation was determined on the basis of the overjet's initial size.^{11,14,16,17,19,26-31} A previous study of the Bass appliance, a removable functional appliance with step-by-step advancement of the mandible used with occipital headgear, used a protocol similar to that of the present study. The previous study^{11,12} had the

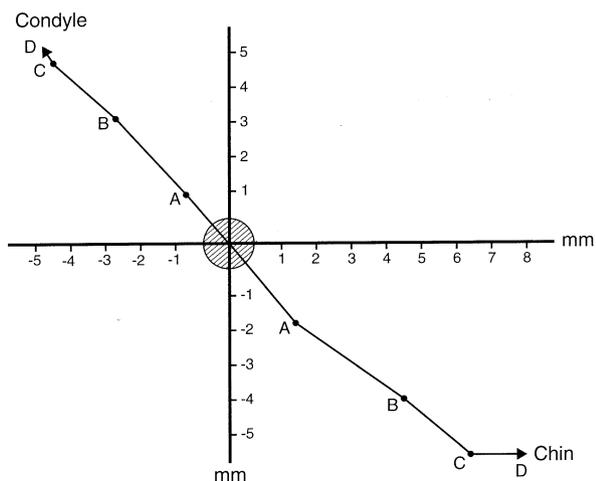


Fig 4. Condylar and grid positions after 6 months of growth (A), initial treatment phase (B), late treatment phase (C), and retention (D).

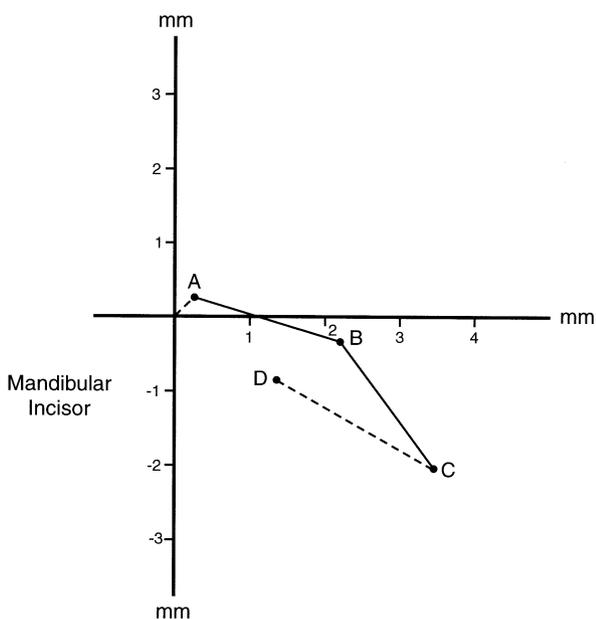


Fig 5. Mandibular incisor edge position after 6 months of growth (A), initial treatment phase (B), late treatment phase (C), and retention (D).

same initial 6 months of treatment and cephalometric analysis, but it included only boys. Changes to the maxilla and mandible resulting from treatment with the Bass appliance were identical to those found in the present study. However, a more recent study of the Bass appliance¹³ did not report the same favorable treatment outcome. The conventional Herbst appliance with maximum jumping of the mandible seemed to

have a less favorable effect on the forward growth of the mandible than did the headgear-Herbst appliance over 6 and 12 months of treatment.^{11,12,23} A recent study⁹ of the effect of a headgear activator with maximum jumping of the mandible used the same protocol as the present study; it found that over the initial 6 months of treatment, the restraint effect on the maxilla was similar to that found in our study, but there was no enhancement of forward growth of the mandible. In the present study, comparison of the treatment changes during the last 6 months of treatment with those of the initial 6 months found that the headgear effect was enhanced with the headgear-Herbst appliance but remained the same with the headgear activator. The mandibular forward growth that occurred with the use of the 2 functional appliances during the late treatment was just normal growth.

The positive effect of the headgear-Herbst appliance has been demonstrated by Wieslander¹⁶ in very young children treated for a short time. The follow-up study¹⁷ showed that it was difficult to maintain the positive treatment results despite retention with activators. It has been shown that the Herbst appliance affected growth during treatment; thereafter, growth was unpredictable.²¹ It has also been shown that an Andresen activator as used by Ahlgren³² might ruin the positive result achieved during the Herbst treatment by allowing eruption of posterior teeth and increasing the lower facial height.³³ When a headgear activator was used as a retainer after the Herbst treatment, a positive growth pattern was maintained (Table V).³³ This study showed that increasing the treatment time further enhanced the effects on the jaw relationship (Tables IV and V).

The dental changes (Table IV) observed during treatment and retention were similar to those reported previously; ie, some of the anchorage loss during active treatment with the Herbst appliance was reversed during the retention with the headgear activator.^{19,34} The headgear activator was adjusted to maintain the new positions of the maxillary teeth and to allow the dental arch to become upright. Apparently the headgear activator allowed the desired changes in the mandibular molars, mandibular incisors, and maxillary incisors, but not in the maxillary molars. After 18 months of active treatment and retention, the net effect on the mandibular incisors seemed to be a significant increase in the inclination without significant protrusion (Table V), resulting in an approximately 1-mm change in the position of the mandibular incisor edge in the sagittal and vertical planes (Table IV and Figure 5).

This study showed that treatment with the Herbst appliance resulted in improved jaw base relationship

caused by the restraint of forward growth of the maxilla; this increased with time and enhanced forward growth of the mandible, which decreased with time. A combination of factors is critical for the successful outcome of treatment with the Herbst appliance: the addition of headgear, step-by-step advancement of the mandible, sufficient length of treatment, and a retention device that maintains a positive growth pattern.

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