

Effectiveness of incremental vs maximum bite advancement during Herbst appliance therapy in late adolescent and young adult patients

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Introduction: The purpose of this research was to compare the effects of Herbst appliance therapy using incremental vs maximum advancement in late adolescent and young adult patients with Class II skeletal malocclusion. **Methods:** Forty-two patients with skeletal Class II malocclusion were treated with cast-splint Herbst appliances. The subjects were randomly allocated into 2 groups according to activation type: incremental advancement (IA) and maximum advancement (MA). Initial forward movement in the IA group was 4 to 5 mm and was followed by subsequent bimonthly advancements of 2 mm. Single-step advancement was achieved in the MA group until an edge-to-edge incisor relationship or an overcorrected Class I molar relationship was obtained. Total treatment times were 9.7 ± 1.1 months for the IA group and 9.5 ± 1.1 months for the MA group. Dental, skeletal, and soft tissue measurements were performed on lateral cephalograms taken just before and at the end of the Herbst appliance therapy. Statistical significance was set at $P \leq 0.05$. **Results:** All mandibular skeletal dimensions increased, and improvements of the sagittal maxillomandibular parameters were found in both groups. Protrusion and proclination of the mandibular incisors were greater in the IA group ($95.90^\circ \pm 5.34^\circ$) compared with the MA group ($92.04^\circ \pm 7.92^\circ$). Other dentoalveolar changes in both groups were intrusion of the maxillary first molars, and extrusion of the mandibular first molars and maxillary incisors. The mentolabial sulcus was flattened, soft tissue convexity was reduced, and forward movement of mandibular soft tissues was seen after Herbst therapy. **Conclusions:** Similar skeletal, dental, and soft tissue changes were obtained in both groups after Herbst therapy. Greater proclination and more protrusion of the mandibular incisors were found in the IA group. (Am J Orthod Dentofacial Orthop 2019;155:48-56)

It is challenging to solve the anteroposterior problems in adults with Class II malocclusion and mandibular retrognathism. The main goal of treatment for skeletal Class II patients is to obtain "lengthening" of the mandible.¹ The effects of functional appliances after cessation of growth are questionable, but similar

condylar growth and glenoid fossa remodeling changes were observed after Herbst therapy in adults and adolescents.² So, Herbst therapy has become a popular method for skeletal Class II treatment in young adults recently.²⁻⁴ The indication for adult Herbst treatment lies between orthodontic camouflage and orthognathic surgery in terms of mandibular skeletal effect.^{5,6}

There are 2 options for the mode of advancement: incremental activation and maximum activation of the appliance. According to results of animal studies, the amount of initial activation is important.^{7,8} Rabie and Al-Kalaly⁸ stated that 4 mm of initial advancement causes significantly more favorable new bone formation on the condyle compared with a 2-mm initial activation. The minimal threshold of activation for achieving growth of the condyle and remodeling of the glenoid fossa was obtained after 4 mm of initial advancement. Significant increases were observed in the production of type II collagen, which is the main component of the cartilage of the mandibular condyle.⁷⁻⁹ On the

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other hand, subsequent advancements play a crucial role in maximizing the number of replicating cells in the condyle and the glenoid fossa. Setting a 2-mm bimonthly anterior activation seems to be the optimal mode to obtain more replicating cells.¹⁰⁻¹²

Correction of a Class II malocclusion is achieved by both skeletal growth and dental changes after Herbst therapy with protrusion of the mandibular incisors as a side effect.¹³ Low forces affecting the incisors and less protrusion of the mandibular incisors with an increase in condylar growth were reported with incremental activation.^{7,14}

No consensus exists about the effectiveness of the treatments achieved with different mandibular activation modes. Martin and Pancherz⁶ showed that greater bite jumping results in greater intrusion, protrusion, and proclination of the mandibular incisors independent of the initial sagittal and vertical jaw relationships, growth period, and age with Herbst appliances. Aras et al¹ compared 2 groups of patients treated with protrusive-acting fixed, rigid functional orthodontic appliance with 2 modes of activation—stepwise and single step—at the peak of pubertal growth and found that stepwise advancement causes greater mandibular advancement, whereas dentoalveolar changes are similar for both groups. According to Purkayastha et al,⁹ a Class II malocclusion can be treated by skeletal and dental changes using the Herbst appliance in adults, but greater amounts of skeletal correction can be achieved with stepwise advancement. In the light of these findings, it may be hypothesized that stepwise advancement causes greater skeletal and fewer dentoalveolar changes compared with single-step advancement in young adults treated with the Herbst appliance. Therefore, the aim of this prospective clinical trial was to compare the effects of Herbst appliance therapy with maximum activations (MA) vs incremental activations (IA) in late adolescent and young adult patients with skeletal Class II malocclusion and mandibular retrognathia.

The null hypothesis tested was that the changes obtained with MA or IA are not significantly different.

MATERIAL AND METHODS

The ethical approval for this study was obtained from the clinical trials ethical committee of Erciyes University, Kayseri, Turkey (number 107). Before the study, all patients and their parents were informed about the details of the study, and their written consents were obtained.

The sample size was calculated (G*Power version 3.1.9.2; Franz Faul, Universität Kiel, Kiel, Germany) according to a 95% statistical power based on a medium effect size, $d = 0.61$ (the effect size in a similar study



Fig 1. Cast-splint Herbst appliance.

by Purkayastha et al⁹; mean difference, 0.5; t , 0.7). This necessitated a minimum sample of 20 subjects in each group to detect a significant difference between groups.

Forty-two patients with skeletal Class II malocclusion were involved in the study. Inclusion criteria were (1) skeletal Class II malocclusion (ANB angle, $>4^\circ$); (2) mandibular retrognathia (SNB, $<78^\circ$) and bilateral Class II molar and canine relationships (at least 3.5 mm); (3) increased overjet (≥ 7 mm) with normal or decreased vertical dimensions (SN-GoGn, $\leq 38^\circ$) and minimal crowding (≤ 4 mm, per arch); and (4) no missing teeth in either arch.

Patients with craniofacial anomalies, musculoskeletal diseases, severe facial asymmetry, severe maxillary transverse deficiency, and poor oral hygiene were excluded from the study.

Skeletal maturity was defined according to the study of Ruf and Pancherz.³ Skeletal ages and growth estimations were determined according to the atlas of Greulich and Pyle.¹⁵ The mean skeletal ages of the subjects were 16.10 ± 1.63 years in the IA group and 16.60 ± 1.27 years in the MA group. They had completed 98.69% and 98.89% of their total growth, respectively.

Cast-splint Herbst appliances were used for the treatment. Lingual arches were used to connect the cast splints in the mandibular part, and a hyrax screw was used in the maxillary cast splints as well (Fig 1).

The patients were randomly divided into 2 groups according to activation type: IA and MA. Assignment of patients to the IA and MA groups was performed at the first appointment by using a computer-generated randomization list. Twenty-one patients (15 girls, 6 boys; mean age, 15.6 ± 1.1 years) were included in the IA group, and appliance therapy was started with an initial forward movement of the mandible of about 4 to 5 mm. Subsequent advancements were done by inserting a 2-mm shim in the pivot ends of the plungers every 2 months until an overcorrected Class I molar relationship or an edge-to-edge incisor relationship was achieved. Total treatment time was 9.7 ± 1.1 months in the IA group.

Table I. Definitions of the measurements

Maxillary skeletal	
SNA (°)	Sella (S)–nasion (N)–A–point (A) angle: the relative anteroposterior position of the maxilla to the cranial base
N perp A (mm)	Distance from A–point to the plane drawn perpendicularly from nasion to the Frankfort horizontal plane
Co–A (female, mm)	Distance between condyion and A–point
Co–A (male, mm)	Distance between condyion and A–point
Maxillary depth (°)	Angle between the Frankfort horizontal plane and N–A line
Maxillary height (°)	Angle between the N–CF and CF–A lines
Mandibular skeletal	
SNB (°)	Sella–nasion–B–point angle: the relative anteroposterior position of the mandible to the cranial base
N perp B (mm)	Distance from pogonion (Pog) to the plane drawn perpendicularly from nasion to the Frankfort horizontal plane
Co–Gn (female, mm)	Distance between condyion and gnathion
Co–Gn (male, mm)	Distance between condyion and gnathion
Maxillomandibular	
ANB (°)	Relative position of the maxilla to the mandible
Maxillomandibular difference (mm)	Difference between the distance between Co–Gn and the distance between Co–A–point
Wits appraisal (mm)	Distance between the projections of points A and B on the occlusal plane
Hard tissue convexity (°)	Angle between nasion–A and A–Pog lines
Vertical skeletal	
y–axis (°)	Angle between the sella–gnathion and Frankfort horizontal planes
SN–GoGn (°)	Angle between the SN and Go–Gn lines
FMA (°)	Angle between Go–Gn and Frankfort horizontal planes
SN–PP (°)	Angle between the sella–nasion and palatal planes
Total (°)	Sum of N–S–Art, S–Art–Go, and Art–Go–Me angles
PP–MP (°)	Angle between the ANS–PNS and Go–Gn lines
S–Go (female, mm)	Distance between sella and gonion
S–Go (male, mm)	Distance between sella and gonion
ANS–Me (female, mm)	Distance between ANS and menton
ANS–Me (male, mm)	Distance between ANS and menton
PFH/AFH (%)	Ratio of posterior face height to anterior face height
Interdental	
Overjet (mm)	Distance sagittally between the incisal edges of the mandibular and maxillary incisors on the occlusal plane
Interincisal angle (°)	Relative spatial position along the long axis of the most prominent (anteriorly positioned) maxillary and mandibular central incisors
Maxillary dentoalveolar	
U1–SN (°)	Determines the inclination of the central incisor relative to the anterior cranial base
U1–PP (°)	Angle between the palatal plane and the long axis of the maxillary incisors
U1–NA (°)	Angle between long axis of the maxillary incisors and NA line
U1–NA (mm)	Distance between the incisal edge of the maxillary incisor and NA line
U1–NF (mm)	Vertical distance between the incisal edge of the maxillary incisor and the palatal plane
U6–NF (mm)	Vertical distance between the tip of the mesiobuccal cusp of maxillary first molar and the palatal plane
Mx1–MxOP (°)	Angle between the long axis of the maxillary incisor and the maxillary occlusal plane
Mandibular dentoalveolar	
IMPA (°)	Incisor mandibular plane angle: axial inclination between the mandibular incisor and the inferior border of the mandible
L1–NB (°)	Angle between the long axis of the mandibular incisor and the NB line
L1–NB (mm)	Distance between the incisal edge of the mandibular incisor and the NB line
L1–MP (mm)	Vertical distance between the incisal edge of the mandibular incisor and mandibular plane
L1–APog (°)	Distance between the incisal edge of the mandibular incisor and A–Pog line
L6–MP (mm)	Vertical distance between the tip of the mesiobuccal cusp of the mandibular first molar and the mandibular plane
Md1–MdOP (°)	Angle between the long axis of the mandibular incisor and mandibular occlusal plane
Soft tissues	
Nasolabial angle (°)	Angle between the lines drawn from pronasale to subnasale and from subnasale to the upper lip vermillion
LL–E plane (mm)	Distance from the lower lip stomion to the E–plane
UL–E plane (mm)	Distance from the upper lip stomion to the E–plane

Table I. Continued

Nasal projection (mm)	Horizontal distance from subnasale to the tip of nose
TVL-A' (mm)	Perpendicular distance of the soft tissue A-point to the true vertical line (TVL)
TVL-upper lip (mm)	Distance from the most proximal point of the upper lip to the subnasal-pogonion plane
TVL-lower lip (mm)	Distance from the most proximal point of the lower lip to the subnasal-pogonion plane
TVL-B' (mm)	Perpendicular distance of the soft tissue B-point to the TVL
TVL-Pog' (mm)	Perpendicular distance of the soft tissue pogonion to the TVL
Soft tissue convexity (°)	Angle between soft tissue nasion, soft tissue subnasale, and soft tissue pogonion
Mentolabial angle (°)	Inner angle between the lines tangent to the lower lip and the soft tissue chin intersecting at sublabiale

Abbreviation: CF, center of face.

The MA group included 21 subjects (12 girls, 9 boys; mean age, 15.7 ± 1.3 years). Advancement was adjusted until an edge-to-edge incisor relationship or an overcorrected Class I molar relationship was obtained. Total treatment time was 9.5 ± 1.1 months in this group. Mean ages were 16.39 ± 1.26 years in the IA group and 16.35 ± 1.15 years in the MA group when the Herbst appliances were removed and lateral cephalometric films were taken. Immediately after appliance removal, all subjects received a modified Hawley appliance with an anterior guide plane for retention and occlusal settling in this study as routinely used in our clinical practice. The patients used this device for at least half of the active treatment time (approximately 4–6 months) until adequate cuspal interdigitation was achieved.

Skeletal, dental, and soft tissue changes were evaluated using lateral cephalometric films taken (cephalometer, Orthoceph OP300; Instrumentarium, Tuusula, Finland) just before appliance placement and after appliance removal. Lateral cephalograms of the patients were taken in mirror-guided natural head position. All subjects were asked to look straight into their own eyes in the mirror located at the same level as the pupils of their eyes. Radiographs were taken with the patients' lips slightly closed and their teeth in centric occlusion. Landmarks and lines used for the evaluation of dental and skeletal changes are given in [Table I](#).

One investigator (N.G.A.) performed all measurements using the same software (version 11.0; Dolphin Imaging and Management Solutions, Chatsworth, Calif), and the software was also used to correct the values of the cephalograms for linear enlargement automatically.

Statistical analysis

All statistical analyses were performed with the Statistical Package for the Social Sciences (version 16.0; SPSS, Chicago, Ill). Arithmetic means and standard deviations were calculated for each measurement. The normality test of Shapiro-Wilks and the Levene variance homogeneity test were applied to the data. Sex differences and intergroup comparisons were evaluated using

independent-samples *t* tests. Intragroup comparisons between the time points were performed using paired-samples *t* tests. Statistical significance was set at $P < 0.05$.

The cephalograms of 20 patients were randomly selected, and tracings were repeated 1 month after the first measurements. The lowest and highest intraclass correlation coefficients were 0.832 for upper lip to true vertical line and 0.992 for overjet. Measurements obtained at the different times were similar.

RESULTS

Forty-two patients were involved in the study. All patients received cast-splint Herbst appliance therapy, and no patients dropped out of the study. Total treatment times were 9.7 ± 1.1 months in the IA group and 9.5 ± 1.1 months in the MA group. Sex distributions and ages were similar for both groups ([Table II](#)).

To determine whether there were any statistical sex differences among the groups, evaluations were performed, and sex differences were found for 4 parameters (Co-A, Co-Gn, S-Go, ANS-Me). The data were pooled for the other measurements. Statistical comparisons of the initial data are given in [Supplemental Table I](#).

Intragroup and intergroup evaluations of the cephalometric comparisons are presented in [Supplemental Table II](#).

There was no significant change for the maxillary measurements in both groups, except for an increase in maxillary height (0.09 ± 1.57 mm, $P = 0.010$) in the IA group. No significant difference was found between the groups regarding the maxillary skeletal measurements except for maxillary depth (1.33 ± 3.16 mm, $P = 0.035$), which increased in the MA group and decreased in the IA group.

Mandibular length (Co-Gn) increased in both groups (3.09 ± 3.41 and 2.85 ± 3.96 mm in the IA and MA groups, respectively), but the difference was not statistically significant for the boys in the MA group. Mandibular positional changes with forward movement of the mandible were observed in both groups. Only the

Table II. Comparisons of ages, activation times, treatment durations, and sex distributions between the groups

	IA group	MA group
Age (y)	15.6 ± 1.1	15.7 ± 1.3
Treatment duration (mo)	9.7 ± 1.1	9.5 ± 1.1
Advancement		
Initial	4-5 mm	Edge-to-edge incisor
Subsequent	2 mm per 2 months	None
Sex (n, %)		
Male	6 (29)	9 (43)
Female	15 (71)	12 (57)

$N \perp$ Pog measurement was not statistically significant in the IA group. The differences between groups regarding mandibular skeletal measurements were not statistically significant.

Significant treatment changes were recorded in each group. ANB angle, Wits appraisal, and hard tissue convexity decreased, and the maxillomandibular difference increased in both groups, but no statistically significant difference was found between groups.

There were no statistically significant changes in vertical skeletal measurements except for the increases in S-Go ($P = 0.001$, both sexes) and ANS-Me ($P = 0.000$, girls only) in the IA group. Similar changes were observed in the MA group with statistically significant increases in S-Go for boys ($P = 0.002$) and ANS-Me ($P = 0.040$ for girls; $P = 0.010$ for boys). Intergroup differences were not statistically significant.

Similar maxillary dentoalveolar changes were recorded for both groups, and no difference was detected for intergroup comparisons. Maxillary incisor extrusion and maxillary molar intrusion were statistically significant in both groups. Maxillary incisor retroclination (Mx1-MxOP, $1.42^\circ \pm 6.31^\circ$; $P = 0.019$) was seen only in the IA group.

All mandibular incisor measurements showed increases, and the changes were statistically significant in both groups except for the vertical positions of incisors that were not different for intragroup and intergroup comparisons. The greatest differences between the groups were observed for the mandibular incisors (L1-NB, $-3.09^\circ \pm 5.64^\circ$, $P = 0.035$; L1-NB, -0.57 ± 1.16 mm, $P = 0.027$; and L1-APog, -0.38 ± 2.63 mm, $P = 0.024$); greater protrusion was recorded for the IA group compared with the MA group.

Mandibular first molar extrusion was calculated in both groups, but the difference was not statistically significant. The decreases in overjet and interincisal angle were statistically significant for both groups and comparable between groups.

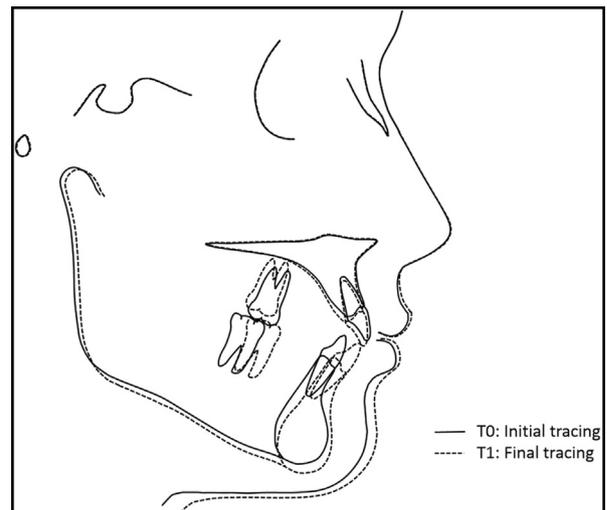


Fig 2. Overall superimposition tracing on sella-nasion line at sella between pretreatment (T_0) and end of Herbst treatment (T_1) of the average of the IA group.

In the IA group, the nasolabial angle decreased ($P = 0.002$), the upper lip moved backward ($P = 0.002$), and the lower lip moved forward ($P = 0.020$) according to the E-plane. All mandibular soft tissue points moved forward according to the true vertical line (TVL). Forward movement of the lower lip (TVL-lower lip, -3.04 ± 1.43 mm, $P = 0.000$), soft tissue B-point, (TVL-B', -3.14 ± 2.00 mm, $P = 0.000$), and soft tissue pogonion (TVL-Pog', -1.95 ± 2.49 mm, $P = 0.002$) were statistically significant. There were statistically significant increases in soft tissue convexity ($-1.90^\circ \pm 2.93^\circ$, $P = 0.007$) and mentolabial angle ($-1.50^\circ \pm 10.32^\circ$, $P = 0.000$).

In the MA group, the upper lip was retruded (UL-E plane, 1.28 ± 1.67 mm, $P = 0.002$), and no significant change was recorded for the lower lip. Soft tissue A-point also moved backward after Herbst therapy (0.52 ± 0.92 mm, $P = 0.018$). All mandibular soft tissue points showed anterior displacement (TVL-lower lip, 0.76 ± 16.02 mm, $P = 0.000$; TVL-B', 3.28 ± 3.87 mm, $P = 0.001$; TVL-Pog', -1.38 ± 2.43 mm, $P = 0.017$). Soft tissue convexity ($2.61^\circ \pm 2.63^\circ$, $P = 0.000$) and mentolabial angle ($1.93^\circ \pm 17.53^\circ$, $P = 0.000$) increased.

All soft tissue measurements showed similar changes in both groups, but only the decrease in the nasolabial angle was greater in the IA group ($3.61^\circ \pm 8.49^\circ$, $P = 0.031$).

Thus, the null hypothesis was rejected.

Regional and total superimpositions based on the average values of the groups are given in Figures 2 through 5.

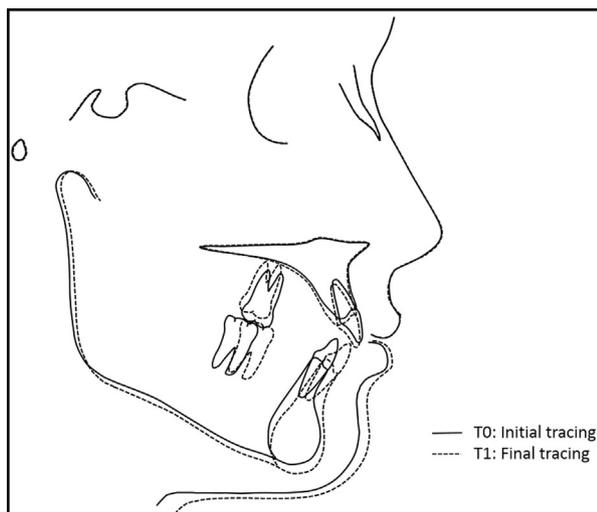


Fig 3. Overall superimposition tracing on sella-nasion at sella between pretreatment (T_0) and end of Herbst treatment (T_1) of the average of the MA group.

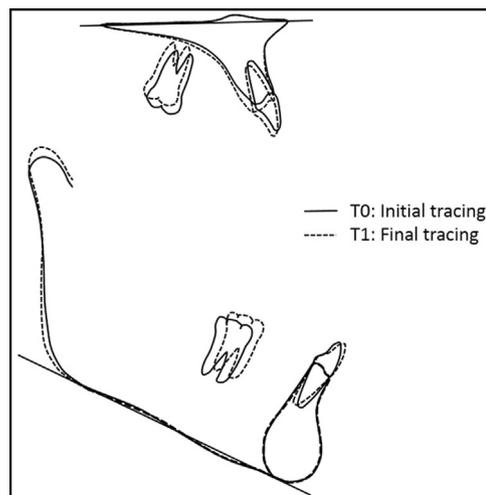


Fig 5. Regional maxillary and mandibular superimposition tracing on ANS-PNS and Go-Me between pretreatment (T_0) and end of Herbst treatment (T_1) of the average of the MA group.

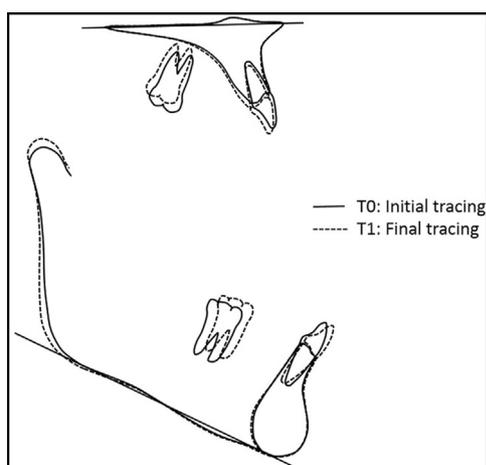


Fig 4. Regional maxillary and mandibular superimposition tracing on ANS-PNS and Go-Me between pretreatment (T_0) and end of Herbst treatment (T_1) of the average of the IA group.

DISCUSSION

The treatment of skeletal Class II malocclusions with the Herbst appliance in adults is an alternative method to orthognathic surgery or orthodontic camouflage treatment.³ Stepwise mandibular advancement during functional therapy was advocated to induce greater skeletal effects than 1-step activation.⁷ The skeletal effect of functional appliances after growth is questionable. Thus, stepwise mandibular activation of the Herbst appliance with a skeletal Class II malocclusion may be

more effective than 1-step activation for achieving greater skeletal response in young adults. Therefore, the aim of this study was to evaluate and compare the skeletal, dental, and soft tissue differences between 2 bite-jumping modes of Herbst appliance therapy in patients at the finishing stage of growth. All subjects with similar skeletal maturity stages were treated by the same clinician (N.G.A.). No control group was used in this study, because all patients had finished their skeletal growth, and also for ethical reasons.

The significance of the initial activation amount was reported in animal studies.^{7,8} Rabie and Al-Kalaly⁸ evaluated different degrees of mandibular advancement on condylar growth. They divided 335 rats into control and experimental groups. The experimental group was further divided into 2-mm and 4-mm activation groups. They found that the 4-mm activation group stimulated more type II collagen than did the 2-mm and control groups, indicating that when more advancement was achieved, greater formation of mesenchymal cells, cartilage, and bone can be obtained.

Various amounts of both initial and subsequent activations of functional appliances have been reported in the literature: eg, the headgear-Herbst combination in which the amount of initial sagittal mandibular activation was 2 mm, followed by additional 2-mm advancements every 2 months^{16,17}; an activator-headgear treatment group used a 4-mm activation every 3 months^{16,18}; Twin-block treatment was achieved with 2-mm advancements at 6-week intervals¹⁹; and Herbst appliance therapy in adults was started with

4-mm initial activations.^{9,20} So, the 4-mm initial advancement of the mandible in the IA group was set with subsequent 2-mm activations at 2-month intervals in our study. Initial advancement in the MA group was adjusted until an edge-to-edge incisor relationship or an overcorrected Class I relationship was obtained.

Chayanupatkul et al²¹ advocated keeping the mandible in the advanced position longer so that the newly developed bone matrix can be converted into a more stable type 1 collagen matrix, and then normal levels of mandibular growth can be secured after removal of the appliance. Approximately 6 to 8 months of treatment has been advocated for Herbst appliance therapy.²² Total treatment times were 9.7 ± 1.1 months in the IA group and 9.5 ± 1.1 months in the MA group; these are sufficient for stable bone formation.

The authors of several studies in the literature presented results regarding step-wise activations of functional appliances. Falck and Fränkel²³ evaluated the stepwise and maximum advancement procedures on 120 subjects, with 170 untreated patients as the control group. They found that the mandibular length (pogonion-condylo-n or pogonion-articulare) increased in both treatment groups, but the anterior projection of pogonion was found only in the stepwise advancement group. The ages of the subjects were not mentioned in this study. Similar results were found by Kumar et al¹⁹ for bionator treatment with stepwise and maximum advancements compared with a control group. They found that the skeletal contribution to sagittal correction was greater in the step-wise advancement group, whereas the treatment effect was due to both skeletal and dental changes by single-step advancement compared with the control group. Illing et al²⁴ evaluated the treatment effects of Bass, bionator, and Twin-block appliances. Three treatment groups and an untreated control group included 87 patients. The activation mode of the Bass appliance was stepwise with a 4-mm initial activation and subsequent 2-mm activations every 6 to 8 weeks, whereas the other appliances were activated with an edge-to-edge incisor relationship. The authors reported greater increases in mandibular length and mandibular incisor to mandibular plane inclination in the Twin-block and bionator groups, whereas a minimal change in mandibular incisor proclination was recorded in the Bass group. Banks et al²⁵ carried out a study on 203 patients (10-14 years of age) treated with Twin-block appliances and reported no advantage of incremental advancement over maximum advancement in terms of treatment outcome. Hägg et al¹⁶ reported the effects of 2 types of headgear-Herbst appliance with maximum and stepwise activations. Greater mandibular

prognathism was found for the maximum activation group. No measurements were given for mandibular incisor proclination. Aras et al¹ evaluated the effects of functional the mandibular advancer with single-step or stepwise mandibular advancement and found similar statistically significant changes in Co-Gn and SNB measurements by condylar growth and forward movement of B-point. Their stepwise advancement group had greater increases in Co-Gn, Pg-horizontal, and SNB measurements. In our study, a Class I occlusion was obtained by lengthening the mandible and with dental changes such as protrusion and proclination of the mandibular incisors at the end of functional appliance therapy with both activation modes. These differences with the abovementioned studies may be attributed to 2 reasons. Initially, the appliances have different designs. For example, the functional mandibular advancer has no telescopic mechanism, and the appliance is located in the posterior dental area, which can cause less mandibular incisor proclination than the Herbst appliance. Second, the ages of the participants were generally 10 to 14 years, or they were at the peak of the pubertal growth spurt in the abovementioned studies, whereas our subjects were young adults. Thus, the results should be interpreted cautiously and are not conclusive because of many conflicting parameters.

The only clinical study that compares the treatment effects of stepwise vs maximum advancement in adult patients with the Herbst appliance was performed by Purkayastha et al,⁹ who reported statistically significant forward movement of pogonion as a result of mandibular growth stimulation by stepwise activation. This difference can be explained by the greater proliferation of replicating cells in the condyle as the result of step-by-step activation, but there are some major problems in the design of the study.^{10,11} First, the sample was not homogeneous. The stepwise and maximum advancement groups were from different ethnic groups (German and Chinese); this can be a conflicting factor for evaluation of the treatment effects of the Herbst appliance. The treatment durations were 7 to 9 months for the single advancement group and 12 months for the gradual advancement group, so more skeletal effect in the gradual advancement group may also be a result of longer treatment. Finally, the German sample had greater pretreatment overjet values, but the skeletal contributions to molar correction were comparable between the groups. According to the sagittal-occlusal analysis, mandibular base changes were similar, and mandibular incisor proclination was greater in the Chinese sample.

Similar to the results of Purkayastha et al,⁹ we found lengthening of the mandible in both groups; this may be assumed as a sign of condylar growth stimulation in adult patients. Even though the increase in Co-Gn was greater in the IA group, there was no statistical significance between the groups. Mandibular dimensions increased, and forward mandibular positioning was observed after Herbst therapy in all patients. No difference was detected between groups, indicating that IA has no advantage over MA in adults.

The restriction effect of Herbst treatment on maxillary growth has been shown.^{26,27} In our study, a greater restriction effect was observed in the IA group according to the maxillary depth measurements. This should be interpreted cautiously because other measurements did not differ between groups.

Proclination of the mandibular incisors is an inevitable result in all Herbst treatments, independent of appliance design.¹³ This anchorage loss in the mandibular arch is attributed to the mesial force created by the telescope mechanism of the Herbst appliance.^{1,26-32} According to Pancherz and Hansen¹³ and Pancherz,²⁷ the greater the amount of initial bite jumping, the greater the movement of the mandibular incisors. The dental effects were explained by the reduction of the forces acting on the incisors via stepwise activation compared with maximum advancement. Wey et al,¹⁸ using a headgear-activator combination, reported that the mandibular incisors maintained their positions unaffectedly when the mandible was advanced with stepwise activation. However, some studies have documented that advancing the mandible with stepwise or single-step advancement leads to comparable effects on the mandibular incisors.^{1,17,26} Banks et al²⁵ suggested that incisor tipping might be independent of the force applied. We found significant proclination and protrusion in the mandibular incisors, and intergroup comparisons showed statistically greater proclination and protrusion in the IA group compared with the MA group. Slight mandibular incisor intrusions were recorded for both groups, but the difference did not reach a statistically significant level. Both groups exhibited statistically significant changes for maxillary incisor positions, whereas palatal tipping was reported in previous functional appliance studies.^{1,33-35}

The effects of both activation modes on the soft tissues were similar and reflect the improvement in the sagittal maxillomandibular discrepancy. Soft tissue changes mainly originated from forward movement of the mandibular soft tissues and were similar in both groups. Increases of the soft tissue convexity and mentolabial angle are common findings after functional appliance therapy, and our results are consistent with the

literature.^{3,36-38} No statistically significant difference at the nose tip and upper lip area in the IA group may be explained by forward positioning of the E-plane as a result of forward movement of soft tissue pogonion.

No significant changes in nasolabial angle and nasal projection were found in the MA group, although statistically significant backward movement of soft tissue A point was seen. Also, in the IA group, a statistically significant decrease was observed in the nasolabial angle even though there were no changes in soft tissue A-point and nasal projection. These deviations can be attributed to individual differences. According to the results of this study, it may be concluded that both activation procedures induce similar soft tissue effects in young adults.

CONCLUSIONS

Within the limitations of this study, we concluded that (1) overjet reduction and Class I occlusion were achieved through the combination of both skeletal and dental changes, (2) mandibular lengthening was obtained with both activation types in skeletally mature patients, (3) less protrusion and proclination of the mandibular incisors was observed in the MA group, and (4) soft tissue convexity decreased in all patients after Herbst appliance therapy due to mandibular changes.

SUPPLEMENTARY DATA

Supplementary data related to this article can be found online at <https://doi.org/10.1016/j.ajodo.2018.02.014>.

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