ORIGINAL ARTICLE

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Herbst appliance anchored to miniscrews with 2 types of ligation: Effectiveness in skeletal Class II treatment

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Introduction: The aim of this study was to evaluate the effectiveness of the treatment of skeletal Class II malocclusions with an acrylic splint Herbst appliance anchored to miniscrews with 2 types of ligation. **Methods:** Sixty patients (mean age, 11.6 years; SD, 1.9) with a bilateral Angle Class II Division 1 malocclusion were retrospectively selected and divided into 3 homogeneous and balanced groups on the basis of the Herbst anchorage used: without anchorage, miniscrews with elastic chains, and miniscrews with metallic ligatures. A cephalometric sagittal occlusion analysis merged with mandibular incisor proclination and skeletal divergence was carried out before and after treatment. To compare the absolute variations within and among the groups, we performed the 1-sample *t* test for repeated measures and 1-way analysis of variance, respectively. **Results:** Overjet was reduced similarly in all groups ($P < 0.05$). The mandibular bone base length increased in the group with elastic chains only ($P = 0.001$). The change in the distance between Point A and pogonion showed the most reduction in the group with elastic chains ($P < 0.05$). Incisive flaring was more pronounced in the group with no anchorage than in the group with elastic chains ($P < 0.001$) and the group with metallic ligatures ($P = 0.003$). **Conclusions:** Anchorage to miniscrews with elastic chains increases the orthopedic effect of the acrylic splint Herbst appliance. It has been confirmed that skeletal anchorage reduces incisor flaring. (Am J Orthod Dentofacial Orthop 2016;149:871-80)

The Herbst appliance is largely used in orthodontics for the correction of Class II malocclusions, which are among the most common problems.[1-3] It has been reported to be one of the most efficient among the different types of functional appliances,[4,5] and it has become increasingly popular both because it does not require patient compliance and because the treatment time is short.[6,7] Its effects are both dental and skeletal and include enhanced sagittal growth of the mandible and anterior displacement of the mandibular arch, together with reduced sagittal growth of the maxilla and posterior displacement of the maxillary arch[8] and temporomandibular joint remodeling.[9] In terms of disadvantages, it is well known that Herbst treatment causes proclination of the mandibular incisors because of anchorage loss in different amounts relative to the type of appliance used.[10,11] Various modifications of the original Herbst, such as the insertion of Class III elastics, reduced cast splints, and total cast splints, have been proposed, but none has been able to completely eliminate the proclination of the mandibular incisors.[12,13]

The introduction of skeletal anchorage into orthodontics not only has allowed for the simplification of many procedures conventionally used for the control of anchorage, but also has reduced the undesirable effects of many appliances.[14] Some authors have demonstrated that such appliances can be used successfully for anchorage during orthodontic therapy.[15,16] The possibility of combining Herbst appliances with skeletal anchorage has been previously described in the literature, and all of those studies reported reductions of mandibular incisor flaring.[17-19] Yet no studies have compared different skeletal anchorage ligations. The aim of this study was to evaluate the effectiveness, in

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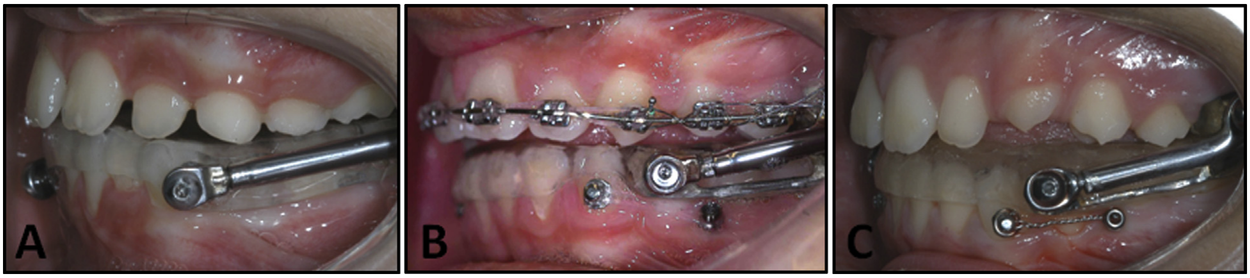

Fig 1. A, Standard acrylic splint Herbst without skeletal anchorage (SH group); **B,** acrylic splint Herbst anchored with TADs and elastic chains (EC group); **C,** acrylic splint Herbst anchored with TADs and metallic ligatures (ML group).

mandibular advancement and anchorage control, of a modified Herbst appliance anchored to miniscrews with 2 types of ligation.

MATERIAL AND METHODS

The inclusion criteria for this study were patients who could benefit from Herbst treatment for a retrusive chin, who had a bilateral Angle Class II Division 1 malocclusion equal to or greater than half a cusp width, who were in the permanent or late mixed dentition, and whose parents had signed an informed consent. Exclusion criteria were poor oral hygiene and motivation, tooth agenesis or premature loss of permanent teeth, transverse or vertical discrepancies, and incomplete records. All patients were evaluated and treated by 1 operator (A.M.) and divided into 3 groups.

Group 1 (standard Herbst [SH]) consisted of 20 subjects treated with an acrylic splint Herbst and no miniscrews; it included 11 boys and 9 girls with a mean age of 11.3 years (SD, 1.7) (Fig 1, *A*).

Group 2 (elastic chain [EC]) consisted of 20 subjects treated consecutively with an acrylic splint miniscrew Herbst anchored with temporary anchorage devices (TADs) and elastic chains; it included 10 boys and 10 girls with a mean age of 11.9 years (SD, 1.7). Miniscrews were placed between the mandibular first and second premolars or between the second premolars and the first molars in the attached gingiva and were ligated with elastic chains (Memory Chain; American Orthodontics, Sheboygan, Wis).[20] During treatment, the elastic chains were replaced every 30 to 60 days (Fig 1, *B*).

Group 3 (metallic ligature [ML]) consisted of 20 subjects treated consecutively with an acrylic splint miniscrew Herbst anchored with TADs and metallic ligatures; it included 11 boys and 9 girls with a mean age of 11.6 years (SD, 2.4). Miniscrews were placed between the mandibular first and second premolars or between the second premolars and the first molars in the attached gingiva and were ligated with metallic ligatures.[20] During treatment, the ligatures were reactivated every 30 to 60 days (Fig 1, *C*).

We chose subjects retrospectively by pairing the data to create groups homogeneous for age. Patients were selected also to balance the distribution of the sexes among the groups.

The miniscrews used (M.A.S.; Micerium, Avegno, Italy) were titanium, 11 mm long, and shaped like a truncated cone with diameters of 1.5 or 1.3 mm (according to the bone level) at the tip and 2.2 mm at the neck. The shanks of the screws measured 1 mm in diameter; the threaded part had a length of 9 to 11 mm, and the heads had a hexagonal slot that could house the head of the screwdriver or a contra-angle handpiece (Fig 2).

Before insertion of the miniscrew, each patient rinsed his or her mouth with 0.1% chlorhexidine gluconate solution; predrilling was carried out, and the miniscrews were inserted with a manual screwdriver.

A metallic ligature or an elastic chain (100 g) linked the miniscrews to metallic buttons bonded to the mandibular canines on each side. Lateral cephalometrics were obtained from all patients before (T1) and at the end (T2) of the Herbst treatment before finishing with a fixed appliance, for evaluation of the outcome of the Herbst therapy only. The sagittal occlusion analysis of Pancherz[8] (analysis of changes in the sagittal occlusion) was carried out for each patient at T1 and T2 for skeletal and dental changes. The operator (M.P.) was blinded to the groups' classifications.

The occlusal line and the occlusal line perpendicular were transferred from the T1 to the T2 cephalometrics by superimposition of the radiographs on the stable bone structures of the anterior cranial base. Parameters not considered in the Pancherz[8] sagittal occlusion analysis were also included, such as mandibular incisor proclination (Ii/GoMe) and skeletal divergence (SN/GoMe); the variables considered are shown in Table 1 and Fig 3.

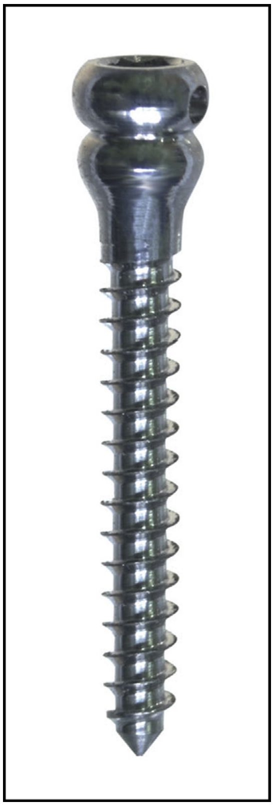

Fig 2. M.A.S. miniscrew (Micerium, Avegno, Italy) used for Herbst skeletal anchorage.

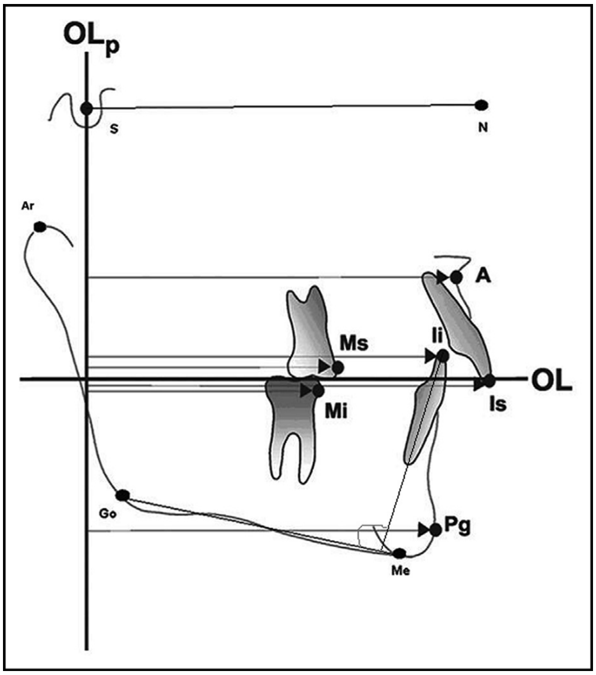

Fig 3. Sagittal occlusion analysis tracing of Pancherz[8] merged with mandibular incisor proclination and skeletal divergence.

Table I. Cephalometric variables

Variable	*Description*
Vertical dimension	SN/GoMe, angle formed by the SN and GoMe lines (°)
Skeletal class	AN/NPg, angle formed by the AN and NPg lines (°)
Maxillary bone base	A/Olp, distance from Point A to the Olp line (mm)
Condylar position	Ar/Olp, distance from Ar to the Olp line (mm)
Mandibular bone base	Pg/Olp, distance from Pg to the Olp line (mm)
Skeletal discrepancy	A/Olp minus Pg/Olp, maxillary bone base minus mandibular bone base (mm)
Maxillary molar position	Ms/Olp, distance from Ms to the Olp line (mm)
Mandibular molar position	Mi/Olp, distance from Mi to the Olp line (mm)
Molar relationship	Ms/Olp − Mi/Olp; maxillary molar minus mandibular molar (mm)
Overjet	Is/Olp − Ii/Olp; maxillary incisor minus mandibular incisor (mm)
Maxillary incisor position	Is/Olp, distance from Is to the Olp line (mm)
Mandibular incisor position	Ii/Olp, distance from Ii to the Olp line (mm)
Mandibular incisor proclination	Ii/GoMe, angle formed by the mandibular incisor axis and the mandibular plane (GoMe) (°)

Ms, Maxillary molar; Mi, mandibular molar.

The intraclass correlation coefficient (ICC) was estimated to assess the reliability of the measurements. The same operator (M.P.) repeated the measurements of 10 patients twice, with a 7-day interval between the recordings. The computed ICC was 99%, which reflected a high level of agreement.

Statistical analysis

Descriptive statistics (means and standard deviations) of all continuous variables were estimated, stratifying patients by appliance type (SH, EC, and ML). The normal distribution of the data was confirmed with a graphic visualization and the Shapiro-Wilk test.

Table II. Descriptive statistics of the sample at T1 stratified by type of appliance

	SH group (n = 20)	EC group (n = 20)	ML group (n = 20)	Comparison of groups at T1* (P)
Ratio of boys to girls	11:9	10:10	11:9	-
T1 age (y), mean (SD)	11.3 (1.7)	11.9 (1.7)	11.6 (2.4)	0.5856
Vertical dimension (SN/GoMe) (°), mean (SD)	32.2 (6.1)	34.2 (6.7)	32.8 (7.2)	0.5908
Skeletal class (AN/NPg) (°), mean (SD)	5.7 (2.3)	5.1 (2.9)	4.4 (2.5)	0.2922
Maxillary bone base (A/Olp) (mm), mean (SD)	77.1 (3.2)	79.3 (4.4)	78.6 (4.3)	0.2024
Condylar position (Ar/Olp) (mm), mean (SD)	8.5 (3.8)	9.2 (3.3)	10.1 (2.9)	0.3448
Mandibular bone base (Pg/Olp) (mm), mean (SD)	77.9 (5.1)	81.7 (6.0)	80.2 (4.7)	0.0782
Maxillary molar position (Ms/Olp) (mm), mean (SD)	52.4 (4.2)	54.9 (4.5)	54.3 (5.9)	0.2444
Mandibular molar position (Mi/Olp) (mm), mean (SD)	50.3 (4.8)	53.8 (5.1)	53.0 (6.6)	0.1243
Molar relationship (Ms/Olp-Mi/Olp) (mm), mean (SD)	2.1 (2.0)	1.1 (1.6)	1.4 (2.0)	0.2307
Overjet (Is/Olp-Ii/Olp) (mm), mean (SD)	7.3 (2.4)	5.8 (1.8)	7.6 (2.5)	0.0281†
Maxillary incisor position (Is/Olp) (mm), mean (SD)	84.2 (4.2)	85.8 (4.9)	86.8 (5.3)	0.2478
Mandibular incisor position (Ii/Olp) (mm), mean (SD)	76.9 (4.2)	80.1 (4.9)	79.2 (5.1)	0.1011
Mandibular incisor proclination (Ii/GoMe) (°), mean (SD)	94.7 (5.3)	99.0 (6.8)	99.6 (5.3)	0.0178‡

*One-way ANOVA; $F_{2,57}$; α level $P < 0.05$; †Bonferroni test: differences were significant between the EC and ML groups ($P = 0.040$); ‡Bonferroni test: differences were significant between the EC and SH groups ($P = 0.017$) and between the ML and SH groups ($P = 0.046$).

The homogeneity at baseline of the 3 groups was tested by 1-way analysis of variance (ANOVA) followed by the multiple-comparison Bonferroni test.

In each group, the changes in cephalometric parameters, after vs before treatment (T2 − T1), were statistically analyzed with the 1-sample *t* test for repeated measures.

To compare the absolute variations in cephalometric values after treatment among the 3 groups, we performed 1-way ANOVA and the Bonferroni test. The power of the test was also calculated.

For evaluation of the change in the distance between pogonion and Point A, a new variable was generated: the difference between the maxillary bone base (A/Olp distance) and the mandibular bone base (Pg/Olp distance). This distance was called the skeletal discrepancy.

The α level was fixed at $P = 0.05$.

All data were analyzed with Stata software (version 12; StataCorp, College Station, Tex).

The sample size was estimated on the basis of data published by Manni et al[21] and hypothesized a minimum difference in pogonion advancement of 2.0 mm among the groups (SD, 2.0; power = 0.8; α level = 0.05). Under these conditions, the output was 16 patients per group.

RESULTS

Following the Herbst therapy, all subjects were successfully treated with comprehensive braces to a bilateral Class I relationship. The mean treatment times (from T1 to T2) were 7.4 months (SD, 0.8) in the SH group, 7.5 months (SD, 0.8) in the EC group, and 7.4 months (SD, 1.0) in the ML group. Mean treatment duration was consistent with the treatment time reported by Baltromejus et al.[22] Fourteen miniscrews had to be replaced because of their mobility during treatment. We registered 2 screw failures in 3 patients (1 patient in the ML group and 2 patients in the EC group), and 1 screw failure in each of 4 patients in both the ML and EC groups, for totals of 8 failures in the EC group and 6 failures in the ML group.

Descriptive statistics and statistical analyses are summarized in Table II.

The 3 groups of patients were homogeneous at T1 for the ratios of boys to girls. No differences were estimated in vertical dimension, skeletal class, maxillary bone base, condylar position, molar position, and maxillary incisor position ($P > 0.05$). The only differences were found in overjet and mandibular incisor proclination. Overjet was larger in the SH group (mean, 7.3 mm; SD, 2.4) and the ML group (mean, 7.6 mm; SD, 2.5) compared with the EC group (mean, 5.8 mm; SD, 1.8). However, a significant difference was found between the ML and EC groups (ANOVA, $F_{2,57} = 3.80$, $P = 0.0281$; Bonferroni test, $P = 0.040$). Mandibular incisor proclination showed a difference among the groups (ANOVA, $F_{2,57} = 4.32$, $P = 0.0178$). The incisors were more proclined in the EC group (mean, 99.0 mm; SD, 6.8) and the ML group (mean, 99.6 mm; SD, 5.3) compared with the SH group (mean, 94.7 mm; SD, 5.3). It resulted in a marginally significant difference between the EC and SH groups (Bonferroni test, $P = 0.065$) and a significant difference between the ML and SH groups (Bonferroni test, $P = 0.027$), but not between the ML and EC groups.

Table III. Descriptive statistics of the sample at T2 stratified by type of appliance

	SH group (n = 20)	EC group (n = 20)	ML group (n = 20)
Vertical dimension (SN/GoMe) (°), mean (SD)	32.7 (6.8)	33.5 (5.1)	32.2 (6.6)
Skeletal class (AN/NPg) (°), mean (SD)	3.8 (2.0)	2.8 (2.9)	3.2 (3.0)
Maxillary bone base (A/Olp) (mm), mean (SD)	76.3 (3.7)	78.6 (4.8)	77.7 (4.3)
Condylar position (Ar/Olp) (mm), mean (SD)	9.0 (3.3)	9.8 (3.7)	10.8 (3.1)
Mandibular bone base (Pg/Olp) (mm), mean (SD)	78.2 (6.6)	84.5 (6.7)	81.0 (5.4)
Maxillary molar position (Ms/Olp) (mm), mean (SD)	49.9 (4.8)	53.2 (4.6)	53.2 (5.6)
Mandibular molar position (Mi/Olp) (mm), mean (SD)	53.3 (5.3)	57.3 (5.8)	55.8 (5.1)
Molar relationship (Ms/Olp-Mi/Olp) (mm), mean (SD)	−3.4 (2.5)	−4.1 (2.9)	−2.6 (2.4)
Overjet (Is/Olp-Ii/Olp) (mm), mean (SD)	3.7 (1.6)	3.1 (1.2)	3.9 (1.7)
Maxillary incisor position (Is/Olp) (mm), mean (SD)	83.4 (5.2)	86.3 (4.9)	85.5 (5.5)
Mandibular incisor position (Ii/Olp) (mm), mean (SD)	79.9 (5.0)	83.2 (4.9)	81.6 (5.1)
Mandibular incisor proclination (Ii/GoMe) (°), mean (SD)	103.8 (7.9)	100.5 (7.4)	103.2 (4.8)

For the changes after Herbst treatment, summary statistics and statistical analyses are reported in Tables III and IV.

1. Vertical dimension (SN/GoMe angle). The mandibular plane did not change during Herbst treatment in any group.
2. Skeletal class (AN/NPg angle). All groups showed a significant reduction in the AN/NPg angle: −2.4° (SD, 1.4; *t* test, $P < 0.001$) in the EC group, 1.2° (SD, 1.7; *t* test, $P = 0.005$) in the ML group, and −2.0° (SD, 2.0; *t* test, $P < 0.001$) in the SH group. These amounts were not statistically different in the comparison among the groups (ANOVA, $F_{2,57} = 2.2$; $P = 0.120$).
3. Maxillary bone base (A/Olp distance). All groups showed a limited reduction in the maxillary bone base distance. In the ML group (mean, −0.8 mm; SD, 1.8), it was marginally significant (*t* test, $P = 0.054$). However, the difference among groups was not significant (ANOVA, $F_{2,57} = 0.01$; $P = 0.992$).
4. Condylar position (Ar/Olp distance). Condyle distance from the vertical line Olp increased slightly after treatment in all groups without reaching significance in the groups and in the comparisons among the groups.
5. Mandibular bone base (Pg/Olp distance). All groups had an increase in mandibular bone base length. However, the positive change was significant in the EC group only, amounting to 2.8 mm (SD, 3.2; *t* test, $P = 0.001$), compared with 0.8 mm (SD, 3.3) in the ML group (*t* test, $P = 0.328$) and 0.3 mm (SD, 2.5) in the SH group (*t* test, $P = 0.591$). The comparison among the groups estimated a significant difference between the EC and SH groups (ANOVA, $F_{2,57} = 3.91$; $P = 0.026$; Bonferroni test, $P = 0.033$).
6. Skeletal discrepancy (A/Pg distance: A/Olp minus Pg/Olp). To estimate the change in the distance between Point A and pogonion—ie, the combined effect of the change in maxillary bone base and mandibular bone base—we generated the new variable skeletal discrepancy as the difference in the A/Olp and Pg/Olp distances.

   The skeletal discrepancy was reduced in all groups. The reductions were significant in the EC group (mean, −3.6; SD, 2.3; *t* test, $P < 0.001$) and the ML group (mean, −1.6; SD, 2.4; *t* test, $P = 0.009$), but not in the SH group (mean, −1.1; SD, 2.5; *t* test, $P = 0.072$). The comparison among groups was significant (ANOVA, $F_{2,57} = 6.04$, $P = 0.0042$). The reduction in the EC group was greater than in the ML group (Bonferroni test, $P = 0.035$) and the SH group (Bonferroni test, $P = 0.005$). The variation of the ML group was not different from that of the SH group (Bonferroni test, $P = 1.000$).
7. Maxillary molar (Ms/Olp distance) and mandibular molar (Mi/Olp distance) positions. The maxillary molars moved significantly back, and the mandibular molars moved significantly forward in all groups, with no differences among the groups (maxillary molar position, ANOVA, $F_{2,57} = 1.17$, $P = 0.317$; mandibular molar position, ANOVA, $F_{2,57} = 0.2$, $P = 0.821$).

   The maxillary molar position was reduced by −1.7 mm (SD, 2.7; *t* test, $P = 0.013$) in the EC group, by −1.2 mm (SD, 2.5; *t* test, $P = 0.046$) in the ML group, and by −2.5 mm (SD, 2.8; *t* test, $P = 0.001$) in the SH group.

   The mandibular molar position was increased by 3.5 mm (SD, 3.3; *t* test, $P < 0.001$) in the EC group, by 2.8 mm (SD, 4.2; *t* test, $P = 0.007$) in the ML group, and by 3.0 mm (SD, 2.6; *t* test, $P < 0.001$) in the SH group. As a consequence of

Table IV. Descriptive statistics (mean differences, standard deviations, and 95% confidence intervals) and statistical analyses (*t* test for repeated measures, 1-way ANOVA, and Bonferroni test) of the changes in cephalometric parameters of the 3 groups after treatment (T2 − T1)

	SH group (n = 20)			*EC group (n = 20)*			*ML group (n = 20)*			*Comparisons among groups*[*]		
	Mean (SD)	*95% CI*	P[†]	*Mean (SD)*	*95% CI*	P[†]	*Mean (SD)*	*95% CI*	P[†]	*F*	P	*Power (%)*
Vertical dimension (SN/GoMe) (°)[‡]	+0.5 (2.6)	−0.8 to 1.7	0.4493	−0.7 (2.3)	−1.8 to 0.4	0.185	−0.7 (2.3)	−1.7 to 0.4	0.199	1.51	0.229	65
Skeletal class (AN/NPg) (°)[‡]	−2.0 (2.0)	−2.9 to −1.0	0.0003	−2.4 (1.4)	−3.0 to −1.7	<0.001	−1.2 (1.7)	−2.0 to −0.4	0.005	2.2	0.120	90
Maxillary bone base (A/Olp) (mm)[§]	+0.8 (2.0)	−0.2 to 1.7	0.118	+0.8 (2.5)	−0.4 to 1.9	0.194	+0.8 (1.8)	0.0 to +1.7	0.054	0.01	0.992	5
Condilar position (Ar/Olp) (mm)[‡]	+0.5 (2.2)	−0.6 to 1.5	0.3793	+0.6 (2.3)	−0.5 to 1.7	0.267	+0.7 (2.3)	−0.4 to 1.8	0.180	0.06	0.941	69
Mandibular bone base (Pg/Olp) (mm)[‖]	+0.3 (2.5)	−0.8 to 1.4	0.591	+2.8 (3.2)	1.3 to 4.3	0.001	+0.8 (3.3)	−0.8 to 2.3	0.328	3.91	0.026[¶]	99
Skeletal discrepancy (A/Pg distance: A/Olp-Pg/Olp) (mm)[§]	+1.1 (2.5)	−0.1 to 2.2	0.072	+3.6 (2.3)	2.5 to 4.6	<0.001	+1.6 (2.4)	0.4 to 2.7	0.009	6.04	0.004[#]	100
Maxillary molar position (Ms/Olp) (mm)[**]	+2.5 (2.8)	1.1 to 3.8	0.0011	+1.7 (2.7)	0.4 to 2.9	0.013	+1.2 (2.5)	0.0 to 2.3	0.046	1.17	0.317	64
Mandibular molar position (Mi/Olp) (mm)[††]	+3.0 (2.6)	1.7 to 4.2	0.0001	+3.5 (3.3)	1.9 to 5.0	<0.001	+2.8 (4.2)	0.8 to 4.8	0.007	0.2	0.821	14
Molar relationship (Ms/Olp-Mi/Olp) (mm)[**]	+5.4 (2.8)	4.1 to 6.7	<0.001	+5.1 (3.1)	3.6 to 6.6	<0.001	+4.0 (3.1)	2.4 to 5.4	<0.001	1.36	0.264	67
Overjet (Is/Olp-Ii/Olp) (mm) [‡,‡‡]	+3.8 (2.4)	2.5 to 4.8	0.001	+2.7 (1.7)	1.9 to 3.4	<0.001	+3.7 (2.3)	2.6 to 4.8	<0.001	1.49	0.234	65
Maxillary incisor position (Is/Olp) (mm)[‡‡]	+0.8 (3.3)	−0.7 to 2.3	0.2876	−0.5 (2.8)	−1.8 to 0.8	0.440	+1.3 (2.1)	0.3 to 2.3	0.012	2.24	0.115	89
Mandibular incisor position (Ii/Olp) (mm)[§§]	+3.0 (2.6)	1.7 to 4.2	0.0001	+3.2 (2.8)	1.9 to 4.4	<0.001	+2.4 (2.6)	1.1 to 3.6	0.001	0.45	0.639	27
Mandibular incisor proclination (Ii/GoMe) (°)[‡]	+9.1 (5.0)	6.7 to 11.5	<0.001	+1.5 (5.6)	−1.1 to 4.1	0.248	+3.5 (4.2)	1.5 to 5.5	0.002	12.37	<0.001[‖‖]	100

The mathematical signs were changed to plus (+) or minus (−) for maxillary bone base, skeletal discrepancy, maxillary molar position, molar relationship, maxillary incisor position, and overjet for favorable (+) or unfavorable (−) changes in skeletal discrepancy, Class II molar relationship, and overjet.[23] Mandibular bone base, mandibular molar position, and mandibular incisor position mathematical signs were kept unchanged because they were consistent with overjet and Class II molar correction.

*One-way ANOVA; $F_{2,57}$; α level, *P* <0.05; [†]One-sample *t* test; α level, *P* <0.05; [‡]Plus (+) and minus (−) signs result from the mathematical differences between T2 and T1; [§]The mathematical signs of difference between T2 and T1 were modified as + or − signs in cases of favorable or unfavorable changes of overjet and Class II molar correction[23]; [‖]Plus (+) and minus (−) mathematical signs of differences between T2 and T1 indicate, respectively, favorable or unfavorable changes for overjet and Class II molar correction[23]; [¶]Bonferroni test: differences were significant between the EC and SH groups (*P* = 0.033); [#]Bonferroni test: differences were significant between the EC group and both the ML (*P* = 0.035) and the SH groups (*P* = 0.005); **The mathematical signs of differences between T2 and T1 were modified as + or–signs in cases of favorable or unfavorable changes for Class II molar correction[23]; [††]Plus (+) and minus (–) mathematical signs of differences between T2 and T1 indicate, respectively, favorable or unfavorable changes for Class II molar correction[23]; [‡‡]The mathematical signs of differences between T2 and T1 were modified as + or − signs in cases of favorable or unfavorable changes for overjet correction[23]; [§§]Plus (+) and minus (–) mathematical signs of differences between T2 and T1 indicate, respectively, favorable or unfavorable changes for overjet correction[23]; [‖‖]Bonferroni test: differences were significant between the EC and the SH groups (*P* <0.001) and between the ML and the SH groups (*P* = 0.003).

these changes, the molar relationship distance (Ms/Olp-Mi/Olp) showed a reduction in all 3 groups.

8. Overjet (Is/Olp-Ii/Olp distance). Overjet decreased similarly and significantly after treatment in all groups. However, although the changes in the groups were significant, the intergroup comparison was not (ANOVA, $F_{2,57}$, 1.49; $P = 0.234$). It was reduced by −2.7 mm (SD, 1.7; t test, $P < 0.001$) in the EC group, by −3.7 mm (SD, 2.3; t test, $P < 0.001$) in the ML group, and by −3.8 mm (SD, 2.4; t test, $P = 0.001$) in the SH group.
9. Maxillary incisor position (Is/Olp distance). Maxillary incisor position increased slightly but not significantly in the EC group (mean, 0.5; SD, 2.8; t test, $P = 0.440$) and decreased in the ML group (mean, −1.3; SD, 2.1; t test, $P = 0.012$). In the SH group, there was also a reduction but without statistical significance (mean, −0.8; SD, 3.3; t test, $P = 0.288$). The comparison among the group changes was not significant (ANOVA, $F_{2,57} = 2.24$, $P = 0.115$).
10. Mandibular incisor position (Ii/Olp distance) and proclination (Ii/GoMe angle). The mandibular incisor position is the distance between the Olp line and the Ii point and combines 2 distances, mandibular bone base length and mandibular incisor proclination. This distance increased in all 3 groups after treatment (EC group, mean, 3.2 mm, SD, 3.8; t test, $P < 0.001$; ML group, mean, 2.4 mm, SD, 2.6; t test, $P = 0.001$; SH group, mean 3.0 mm, SD, 2.6; t test, $P < 0.001$). The change was not different among the groups (ANOVA, $F_{2,57}$, 0.45; $P = 0.639$).

    When the mandibular incisor proclination was considered exclusively, only the ML and SH groups showed significant increases in incisor flaring (EC group, mean, 1.5°, SD, 5.6; t test, $P = 0.248$; ML group, mean, 3.5°, SD, 4.2; t test, $P = 0.002$; SH group, mean, 9.1°, SD, 5.0; t test, $P < 0.001$). The change reached significance in the comparison among groups (ANOVA, $F_{2,57} = 12.37$; $P < 0.001$). The EC group (Bonferroni test, $P < 0.001$) and the ML group (Bonferroni test, $P = 0.003$) had less incisive flaring than did the SH group. The difference between the EC and ML groups was not significant (Bonferroni test, $P = 0.618$).

When the descriptive statistics were evaluated, it was evident that the amounts of change in some variables showed wide standard deviations together with a small difference between the means. As a consequence of this and the small sample size, the statistics of these variables did not reach the recommended minimum level of 80% in power of the ANOVA (Table III). It is a matter of fact that the test was underpowered and inconclusive (type II error).

However, an adequate statistical power of the ANOVA was estimated for the variables of skeletal class, mandibular bone base, skeletal discrepancy, maxillary incisor position, and mandibular incisor proclination, which are also the meaningful variables with regard to the aim of this study.

DISCUSSION

Our results showed that all 3 Herbst treatments were effective in correcting Class II malocclusion, and a bilateral molar Class I was achieved in all patients. All Herbst treatments resulted in a significant decrease of overjet, with mesial movement of the mandibular molars and no variation of the maxillary bone base position. Also, in agreement with results from other studies, skeletal divergence was not affected by the treatment.[23,24]

However, in the comparison of the amounts of change in the 3 groups, miniscrew Herbst treatment with an elastic chain showed a greater skeletal effect and better control of mandibular incisor proclination. Only in this group did the mandibular bone base (Pg/OLp) advance significantly during treatment, although the net change was significantly different exclusively from that in the standard Herbst group. When the change in distance between Point A and pogonion—that is, skeletal discrepancy (the combined effect of changes in the maxillary and mandibular bone bases)—was considered, all groups showed a significant reduction, with the EC group reaching the highest reduction.

Due to the reduced overjet and the increased incisor proclination at T1 in the ML and EC groups if compared with the SH group, one could consider those patients as having a less severe Class II malocclusion. However, all patients had a retrusive chin, independent of the amount of overjet, where treatment with the Herbst is indicated.

The difference in overjet and incisor proclination at T1 could have been hypothesized as an obstacle toward mandibular advancement. Pancherz[8] reported: "For a maximal treatment response, it is suggested that the Herbst appliance be constructed with the mandible jumped anteriorly as much as possible, namely, to an incisal edge-to-edge position."

Consequently, patients treated with a Herbst anchored with miniscrews, who showed more proclined mandibular incisors and less overjet, allowing a reduced mandibular anterior bite jump, should have had less mandibular response. On the contrary, they showed a mandibular advancement more relevant than in patients with less pretreatment incisor flaring. It cannot be excluded that the anchorage control on the mandibular incisor guaranteed by the miniscrews combined with elastic chains preserved the overjet reduction, favoring the mandibular advancement.

In contrast, the change in skeletal class did not differ among the groups, possibly because of the inclusion of nasion as a cephalometric reference point.[25]

The combination of the acrylic splint Herbst and miniscrews allowed for significantly greater control of incisor proclination, compared with that achievable with the SH without miniscrews. Incisor flaring after treatment increased by 1.5° in the EC group, by 3.5° in the ML group, and by 9.0° in the SH group.

Nevertheless, the wide range of standard deviations, mainly in the EC group, could raise doubts about the effectiveness in the reduction of incisor flaring. The mean value was 1.5°, but the standard deviation actually amounted to 5.6°. Therefore, the incisors had a tendency to procline in this group as well. Despite this, the upper limit of the confidence interval in the EC group was the lowest, and it was 2.6° below the lower bound of the SH group without an overlap between the 2 confidence intervals. Moreover, it could be hypothesized that a stricter protocol about the replacement of the elastic chain (maximum of every 3 weeks and not 4 to 8 weeks) could reduce the loss of elasticity, making the anchorage control more effective. Studies have reported that for elastic chains, the greatest force decay occurs in the first hour, and the greater the initial force, the greater the force decay. Moreover, at the end of the third week, only about 50% of the force remains, and at the end of the sixth week, the remaining force is reduced to about a third.[26] However, a more recent study by Buchmann et al[27] showed that the loss of force depends only on the type of chain being tested, not on the initial activation; in that study, they tested, among others, American Orthodontics' elastic chain (Memory Chain), which was used in our study. It displayed superior characteristics compared with other chains in terms of loss of force: over 21 days, it lost about 40% of its force, with strains of both 50% and 100%. The force of elastic chains is affected by environmental factors such as temperature and beverages consumed,[28,29] and previously cited works were in-vitro studies that did not consider these variables. In this study, elastic chains were kept in place for about 30 to 60 days, depending on patient compliance; the initial force was 200 g. Even though it is almost impossible to determine, we can hypothesize that compliant patients had their elastic chains replaced when the remaining force was approximately 50% (100 g), and that noncompliant patients, in contrast, had their elastics changed when the remaining force was about a third (60 g).

Ideally, the force should be constant, such as that exerted by a nickel-titanium closed-coil spring; however, if placed in that position, a mandibular nickel-titanium closed-coil spring can embed in the attached tissues and be painful for patients, who may report ulcerations.

Luzi et al,[30] in their preliminary study, showed that the rational association of TADs with the Herbst appliance can optimize treatment efficiency and skeletal response by reducing excessive mandibular incisor proclination. Their sample, however, was too small for statistical analysis, and only metallic ligatures were used. Manni et al[21] reported similar results, also with only metallic ligatures.

There is no statistically demonstrated scientific evidence that skeletal response can be increased by controlling mandibular incisor flaring; however, clinical experience suggests that control of mandibular incisor proclination allows more space for the mandible to protrude.

In a recent study, von Bremen et al[19] concluded that the use of miniscrews with the Herbst appliance cannot be recommended routinely because of the small anchorage benefit compared with the additional expense. Their study, however, followed a different protocol: a Herbst/multibracket appliance was used, while in the literature it seems that the acrylic splint Herbst has better control of incisor flaring.[31] Also, they reported a miniscrew failure rate of 30%; in this study, the failure rate was 17.5%, in accordance with reports in the literature.[20] This may be explained by the difference in diameters and lengths of the screws, since those used in this protocol were longer. In contrast, the percentage of miniscrew failures was not a relevant clinical aspect; in most cases, the screw could be immediately reinserted in a nearby or different site. Thus, the use of elastic chains seems to influence the control of incisor flaring.

From our results, it was not possible to identify a causal effect between the control of mandibular incisor proclination and the increase in skeletal effects of the Herbst appliance. The small sample size did not allow us to run a linear regression to evaluate the association between the outcome of pogonion advancement and the exposures: in particular, the incisor proclination and the type of appliance. The analysis of the data showed only that the mandibular molars moved forward in all groups, and all patients had an overjet correction. In the groups with TADs, the skeletal effect was more relevant, and the loss of anchorage in incisive areas was lower than in the SH group. As a result, it could be hypothesized that the Herbst appliance without TADs had a dominant effect on alveolar bone and teeth. On the contrary, the Herbst appliance anchored with miniscrews induced mainly an orthopedic correction of skeletal Class II malocclusion. A stricter study protocol and a larger sample size are necessary for a more in-depth evaluation of the association and causality between the skeletal effects of the Herbst appliance and incisor flaring.

CONCLUSIONS

An acrylic splint Herbst appliance associated with miniscrews and ligated with an elastic chain, which can express an active force, allows for a greater skeletal effect than an acrylic splint Herbst without skeletal anchorage or anchored with TADs and metal ligatures.

It has been confirmed that skeletal anchorage with TADs reduces incisor flaring.

Further studies are needed to evaluate mandibular incisor proclination following fixed orthodontic treatment performed after Herbst treatment. Moreover, mechanics to prevent mandibular incisor proclination after Herbst treatment should be considered.

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