Thirty-two-year follow-up study of Herbst therapy: A biometric dental cast analysis

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Introduction: The aim of this study was to analyze the very long-term effects of Herbst treatment on tooth position and occlusion. **Subjects:** Fourteen patients from a sample of 22 with Class II Division 1 malocclusions consecutively treated with the banded Herbst appliance were reexamined 32 years after therapy. **Methods:** Dental casts were analyzed from before (T1) and after (T2) treatment, and at 6 years (T3) and 32 years (T4) after treatment. **Results:** Minor changes in maxillary and mandibular dental arch perimeters and arch widths were seen during treatment (T1-T2) and posttreatment (T2-T4). Mandibular incisor irregularity remained, on average, unchanged from T1 to T2 but increased continuously during the 32-year follow-up period (T2-T4). Class II molar and canine relationships were normalized in most patients from T1 to T2. During the early posttreatment period (T2-T3), there was a minor relapse; during the late posttreatment period (T3-T4), molar and canine relationships remained, on average, unchanged. Overjet and overbite were reduced to normal values in all subjects during treatment (T1-T2). After treatment (T2-T4), overjet remained, on average, unchanged, but overbite increased insignificantly. **Conclusions:** Thirty-two years after Herbst therapy, overall, acceptable long-term results were seen. Stability was found in 64% of the patients for sagittal molar relationships, in 14% for sagittal canine relationships, in 86% for overjet, and in 86% for overbite. A Class II relapse seemed to be caused by an unstable interdigitation of the occluding teeth, a persisting oral habit, or an insufficient retention regimen after treatment. Most posttreatment changes occurred during the first 6 years after treatment. After the age of 20 years, only minor changes were noted. Long-term posttreatment changes in maxillary and mandibular dental arch perimeters and widths as well as in mandibular incisor irregularity seemed to be independent of treatment and a result of physiologic dentoskeletal changes throughout adulthood. (Am J Orthod Dentofacial Orthop 2014;145:15-27)

The great potential of the Herbst appliance in the clinical management of Class II malocclusions has been documented in several investigations and summarized in the textbook of Pancherz and Ruf.¹ Corrections of the Class II dental arch relationship and overjet are mainly accomplished by anterior advancement of the mandible (stimulation of condylar growth), distal movement of the maxillary lateral teeth, and proclination of the mandibular incisors.² Overbite

reduction results from extrusion of the mandibular molars and intrusion of the mandibular incisors.³ The Herbst appliance cannot relieve mandibular crowding. Thus, in crowded Class II malocclusion cases, extractions of teeth (mostly the 4 premolars) must often be performed; after that, the Class II problem has been solved with the Herbst appliance. In previous articles on changes after Herbst therapy, the follow-up periods varied between 1 and 10 years, and they usually end in late adolescence or early adulthood,⁴⁻¹⁶ when growth-related dentoskeletal changes still can occur.^{17,18}

To date, there has been no long-term follow-up study after Herbst therapy in adolescent patients in which the follow-up period ends in the patients' middle life, when growth-related changes in tooth position and occlusion must be considered to be at a minimum or at an end.

Therefore, the aim of this very long-term follow-up investigation after Herbst treatment was to reexamine previous adolescent patients (age, 12-14 years) at least 30 years after treatment. The study was planned to comprise 3 parts: (1) a biometric analysis of dental casts,

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(2) a cephalometric radiographic analysis of lateral head films, and (3) a functional analysis of the masticatory system with special reference to the temporomandibular joint.

MATERIAL AND METHODS

The patients in this study were derived from a well-defined sample of 22 consecutive patients with Class II Division 1 malocclusion treated with the Herbst appliance at the University of Malmö in Lund, Sweden, in 1977 and 1978. These subjects were presented in 2 articles in 1982.^{2,3} However, in these articles, only cephalometric changes from before treatment to the end of active treatment were considered. Superimposed head-film tracings from every patient were shown.²

In 2011 and 2012, 30 to 33 years after Herbst therapy, these 22 subjects were recalled to the orthodontic department in Malmö for a follow-up investigation. At this time, they were 42 to 48 years of age. Two persons were deceased, and 6 did not come, for several reasons. Thus, the final follow-up sample comprised 14 subjects (12 men, 2 women) and is presented in detail in Table 1. Before Herbst treatment, 12 subjects had a bilateral distal molar relationship greater than 0.75 cusp width, and 2 had a 0.5 cusp-width distal molar relationship. All 14 subjects had a bilateral distal canine relationship greater than 0.75 cusp width. Overjets ranged from 6.5 to 13 mm, and overbites from 3 to 7.5 mm.

Treatment of all subjects was performed by an author (H.P.) using a banded-type Herbst appliance with a simple anchorage system.² Because of major tooth irregularities after Herbst therapy in 2 patients (patients 1X and 8X), extractions of 4 premolars were performed, and maxillary and mandibular multibracket appliances were placed for about a year. Furthermore, for tooth alignment in a nonextraction patient (patient 12), a maxillary multibracket appliance treatment phase was instituted for 6 months after the Herbst phase. In these 3 patients, multibracket treatment after the Herbst phase did not aim to affect the occlusion but only to align the teeth, after the Class II dental arch and overjet corrections were achieved by the Herbst appliance.

Dental casts in centric occlusion secured by a wax bite were analyzed at 4 occasions: T1, before Herbst treatment; T2, after treatment, about 12 months after the Herbst appliance was removed and the occlusion had settled (for the 2 extraction patients [1X and 8X], T2 implied that the dental casts were analyzed after removal of the multibracket appliance); T3, 6 years after treatment at an average age of 20 years when the radius epiphysis/diaphysis plate was closed (hand-wrist stage

R-J, according to Hägg and Taranger¹⁹); and T4, 32 years after treatment at an average age of 46 years.

The changes in tooth position and occlusion were analyzed during the following observation periods: T1-T2, treatment changes; T2-T3, early posttreatment changes; T3-T4, late posttreatment changes; and T2-T4, total posttreatment changes.

The dental casts from T1, T2, T3, and T4 were digitally photographed using a standard setup. The pictures were then evaluated with measurement analysis software (FACAD; Illexis AB, Linköping, Sweden). A millimeter ruler was included in the photographic setup and used for calibrating the photographic illustrations of the casts.

The biometric analysis comprised the following variables.^{20,21}

1. Arch perimeter: the maxillary and mandibular arch perimeters were measured sectionally with (a) the distance from the distal contact point of the second premolar (or deciduous second molar) to the mesial contact point of the first premolar (or deciduous first molar); (b) the distance from the mesial contact point of the first premolar (or deciduous first molar) to the distal contact point of the lateral incisor; and (c) the distance from the distal contact point of the lateral incisor to the midline point between the 2 central incisors. Arch perimeter was calculated as the sum of these 3 measurements.
2. Maxillary and mandibular arch widths: intermolar arch width is the distance between the mesiobuccal cusp tips of the first molars, and intercanine arch width is the distance between the cusp tips or estimated cusp tips in case of wear facets.
3. Mandibular incisor irregularity index: the linear displacement of the anatomic contact points of the mandibular incisors mesially to the canines according to the method of Little.²²
4. Sagittal dental arch relationships: molar and canine relationships of the left and right sides were recorded with the precision of half a cusp. Normal, mesial, or distal relationships were assessed. The results from the left and right sides were pooled and averaged.
5. Overjet: the distance from the incisal edge of the most labial maxillary incisor to the opposing mandibular central incisor was recorded with a steel ruler with a precision of 0.5 mm.
6. Overbite: the vertical overlap of the maxillary and mandibular incisors was measured with a steel ruler with a precision of 0.5 mm.

Maxillary and mandibular arch perimeters, intermolar and intercanine widths, and the mandibular incisor

Table I. Characteristics of 14 patients with Class II Division 1 malocclusion treated with the Herbst appliance and followed for 32 years after therapy

Patient	Sex	Treatment	Age (y)				Follow-up periods (y)			Retention	Treatment result
			T1	T2	T3	T4	T2-T3	T3-T4	T2-T4	Fixed (F) or removable (R)	Stable (S) or relapsed (R)
1X	Male	Herbst/extraction	13	17*	21	48	4	27	31	F/R (2 y)	S
2	Male	Herbst	13	14.5	20.5	48	6	27.5	33.5	No retention	S
3	Male	Herbst	11	12.5	19	45	6.5	26	32.5	No retention	S
4	Male	Herbst	13	14.5	20.5	47.5	6	27	33	R (4 y)	S
5	Male	Herbst	13.5	15	19	46.5	4	27.5	31.5	R (3 y)	R (partial)
6	Male	Herbst	13	14.5	20.5	47.5	6	27	33	No retention	R (total)
7	Female	Herbst	13	14.5	20.5	48	6	27.5	33.5	R (2 y)	S
8X	Male	Herbst/extraction	13	15	22	48	7	26	33	F/R (4 years)	S
9	Male	Herbst	12.5	14	20	45	6	25	31	R (2 y)	S
10	Male	Herbst	12	14	20	44	6	24	30	No retention	S
11	Female	Herbst	11	12.5	18.5	42.5	6	24	30	R (2 y)	S
12	Male	Herbst	12.5	14	21	46	7	25	32	F/R (3 y)	R (1 side)
13	Male	Herbst	12.5	14	21	45	7	24	31	R (2 y)	R (partial)
14	Male	Herbst	12.5	14	22	45	8	23	31	R (2 y)	R (1 side)
Summary/ Mean	12 men 2 women	12 Herbst 2 Herbst/extraction	12.5	14.3	20.4	46.1	6.1	25.7	31.8	4 no retention 10 retention	9 stable 5 relapsed

Patients 1X and 8X were treated with extractions. T1, Before treatment; T2, after treatment (12 months after the Herbst appliance was removed and the occlusion had settled); T3, 6 years after treatment; T4, 32 years after treatment.

*Includes a 2-year break in treatment during the period T1-T2.

irregularity index were measured by an observer (B.L.S.) using the FACAD analysis software. Sagittal molar and canine relationships as well as overjet and overbite were measured directly on the dental casts by another observer (K.H.).

Statistical analysis

The data generated from the FACAD program and the direct cast measurements were imported to the SPSS software package (version 20.0; IBM, Armonk, NY) for statistical analysis.

The arithmetic means and standard deviations were calculated. Paired *t* tests were performed to assess the statistical significance of changes during the different observation periods. The levels of significance used were $P < 0.001$, $P < 0.01$, and $P < 0.05$. $P \geq 0.05$ was considered not significant.

The error of the method, determined according to Dahlberg's formula,²³ was negligible for the assessment of sagittal molar and canine relationships. For the other variables, the errors ranged from 0.2 to 0.8 mm. The precision of the registrations was tested by double measurements of 10 randomly selected photos and dental casts.

The study was approved by the ethical committee at the University of Lund in Sweden (number 2012/44).

RESULTS

For each variable, the changes are shown graphically in Figures 1 through 7. The arithmetic means and

standard deviations at each time of examination as well as the statistical evaluations of changes during the different examination periods are given in Table II. Because treatment (T1-T2) changes for the variables of arch perimeter and arch width have been reported extensively in earlier Herbst studies, for these parameters in the discussion below, emphasis will be placed on the posttreatment (T2-T4) changes.^{20,21} However, for the mandibular incisor irregularity and occlusion variables, attention will be placed on both the treatment and posttreatment changes.

For the arch perimeter changes in the posttreatment period (T2-T4), we found the following. For the maxillary arch perimeter in the 14 subjects, except for an extraction patient (8X), the arch perimeter decreased continuously during both the early follow-up period of 6 years (T2-T3) (mean, 2.9 mm; $P < 0.05$) and the late follow-up period of 26 years (T3-T4) (mean, 1.5 mm; $P < 0.001$) (Table II; Fig 1, A). For the mandibular arch perimeter in the 14 subjects, the arch perimeter decreased during the early follow-up period of 6 years (mean, 2.5 mm; $P < 0.05$) and remained unchanged during the late follow-up period of 26 years (T3-T4) (Table II; Fig 1, B).

For the arch width changes in the posttreatment period (T2-T4), we found the following. For the maxillary intermolar arch width in the 14 subjects, arch width decreased during the early follow-up period of 6 years (T2-T3) (mean, 1.3 mm; $P < 0.05$) and increased insignificantly (mean, 0.5 mm) during the late follow-up

Fig 1. Assessments of arch perimeter change in 14 subjects treated with the Herbst appliance in graphs of 12 nonextraction and 2 extraction patients (1X and 8X): **A**, maxillary arch; **B**, mandibular arch. *T1*, Before treatment; *T2*, after treatment (12 months after the Herbst appliance was removed and the occlusion had settled); *T3*, 6 years after *T2* at an average age of 20 years; *T4*, 32 years after *T2* at an average age of 46 years.

Fig 2. Assessments of arch width change in 14 subjects treated with the Herbst appliance in graphs of 12 nonextraction and 2 extraction patients (1X and 8X): **A**, maxillary intermolar arch width; **B**, mandibular intermolar arch width. *T1*, Before treatment; *T2*, after treatment (12 months after the Herbst appliance was removed and the occlusion had settled); *T3*, 6 years after *T2* at an average age of 20 years; *T4*, 32 years after *T2* at an average age of 46 years.

period of 26 years (*T3-T4*) (Table II). In the 2 extraction subjects (1X and 8X), there were, for natural reasons, larger decreases in maxillary intermolar arch width than in the 12 nonextraction subjects (Fig 2, A).

For the mandibular intermolar arch width in the 14 subjects, arch width decreased during the early follow-up period of 6 years (mean, 1.0 mm; $P < 0.05$) and increased insignificantly (mean, 0.8 mm) during the late follow-up period of 26 years (*T3-T4*) (Table II). In 1 extraction subject (1X), there was a decrease in arch width during the first follow-up period (*T2-T3*), whereas it remained unchanged during the second follow-up period (*T3-T4*). In the other extraction subject

(8X), no change in intermolar arch width was seen in either follow-up period (Fig 2, B).

For maxillary intercanine arch width in the 14 subjects, there were insignificant changes, during both the early follow-up period of 6 years (*T2-T3*) and the late follow-up period of 26 years (*T2-T4*) (Table II). No difference existed between the 2 extraction and the 12 nonextraction subjects (Fig 3, A).

The mandibular intercanine arch width in the 14 subjects decreased during the early follow-up period (*T2-T3*) of 6 years (mean, 0.9 mm; $P < 0.05$) and the late follow-up period (*T3-T4*) of 26 years (mean, 0.5 mm) (Table II). No differences existed

Fig 3. Assessments of arch width changes in 14 subjects treated with the Herbst appliance in graphs of 12 nonextraction and 2 extraction patients (1X and 8X): **A**, maxillary intercanine arch width; **B**, mandibular intercanine arch width. *T1*, Before treatment; *T2*, after treatment (12 months after the Herbst appliance was removed and the occlusion had settled); *T3*, 6 years after *T2* at an average age of 20 years; *T4*, 32 years after *T2* at an average age of 46 years.

Fig 4. Assessments of mandibular incisor irregularity in 14 subjects treated with the Herbst appliance in graphs of 12 nonextraction and 2 extraction patients (1X and 8X). *T1*, Before treatment; *T2*, after treatment (12 months after the Herbst appliance was removed and the occlusion had settled); *T3*, 6 years after *T2* at an average age of 20 years; *T4*, 32 years after *T2* at an average age of 46 years.

between the 2 extraction and the 12 nonextraction patients (Fig 3, B).

We measured the mandibular incisor irregularity index for the treatment (T1-T2) and posttreatment (T2-T4) changes. For the 14 subjects, the irregularity index decreased insignificantly during the treatment and settling period of 19 months (mean, 0.5 mm) and increased continuously during the 2 follow-up periods T2-T3 (mean, 1.2 mm, not significant) and T3-T4 (mean, 0.8 mm; not significant). During the total follow-up period of 32 years (T2-T4), however, there

was a significant increase (mean, 2.0 mm; $P < 0.05$) in the mandibular incisor irregularity index (Table II). In 1 nonextraction subject (patient 2), incisor tooth irregularity increased more than in any other subject (Fig 4). There were no real differences between the 2 extraction subjects and the remaining 11 nonextraction subjects (Fig 4).

We measured the sagittal molar relationship for the treatment (T1-T2) and posttreatment (T2-T4) changes in the 14 subjects. The Class II sagittal molar relationship changed to a Class I relationship in all but 1 subject during the treatment and settling period of 19 months (T1-T2) (mean, 0.9 cusp width; $P < 0.001$) (Table II). The molar relationship rebounded minimally in the direction of a Class II relationship during the early follow-up period (T2-T3) of 6 years (mean, 0.2 cusp width; $P < 0.05$) and remained unchanged during the late follow-up period (T3-T4) of 26 years (Table II). During the total follow-up period (T2-T4) of 32 years, the molar relationship remained Class I in 9 subjects (64%) and rebounded partially (0.5 cusp width) in the direction of a Class II relationship in 5 subjects (Fig 5, A). From T1 to T4, there was an average improvement in the Class II molar relationship toward a Class I relationship of 0.7 cusp width (Table II).

We measured the sagittal canine relationship for the treatment (T1-T2) and posttreatment (T2-T4) changes in the 14 subjects. The sagittal Class II canine relationship changed to a Class I relationship in 6 subjects and improved by 0.5 cusp width in 8 subjects during the treatment and settling period of 19 months (T1-T2) (mean, 0.7 cusp width; $P < 0.001$). The canine relationship rebounded insignificantly in the direction

Fig 5. Assessments of sagittal relationship in 14 subjects treated with the Herbst appliance in graphs of 12 nonextraction and 2 extraction patients (1X and 8X): **A**, sagittal molar relationship; **B**, sagittal canine relationship. *T1*, Before treatment; *T2*, after treatment (12 months after the Herbst appliance was removed and the occlusion had settled); *T3*, 6 years after *T2* at an average age of 20 years; *T4*, 32 years after *T2* at an average age of 46 years.

Fig 6. Assessments of overjet in 14 subjects treated with the Herbst appliance in graphs of 12 nonextraction and 2 extraction patients (1X and 8X). *T1*, Before treatment; *T2*, after treatment (12 months after the Herbst appliance was removed and the occlusion had settled); *T3*, 6 years after *T2* at an average age of 20 years; *T4*, 32 years after *T2* at an average age of 46 years.

Fig 7. Assessments of overbite in 14 subjects treated with the Herbst appliance in graphs of 12 nonextraction and 2 extraction patients (1X and 8X). *T1*, Before treatment; *T2*, after treatment (12 months after the Herbst appliance was removed and the occlusion had settled); *T3*, 6 years after *T2* at an average age of 20 years; *T4*, 32 years after *T2* at an average age of 46 years.

of a Class II relationship (mean, 0.1 cusp width) during the early follow-up period (*T2-T3*) of 6 years and improved again to a Class I relationship (mean, 0.1 cusp width; not significant) during the late follow-up period (*T3-T4*) of 26 years (Table II). During the total follow-up period (*T2-T4*) of 32 years, the canine relationship remained Class I in 2 subjects (14%) and rebounded partially (0.5 cusp width) to a Class II in 12 subjects (86%) (Fig 5, B). From *T1* to *T4*, there was an average improvement in canine relationship toward a Class I relationship of 0.7 cusp width (Table II).

We measured overjet for treatment (*T1-T2*) and posttreatment (*T2-T4*) changes in the 14 subjects. Overjet was reduced in all subjects during the treatment and settling period of 19 months (*T1-T2*). The average reduction of overjet was 4.2 mm ($P < 0.001$) (Table II). During the total follow-up period (*T2-T4*) of 32 years, there was an insignificant rebound (0.3 mm) in overjet (Table II). Overjet increased by less than 1.5 mm in 5 subjects (36%), increased by 2.5 mm in 1 subject and by 4.0 mm in another (patient 6), and was stable

Table II. Dental cast measurements in 14 patients with Class II Division 1 malocclusions treated with the Herbst appliance and followed for 32 years after therapy, with registrations (mean, SD) at 4 examinations and statistical evaluations of changes (*t* test and *P* values)

Variable (mm or cusp width)	T1		T2		T3		T4		T1-T2		T2-T3		T3-T4		T2-T4	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	<i>t</i>	P	<i>t</i>	P	<i>t</i>	P	<i>t</i>	P
Maxillary arch perimeter	78.0	5.45	78.0	6.23	75.1	5.73	73.6	5.75	0.04	NS	2.95	<0.05	5.07	<0.001	4.15	<0.01
Mandibular arch perimeter	69.0	5.67	66.0	5.20	63.5	5.85	63.4	5.18	0.01	<0.05	2.67	<0.05	0.06	NS	1.47	NS
Maxillary intermolar width	50.3	1.85	52.1	3.09	50.8	3.06	51.3	3.26	-2.72	<0.05	2.61	<0.05	-1.33	NS	1.30	NS
Mandibular intermolar width	44.9	2.05	44.6	3.20	43.6	3.24	44.4	2.74	0.63	NS	2.87	<0.05	-1.01	NS	0.15	NS
Maxillary intercanine width	33.7	1.79	34.8	2.03	34.4	2.19	34.5	2.27	-2.07	NS	1.13	NS	-0.58	NS	0.69	NS
Mandibular intercanine width	26.6	2.80	26.0	2.03	25.1	2.12	24.6	2.26	1.12	NS	2.56	<0.05	2.14	NS	2.78	<0.05
Irregularity index	3.5	2.28	3.0	2.40	4.2	3.89	5.0	4.06	1.06	NS	-1.91	NS	-1.66	NS	-2.66	<0.05
Sagittal molar relationship*	+0.9	0.21	0.0	0.15	+0.2	0.30	+0.2	0.30	13.98	<0.001	-2.60	<0.05	0.43	NS	-3.05	<0.01
Sagittal canine relationship*	+0.9	0.15	+0.2	0.22	+0.3	0.24	+0.2	0.24	11.11	<0.001	-0.45	NS	0.37	NS	0.25	NS
Overjet	8.1	1.62	3.9	0.89	4.0	1.13	4.2	1.67	7.23	<0.001	-0.31	NS	-0.72	NS	-0.67	NS
Overbite	5.0	1.23	3.5	1.06	3.8	0.78	3.8	0.83	3.20	<0.01	-0.74	NS	-1.00	NS	-0.36	NS

T1, Before treatment; T2, after treatment (12 months after the Herbst appliance was removed and the occlusion had settled); T3, 6 years after treatment; T4, 32 years after treatment; NS, not significant.

*+ indicates distal (Class II) molar and canine relationships (in cusp width); 0 indicates neutral (Class I) molar relationship.

or further reduced in the remaining 7 subjects (50%) (Fig 6). Thus, an acceptable and stable long-term result in overjet was found in 86% of the subjects.

We measured overbite for treatment (T1-T2) and posttreatment (T2-T4) changes in the 14 subjects. Overbite was reduced in 11 subjects and remained unchanged in 3 subjects during the treatment and settling period of 19 months (T1-T2). The average reduction in overbite was 1.5 mm ($P < 0.01$). During the total follow-up period (T2-T4) of 32 years, there occurred an insignificant rebound (0.3 mm). Overbite increased by less than 1.0 mm in 5 subjects (36%), increased by 2 mm (patient 10) and by 3.0 mm (patient 8X) in 2 subjects, and was stable or further reduced in the remaining 7 subjects (50%) (Fig 7). Thus, an acceptable and stable long-term result in overbite was found in 86% of the subjects.

The dental casts of 4 representative subjects (patients 4, 8X, 10, and 13) are shown to demonstrate the very long-term effects of Herbst treatment on the dental arches and arch relationships (Figs 8-11).

DISCUSSION

When judging the treatment and posttreatment results in these patients, one must remember that in contrast to the cast splint Herbst appliance used today, all were treated with the simple banded design of the appliance used more than 30 years ago. However, clinical experience has shown that for Class II correction, the 2 types of appliances are equally efficient.¹

Two patients (1X and 8X) were treated with extractions of teeth after Herbst treatment, and a multibracket treatment phase was used for final tooth

alignment. The same was true for a nonextraction patient (12) in whom a maxillary multibracket appliance was used after the Herbst. In current orthodontic practice with the cast splint Herbst appliance, a multibracket phase after the Herbst is a general procedure for final tooth alignment in both non-extraction and extraction patients. Thus, in these patients, the multibracket treatment phase after the Herbst phase was not aimed to change the occlusion but only to align the teeth.

A hand-wrist radiographic stage R-J was present in all 14 patients at the age of 20 years (T3).¹⁹ This maturity stage, however, is not a reliable indicator of completed growth.^{17,18} On the other hand, it could be expected that after 20 years of age, changes in tooth position and occlusion during the late posttreatment period (T3-T4) were for the most part a result of the continuous physiologic processes throughout adulthood.²⁴⁻²⁹

The subjects in this investigation were derived from a sample of 22 consecutively treated Herbst patients (20 men, 2 women).^{1,2} At their recall, the attendance rate was 70%, which must be considered high because the follow-up period was long (30-33 years). When we looked closer at the 6 patients who did not attend (5 men, 1 woman), they did not differ from the attending ones with respect to patient characteristics, length of treatment, and immediate treatment results. Thus, the 14 subjects must be considered as an unbiased group for a reliable follow-up study.

The reason for using 1 year after removal of the Herbst appliance as the posttreatment (T2) measurement was that directly after removal of the appliance, the teeth are usually in a state of instability; the sagittal lateral

Fig 8. Patient 4: facial photographs and dental casts of a nonextraction Herbst patient with a stable long-term result. *T1*, Before Herbst treatment (age, 13 years). Note the full Class II malocclusion and the increased overjet and overbite; mandibular incisor irregularity was negligible. *T2*, After treatment (12 months after active treatment of 6 months when the occlusion had settled; age, 14.5 years). Note the Class I occlusion and the normalized overjet and overbite. Retention after *T2* was performed with an activator for 4 years. *T3*, Six years after *T2* (age, 20.5 years) and 2 years after retention. Note the stable Class I treatment result and the increase in mandibular incisor irregularity. *T4*, Thirty-three years after *T2* (age, 47.5 years). Note the stable long-term Class I treatment result. The mandibular incisor irregularity remained unchanged from *T3* to *T4*.

occlusion and overjet are overcorrected, and the vertical lateral occlusion has an open-bite tendency, with the incisors in an edge-to-edge position.^{7,21} During the first year (especially during the first 6 months) after treatment, the occlusion generally settles into a Class I relationship.^{7,21} This settling of the occluding teeth might occur spontaneously but will be favored by the use of a functional appliance (activator) for active retention.³⁰ Decisive for a successful long-term result of Herbst treatment seems to be, besides a sufficient time of retention, a firm Class I interdigitation of the teeth and no oral habits.^{5,6} In the 5 relapsed patients, however, there was no retention after treatment for 1 subject (6), and oral habits persisted in 4 subjects (5, 12, 13, and 14).

There were some arch perimeter changes during the Herbst treatment (*T1*-*T2*). The increase in maxillary arch perimeter in the 12 nonextraction subjects was certainly

due to the headgear effect of the Herbst appliance, distalizing the maxillary molars by the posterior directed push force of the telescopes.³¹ The reduction of mandibular arch perimeter, as seen in all 14 subjects, could be explained partly by the age-dependent normal growth processes in children,^{32,33} and by the telescoping push force, which in the mandible works on the dentition in a mesial direction.⁷ Due to space closure in the 2 extraction patients (1X and 8X), they had pronounced decreases in maxillary (Fig 1, A) and mandibular (Fig 1, B) arch perimeters.

The posttreatment changes included continuous decreases in the maxillary and mandibular arch perimeters during both the early follow-up period of 6 years (*T2*-*T3*) and the late follow-up period of 26 years (*T3*-*T4*); these were most likely the result of age-related physiologic processes.^{25,26,29}

There were some arch width changes during treatment (*T1*-*T2*). The increase in maxillary intermolar

Fig 9. Patient 8: facial photographs and dental casts of an extraction Herbst patient with a stable long-term result. *T1*, Before Herbst treatment (age, 13 years). Note the full Class II malocclusion and the large overjet and overbite, with mandibular incisor irregularity. *T2*, After Herbst treatment of 7 months, extraction of the 4 first premolars, and the multibracket appliance treatment phase of 17 months (age, 15 years). Note the Class I molar occlusion and the normalized overjet and overbite. Mandibular incisor irregularity was reduced by treatment. Retention after T2 with a maxillary Hawley plate and a mandibular fixed canine-to-canine retainer for 4 years. *T3*, Six years after T2 (age, 22 years), 2 years after retention. Note the stable Class I molar occlusion, the minor rebounds in overjet and overbite and the increase in mandibular incisor irregularity. *T4*, Thirty-three years after T2 (age, 48 years). Note the unchanged occlusion compared with T3. The mandibular incisor irregularity had increased from T3 to T4.

arch width in all nonextraction patients can for the most part be explained by normal growth processes in growing children at ages 12 to 14 years.³² However, a contributing factor could be the buccally directed force vector of the telescope mechanism that increased the intermolar distance.

In children, the mandibular intermolar arch width normally increases with age.³² In our subjects, however, both increases (9 subjects) and decreases (5 subjects) in mandibular molar width were found during the treatment period (T1-T2).

Maxillary intercanine arch width increased in 11 of the 12 nonextraction Herbst subjects from T1 to T2. This is in accordance with the normal growth changes.³² The decrease in intercanine width seen in the 2 extraction patients (1X and 8X) was thought to be a result of the

multibracket treatment phase after the Herbst therapy to close the extraction spaces and align the dental arches.

Concerning mandibular intercanine width, insignificant changes were recorded from T1 to T2. This is in accordance with the growth standards of Moyers et al,³² demonstrating unchanged average measurements after the age of 8 years.

There were posttreatment changes during the early follow-up period (T2-T3). Maxillary and mandibular molar arch widths decreased. For the maxilla, most likely, this was due to posttreatment rebound. The subsequent insignificant increase in the arch widths during the late follow-up period (T3-T4) was thought to be a result of age-related growth changes in adults.^{25,29}

Maxillary intercanine arch width in the 14 Herbst subjects did not change to any marked degree during

Fig 10. Patient 10: facial photographs and dental casts of a nonextraction Herbst patient without retention and a stable long-term result. *T1*, Before Herbst treatment (age, 12 years). Note the full Class II malocclusion and the increased overjet and overbite. Mandibular incisor irregularity was negligible. *T2*, After treatment (12 months after active treatment of 7 months when the occlusion had settled; age, 14 years). Note the Class I occlusion and the normalized overjet and overbite. Mandibular incisor irregularity remained negligible. No retention and no further treatment with a multibracket appliance was performed after *T2*. *T3*, Six years after *T2* (age, 20 years). Note the stable Class I treatment result and the increase in mandibular incisor irregularity. *T4*, Thirty years after *T2* (age, 44 years). Note the stable long-term Class I treatment result. The mandibular incisor irregularity had increased from *T3* to *T4*.

either follow-up period. This disagrees with the results of Harris²⁵ and Tsiopas et al,²⁹ who found decreases in arch width when screening untreated 20-year-old subjects over 35 to 40 years.

In agreement with the results of Harris²⁵ and Tsiopas et al,²⁹ mandibular intercanine arch widths decreased markedly over the 32-year follow-up period (*T2*-*T4*). This could result from the mesial drift of the permanent first molars (reflected by the reduction of the mandibular arch perimeter); this consequently leads to reduced space for the mandibular incisors and increased incisor irregularity.

However, the treatment and posttreatment changes in the maxillary and mandibular arch perimeters and arch widths (except for mandibular intercanine width) were of minor clinical importance.

There were treatment changes in the irregularity index. With the exception of patient 2, mandibular

irregularity had a tendency to be reduced during Herbst treatment (*T1*-*T2*). This can be explained by the fact that the mandibular incisors were proclined by the appliance, thus increasing the length of the anterior part of the dental arch and creating more space for the teeth.²¹ Opinions differ about the amount of stable proclination of the mandibular incisors that can be achieved during orthodontic treatment.^{34,35} The consensus of evidence supports the view, however, that excessive mandibular incisor proclination should be avoided unless lifelong retention is planned. In our 14 subjects, either no retention or short-term retention of 2 to 4 years was performed; this could have contributed to the posttreatment changes. However, deterioration in mandibular incisor alignment during the second, third, and fourth decades of life has been reported in several studies of untreated subjects, and in subjects with

Fig 11. Patient 13: facial photographs and dental casts of a nonextraction Herbst patient with a Class II relapse in the long term. *T1*, Before Herbst treatment (age, 12.5 years). Note the full Class II malocclusion and the increased overjet and overbite. Mandibular incisor irregularity was negligible. *T2*, After treatment (12 months after active treatment of 6 months when the occlusion had settled; age, 14 years). Note the Class I molar occlusion. The canine relationship was still Class II, and overjet was still somewhat increased. An increase in mandibular incisor irregularity was present. Retention after *T2* was performed with an activator for 2 years. *T3*, Six years after *T2* (age, 21 years), 4 years after retention. Note the Class II molar rebound of 0.5 cusp width, the increase in overjet, and the increase in mandibular incisor irregularity. The patient had a persisting tongue dysfunction habit. *T4*, Thirty-one years after *T2* (age, 45 years). Note the unchanged Class II occlusion in relation to *T3* and the increase in mandibular incisor irregularity.

previous orthodontic treatment followed by retention.^{36,37} Such changes are now recognized to be a normal rather than an exceptional occurrence throughout life.

After treatment of these subjects, there was a continuous increase in incisor irregularity during both posttreatment periods (*T2-T3* and *T3-T4*). This was most certainly due to the reduction in mandibular arch perimeter and mandibular intercanine width, especially during the first posttreatment period (Table II). The results agree with a previous 6-year follow-up Herbst study²¹ and with normal growth changes.²⁹ In patient 2, tooth irregularity increased to a large extent during the posttreatment period (*T2-T4*) (Fig 4). The patient was offered multibracket therapy with extractions of 4 premolars after the Herbst treatment, but he declined.

There were sagittal molar and canine occlusion, and overjet and overbite changes during treatment (*T1-T2*). In the 14 subjects, there was normalization of Class II molar relationships (all subjects) and canine relationships (6 subjects). Because the maxillary part of the Herbst anchorage system only included the teeth distal to the canines,² the posterior-directed force of the telescope mechanism on the maxillary lateral teeth and the headgear effect of the Herbst appliance did not include the canines.³² Furthermore, there were large reductions in overjet and overbite in all subjects. All the sagittal changes in occlusion were due to the skeletal and dental treatment effects of the Herbst appliance: mandibular growth was increased, the maxillary lateral teeth (distal to the canines) were moved posteriorly, and all mandibular teeth were moved anteriorly.^{2,7,38} The reduction of

overbite was most likely due to dental changes in the mandible: intrusion of the incisors and extrusion of the lateral teeth.² Comparable results were found in the Herbst study of Hansen et al.²¹

Of the posttreatment changes, except for the canine relationship, a minor rebound in the occlusal variables was found during the early follow-up period (T2-T3); after that (T3-T4), the posttreatment changes were negligible, and the treatment result was rather stable.²¹ The findings were in accordance with normal growth-related changes in adults.^{25-27,29} The extractions in patients 1X and 8X performed after the Herbst appliance was removed did not aim to affect the occlusion but only to align deteriorated teeth. Thus, for the long-term evaluations of the sagittal occlusion, overjet, and overbite, the extractions had minor importance.

CONCLUSIONS

Thirty-two years after therapy with a banded Herbst appliance in 14 consecutively treated patients with Class II Division 1 malocclusions, an overall acceptable long-term result was seen. Stability in the sagittal molar relationship was found in 64% of the subjects, stability in the sagittal canine relationship was found in 14%, stability in overjet was found in 86%, and stability in overbite was also found in 86%. A Class II relapse after treatment seemed to be caused by an unstable interdigitation of the occluding teeth, persistence of oral habits after treatment, or an inconsistent retention regimen. Most of the posttreatment changes occurred during the first 6 years after treatment. After the age of 20 years, however, only minor changes were noted. Long-term posttreatment changes in maxillary and mandibular dental arch perimeters and widths as well as in mandibular incisor irregularity seemed not to depend on treatment and to be a result of physiologic dentoskeletal changes throughout adulthood.

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