Long-term effects of Herbst treatment on the mandibular incisor segment: A cephalometric and biometric investigation

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The purpose of this study was to analyze mandibular incisor changes during and after Herbst treatment with respect to tooth inclination and anterior crowding. The sample consisted of 24 Class II, Division 1 subjects (15 boys and 9 girls) treated with the Herbst appliance. Dental casts and lateral head films from before and after treatment, 6 months after treatment and at the end of the growth period (at least 5 years after treatment) were analyzed. During treatment, the lower incisors were proclined (ILi/ML) an average of 10.8° and the incisal edge (Ii) moved anteriorly by 3.2 mm. The available space and the irregularity index in the lower anterior region were in general unaffected by therapy. During the first posttreatment period of 6 months, the lower incisor inclination (ILi/ML) recovered an average of 7.9° and the incisal edge (Ii) moved posteriorly by 2.5 mm. However, the available space was almost unchanged. During the second posttreatment period, i.e., from 6 months after treatment to the end of growth, the lower incisor inclination remained on average unchanged in relation to the mandibular plane (ILi/ML) but the teeth retroclined in relation to the nasion-sella line (ILi/NSL). The available space decreased (mean 0.8 mm, $p < 0.01$) and the irregularity index increased (mean 2.0 mm, $p < 0.01$). The correlation between changes in the ILi/NSL and in the NSL/ML angles was moderate ($r = -0.57$, $p < 0.01$), indicating that the reduction in the ILi/NSL angle was partly a result of anterior mandibular growth rotational changes. In conclusion, it can be said that the proclination of the lower front teeth during Herbst treatment did not result in incisor crowding after treatment. In a long-term perspective, the development of incisor crowding was thought to be associated with normal craniofacial growth changes. (Am J Orthod Dentofac Orthop 1997;112:92-103.)

The short- and long-term effects of Herbst appliance treatment[1,2] in consecutively treated patients with Class II, Division 1 malocclusions have been investigated in several studies.[3-9] Class II correction is generally accomplished within 6 to 8 months of treatment and is a result of skeletal and dental changes.[6] The lower incisors are subjected to extensive anterior movements during treatment[8] and recovering posterior movements during the immediate posttreatment period that resulted in a slightly anterior positioning of the teeth as a net effect.[8,10] In a short-term perspective, the movements of the incisors do not seem to cause lower anterior crowding.[10] In a long-term perspective however, the effect of Herbst treatment on the lower incisor segment has received less attention.[9,11] The purpose of this long-term follow-up study of patients treated with the Herbst appliance was to analyze the lower incisor segment with respect to (1) changes of the inclination of the teeth and (2) the possible development of anterior crowding.

SUBJECTS AND METHODS

The total sample of patients with Class II, Division 1 malocclusion who were treated with the Herbst appliance at the Department of Orthodontics, Faculty of Odontology, Lund University, Malmö, Sweden, between the years 1977 and 1990 comprised of 152 patients. Twenty-four patients (15 males and 9 females) fulfilling the following criteria were selected for this study:

- No permanent teeth extracted before or after Herbst treatment,
- Eruption of all permanent canines before treatment,
- Maximum anchorage[10] in the maxilla and in the mandible, incorporating all the teeth from first molar to first molar,

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Table I. Age and sex distribution of 24 Class II, Division 1 malocclusions treated with the Herbst appliance

	Age at start (years)	*Treatment period (years)*	*First posttreatment period (years)*	*Second posttreatment period (years)*	*Total observation period (years)*	*Age at follow-up (years)*
Males (N = 15)						
Mean	13.2	0.5	0.5	5.4	6.4	19.7
SD	1.3	0.1	0.0	0.8	0.8	0.9
Females (N = 9)						
Mean	12.7	0.6	0.5	5.6	6.7	19.4
SD	1.4	0.1	0.0	1.5	1.5	1.6
Total (N = 24)						
Mean	13.0	0.6	0.5	5.5	6.5	19.6
SD	1.3	0.1	0.0	1.1	1.1	1.2

- No retention (n = 7) or retention with activators and canine-to-canine retainers (n = 17),
- All subjects out of retention for at least 3 years before the final examination,
- An observation period of at least 5 years after treatment,
- Growth completed at the end of the follow-up period.[11,12]

The age and sex distribution of the patients are shown in Table I.

Lateral head films and dental casts were analyzed in habitual occlusion. Registrations were performed before treatment, after treatment, 6 months after treatment, and at follow-up when growth was completed (at least 5 years after treatment). Tooth inclination and available space changes were analyzed during the following observation periods:

- Treatment period (T): From before to after treatment.
- First posttreatment period (P1): From after treatment to 6 months after treatment.
- Second posttreatment period (P2): From 6 months after treatment to end of growth.
- Total observation period (O): From before treatment to end of growth.

Analysis of the Lateral Head Films

In the analysis of the head films, the registration landmarks were marked directly on the radiographs with a well-sharpened All-stabilo pencil (Schwan-Stabilo, Germany). The radiographs and tracings were digitized with a Scriptel RDT digitizer (Scriptel Corporation), and the measurements and calculations were made by a computer. No corrections were made for linear enlargement (approximately 7%). To assess treatment and posttreatment changes, the various posttreatment head films were superimposed on the before treatment film, using stable skull structures in the anterior cranial base for orientation.[13]

An analysis of sagittal skeletal and dental changes was performed according to the method of Pancherz.[6] The occlusal line (OL) and the occlusal line perpendicular (OLp) through sella (s) were used as a reference grid (Fig. 1). The nasion (n) sella (s) line (NSL) and the reference grid from the first radiograph were transferred to the following radiographs after superimposition of the head films.

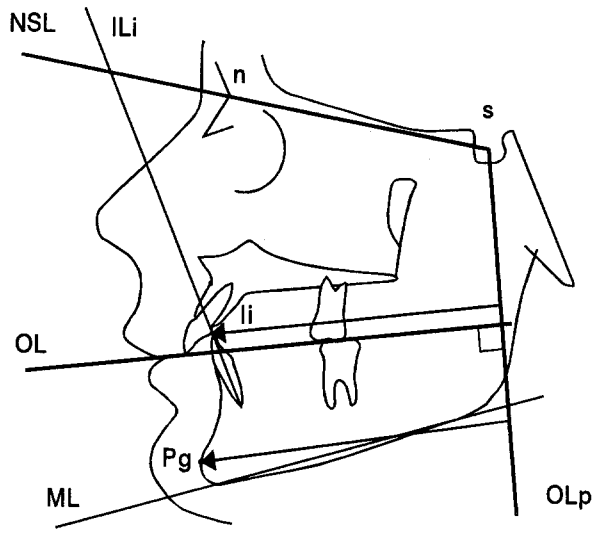

Fig. 1. Measuring points used in cephalometric analysis. Nasion-sella line (*NSL*) and reference grid (*OL* and *OLp*) are shown.

The cephalometric analysis comprised the following variables (Fig. 1) as defined by Björk[14] and Pancherz.[6]

Angular measurements

- NSL/ML: Inclination of the mandible in relation to the cranial base (mandibular plane angle).
- ILi/NSL: Inclination of the lower incisors in relation to the cranial base.
- ILi/ML: Inclination of the lower incisors in relation to the mandibular plane.

Linear measurement

- Pg-Ii: Position of the mandibular central incisor in relation to the mandibular base (Pg-OLp minus

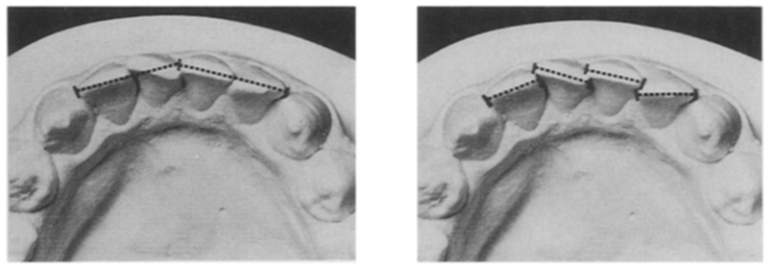

Fig. 2. Lower anterior available space evaluation: dental arch length (left) minus sum of mesiodistal crown width of four lower incisors (right).

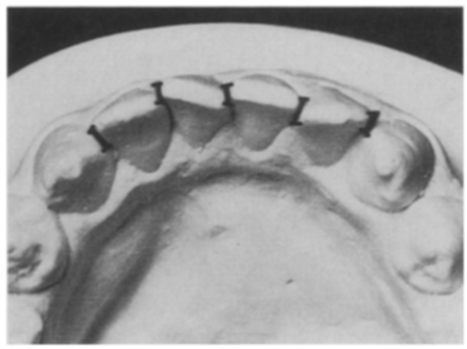

Fig. 3. Lower anterior irregularity index evaluation: sum of displacement of anatomic contact points of each mandibular incisor.

Ii-OLp; Pg-OLp: Position of the mandibular jaw base; Ii-OLp: Position of the mandibular central incisor).

Analysis of the Dental Casts

The biometric analysis comprised the following variables:

- **Lower anterior available space** (Fig. 2): The distance along the dental arch between the mesial surface of the mandibular canines[15] minus the sum of the mesiodistal widths of the lower incisors. The measurements along the dental arch were made sectionally to reduce the errors that exist with direct measurement of a curved section of the dental arch.[16] A negative value indicates lack of space (crowding) and a positive value indicates excess of available space (spacing).
- **Lower anterior irregularity index** (Fig. 3): The degree of lower incisor irregularity was evaluated by measuring the linear displacement of the anatomic contact points of the mandibular incisors mesially to the canines, according to the method of Little.[17]

The measurements for the available space and the anterior irregularity index were performed with a sliding calliper, equipped with a vernier scale to a level of precision of 0.1 mm.

All measurements on the lateral radiographs and dental casts were performed twice by one observer (T.K.). The mean values of the two measurements were used in the analysis.

Statistical Methods

The arithmetic mean (M) and standard deviation (SD) for each variable were calculated. For the total sample, t tests for paired samples were performed to assess the statistical significance of changes occurring during the different observation periods. To assess differences between gender, t tests for independent samples were used. The associations between variables were evaluated with the Pearson's correlation coefficient (r). A stepwise multiple regression analysis was performed to look for cephalometric variables associated with changes in available space during the second posttreatment period.

The levels of significance used were $p < 0.001$ (***), $p < 0.01$ (**), and $p < 0.05$ (*). The $p > 0.05$ was considered not significant (NS).

The differences between the first and second measurements, for the various variables, were evaluated by calculating the standard deviation of a single measurement[18]

$$S = \pm \sqrt{(\Sigma d^2/2n)}$$

where d is the difference between two registrations of a pair and n is the number of double registrations). The results are presented in Table II.

RESULTS

Standard cephalometric measures and the variables investigated are shown in Table III.

Treatment Period (T)

During the treatment period the lower incisors (ILi/ML) proclined on average 10.8° (Fig. 4, Table IV) and Ii moved 3.3 mm anteriorly in relation to Pg (Table IV). The mandibular plane angle (NSL/ML) increased 0.4° (NS) on the average. As a result of the mandibular incisor proclination, the arch length became longer, the available space increased from

Table II. Evaluation of the differences between the first and second measurement

Variable	Before S	After S	6-months S	Follow-up S
NSL/ML (degrees)	0.6	0.6	0.6	0.8
ILi/NSL (degrees)	1.3	1.2	1.7	1.3
ILi/ML (degrees)	1.4	1.2	1.6	1.0
Pg-Ii (mm)	0.5	0.4	0.5	0.7
Irregularity index (mm)	0.5	0.4	0.4	0.6
Available space (mm)	0.2	0.2	0.2	0.2

S = standard deviation of a single measurement.

Table III. Cephalometric records of 24 patients (13 males and 15 females) treated with the Herbst appliance

	Before		After		6 months		Follow-up	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Angular								
SNA	81.7	3.7	81.1	3.7	81.4	3.6	80.8	3.8
SNB	76.5	3.2	77.8	3.2	77.7	3.3	77.9	3.2
ANB	5.2	1.5	3.4	1.9	3.7	1.7	3.0	1.5
NSL/NL	7.6	3.0	8.2	2.9	8.2	2.8	8.3	2.5
NSL/ML	32.0	5.4	32.4	5.4	32.0	5.4	29.8	5.2
NL/ML	24.4	4.5	24.2	4.2	23.8	4.1	21.4	4.2
ILs/NL	112.4	6.5	105.8	5.9	108.2	4.8	110.0	6.0
ILi/NSL	49.4	7.3	38.1	5.9	46.5	6.7	49.0	6.6
ILi/ML	98.6	7.6	109.4	6.2	101.6	7.3	101.2	7.3
ILs/ILi	124.6	8.2	120.5	7.3	126.5	7.6	127.3	9.1
Linear								
A-OLp (mm) Maxillary base	78.4	3.7	78.5	3.9	79.3	3.9	80.5	4.0
Pg-OLp (mm) Mandibular base	81.1	3.9	84.2	4.3	84.4	4.2	87.4	5.1
Pg-Ii (mm)	1.0	3.4	−2.2	3.3	0.3	3.5	2.0	3.7
Ii-APg (mm)	0.7	2.4	5.6	2.3	2.9	2.3	2.4	2.7

−0.3 mm to 0 mm (Table V) and the irregularity index decreased from 3.5 to 2.8 (Table V).

First Posttreatment Period (P1)

During the first posttreatment period, the mandibular incisors (ILi/ML) recovered by an average of 7.9° (Fig. 4, Table IV) and Ii moved 2.5 mm posteriorly in relation to Pg. The mandibular plane angle decreased by an average of 0.4° ($p < 0.05$). The available space was almost unchanged (Table VI) and the irregularity index continued to decrease (from 2.8 to 2.4, NS; Table V).

Second Posttreatment Period (P2)

The changes that occurred during the period from 6 months after treatment to the time of follow-up, when growth was completed, are shown in Fig. 4, Tables IV and VI. The mandibular incisors remained on average almost unchanged when measuring tooth inclination to the mandibular plane (ILi/ML; Table IV), but the teeth retroclined by an average of 2.5° ($p < 0.01$) in relation to the nasion-sella line (ILi/NSL). The mandibular plane angle decreased significantly by 2.3° ($p < 0.001$) and there was a statistically significant correlation ($r = 0.57$, $p < 0.01$) between the decrease in the mandibular plane angle and the retroclination of the mandibular incisors, when measured to the nasion-sella line (ILi/NSL).

In relation to pogonion (Pg), the lower incisors moved posteriorly an average of 1.7 mm ($p < 0.001$). There was a significant correlation ($r = 0.56$, $p < 0.01$) between the changes of the mandibular incisor position (Pg-Ii) and the decrease in the mandibular plane angle.

The available space decreased during this period by 0.8 mm ($p < 0.001$) and the irregularity index increased by 2.0 ($p < 0.001$). A statistically significant

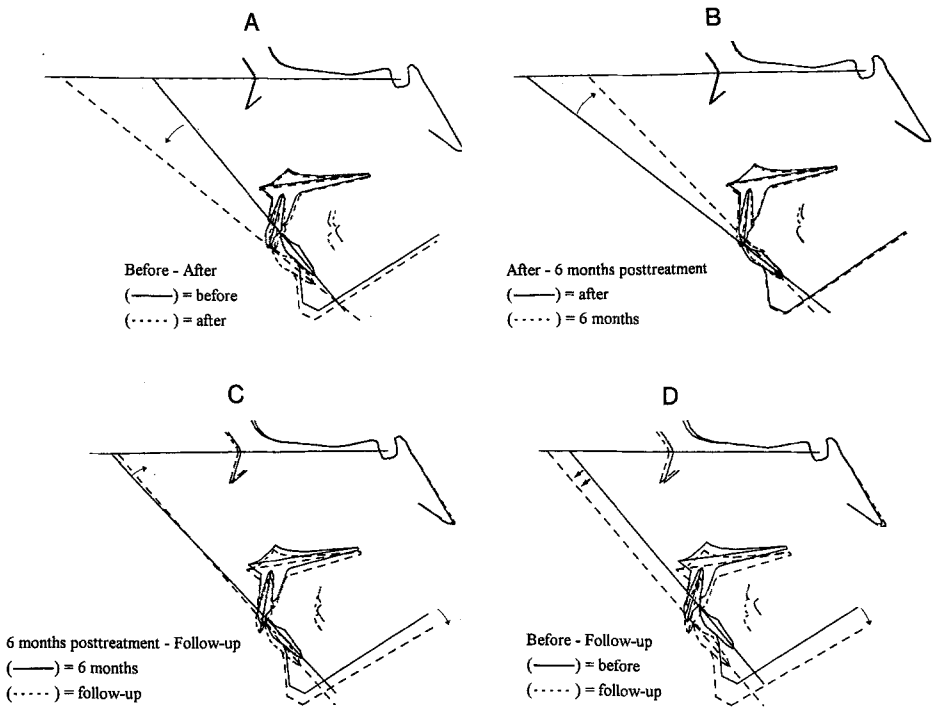

Fig. 4. A through **D**. Composite tracings of 24 (15 males and 9 females) Class II, Division 1 malocclusions treated with Herbst appliance.

Table IV. Changes in the cephalometric variables occurring during the four observation periods

	Treatment		*First posttreatment*		*Second posttreatment*		*Total*	
	Mean	*SD*	*Mean*	*SD*	*Mean*	*SD*	*Mean*	*SD*
NSL/ML								
Female (9)	1.0 *	1.1	−0.8	0.6	−2.0	1.7	−1.9	1.0
Male (15)	0.0	0.9	−0.1	0.9	−2.4	1.7	−2.5	1.9
Total (24)	0.4	1.1	−0.4*	0.8	−2.3***	1.7	−2.2***	1.6
ILi/NSL								
Female (9)	−10.9	3.2	7.6	3.3	2.3	5.1	−0.9	4.7
Male (15)	−11.5	5.0	8.9	3.9	2.6	3.5	−0.1	4.5
Total (24)	−11.3***	4.3	8.4***	3.6	2.5**	4.1	−0.4	4.5
ILi/ML								
Female (9)	9.9	3.8	−6.7	3.3	−0.2	4.1	3.0	4.7
Male (15)	11.4	4.6	−8.5	3.8	−0.4	2.9	2.4	4.5
Total (24)	10.8***	4.3	−7.9***	3.7	−0.3	3.3	2.6**	4.5
Pg-Ii								
Female (9)	−3.3	0.8	2.1	1.4	1.5	2.0	0.4	1.5
Male (15)	−3.2	1.6	2.7	1.3	1.8	1.7	1.3	1.8
Total (24)	−3.2***	1.3	2.5***	1.3	1.7***	1.8	0.9*	1.8

*Significant changes or differences between males and females at the level of 0.05.
**Significant changes or differences between males and females at the level of 0.01.
***Significant changes or differences between males and females at the level of 0.001.

correlation ($r = -0.50$, $p < 0.01$) was found between changes in irregularity index and available space.

Of all cephalometric variables (Table III), the increase in the distance A-OLp coincided most ($r = 0.69$) with the changes of the available space (Table VII).

Total Observation Period (O)

The changes that occurred during the period from before treatment to the end of growth are shown in Fig. 4 and in Table IV. The net effect on the mandibular incisors was a proclination in rela-

Table V. Mean and standard deviation of dental cast records at the four stages of examinations

	Before		After		6 months		Follow-up	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Irregularity Index								
Female (9)	2.8	1.4	2.2	1.5	2.4	1.7	4.2	1.7
Male (15)	3.8	1.3	3.3	1.5	2.4	1.0	4.5	2.4
Total (24)	3.5	1.4	2.8	1.5	2.4	1.3	4.4	2.1
Available space								
Female (9)	−0.5	0.6	−0.5 *	0.6	−0.2	1.0	−0.9	0.8
Male (15)	−0.2	1.2	0.3	1.0	0.0	0.6	−0.9	0.9
Total (24)	−0.3	1.0	0.0	0.9	−0.1	0.7	−0.9	0.8

*Significant differences between males and females at the level of 0.05.

Table VI. Changes in the dental cast measurements occurring during the four observation periods

	Treatment		First posttreatment		Second posttreatment		Total	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Irregularity Index								
Female (9)	−0.7	0.5	0.2	1.7	1.8	1.5	1.4	1.6
Male (15)	−0.6	1.9	−0.8	1.6	2.1	2.5	0.7	2.9
Total (24)	−0.6	1.5	−0.4	1.7	2.0***	2.1	0.9	2.5
Available space								
Female (9)	−0.1 *	0.4	0.3	0.9	−0.7	0.7	−0.5	0.5
Male (15)	0.5	0.8	−0.3	0.8	−0.9	0.8	−0.7	1.1
Total (24)	0.3	0.8	−0.1	0.8	−0.8***	0.8	−0.6**	0.9

*Significant changes or differences between males and females at the level of 0.05.
**Significant changes or differences between males and females at the level of 0.01.
***Significant changes or differences between males and females at the level of 0.001.

tion to the mandibular plane (ILi/ML) by an average of 2.6° ($p < 0.01$). However, in relation to the nasion-sella line (ILi/NSL) the incisors remained almost unchanged (Table IV). The incisal edge of the lower incisors, on the other hand, moved posteriorly by 0.9 mm ($p < 0.05$) in relation to Pogonion (Pg-Ii). During the period, the mandibular plane angle decreased in the total sample by 2.2° ($p < 0.001$).

The available space decreased by an average of 0.6 mm ($p < 0.01$; Table VI) and the irregularity index increased by 0.9 mm (NS; Table VI).

DISCUSSION

The irregularity index measures only irregularity. When the axial inclination of the anterior teeth diverges or when teeth are displaced, but do not overlap, the irregularity index does not give any information whether there is an adequate space to permit tooth alignment. In these instances, the available space analysis gives better information about the amount of space available for alignment. On the other hand, the available space analysis does not consider axiversions of the anterior teeth. So the two methods measure complementary aspects of "crowding" in the lower anterior segment.

Table VII. Variables from the stepwise multiple regression analysis that were associated with changes in available space during the second posttreatment period

	r	r^2
A-OLp	0.69	0.47
ILs/NSL	0.33	0.11
Total		0.58

Treatment Period (T)

The lower incisors moved extensively during Herbst treatment, due to difficulties in anchorage control.[10]

The irregularity index decreased insignificantly during treatment in the total sample. However, the index value was higher than reported by Glenn et al.[19] and Little et al.[20] This could be explained by the larger proclination of the lower incisors, due to anchorage loss, that could cause spacing in some

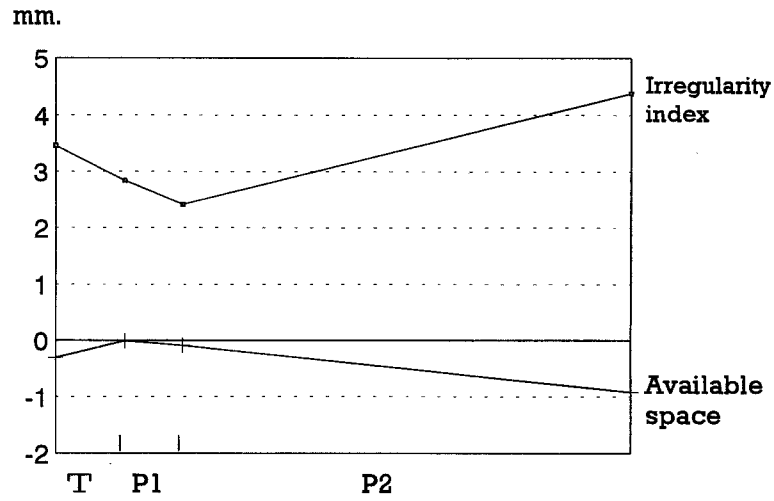

Fig. 5. Diagram showing changes in irregularity index and available space at three observation periods: *T* = treatment period, *P1* = 1st posttreatment period, and *P2* = 2nd posttreatment period.

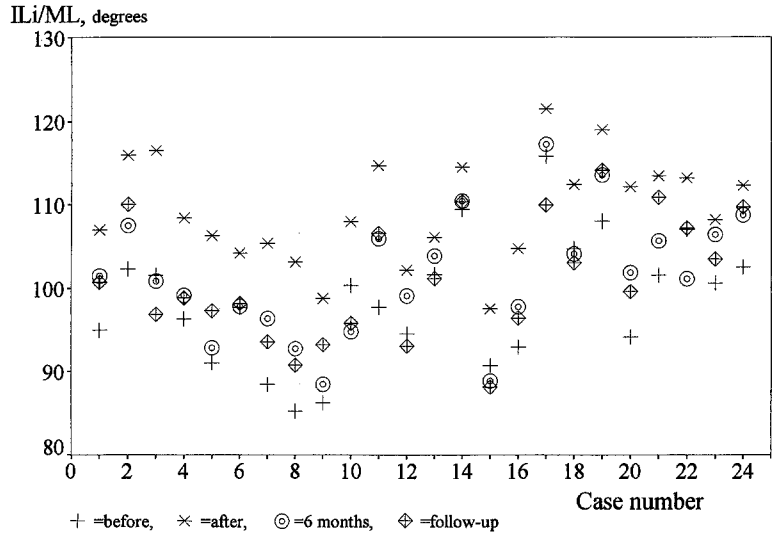

Fig. 6. Diagram showing individual values of ILi/ML angle at four stages of examination. Cases 1 to 24.

cases and thus lead to a higher irregularity index value (the irregularity index is defined as the distance between contact points irrespective whether the teeth are in contact or not, i.e., spacing is registered as an "irregularity"). In the available space analysis, it was evident that minor spacing occurred during treatment, especially in the male sample (Table V, Fig. 5). In the female sample, however, the available space was unchanged during treatment and remained negative (−0.5 mm, SD 0.6) after treatment. This finding was not expected, because the lower incisors were controlled by sectional arches.

First Posttreatment Period (P1)

Orthodontically moved teeth tend to return to their original position and angulation after treatment.[21-24] In the current study, the lower incisors

Table VIII. Associations between the changes in the cephalometric variables during the 4 observation periods

	NSL/ML r	*ILi/NSL* r	*ILi/ML* r	*PG/Ii* r
NSL/ML				
T		−0.12	−0.13	−0.12
P1		0.00	−0.20	−0.23
P2		−0.57 (**)	0.23	−0.56 (**)
O		−0.17	−0.18	−0.32
ILi/NSL				
T	−0.12		−0.97 (***)	0.81 (***)
P1	0.00		−0.97 (***)	0.80 (***)
P2	−0.57 (**)		−0.92 (***)	0.88 (***)
O	−0.17		−0.93 (***)	0.78 (***)
ILi/ML				
T	−0.13	−0.97 (***)		−0.78 (***)
P1	−0.20	−0.97 (***)		−0.73 (***)
P2	0.23	−0.92 (***)		−0.81 (***)
O	−0.18	−0.93 (***)		−0.66 (***)
PG-Ii				
T	−0.12	0.81 (***)	−0.78 (***)	
P1	−0.23	0.80 (***)	−0.73 (***)	
P2	−0.56 (**)	0.88 (***)	−0.81 (***)	
O	−0.32	0.78 (***)	−0.66 (***)	

*Significant association at 0.05 level.
**Significant association at 0.01 level.
***Significant asociation at 0.001 level.
r = Pearson's correlation coefficient, *T* = treatment period, *P1* = first posttreatment period, *P2* = second posttreatment period, and *O* = total observation period.

recovered after Herbst treatment, although a net increase of an average of 3° of proclination still remained 6 months after treatment.

Changes in available space were small during the first posttreatment period, even if the irregularity index decreased slightly (Table VI). In the male sample, the available space decreased from 0.3 to 0 mm (elimination of spacing), and in the female sample, it decreased from −0.5 to −0.2. These changes explained the decrease in irregularity index at least for the male group (Table VI).

Second Posttreatment Period (P2)

During this period, which covered the changes from 6 months after treatment to the end of the growth period, the lower incisor inclination seemed to remained unchanged in relation to the mandibular plane (ILi/ML) (Table IV), but increased significantly (increase = retroclination) in relation to the nasion-sella line (Table IV). However, the individual variation was large (Fig. 6). The changes of the ILi/ML and ILi/NSL angles ranged from −7.3° to 6.1° and −5.1° to 11.0°, respectively, and the association between these angles was by natural reasons high ($r = 0.92$, $p < 0.001$; Table VIII). The difference between the ILi/ML and ILi/NSL angles is of course the changes in the mandibular plane angle (NSL/ML). The associations between the changes in the incisor inclination and in the mandibular plane angle indicated, however, that the lower incisors did not procline in relation to the mandibular plane to compensate for the rotation of the mandible (ILi/ML − NSL/ML, $r = 0.23$, NS; Table VIII) as suggested by Björk and Skieller.[24] Instead the lower incisors, on average, retroclined in relation to the NSL line (ILi/NSL − NSL/ML, $r = -0.57, p > 0.01$) as a result of the mandibular rotation.

Table IX. Associations between the changes in the dental cast measurements during the 4 observation periods

	Irregularity Index r
Available space	
T	0.02
P1	−0.01
P2	−0.50 (**)
O	−0.37

**Significant association at 0.01 level.
r = Pearson's correlation coefficient, *T* = treatment period, *P1* = first posttreatment period, *P2* = second posttreatment period, and *O* = total observation period.

The distance Pg-Ii increased during the examination period. This finding could also be explained by the anterior mandibular rotation. As the incisor

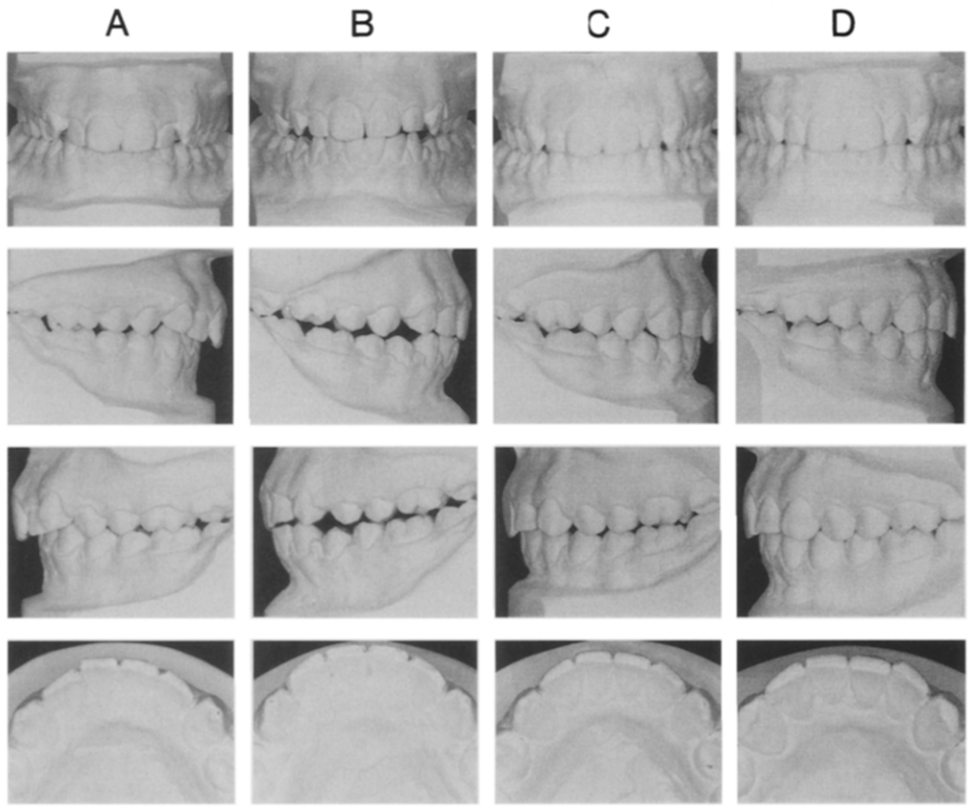

Fig. 7. Case 1: Female Herbst patient at age of 13.9 years before treatment. **A.** Before treatment: 4.3 overjet, 5.0 overbite,1.8 Irregularity Index, −0.1 available space. **B.** After treatment: 1.0 overjet, 0.5 overbite, 0.5 Irregularity Index, −0.2 available space. **C.** 6 months after treatment: 2.0 overjet, 3.0 overbite,1.8 Irregularity Index, −0.8 available space. **D.** 5.1 years after treatment: 2.5 overjet, 4.0 overbite, 2.0 Irregularity Index, −0.9 available space.

inclination was unchanged in relation to the ML line, the incisal edge would move less forward than Pg during an anterior mandibular rotation.

During the second posttreatment period, the irregularity index had increased significantly in both the male and the female samples (Table VI, Fig. 5). However, in four subjects (17%), a decrease was found. In one case, the index remained unchanged and in the rest of the cases (19 cases, 79%), the index increase ranged from 0.3 to 7 mm. The average irregularity index registered at the end of the follow-up period (4.4 mm; Table V) could, according to Little,[17] be described as moderate. Studies with higher and lower values for the mean irregularity index have been reported regarding stability of the mandibular incisor segment after orthodontic treatment.[19,20,25,26]

The changes in available space (Fig. 5) ranged from +0.2 to −0.5 mm in 10 cases (42%) and from −0.6 to −2.2 mm in 14 cases (58%). The mean value for the available space recorded at the end of the follow-up period was −0.9 mm (Table V). A moderate correlation was found between increase in lower anterior irregularity index and decrease in available space ($r = -0.50$, $p < 0.01$; Table IX).

The multiple regression analysis used to analyze the associations between changes in the available space and in the cephalometric variables (Table VII) showed an association between a decrease in available space and increased sagittal maxillary growth. The reason why maxillary growth was more highly correlated ($r = -0.69$, $p < 0.001$) than mandibular growth ($r = -0.55$, $p < 0.01$) might be that maxillary growth is more linear than mandibular growth (mandibular growth has an rotational component as expressed by changes in the NSL/ML angle). Late mandibular growth and complex growth patterns (mandibular growth exceeding maxillary growth) have been discussed in relation to lower arch crowding.[27] Richardson[28] found a weak but

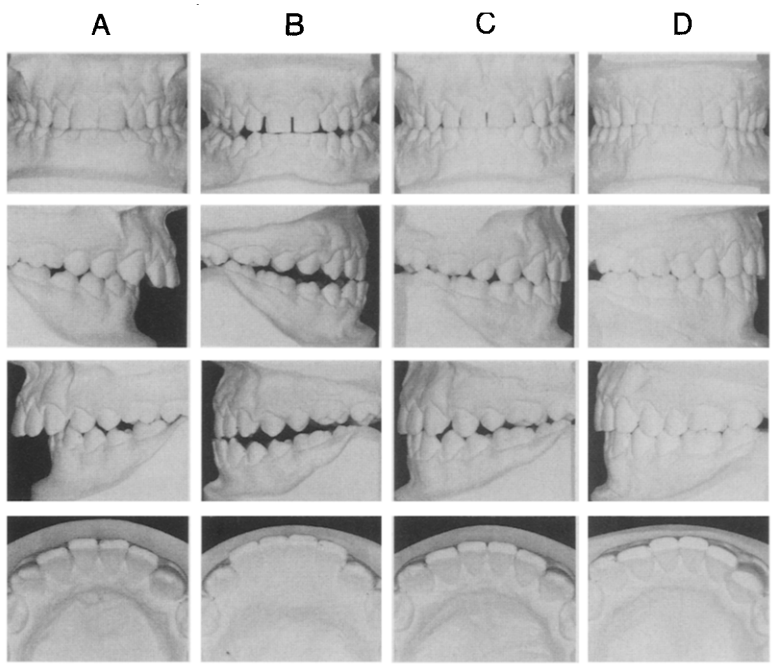

Fig. 8. Case 2: Male Herbst patient at the age of 12.6 years before treatment. **A**. Before treatment: 10.0 overjet, 5.0 overbite, 5.0 Irregularity Index, −0.2 available space. **B**. After treatment: −1.0 overjet, 0.0 overbite, 5.3 Irregularity Index, −0.1 available space. **C**. 6 months after treatment: 2.0 overjet, 2.0 overbite, 3.5 Irregularity Index, −0.2 available space. **D**. 5.1 years after treatment: 2.5 overjet, 2.5 overbite, 3.8 Irregularity Index, −0.8 available space.

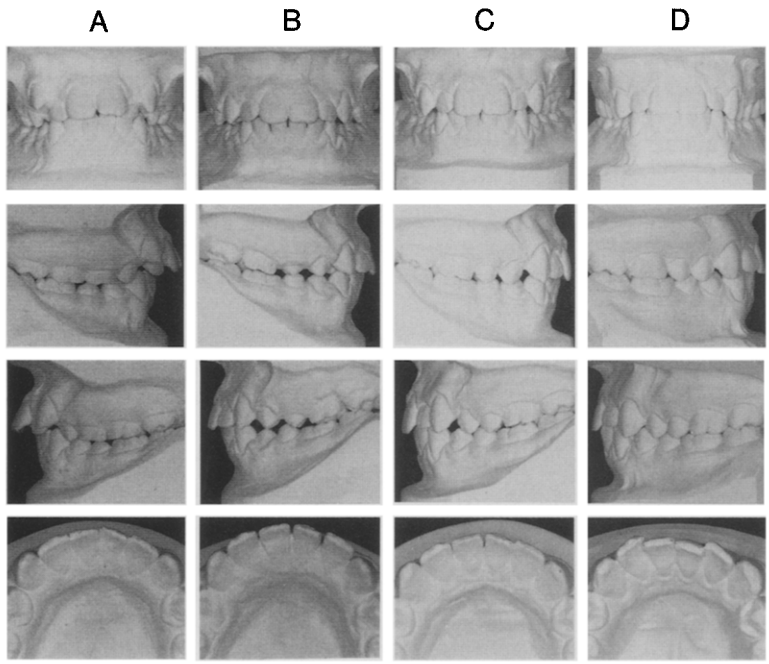

Fig. 9. Case 3: Male Herbst patient at the age of 13.2 years before treatment. **A**. Before treatment: 6.3 overjet, 1.8 overbite, 3.5 Irregularity Index, 0.0 available space. **B**. After treatment: 3.0 overjet, 2.0 overbite, 2.8 Irregularity Index, 1.0 available space. **C**. 6 months after treatment: 3.0 overjet, 3.0 overbite, 2.5 Irregularity Index, 0.3 available space. **D**. 5.1 years after treatment: 3.0 overjet, 2.5 overbite, 6.0 Irregularity Index, −1.8 available space.

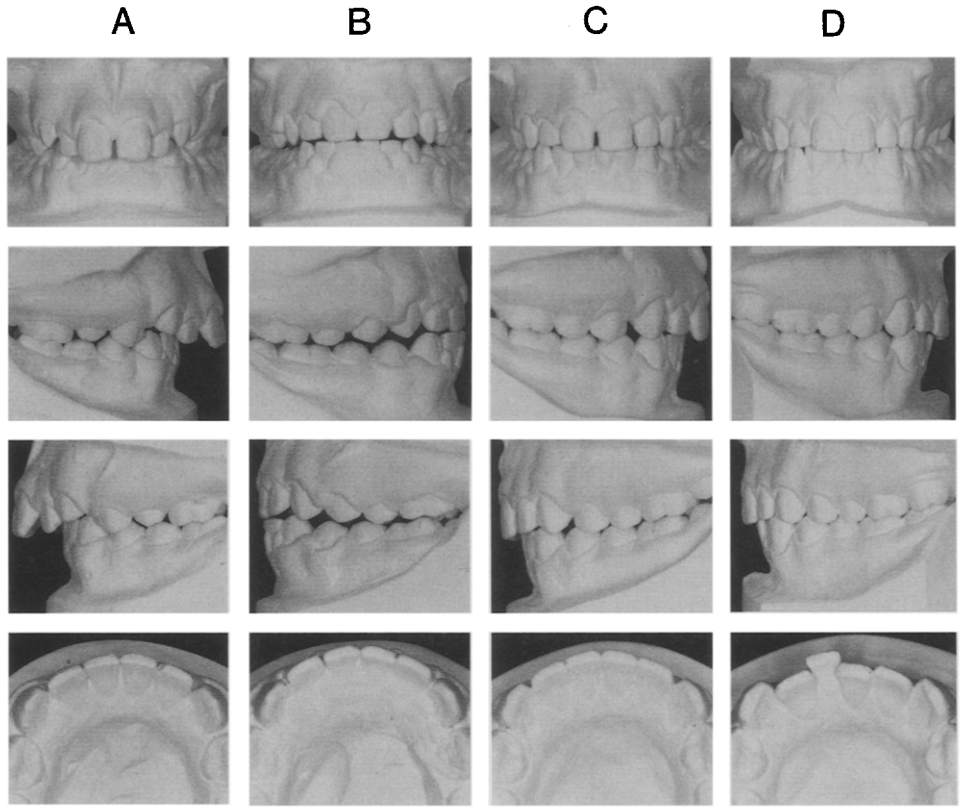

Fig. 10. Case 4: Male Herbst patient at the age of 13.7 years before treatment. **A.** Before treatment: 10.8 overjet, 4.0 overbite, 1.8 Irregularity Index, 0.3 available space. **B.** After treatment: 0.0 overjet, 0.0 overbite, 1.5 Irregularity Index, 0.3 available space. **C.** 6 months after treatment: 4.0 overjet, 2.0 overbite, 1.5 Irregularity Index, 0.2 available space. **D.** 5.1 years after treatment: 5.0 overjet, 1.8 overbite, 8.5 Irregularity Index, −1.9 available space.

significant association between horizontal maxillary growth and increased crowding. In the current study, a stronger association was found. However, no significant associations were found regarding decrease in available space and improvement in jaw base relationship (ANB $r = -0.22$, A-Pg $r = 0.03$) or changes in angular incisor measurement (Ili/NSL $r = -0.27$, Ili/ML $r = 0.20$). If late mandibular growth or complex growth pattern[27] had been causative factors for available space reduction, these associations should have been larger. Even if the associations between maxillary and mandibular growth changes and changes in the available space cannot be explained satisfactory, normal craniofacial growth changes seem to be associated with the development of incisor crowding in a long-term perspective. From a clinical point of view, this association justifies the retention of the mandibular incisors at least until the end of the growth period.

Total Observation Period (O) Changes

During the total observation period (treatment and posttreatment changes), the lower incisors proclined significantly (2.6°, $p < 0.01$) in relation to the mandibular plane (ILi/ML), but remained unchanged in relation to nasion-sella line (ILi/NSL). This is in agreement with the dentoalveolar compensatory mechanism described by Björk and Skieller.[24]

The mandibular incisors were more proclined before treatment than would be expected in a "normal" sample, i.e., the Bolton Standards.[29] In the Bolton sample, the inclination was on average 92.9° (SD 5.76°) at the age of 13 and 90.6° (SD 5.77°) at the age of 18. The corresponding values for the Herbst group were 98.6° (SD 7.6°) before treatment and 101.2° (SD 7.3°) at the time of follow-up. Furthermore, the proclination was more pronounced in the female sample at all stages. Of course, the proclination is part of the mechanism to compensate for the postnormality

in the jaw base relationship, which exists even after Herbst treatment.[9]

A minor mean increase in the irregularity index (Fig. 5) of less than 1 mm and a reduction of the available space of only 0.6 mm (Fig. 5) occurred. These changes were similar to those seen in untreated normal subjects[30] during the same age interval. Thus Herbst treatment was not thought to result in exceptionally large anterior crowding on a long-term basis. However, individual variations existed (Figs. 6 through 10).

CONCLUSIONS

In conclusion, it can be said that the proclination of the lower anterior teeth during Herbst treatment did not result in incisor crowding after treatment. In a long-term perspective, the development of incisor crowding was thought to be associated with normal craniofacial growth changes.

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