ORIGINAL ARTICLE

Temporomandibular joint growth changes in hyperdivergent and hypodivergent Herbst subjects. A long-term roentgenographic cephalometric study

Hans Pancherz, DDS, Odont Dr, FCDSHK (Hon),[a] and Chrysoula Michailidou, DDS, Dr med dent[b]
Giessen, Germany

The aim of this long-term study was to assess the amount and direction of glenoid fossa displacement, condylar growth, and "effective" temporomandibular joint (TMJ) changes (= the sum of glenoid fossa displacement, condylar growth, and condylar position changes in the fossa) in 3 vertical facial-type groups of Class II Division 1 malocclusions treated with the Herbst appliance. A comparison was made between 38 normodivergent (ML/NSL= 26.5°-36.5°), 17 hypodivergent (ML/NSL ≤ 26°), and 13 hyperdivergent (ML/NSL ≥ 37°) subjects. Lateral headfilms from before, after, and 5 years after treatment were scrutinized. Glenoid fossa displacement, condylar growth, and "effective" TMJ changes were analyzed. Treatment changes: in all facial-type groups, the glenoid fossa was displaced anteriorly and inferiorly. No differences existed between the 3 groups. Condylar growth and "effective" TMJ changes were directed posteriorly and superiorly. The changes in posterior direction were more apparent in the hyperdivergent group than in the normodivergent and hypodivergent groups. Posttreatment changes: in all facial-type groups, the fossa was displaced posteriorly. No differences existed between the 3 groups. Condylar growth and "effective" TMJ changes were directed more vertically compared with the treatment changes. The changes in posterior direction were more pronounced in the hyperdivergent group than in the other 2 groups. It was found that the amount and direction of TMJ growth changes (fossa displacement, condylar growth, and "effective" TMJ changes) were only temporarily affected favorably in the sagittal direction by Herbst treatment. Condylar growth and "effective" TMJ changes were directed more posteriorly in hyperdivergent than in hypodivergent Herbst subjects. This was true for both treatment and posttreatment period changes. (Am J Orthod Dentofacial Orthop 2004;126:153-61)

The effects of the Herbst appliance on vertical facial dimensions have been the focus of attention in several articles.[1-5] Windmiller [6] and Ruf and Pancherz[7] showed that Herbst treatment is successful in both hypodivergent (small mandibular plane angle) and hyperdivergent (large mandibular plane angle) Class II subjects. Furthermore, on a long-term basis, Ruf and Pancherz[7] demonstrated that the Herbst appliance in hypodivergent and hyperdivergent subjects had no influence on mandibular rotation.

Three adaptive processes in the temporomandibular joint (TMJ) are thought to be responsible for the increase in mandibular prognathism during Herbst treatment: (1) increased condylar growth due to condylar remodeling, (2) anterior glenoid fossa displacement due to fossa remodeling, and (3) anterior positioning of the condyle within the fossa.

In previous clinical Herbst studies, the 3 TMJ adaptive mechanisms were analyzed as single factors by using profile cephalometric roentgenograms,[8-12] orthopantomograms,[13] computerized tomography scans,[14] bone scintographs,[15] and magnetic resonance imaging (MRI).[3,16] In 3 Herbst studies,[3,16,17] the summation effect of the 3 TMJ adaptive mechanisms (condylar growth, glenoid fossa displacement, and condyle-fossa relationship changes) was assessed by using lateral headfilms.

However, for the TMJ growth changes during Herbst therapy, no study takes into account patients' vertical facial types. The aim of this long-term cephalometric roentgenographic study was to compare hypodivergent and hyperdivergent Herbst subjects by analyzing the amount and direction of condylar growth and fossa displacement changes as single factors as well as

From the Department of Orthodontics, University of Giessen, Giessen, Germany.
[a]Professor and chairman.
[b]Assistant professor.
Reprint requests to: Prof Dr Hans Pancherz, Department of Orthodontics, School of Dentistry, University of Giessen, Schlangenzahl 14, D-35392 Giesssen, Germany; e-mail, hans.pancherz@dentist.med.uni-giessen.de.
Submitted, January 2003; revised and accepted, July 2003.
0889-5406/$30.00

doi:10.1016/j.ajodo.2003.07.015

the 3 TMJ adaptive processes (condylar growth, glenoid fossa displacement, and condylar-fossa relationship changes) in combination.

MATERIAL AND METHODS

The original patient sample of consecutive Class II Division 1 malocclusions treated with the banded type of Herbst appliance[18] comprised 118 subjects. Herbst therapy resulted in Class I or overcorrected Class I dental-arch relationships in all 118 patients. From this sample, 68 subjects (42 boys and 26 girls) were selected for whom no other active treatment was performed after Herbst treatment and complete records existed at all examination times. The pretreatment age of the subjects ranged from 10 to 16 years (mean age, 12.4 years). The average treatment time was 7 months (5 to 12 months), and no teeth were extracted.

Lateral cephalometric roentgenograms in habitual occlusion and with the mouth wide open were available for all subjects. The headfilms were analyzed at 3 times: before treatment (T1), after treatment (T2), and 5 years (4 to 6 years) after treatment (T3). All roentgenograms were taken with the same apparatus. By using the mandibular plane angle (ML/NSL) measurement at T1, the subjects were divided into 3 facial-type groups:

- Normodivergent: ML/NSL = 26.5°-36.5° (38 subjects, 24 boys and 14 girls)
- Hypodivergent: ML/NSL ≤ 26° (17 subjects, 10 boys and 7 girls)
- Hyperdivergent: ML/NSL ≥ 37° (13 subjects, 8 boys and 5 girls)

The age distribution of the subjects was comparable in the 3 groups.

To reduce the method error in defining the different measuring points and reference structures, all headfilms were analyzed twice by the same person (C.M.) with a 2-week interval between the recordings. The mean value of the 2 recordings was used as final measuring value. Furthermore, at each recording session, all roentgenograms in a series from each subject were traced and evaluated. Linear measurements were made with a ruler to the nearest 0.5 mm. The linear roentgenographic enlargement of 7% was not corrected for.

In evaluating the headfilms, the methods (in modified form) of Buschang and Santos-Pinto[19] and Creekmore[20] were used.

The habitual occlusion headfilms in a series for each subject (T2 and T3) were superimposed on the T1 film. By using stable bone structures for orientation, anterior cranial base and mandibular superimpositions were performed according to the method of Björk and Skieller.[21] The condylar head was identified on the mouth-open headfilm and transferred to the mouth-closed film after mandibular superimpositions of the radiographs.

A reference line/reference-line perpendicular grid was defined on the T1 headfilm and then transferred to the other headfilms in a series (T2 and T3) after superimposing the films on the stable bone structures of the anterior cranial base.[21] The treatment and posttreatment changes of the measuring points were related to the reference line/reference-line perpendicular grid. The sagittal (x) and vertical (y) coordinates of the measuring points were assessed on all films (T1 to T3). The lines of the grid were defined as follows:

Reference line (RL): a line that connects the incisal edge of the most prominent mandibular central incisor and the distobuccal cusp tip of the first permanent mandibular molar; it corresponds to the x-axis of the grid.

Reference line perpendicular (RLp): a line perpendicular to RL through the midpoint of sella turcica; it corresponds to the y-axis of the grid.

Measuring points were defined as follows:

Anatomic condylar point (Co): the most superior-posterior point of the condylar head in relation to the RL/RLp grid. This point was defined on each headfilm in a series (T1 to T3).

Arbitrary condylar point (Co-A): an arbitrary point in the area of the condylar head.[20] The point was defined on the T1 headfilm and transferred to the other headfilms in a series (T2 and T3) after superimposing the headfilms on the stable bone structures of the cranial base.[21]

Measuring variables

To assess glenoid fossa displacement, the radiographs (T1, T2, T3) were superimposed on the stable bone structures of the cranial base.[21] The changes of Co in relation to its T1 position represent the fossa displacement (Fig 1). The validity of the method depends on an unchanged condyle/fossa relationship at all times of registration (T1, T2, T3).

To assess condylar growth, the radiographs (T1, T2, T3) were superimposed on the stable bone structures of the mandible.[21] The changes of Co in relation to its T1 position represent condylar growth (Fig 2).

To assess "effective" TMJ changes, Co-A marked on the T1 radiograph was transferred to the other radiographs (T2 and T3) after superimposing the headfilms on the stable bone structures of the cranial base.[21] Thereafter, the radiographs (T1, T2, T3) were superimposed by using the

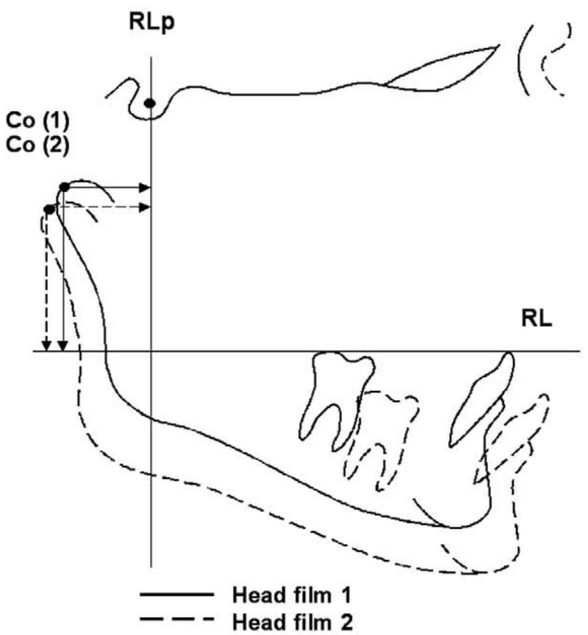

Fig 1. Glenoid fossa displacement. Changes of Co point after cranial base superimposition of radiographs.

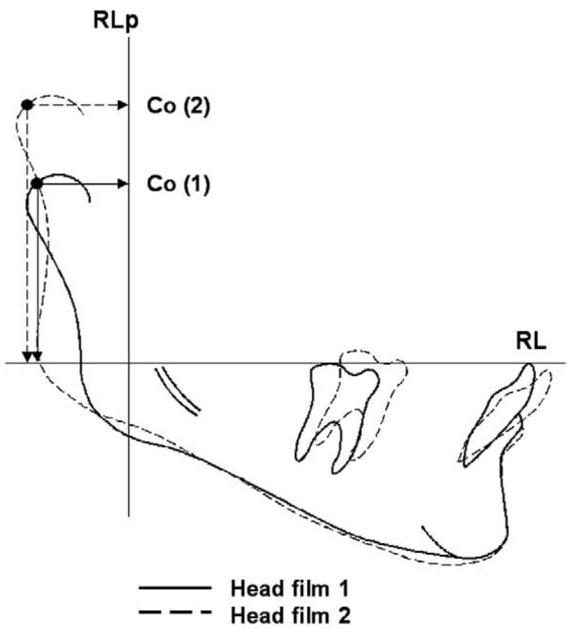

Fig 2. Condylar growth. Changes of Co point after mandibular superimposition of radiographs.

stable bone structures of the mandible.[21] The changes of Co-A in relation to its T1 position represent the "effective" TMJ changes (Fig 3) that are the sum of glenoid fossa displacement, condylar growth, and displacement of the condyle in the fossa.[20]

Statistical methods

The mean value (mean) and the standard deviation (SD) were calculated for each variable. Student *t* tests for paired samples were used to test the significance of changes during different examination periods. Student *t* tests for unpaired samples were used to test the significance of differences between the examination groups and between sexes. The significance levels were $P < .001$, $P < .01$, and $P < .05$; $P > .05$ was considered not significant. All calculations were performed with the software SPSS for Windows (SPSS, Chicago, Ill).

RESULTS

Most of the TMJ growth changes (glenoid fossa, condyle, "effective" TMJ changes) during the treatment (T2-T1) and posttreatment (T3-T2) periods were insignificantly larger in the boys than in the girls. Statistically significant differences were found for sagittal fossa changes (T2-T1; $P < .001$) and vertical condylar changes (T3-T2; $P < .05$) in the hypodivergent group. However, because the proportions of boys and girls were comparable in the 3 groups, no sex differentiation was done.

Table I gives the position of the measuring points in the 3 facial-type groups at the different examination times. Table II shows the corresponding treatment and posttreatment changes of the measuring points. The comparisons of the 3 groups are given in Table III.

As an expression of glenoid fossa displacement (Tables II and III; Fig 4), the position change of Co was assessed by using a cranial base superimposition technique of the headfilms (Fig 1).

In all 3 facial-type groups, the fossa was, on average, displaced in an anterior ($P < .05$) and inferior ($P < .05$ to $P < .001$) direction during treatment (T2-T1). For the amount of both sagittal and vertical fossa displacements, no statistically significant (ns) group differences existed.

At posttreatment (T3-T2) in all 3 groups, the fossa was, on average, displaced in a posterior direction ($P < .001$). No vertical fossa displacement could be verified statistically (ns). For the amount of sagittal fossa displacement, no statistically significant group differences existed.

As an expression of condylar growth (Tables II and III; Fig 5), the position change of Co was assessed by using a mandibular base superimposition technique of the headfilms (Fig 2).

In all 3 facial-type groups, condylar growth was, on

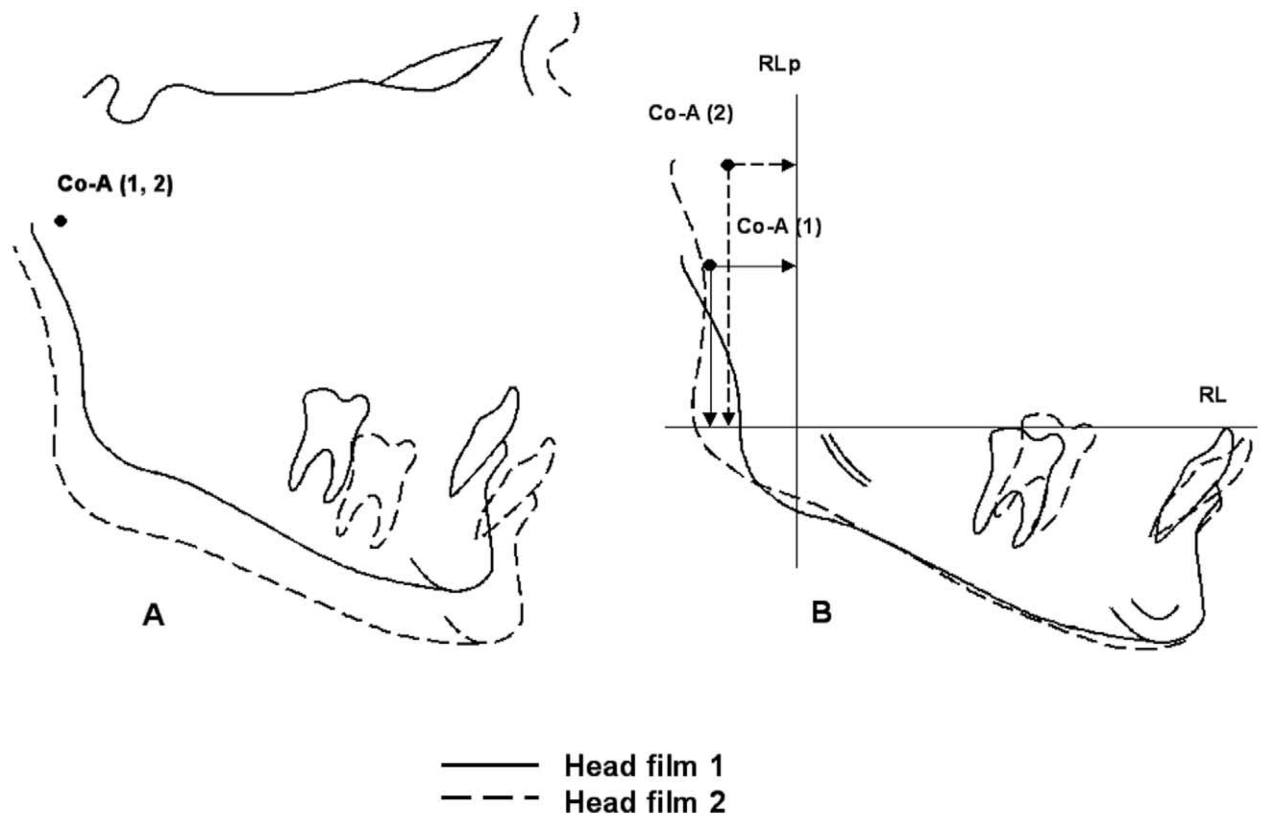

Fig 3. "Effective" TMJ changes. **A,** Transference of Co-A point from first headfilm to second headfilm after cranial base superimposition of radiographs. **B,** Changes of Co-A point after mandibular superimposition of radiographs.

average, directed posteriorly ($P < .01$ to $P < .001$) and superiorly ($P < .01$ to $P < .001$) during treatment (T2-T1). However, growth was directed more posteriorly in the hyperdivergent group than in the normodivergent and hypodivergent groups (Fig 5). For the amount of sagittal condylar growth, no statistically significant group differences existed. For vertical condylar growth, the amount was greater in the normodivergent than in the hyperdivergent group ($P < .05$).

At posttreatment (T3-T2) in all 3 groups, condylar growth was, on average, directed posteriorly ($P < .05$ to $P < .001$) and superiorly ($P < .001$). Condylar growth in the posttreatment period was directed more posteriorly in the hyperdivergent group than in the normodivergent and hypodivergent groups. However, compared with the treatment changes, the posttreatment changes in all 3 facial-type groups were more vertically oriented.

The amount of sagittal condylar growth was greater in the hyperdivergent group than in the normodivergent ($P < .01$) and hypodivergent ($P < .01$) groups. For the amount of vertical condylar growth, no statistically significant group differences existed.

As an expression of "effective" TMJ changes (the sum of fossa displacement, condylar growth, and condylar displacement in the fossa) (Tables II and III; Fig 6), the position change of Co-A was assessed by using a mandibular superimposition technique of the headfilms (Fig 3).

The direction of the "effective" TMJ changes in the 3 facial-type groups was, on average, similar to that of condylar growth during reatment (T2-T1): the changes were directed posteriorly ($P < .001$) and superiorly ($P < .001$). Posteriorly directed changes were more apparent in the hyperdivergent group than in the normodivergent and hypodivergent groups. However, compared with the condylar growth changes, the amount of sagittal and vertical "effective" TMJ changes in all groups was greater. For the amount of sagittal "effective" TMJ changes, no statistically significant group differences existed. The amount of vertical "effective" TMJ changes, on the other hand, was greater in the hypodivergent than in the hyperdivergent group ($P < .01$).

At posttreatment (T3-T2) in all 3 facial-type groups, the "effective" TMJ changes were, on average,

Table I. Position (mean, SD) of measuring points in 38 normodivergent (Normo), 17 hypodivergent (Hypo), and 13 hyperdivergent (Hyper) Herbst patients at T1 (before treatment), T2 (after treatment), T3 (5 years after treatment)

			T1		*T2*		*T3*	
Variable		*Group*	*Mean*	*SD*	*Mean*	*SD*	*Mean*	*SD*
Fossa position - sagittal (CBS)	mm	Normo	14.5	2.63	13.9	3.24	16.1	3.40
Co/RLp		Hypo	16.7	2.53	16.2	2.58	18.3	2.61
		Hyper	14.2	2.89	13.5	2.55	16.0	2.62
Fossa position - vertical (CBS)	mm	Normo	35.4	5.02	34.6	5.12	34.3	5.47
Co/RL		Hypo	40.8	5.61	39.4	5.73	39.6	5.51
		Hyper	33.3	3.22	32.5	3.91	32.6	3.49
Condylar position - sagittal (MBS)	mm	Normo	14.5	2.62	16.3	3.42	19.7	5.12
Co/RLp - anatomical point		Hypo	16.6	2.52	18.0	2.57	19.2	3.18
		Hyper	14.2	1.89	16.5	3.77	20.8	4.72
Condylar position - vertical (MBS)	mm	Normo	35.4	5.01	38.3	6.04	45.1	5.72
Co/RL - anatomical point		Hypo	40.8	5.61	43.4	6.26	51.1	6.72
		Hyper	33.3	3.22	35.1	4.26	41.8	5.07
Condylar position - sagittal (MBS)	mm	Normo	10.8	2.62	13.2	3.03	14.4	4.38
Co-A/RLp - arbitrary point		Hypo	12.3	2.75	14.0	3.07	13.2	3.51
		Hyper	10.1	3.03	13.0	4.43	14.9	5.43
Condylar position - vertical (MBS)	mm	Normo	31.8	4.81	35.4	5.85	42.6	5.75
Co-A/RL - arbitrary point		Hypo	36.1	5.73	40.1	6.22	47.6	6.67
		Hyper	29.6	3.36	32.2	3.76	38.9	4.77

CBS, Cranial base superimposition.
MBS, Mandibular base superimposition.

directed posteriorly (ns to $P < .05$) and superiorly ($P < .001$). The "effective" TMJ changes in the posttreatment period were directed more posteriorly in the hyperdivergent than in the normodivergent and hypodivergent groups. Compared with the posttreatment condylar growth changes, the postreatment "effective" TMJ changes in all 3 groups were more vertically oriented. The amount of sagittal "effective" TMJ changes was greater in the hyperdivergent group than in the normodivergent ($P < .05$) and hypodivergent ($P < .05$) groups. For the amount of vertical "effective" TMJ changes, no statistically significant group differences existed.

DISCUSSION

This is the first study that examines the growth effects of the Herbst appliance, or of any orthodontic or orthopedic appliance, on the TMJ and compares Class II subjects with different vertical facial morphologies. For this kind of research, the Herbst appliance has many advantages when compared with removable functional appliances such as the activator, the bionator, and the Fränkel. The Herbst appliance is fixed to the teeth, works continuously 24 hours a day, and does not depend on compliance for its correct function.

In interpreting the present findings, it must be remembered that anterior-directed glenoid fossa displacement changes and posterior-directed condylar growth and "effective" TMJ changes are favorable in skeletal Class II treatment. All changes contribute to increase mandibular prognathism. On the other hand, posterior-directed fossa displacement and anterior-directed condylar growth and "effective" TMJ changes are unfavorable for Class II correction. These changes contribute to decrease mandibular prognathism. When considering vertical TMJ changes, they will only indirectly contribute to the outcome of Class II treatment by affecting mandibular growth rotation.[17]

For the analysis of glenoid fossa displacement changes, the method of Buschang and Santos-Pinto[19] was used. The prerequisite for this method to be valid is an unchanged condyle-fossa relationship at all examination times (T1, T2, and T3). In case of a changed position of the condyle in the fossa (not possible to ascertain in the analysis of lateral headfilms), this will misleadingly be appraised as a fossa displacement. Ruf and Pancherz,[3] using MRI of the TMJ, showed an unaffected condyle-fossa relationship by Herbst therapy; this means that the condyle had the same position before and after treatment. Furthermore, on a long-term basis, Hansen et al,[22] using the method of lateral TMJ tomography, demonstrated a normal centered position of the condyle in the fossa in Herbst patients 7.5 years posttreatment.

For the analysis of condylar growth changes, an anatomic condylar point was defined. Because the

Table II. Changes (mean) of measuring points in 38 normodivergent (Normo), 17 hypodivergent (Hypo), and 13 hyperdivergent (Hyper) Herbst patients; T1 (before treatment), T2 (after treatment), T3 (5 years after treatment)

			T2-T1			T3-T2			T3-T1		
Variable		*Group*	*Mean*	*t*	*Sig*	*Mean*	*t*	*Sig*	*Mean*	*t*	*Sig*
Fossa displacement - sagittal (CBS)	mm	Normo	−0.6	−2.58	*	+2.2	+7.99	***	+1.6	+6.72	***
Co/RLp		Hypo	−0.5	−2.16	*	+2.1	+7.40	***	+1.6	+4.26	**
		Hyper	−0.7	−2.41	*	+2.5	+6.59	***	+1.8	+5.39	***
Fossa displacement - vertical (CBS)	mm	Normo	−0.8	−3.16	**	−0.3	−1.53	ns	−1.1	−4.11	***
Co/RL		Hypo	−1.4	−4.38	***	+0.2	+0.62	ns	−1.2	−2.84	*
		Hyper	−0.8	−2.44	*	+0.1	+0.11	ns	−0.7	−1.40	ns
Condylar growth - sagittal (MBS)	mm	Normo	+1.8	+7.16	***	+3.4	+5.15	***	+5.2	+7.77	***
Co/RLp		Hypo	+1.4	+4.39	**	+1.2	+2.11	*	+2.6	+4.47	***
		Hyper	+2.3	+5.58	***	+4.3	+4.39	***	+6.6	+5.89	***
Condylar growth - vertical (MBS)	mm	Normo	+2.9	+9.06	***	+6.8	+9.71	***	+9.7	+15.95	***
Co/RL		Hypo	+2.6	+5.50	***	+7.7	+4.81	***	+10.3	+6.40	***
		Hyper	+1.8	+3.59	**	+6.7	+5.52	***	+8.5	+7.30	***
"Effective" TMJ changes - sagittal (MBS)	mm	Normo	+2.4	+9.41	***	+1.2	+2.12	*	+3.6	+6.21	***
Co-A/RLp		Hypo	+1.7	+4.88	***	−0.8	−1.35	ns	+0.9	+1.87	ns
		Hyper	+2.9	+5.44	***	+1.9	+1.76	ns	+4.8	+3.87	**
"Effective"TMJ changes - vertical (MBS)	mm	Normo	+3.6	+11.08	***	+7.2	+9.4	***	+10.7	+15.39	***
Co-A/RL		Hypo	+4.0	+12.78	***	+7.5	+4.72	***	+11.5	+7.71	***
		Hyper	+2.6	+7.49	***	+6.7	+7.00	***	+9.3	+9.61	***

CBS, Cranial base superimposition.
MBS, Mandibular base superimpositiiton.

Levels of significance	Plus (+) means:	Minus (−) means:
***($P < .001$)	Posterior condylar growth	Anterior condylar growth
**($P < .01$)	Superior condylar growth	Inferior condylar growth
*($P < .05$)	Posterior fossa displacement	Anterior fossa displacement
ns ($P \geq .05$)	Superior fossa displacement	Inferior fossa displacement
	Posterior "effective" TMJ change	Anterior "effective" TMJ changes
	Superior "effective" TMJ change	Inferior "effective" TMJ changes

condylar head is difficult or impossible to identify on habitual occlusion headfilms, mouth-open headfilms were also used to visualize the condyle and then to transfer its countour to the mouth-closed films after mandibular superimposition of the radiographs.

To circumvent the problem of defining reliable anatomic measuring points for assessing fossa displacement and condylar growth changes, the "effective" TMJ changes[20] were calculated by using an arbitrary condylar point (Co-A). Thus, it was possible to assess quantitatively the sum of fossa displacement, condylar growth, and possible condylar position changes in the fossa.

Glenoid fossa displacement

During normal growth, the glenoid fossa is displaced in a posterior-inferior direction.[19,23] During Herbst treatment (T2-T1), the fossa in all groups was displaced in an anterior and inferior direction. This was most likely the result of remodeling processes at the posterior fossa wall as has been demonstrated histologically in mandibular-protrusion experiments in animals[24-30] and in earlier clinical Herbst studies with MRI of the TMJ region.[3,16]

During the posttreatment period (T3-T2), fossa displacement in all facial-type groups was in a posterior direction. Therefore, in the total observation period (T3-T1), the direction of fossa displacement posteriorly and inferiorly corresponded to that of normal growth changes.[19,25]

When comparing the 3 facial-type groups for the amount and direction of fossa dispalcement changes during the treatment and posttreatment periods, no differences were found.

It seems that the Herbst appliance has only a temporary impact on glenoid fossa displacement in an anterior direction during the active phase of treatment, thus contributing to mandibular advancement and facilitating Class II correction. The amount and direction of the fossa changes seem to be independent of the patients' vertical facial types.

Table III. Changes (mean) of measuring points in 38 normodivergent (Normo), 17 hypodivergent (Hypo), and 13 hyperdivergent (Hyper) Herbst patients; T1 (before treatment), T2 (after treatment), T3 (5 years after treatment)

			T2-T1			T3-T2			T3-T1		
Variable		*Group*	*Mean*	*t*	*Sig*	*Mean*	*t*	*Sig*	*Mean*	*t*	*Sig*
Fossa displacement - sagittal (CBS)	mm	Normo-Hypo	−0.1	−0.51	ns	+0.1	+0.33	ns	+0.0	+0.48	ns
Co/RLp		Normo-Hyper	+0.1	+0.36	ns	−0.3	−0.74	ns	+0.2	+0.53	*
		Hypo-Hyper	+0.2	+0.80	ns	−0.4	−0.49	ns	−0.2	−0.35	ns
Fossa displacement - vertical (CBS)	mm	Normo-Hypo	−0.6	−1.52	ns	−0.5	−1.48	ns	+0.1	+0.61	ns
Co/RL		Normo-Hyper	+0.0	+0.19	ns	−0.4	−0.73	ns	−0.4	−0.59	ns
		Hypo-Hyper	−0.6	−1.12	ns	+0.1	+0.19	ns	−0.5	−0.57	ns
Condylar growth - sagittal (MBS)	mm	Normo-Hypo	+0.4	+0.86	ns	+2.2	+2.69	**	+2.6	+2.98	**
Co/RLp		Normo-Hyper	−0.5	−1.06	ns	−0.9	−0.79	ns	−1.4	−1.11	ns
		Hypo-Hyper	−0.9	−1.64	ns	−3.1	−2.87	**	−4.0	−3.22	**
Condylar growth - vertical (MBS)	mm	Normo-Hypo	+0.3	+0.42	ns	−1.1	−0.56	ns	−0.6	−0.42	ns
Co/RL		Normo-Hyper	+1.1	+1.89	*	+0.1	+0.00	ns	+1.2	+1.00	ns
		Hypo-Hyper	+0.8	+1.35	ns	+1.0	+0.49	ns	+1.8	+0.96	ns
"Effective" TMJ changes - sagittal (MBS)	mm	Normo-Hypo	+0.7	+1.45	ns	+2.0	+2.43	*	+2.7	+3.55	***
Co-A/RLp		Normo-Hyper	−0.5	−0.97	ns	−0.7	−0.55	ns	−1.2	−0.91	ns
		Hypo-Hyper	−1.2	−1.87	ns	−2.7	−2.19	*	−3.9	−2.93	**
"Effective" TMJ changes - vertical (MBS)	mm	Normo-Hypo	−0.4	−1.14	ns	−0.3	−0.19	ns	−0.8	−0.51	ns
Co-A/RL		Normo-Hyper	+1.0	+1.92	ns	+0.5	+0.39	ns	+1.4	+1.15	ns
		Hypo-Hyper	+1.4	+3.00	**	+0.8	+0.43	ns	+2.2	+1.24	ns

CBS, Cranial base superimposition.
MBS, Mandibular base superimposition.
Levels of significance
***($P < .001$)
**($P < .01$)
*($P < .05$)
ns ($P \geq .05$)

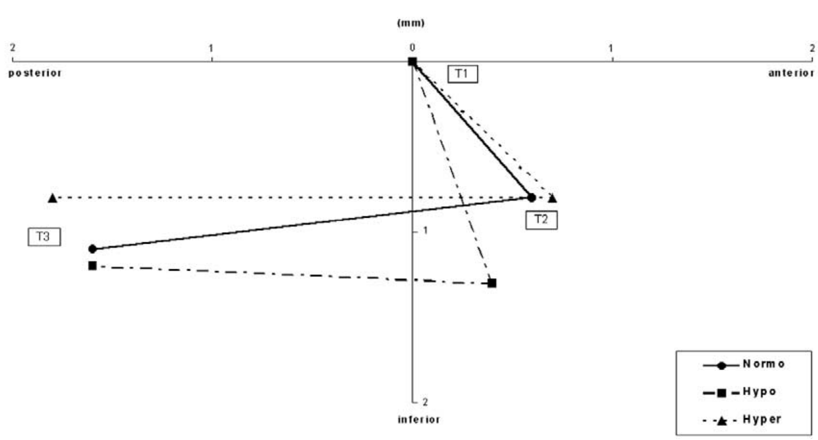

Fig 4. Glenoid fossa displacement. Average changes of Co point in 38 normodivergent (*Normo*), 17 hypodivergent (*Hypo*), and 13 hyperdivergent (*Hyper*) Herbst subjects. *T1*, before treatment; *T2*, after treatment; *T3*, 5 years after treatment.

Condylar growth

In untreated subjects having different vertical facial morphologies, Björk and Skieller[21] demonstrated a vertical condylar growth pattern (predominantly superior-directed condylar growth) in hypodivergent subjects and a sagittal condylar growth pattern (predominantly posterior-directed condylar growth) in hyperdivergent subjects. These growth patterns correspond to those of our hypodivergent and hyperdivergent Herbst subjects. However, Herbst treatment stim-

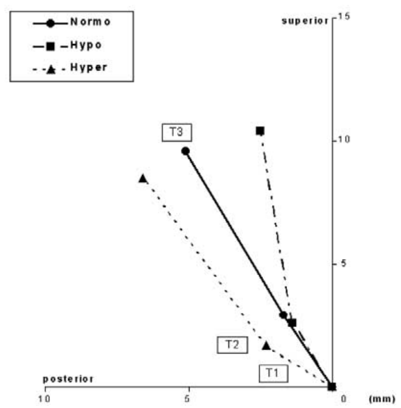

Fig 5. Condylar growth. Average changes of Co point in 38 normodivergent (*Normo*), 17 hypodivergent (*Hypo*), and 13 hyperdivergent (*Hyper*) Herbst subjects. *T1*, before treatment; *T2*, after treatmentl; *T3*, 5 years after treatment.

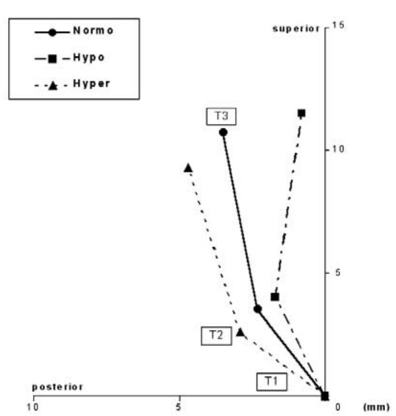

Fig 6. "Effective" TMJ changes. Average changes of Co-A point in 38 normodivergent (*Normo*), 17 hypodivergent (*Hypo*), and 13 hyperdivergent (*Hyper*) Herbst subjects. *T1*, before treatment; *T2*, after treatment; *T3*, 5 years after treatment.

ulates condylar growth in a posterior direction,[8,12,30] and this seems particularly to be the case in hyperdivergent subjects. A stimulation of condylar growth in especially the posterior direction as a response to mandibular advancement appliances has also been verfied histologically in animals[25,29-33] and with radiography[13,14] and MRI[3,16] in humans.

When comparing the treatment (T2-T1) and posttreatment (T3-T2) period changes, condylar growth direction in all facial-type groups became more vertically oriented posttreatment. This could be due to recovery after Herbst therapy. The amount and direction of growth return to their original patterns.[9,12]

The results indicate that Herbst treatment temporarily stimulates condylar growth, especially in the posterior direction, and that hyperdivergent subjects react more readily than hypodivergent subjects. Clinically, this implies that, for the mandibular growth contribution to Class II correction, the Herbst appliance is more efficient in hyperdivergent than in hypodivergent subjects.[34]

"Effective" TMJ changes

The "effective" TMJ changes represent the sum of glenoid fossa displacement, condylar growth, and condylar position changes in the fossa. The pattern of "effective" TMJ changes in the 3 facial-type groups was basically the same as that of condylar growth.

However, during treatment (T2-T1) in all groups, the amount of vertical "effective" TMJ changes was greater than the corresponding amount of vertical condylar growth changes. Furthermore, during the posttreatment period (T3-T2), the growth direction changes to a more vertical pattern were more pronounced for "effective" TMJ changes (Fig 6) than for condylar growth (Fig 5). Additionally, in the normodivergent and hypodivergent groups, the amount of vertical "effective" TMJ change was greater than the corresponding condylar growth changes.

When comparing these patterns of "effective" TMJ changes and condylar growth, the differences could be explained by the opposing glenoid fossa displacement changes during and after Herbst thearpy (Fig 4). In "effective" TMJ changes, anterior and inferior fossa displacement changes during treatment (T2-T1) are added to posterior and superior condylar growth, whereas posterior fossa displacement changes posttreatment (T3-T2) are subtracted from posterior condylar growth.

The results indicate that, in the 3 facial-type groups, the "effective" TMJ changes mainly reflect the corresponding condylar growth changes. Glenoid fossa displacement changes during and after Herbst treatment affect, however, the pattern of the "effective" TMJ changes.

CONCLUSIONS

The amount and direction of TMJ growth changes (fossa displacement, condylar growth, and "effective" TMJ changes) were only temporarily affected favorably in the sagittal direction by Herbst treatment. For glenoid fossa displacement changes, no differences existed between hypodivergent and hyperdivergent subjects at any examination period. But condylar growth and "effective" TMJ changes, on the other hand, were directed more posteriorly in hyperdivergent than in hypodivergent Herbst subjects during treatment and posttreatment.

REFERENCES

1. Pancherz H. Vertical dentofacial changes during Herbst appliance treatment. A cephalometric investigation. Swed Dent J 1982;15(Suppl 15):189-96.
2. Pancherz H, Anehus-Pancherz M. The head-gear effect of the Herbst appliance. A cephalometric long-term study. Am J Orthod Dentofacial Orthop 1993;103:510-20.
3. Ruf S, Pancherz H. Temporomandibular joint growth adaptation in Herbst treatment: a prospective magnetic resonance imaging and cephalometric roentgenographic study. Eur J Orthod 1998; 20:375-88.
4. Kruse J. Rotationsformen des Unterkiefers bei der Herbst-Behandlung. Eine röntgenkephalometrische Untersuchung der Langzeitveränderungen der Total-, Matrix- und Intramatrix-Rotation [dissertation]. Giessen, Germany: University of Giessen; 1999.
5. Croft RS, Buschang PH, English JD, Meyer R. A cephalometric and tomographic evaluation of Herbst treatment in the mixed dentition. Am J Orthod Dentofacial Orthop 1999;116:435-43.
6. Windmiller EC. The acrylic-splint Herbst appliance: a cephalometric evaluation. Am J Orthod Dentofacial Orthop 1993;104: 73-84.
7. Ruf S, Pancherz H. The effect of Herbst appliance treatment on the mandibular plane angle: a cephalometric roentgenographic study. Am J Orthod Dentofacial Orthop 1996;110:225-9.
8. Pancherz H. Treatment of Class II malocclusion by jumping the bite with the Herbst appliance. A cephalometric investigation. Am J Orthod 1979;76:423-42.
9. Pancherz H. The effect of continuous bite jumping on the dentofacial complex: a follow-up study after Herbst appliance treatment of Class II malocclusion. Eur J Orthod 1981;3:49-60.
10. Wieslander L. Intensive treatment of severe Class II malocclusions with a headgear-Herbst appliance in the early mixed dentition. Am J Orthod 1984;86:1-13.
11. Pancherz H, Hägg U. Dentofacial orthopedics in relation to somatic maturation. An analysis of 70 consecutive cases treated with the Herbst appliance. Am J Orthod 1985;88:273-87.
12. Pancherz H, Littmann C. Morphologie und Lage des Unterkiefers bei der Herbst-Behandlung: eine kephalometrische Analyse der Veränderungen bis zum Wachstumsabschluss. Inf Kieferorthop 1989;8:215-28.
13. Paulsen HU. Changes of the condyles of 100 patients treated with the Herbst appliance from puberty to adulthood: a long-term radiographic study. Eur J Orthod 1997;19:657-8.
14. Paulsen HU, Karle A, Bakke M, Herskind A. A CT-scanning and radiographic analysis of temporomandibular joints and cephalometric analysis in a case of Herbst treatment in late puberty. Eur J Orthod 1995;17:165-75.
15. Paulsen HU, Rabol A, Sorensen S. Bone scintigraphy of human temporomandibular joints during Herbst treatment: a case report. Eur J Orthod 1988;20:369-74.
16. Ruf S, Pancherz H. Temporomandibular joint remodeling in adolescents and young adults during Herbst treatment: a prospective longitudinal magnetic resonance imaging and cephalometric radiographic investigation. Am J Orthod Dentofacial Orthop 1999;115:607-18.
17. Pancherz H, Ruf S, Kohlhas P. "Effective condylar growth" and chin position changes in Herbst treatment: a cephalometric roentgenographic long-term study. Am J Orthod Dentofacial Orthop 1998;114:437-46.
18. Pancherz H. The Herbst appliance—its biologic effects and clinical use. Am J Orthod 1985;87:1-20.
19. Buschang P, Santos-Pinto A. Condylar growth and glenoid fossa displacement during childhood and adolescence. Am J Orthod Dentofacial Orthop 1998;113:437-42.
20. Creekmore T. Inhibition or stimulation of the vertical growth of the facial complex, its significance to treatment. Angle Orthod 1967;37:285-97.
21. Björk A, Skieller V. Normal and abnormal growth of the mandible. A synthesis of longitudinal cephalometric implant studies over a period of 25 years. Eur J Orthod 1983;5:1-46.
22. Hansen K, Pancherz H, Petersson A. Long-term effects of the Herbst appliance on the craniomandibular system with special reference to the TMJ. Eur J Orthod 1990;12:244-53.
23. Björk A, Skieller V. Facial development and tooth eruption. An implant study at the age of puberty. Am J Orthod 1972;62:339-83.
24. Breitner C. Experimentelle Veränderungen der mesiodistalen Beziehungen der oberen und unteren Zahnreihen. Zschr Stomatol 1930;28:620-35.
25. Stöckli PW, Willert HG. Tissue reactions in the temporomandibular joint resulting from anterior displacement of the mandible in the monkey. Am J Orthod 1971;60:142-55.
26. Woodside DG, Metaxas A, Altuna G. The influence of functional appliance therapy on glenoid fossa remodeling. Am J Orthod Dentofacial Orthop 1987;92:181-98.
27. Rabie ABM, Zhao Z, Shen G, Hägg U, Robinson W. Osteogenesis in the glenoid fossa in response to mandibular advancement. Am J Orthod Dentofacial Orthop 2001;119:390-400.
28. Rabie ABM, Chayanupatkul A, Hägg U. Stepwise advancement using functional appliances. Experimental perspective. Semin Orthod 2003;9:41-6.
29. Peterson JE, McNamara JA. Temporomandbular joint adaptation associated with Herbst appliance treatment in juvenile rhesus monkeys (Macaca mulatta). Semin Orthod 2003;9:12-25.
30. McNamara JA, Peterson JE, Pancherz H. Histologic changes associated with the Herbst appliance in adult rhesus monkeys (Macaca mulatta). Semin Orthod 2003;9:26-40.
31. McNamara JA, Carlson DS. Quantitative analysis of temporomandibular joint adaptation to protrusive function. Am J Orthod 1979;76:593-611.
32. McNamara JA, Hinton RJ, Hoffman DL. Histologic analysis of temporomandibular joint adaptation to protrusive function in young adult rhesus monkeys (*Macaca mulatta*). Am J Orthod 1982;82:288-98.
33. Woodside DG, Altuna G, Harvold E, Herbert M, Metaxas A. Primate experiments in malocclusion and bone induction. Am J Orthod 1983;83:460-8.
34. Ruf S, Pancherz H. The mechanism of Class II correction during Herbst therapy in relation to the vertical jaw base relationship: a cephalometric roentgenographic study. Angle Orthod 1997;67: 271-6.