

ORIGINAL ARTICLE

Temporomandibular joint remodeling in adolescents and young adults during Herbst treatment: A prospective longitudinal magnetic resonance imaging and cephalometric radiographic investigation

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The aim of this prospective study was to analyze and compare the temporomandibular joint adaptive mechanisms in 25 adolescent and 14 young adult Class II malocclusions treated with the Herbst appliance. Temporomandibular joint remodeling was analyzed by magnetic resonance imaging. In each subject, 4 magnetic resonance images of both temporomandibular joints were available: before treatment, at the start of treatment (when the Herbst appliance was placed), during treatment (6 to 12 weeks after appliance placement), and after treatment (when the appliance was removed). Furthermore, effective temporomandibular joint changes (the sum of condylar remodeling, fossa remodeling, and condyle-fossa relationship changes) were analyzed with the aid of lateral cephalometric radiographs from before and after treatment. All subjects were treated to Class I or overcorrected Class I dental arch relationships, and their mandibles became significantly ($P < .001$) more prognathic. After 6 to 12 weeks of Herbst treatment, signs of condylar remodeling were seen at the posterosuperior border in 48 of the 50 adolescent condyles and in 26 of the 28 young adult condyles. Bilateral remodeling of the mandibular ramus could be detected in 1 adolescent and 2 young adult patients. Signs of glenoid fossa remodeling at the anterior surface of the postglenoid spine were noted in 36 adolescent and 22 young adult temporomandibular joints. Effective temporomandibular joint changes during treatment were more horizontally directed and larger in both adolescents and young adult patients treated with the Herbst appliance than in an untreated group of subjects with ideal occlusion (Bolton standards). The increase in mandibular prognathism accomplished by Herbst therapy in both adolescents and young adults seems, in particular, to be a result of condylar and glenoid fossa remodeling. Because the Herbst appliance is most successful in Class II patients also at the end of the growth period, the treatment method could be an alternative to orthognathic surgery in borderline skeletal Class II cases. Magnetic resonance imaging renders an excellent opportunity to visualize the temporomandibular joint remodeling growth processes. (*Am J Orthod Dentofacial Orthop* 1999;115:607-18)

The mechanism by which the temporomandibular joint (TMJ) responds to functional appliance therapy is a matter of controversy.^{1,2} Histologically, several mandibular protrusion experiments in growing animals have demonstrated that condylar growth can be stimulated and that the glenoid fossa can be remodeled.³⁻¹² Some experiments in adult animals show similar condylar^{6,13,14} and glenoid fossa^{6,12-14} remodeling as seen in growing animals, although other studies show negligible or no adaptive changes.^{7-9,15-19}

In the treatment of Class II malocclusions, the Herbst appliance²⁰ has been shown to increase mandibular length.²¹⁻²⁴ In TMJ radiographs, double contours of the anterior surface of the postglenoid spine have been visualized in some patients treated with the Herbst appliance.^{21,25,26} On orthopantomograms, double contours on the posterior aspect of the condyle have also been detected.^{27,28} When using computed tomography scans in a single postpubertal Herbst patient, double contours as signs of TMJ remodeling could be verified in the glenoid fossa and in the posterosuperior part of the condyle.²⁹ Furthermore, with magnetic resonance imaging (MRI), condylar and glenoid fossa remodeling have been demonstrated in consecutive patients treated with the Herbst appliance.^{30,31}

Clinical experience has shown that the Herbst appliance can be most effective even in elderly subjects. Therefore if Herbst treatment proves to result in

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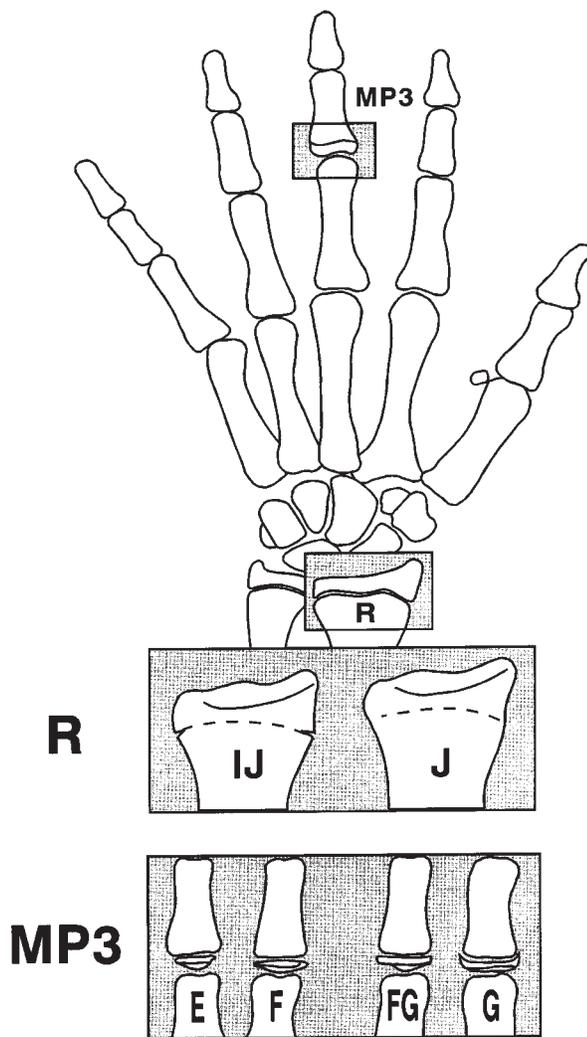


Fig 1. Skeletal maturity stages³³ of radius (*R*) and of middle phalanx of third finger (*MP3*) used to define adolescence and young adulthood. (Early adolescence: stage *MP3-E*, epiphysis is not yet as wide as metaphysis; stage *MP3-F*, epiphysis is as wide as metaphysis; stage *MP3-FG*, epiphysis is as wide as metaphysis, and there is a distinct medial and/or lateral border of epiphysis forming a line of demarcation at right angles to distal border; stage *MP3-G*, sides of epiphysis have thickened and also cap its metaphysis, forming a sharp edge distally at one or both sides. Young adulthood: stage *R-IJ*, fusion of epiphysis with its metaphysis is almost completed (residual small gap at one or both margins); stage *R-J*, fusion of epiphysis with its metaphysis is completed.)

TMJ-growth adaptation in young adults, the indications for orthopedic Class II correction may be extended beyond the age limitation recommended by Weaver et al.³² Thus both risks and costs could be reduced in comparison with orthognathic surgery approaches.

Therefore with the use of MRI and cephalometric radiography, the present study aimed at investigating and comparing the adaptive TMJ mechanisms in adolescents and young adults treated with the Herbst appliance.

SUBJECTS

Of all Class II patients applying for treatment at the Department of Orthodontics, University of Giessen, since 1995, the first 25 adolescents (12 girls and 13 boys) and the first 14 young adults (10 girls and 4 boys) were selected for Herbst treatment. Early adolescence was defined by the handwrist radiographic stages *MP3-E* to *MP3-G*, and young adulthood was defined by the handwrist radiographic stages *R-IJ* or *R-J*³³ (Fig 1). All patients in both maturity groups were treated with a fixed casted splint Herbst appliance.³⁴ The mean pretreatment age of the adolescents was 12.8 years (range, 11.4-15.7 years) and of the young adults was 16.5 years (range, 13.6-19.8 years). At the start of treatment, the mandible was advanced to an incisal edge-to-edge position in all subjects. Treatment time was, on average, 7.1 months for the adolescents and 8.5 months for the young adults. The distribution of the subjects in relation to skeletal maturity is given in Fig 2.

METHODS

Magnetic Resonance Imaging

MRIs of the TMJ were obtained by means of a Magnetom Expert 1.0 Tesla (Siemens AG) equipped with TMJ coils for simultaneous imaging of the left and right joint. Closed mouth parasagittal proton density weighted spin echo images (TR 2000/TE 40/MATRIX 252×256/FOV 150×150) were obtained from both joints in all subjects. Slice thickness was 3 mm with no interslice gap. The parasagittal MRIs were performed at right angle to the long axis of the condyle.

The MRIs were taken at the following treatment stages:

T0 = before Herbst treatment (mean, 66 days before start of treatment);

T1 = at start of Herbst treatment, when the appliance was placed (mean, 6 days after appliance placement);

T2 = during Herbst treatment (6-12 weeks after appliance placement);

T3 = at end of Herbst treatment, when the appliance was removed (mean, 6 days after appliance removal).

Closed-mouth images taken before treatment (T0) and after treatment (T3) were taken with the teeth in habitual occlusion. At treatment start (T1) and during treatment (T2), the closed mouth images were taken with the appliance in place and the front teeth in contact.

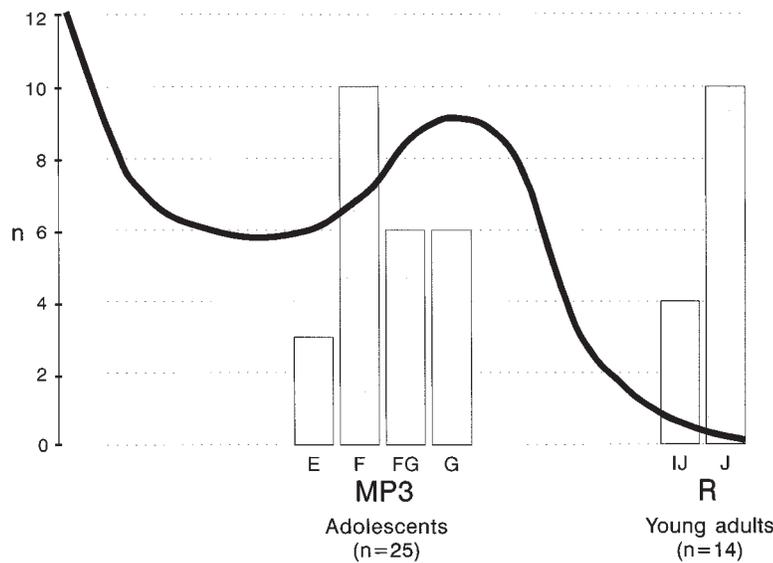


Fig 2. Distribution of early adolescent (n = 25) and young adult (n = 14) subjects with respect to skeletal maturity stages and schematic body height velocity growth curve.

The possible remodeling processes of the condyle and glenoid fossa during Herbst therapy were analyzed by visual inspection of the MRIs.

Radiographic Cephalometry

Lateral head films in habitual occlusion were taken before (T0) and after (T3) Herbst treatment. The radiographs were traced and effective TMJ changes (the sum of condylar remodeling, glenoid fossa remodeling, and positional changes of the condyle within the fossa) were assessed to the nearest 0.5 mm with a modification of the method described by Creekmore³⁵ (Fig 3). All tracings and registrations were performed twice, and the mean value of the duplicate registrations was used in the final evaluation. The effective TMJ changes were related to a reference grid comprising of the occlusal line (OL) and the OL perpendicular through sella (OLp) defined on the before-treatment (T0) radiograph. The following distances were measured: Co/OLp (distance Co to OLp) = horizontal condylar (Co) position and Co/OL (distance Co to OL) = vertical condylar (Co) position.

The effective TMJ changes of the patients treated with the Herbst appliance were compared with those of untreated subjects with ideal occlusion (Bolton Standards).³⁶ The Standards were age related to the individual Herbst patients. In those Herbst patients with an age exceeding 18 years (end of the Bolton Standard data) the 17- to 18-year Standards were used.

In the cephalometric evaluation, no correction

for linear enlargement (approximately 6% for both the Herbst patients and the Bolton Standards) was made.

STATISTICAL METHODS

For the cephalometric variables the arithmetic mean (mean), the SD, and the maximum and minimum were calculated. Student *t* tests for unpaired samples were performed to assess skeletal maturity group differences. Statistical significance was determined at the 0.1%, 1%, and 5% levels of confidence. A confidence level larger than 5% was considered statistically not significant.

Error of the Method

All profile radiographs from 2 examination times (T0, T3) were traced and evaluated twice. The following formula was used for the method error (ME) calculation:

$$ME = \sqrt{\frac{\sum d^2}{2n}}$$

where *d* is the difference between 2 measurements of a pair and *n* is the number of subjects. For the analysis of effective TMJ changes during the period T0 to T3 the method error for horizontal changes (Co/OLp) was 0.6 mm and for vertical changes (Co/OL) was 0.5 mm.

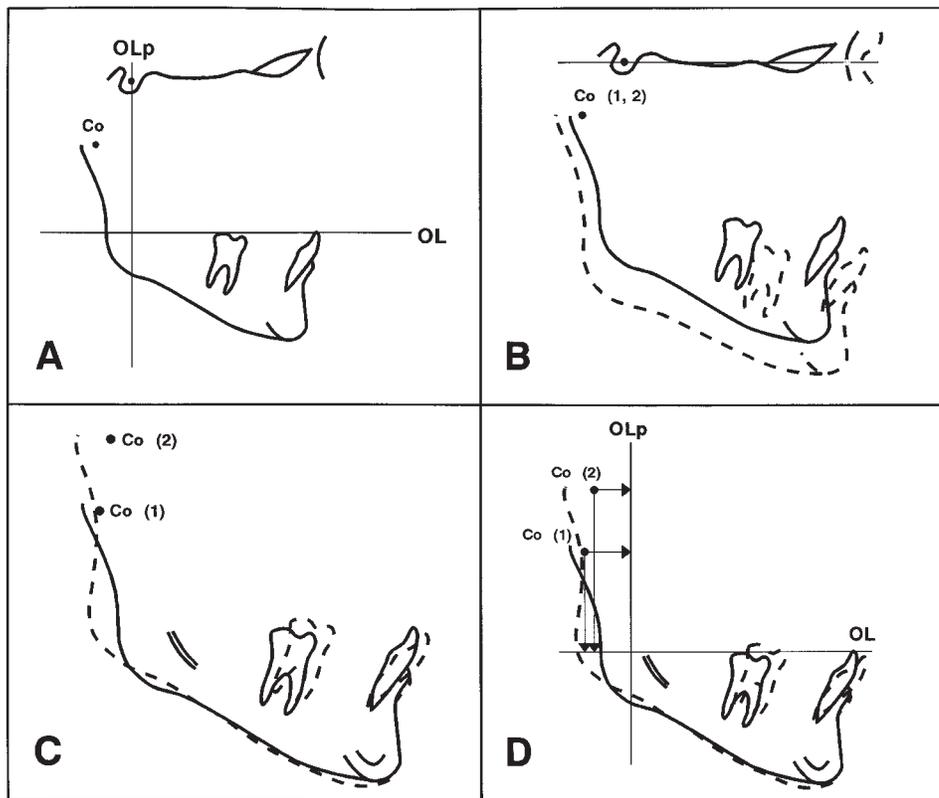


Fig 3. Method for evaluation of effective TMJ changes. **A**, Marking of arbitrary condylar point (Co) on pretreatment head film. **B**, Transfer of Co point to posttreatment head film after superimposition of radiographs on nasion sella line at sella. **C**, Analysis of effective TMJ changes by superimposition of mandibles of 2 head films with anterior contour of symphysis and mandibular canal for orientation. **D**, Measurement of positional changes of Co point in relation to reference grid (OL/OLp).

RESULTS

All subjects were treated to Class I or overcorrected Class I dental arch relationships. During treatment, mandibular prognathism (SNPg-angle) was increased ($P < .001$) by an average of 1.8° in the adolescents and 1.3° in the young adults. The group difference was statistically not significant.

Magnetic Resonance Imaging

Condylar remodeling (Figs 4 and 5). At start of the Herbst treatment (T1), the mandible in all subjects was advanced to an incisal edge-to-edge position. Thereby the condyles were displaced anteriorly out of the glenoid fossa and became positioned on the top of the articular eminence. After 6 to 12 weeks of therapy (T2), the condyles were partially relocated in the fossa. On the MRIs at the time of T2, signs of condylar remodeling were seen in 48 of the 50 TMJs of adolescents and in 26 of the 28 TMJs of young adults. The posteroinferior region of the condyle showed a distinct

area of increased signal intensity (bright areas) immediately below the signal-poor zone surrounding the condyle. In 1 young adult, signs of remodeling could first be identified at the end of the Herbst treatment (T3), when the condyles of all subjects had returned to the original fossa position.

In the young adults, the area of increased signal intensity visible at T2 was situated between 2 signal poor zones (dark areas). One signal poor zone surrounded the condyle, and the other one was situated just above the area of intermediate signal intensity of the bone marrow. This bone marrow demarcation line, which resembled a double contour, was missing in the adolescent subjects.

In young adults the bright area at the condyle could still be seen at the time of removal of the appliance (T3) and occasionally even increased in brightness when compared with T2. On the other hand, for all adolescent subjects, a decrease in signal intensity between T2 and T3 was characteristic. Thus in most

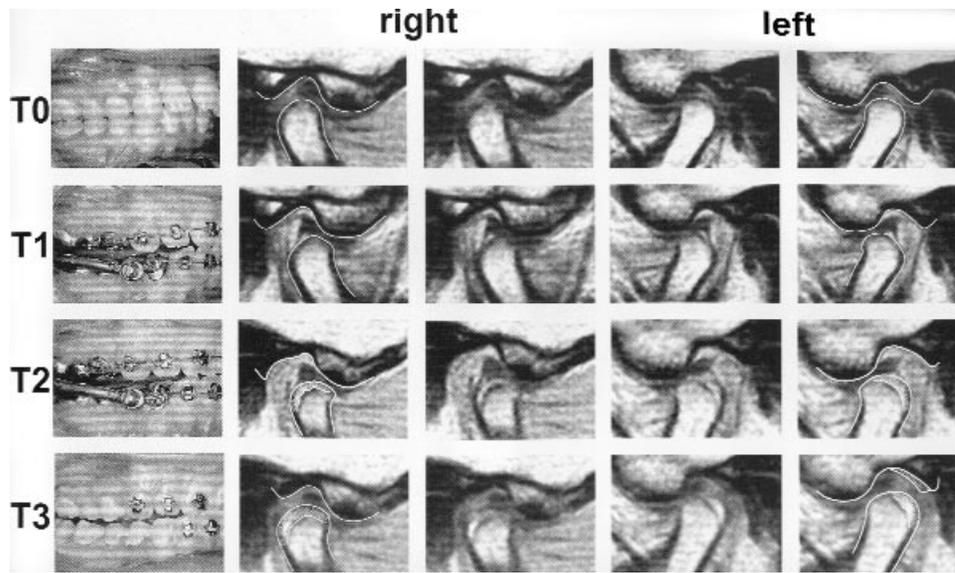


Fig. 4. Case 1: Young adult girl aged 16 years 1 month before Herbst treatment. She is in skeletal maturity stage R-IJ. Intraoral photographs, proton density weighted parasagittal MRIs of left and right TMJ and corresponding tracings of TMJ area from different treatment stages, are shown: before treatment (T0), at start of treatment (T1), at 12 weeks of treatment (T2) and after treatment (T3). Outline of condyle and glenoid fossa and appositional areas are marked in tracings.

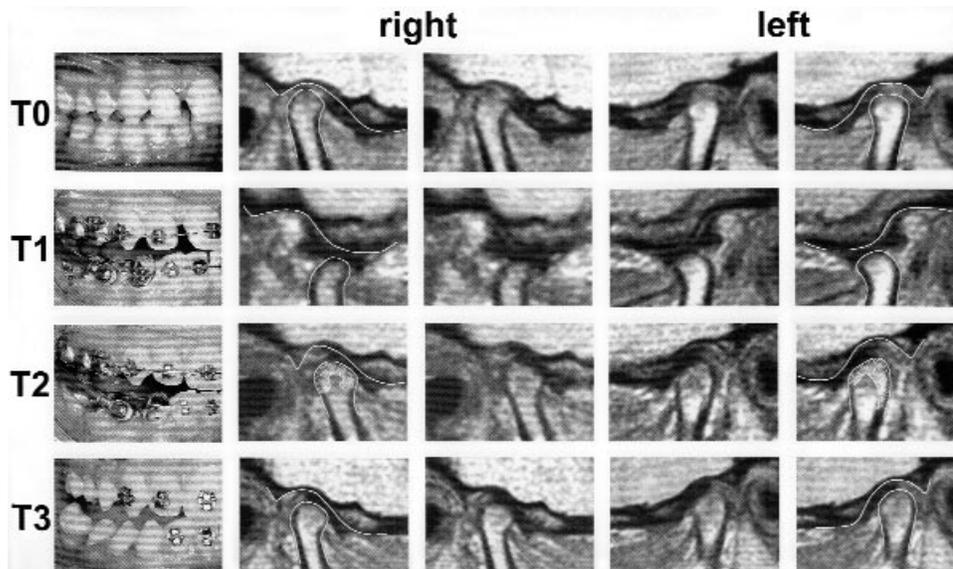


Fig 5. Case 2: Adolescent boy aged 11 years 11 months before Herbst treatment. He is in skeletal maturity stage MP3-E. Intraoral photographs, proton density weighted parasagittal MRIs of left and right TMJ and corresponding tracings of TMJ area from different treatment stages are shown: before treatment (T0), at start of treatment (T1), at 12 weeks of treatment (T2), and after treatment (T3). Outline of condyle and glenoid fossa and appositional areas are marked in tracings. Disc displacement with reduction present before treatment could be reduced.

adolescents, a normal condylar MRI appearance without signs of remodeling was seen at time of removal of the appliance (T3).

However, it must be pointed out that the size and visi-

bility of the zone of increased signal intensity varied between individuals, independent of the skeletal maturity.

Ramus remodeling (Figs 6 and 7). In a few subjects of both skeletal maturity groups (1 adolescent, 2 young

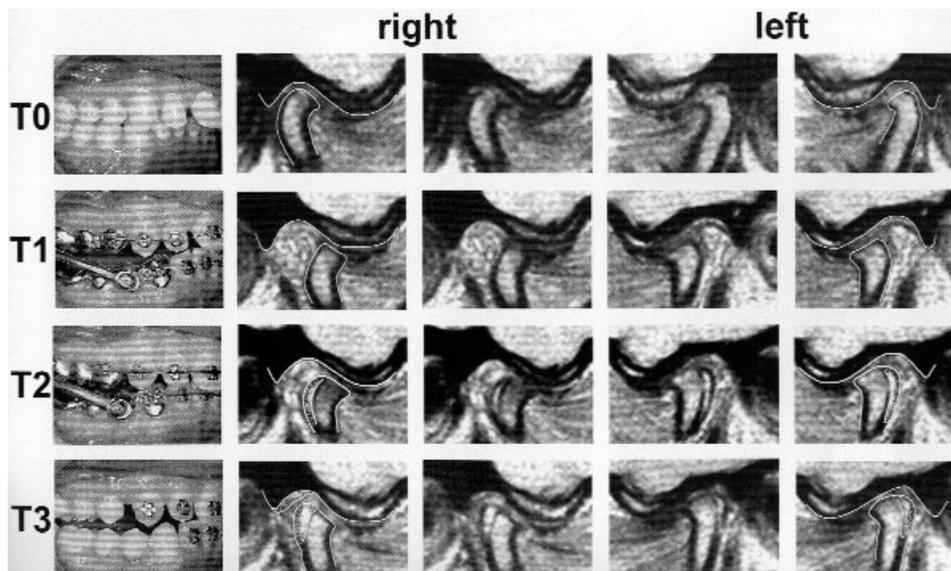


Fig 6. Case 3: Young adult boy aged 19 years 10 months before Herbst treatment. He is in skeletal maturity stage R-J. Intraoral photographs, proton density weighted parasagittal MRIs of left and right TMJ and corresponding tracings of TMJ area from different treatment stages are shown: before treatment (T0), at start of treatment (T1), at 12 weeks of treatment (T2), and after treatment (T3). Outline of condyle and glenoid fossa and appositional areas are marked in tracings. Please note remodeling of mandibular ramus. Disc displacement without reduction was present before treatment and could not be reduced.

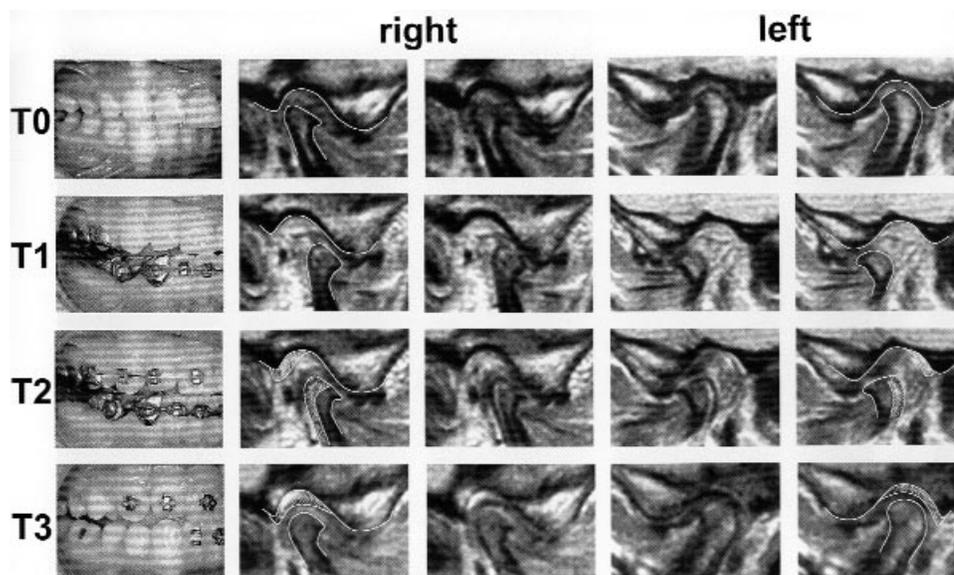


Fig 7. Case 4: Adolescent girl aged 12 years 8 months before Herbst treatment. She is in skeletal maturity stage MP3-FG. Intraoral photographs, proton density weighted parasagittal MRIs of left and right TMJ and corresponding tracings of TMJ area from different treatment stages are shown: before treatment (T0), at start of treatment (T1), at 12 weeks of treatment (T2), and after treatment (T3). Outline of condyle and glenoid fossa and appositional areas are marked in tracings. Please note remodeling of mandibular ramus. At T3 appositional area of glenoid fossa showed no clear demarcation. Disc displacement without reduction was present before treatment and could not be reduced.

adults), the area of increased signal intensity on the posterosuperior region of the condyle extended down the posterior border of the mandibular ramus. This sign of ramus remodeling appeared at time of T2 independent of skeletal maturity. Analogous to condylar remodeling, the signs of ramus remodeling increased between T2 and T3 in the 2 young adults and decreased in the adolescent subject. Interestingly 2 of the subjects (1 young adult, 1 adolescent) exhibited a pretreatment anterior disc displacement without reduction, which could not be reduced during treatment.

Glenoid fossa remodeling (Figs 4 and 7). Signs of fossa remodeling could be visualized in 36 of the 50 TMJs of the adolescents and in 22 of the 28 TMJs of the young adults. In contrast to condylar remodeling, glenoid fossa changes seemed to develop later in the course of treatment, between T2 and T3. This was true for both skeletal maturity groups. In all subjects the adaptive processes were located at the anterior surface of the postglenoid spine. The remodeling was most intensive at the inferior part of the spine and decreased toward the top of the fossa, thus leading to a slight anteclination of the postglenoid spine. In some cases, a double contour of the anterior surface of the postglenoid spine could be seen. In most subjects the amount of the glenoid fossa remodeling was smaller than the amount of condylar remodeling and seemed to be more pronounced in the young adult group.

Radiographic Cephalometry

Effective TMJ changes (Fig 8). In comparison to the age-related Bolton control group, the amount of effective TMJ changes in the adolescent patients treated with the Herbst appliance was, on average, 6 times larger ($P < .001$) in the horizontal and 3 times larger ($P < .001$) in the vertical direction (Table I). In the young adult patients with the Herbst appliance, the horizontal effective TMJ changes were on average 11 times larger ($P < .001$), and the vertical changes were 2 times larger ($P < .01$) than in the Bolton group (Table II). The comparison of the effective TMJ changes between the 2 Herbst groups revealed that, on average, the horizontal and vertical changes were twice as large ($P < .01$) in the adolescent than in the young adult group.

Furthermore, in 19 of the 25 adolescent and in 13 of the 14 young adult patients with the Herbst appliance, the direction of TMJ changes was relatively more horizontal when compared with the Bolton Standards.

DISCUSSION

In the present study, young adulthood was defined by the handwrist radiographic stages R-IJ and R-J, which implied that the subjects were at the end of the

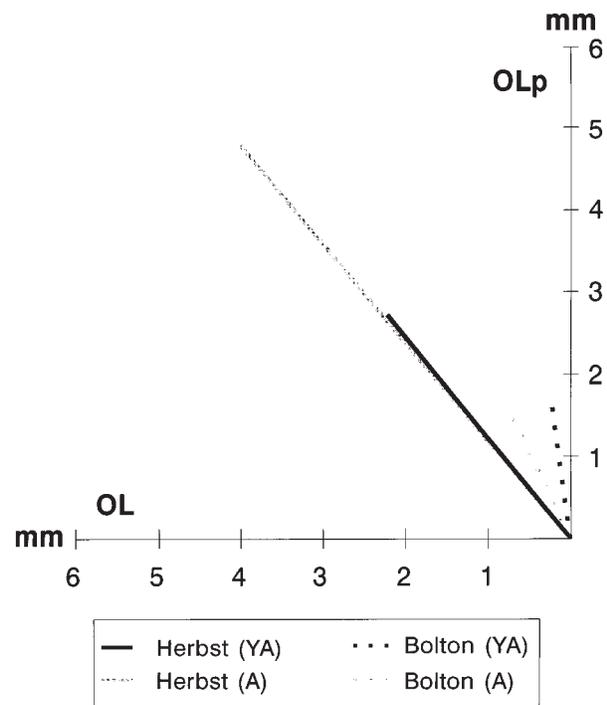


Fig 8. Effective TMJ changes during Herbst treatment in 25 adolescent (A) and 14 young adult (YA) patients treated with Herbst appliance. Age-related effective TMJ changes of Bolton Standards are given. OL/OLp reference grid is shown.

postpubertal growth period (Fig 2) with either minimal (R-IJ) or no residual (R-J) growth.³³ Early adolescence was defined by the handwrist radiographic stages MP3-E to MP3-G, which implied that the subjects were in the acceleration phase of the pubertal growth spurt³³ (Fig 2). This maturity group was intentionally chosen to have a comparison-group with optimal conditions for TMJ growth adaptation to Herbst treatment.^{24,37}

Both skeletal maturity groups exhibited a large pretreatment overjet and a pronounced Class II molar relationship and were comparable in terms of malocclusion severity. All subjects were treated to a Class I or overcorrected Class I dental arch relationship. As shown in an earlier cephalometric study of the same subject, material Class II correction was the result of a combination of dental (posterior movement of the maxillary dentition, anterior movement of the mandibular dentition) and skeletal changes (mandibular length increase, mandibular base advancement). This was true for both the young adults and the adolescents.³⁸

Condylar Remodeling

Even though condylar cartilage matures with age to an adult nonhyperthrophic form,³⁹⁻⁴³ zones of unmin-

Table 1. Effective TMJ changes in 25 adolescents with Class II malocclusion treated with the Herbst appliance and in age-related Bolton Standards. The horizontal (Co/OLp) and vertical (Co/OL) components of TMJ changes are given.

Case	Horizontal changes Herbst Co/OLp (mm)	Vertical changes Herbst Co/OL (mm)	Horizontal changes Bolton Co/OLp (mm)	Vertical changes Bolton Co/OL (mm)	Group difference (horizontal changes) Co/OLp (mm)	Group difference (vertical changes) Co/OL (mm)
1	5.5	4.0	0.8	1.1	4.7	2.9
2	2.8	4.5	0.1	1.5	2.7	3.0
3	3.8	4.8	0.8	1.3	3.0	3.5
4	3.5	5.5	0.9	1.6	2.6	3.9
5	6.3	4.8	0.1	1.8	6.2	3.0
6	1.8	5.0	0.1	1.8	1.7	3.2
7	5.3	11.0	0.8	1.6	4.5	9.4
8	6.5	8.0	1.3	1.3	5.2	6.7
9	3.0	4.3	0.0	1.3	3.0	3.0
10	4.5	4.5	1.1	1.3	3.4	3.2
11	4.8	6.5	0.0	2.0	4.8	4.5
12	4.8	7.5	0.2	1.8	4.6	5.7
13	3.0	5.5	0.3	1.8	2.7	3.7
14	3.5	3.3	1.0	1.0	2.5	2.3
15	4.0	4.0	0.0	0.9	4.0	3.1
16	4.0	3.5	1.3	1.3	2.7	2.2
17	4.5	5.0	0.0	1.8	4.5	3.2
18	2.3	2.5	1.0	1.0	1.3	1.5
19	4.5	2.5	0.9	1.8	3.6	0.7
20	3.8	3.0	0.5	1.5	3.3	1.5
21	2.8	4.3	1.0	1.0	1.8	3.3
22	6.0	5.3	0.0	1.8	6.0	3.5
23	3.5	5.5	1.3	1.8	2.2	3.7
24	3.8	2.5	0.0	2.0	3.8	0.5
25	2.8	4.0	1.2	1.2	1.6	2.8
Mean	4.0	4.9	0.7	1.5	3.5*	3.4*
SD	1.2	1.9	0.6	0.4	1.3	1.8
Maximum	6.5	11.0	1.3	1.8	6.2	9.4
Minimum	1.8	2.5	0.0	1.0	1.3	0.5

* $P < .001$.

eralized growth cartilage⁴⁴ and undifferentiated mesenchyme^{39,45} are seen in the adult mandibular condyle.

Proof that the adult human TMJ is capable of remodeling is derived from observations in connection with condylar fracture therapy,^{46,47} mandibular osteotomies,^{48,49} and anterior mandibular repositioning in disc displacement therapy.⁵⁰⁻⁵³

In interpreting the MRIs the following can be said. During condylar growth, a significant increase in cartilage matrix, which consists to 80% to 90% of water, takes place.⁵⁴ The hydrogen proton in water is highly susceptible to the effects of the magnetic fields because of the high electronegativity of the oxygen. In the proton density-weighted MRIs used in the present study, the contrast of the image reflects the differences in the proton densities (relative number of hydrogen protons per unit volume) between the tissues. Tissues with a high proton density have a high signal and therefore appear bright; tissues with a low proton density have a low signal and appear dark on the MRI. An increase in the relative num-

ber of hydrogen protons per unit volume is thus reflected as an area of intermediate to high signal.

Therefore the increase in MRI signal intensity on the posterosuperior aspect of the condyle found in the MRIs of patients treated with the Herbst appliance taken at 6 to 12 weeks of treatment could possibly resemble the histologically proven hyperplasia of the prechondroblastic-chondroblastic area.^{3,4,6,9,10,55,56} In the adult patients treated with the Herbst appliance this would be the result of a reactivation of the cells of the prechondroblastic zone, thus representing an area of active condylar growth. This interpretation is supported by earlier studies that demonstrated increased cell proliferation⁵⁷ and increased cyclic nucleotide concentrations⁵⁸ in the prechondroblastic zone of adult rats, as a reaction to occlusal alterations. Furthermore, this hypothesis is underlined by the fact that the changes in MRI signal of the patients treated with the Herbst appliance correspond in time to the histologic changes reported in animal studies. In young adult patients

Table II. Effective TMJ changes in 14 young adults with Class II malocclusion treated with the Herbst appliance and in age-related Bolton Standards. The horizontal (Co/OLp) and vertical (Co/OL) components of TMJ changes are given.

Case	Horizontal changes Herbst Co/OLp (mm)	Vertical changes Herbst Co/OL (mm)	Horizontal changes Bolton Co/OLp (mm)	Vertical changes Bolton Co/OL (mm)	Group difference (horizontal changes) Co/OLp (mm)	Group difference (vertical changes) Co/OL (mm)
1	2.5	4.8	0.0	0.8	2.5	4.0
2	2.3	2.8	0.1	1.8	2.2	1.0
3	0.8	2.8	0.1	2.2	0.7	0.6
4	1.8	2.3	0.0	0.6	1.8	1.7
5	3.3	3.0	0.4	2.0	2.9	1.0
6	2.3	4.0	0.5	2.3	1.8	1.7
7	3.8	2.3	0.4	2.0	3.4	0.3
8	-0.3	3.8	0.0	1.2	-0.3	2.6
9	2.0	2.3	0.3	1.6	1.7	0.7
10	3.0	2.8	0.3	1.6	2.7	1.2
11	1.8	2.0	0.0	1.1	1.8	0.9
12	2.5	5.0	0.0	1.2	2.5	3.8
13	3.3	1.3	0.3	1.7	3.0	-0.4
14	1.8	-0.8	0.4	2.1	1.4	-2.9
Mean	2.2	2.7	0.2	1.6	2.0*	1.1†
SD	1.1	1.5	0.2	0.5	1.0	1.7
Maximum	3.8	5.0	0.5	2.3	3.4	4.0
Minimum	-0.3	-0.8	0.0	0.6	-0.3	-2.9

**P* < .001.

†*P* < .01.

treated with the Herbst appliance, the MRI signal changes were seen at T2 and persisted until T3, a phenomenon that has also been reported for the histologic tissue reaction of nongrowing monkeys.¹³ However, in adolescents the MRI signal changes were at their maximum at T2 and faded until T3 just as in histologic sections in juvenile monkeys.¹⁰ The size and visibility of this area exhibited large interindividual variation in both skeletal maturity groups. Unlike histologic sections, however, MRI does not allow a specific histodifferentiation and thus cannot definitely prove the described histologic changes.

In contrast to adolescents, the area of condylar remodeling in young adults was located between 2 signal poor zones, 1 surrounding the condyle and the other just above the area of intermediate signal intensity of the bone marrow. This inner “demarcation line” most probably resembles the continuous bony plate at the cartilage-bone interface characteristic of adult condylar morphologic condition.^{13,44} This cartilage-bone interface becomes highly invaginated in young adult monkeys, responding to protrusive function with cartilage hypertrophy, but remains visible in histologic sections.¹³ Because this bony plate at the cartilage-bone interface is missing in growing animals^{13,44} no inner demarcation line was detectable in the MRIs of adolescent patients treated with the Herbst appliance.

Although a marked condylar growth response could be seen in all the present adult Herbst subjects, this was

the case in only a few adult experimental monkeys.^{6,13,16-19} The difference in the findings could be due to a relatively higher age with a decreased cartilage growth potential in the nonresponding animals.⁶ Additionally, the amount of bite jumping in the monkeys¹⁶⁻¹⁹ was considerably smaller (1.5 mm) than in the present patients (mean, 7.4 mm), which could be responsible for the lack in tissue response found in the animals. Finally, it is possible that the stimulus for condylar growth in the older monkeys was reduced as the result of the observation that the animals avoided biting on the protrusion splints used in the experiments.^{6,13}

Ramus Remodeling

The prechondroblastic-chondroblastic layer of the condyle has been shown in animals to correspond to the inner osteogenic layer of the condylar neck and mandibular ramus.^{59,60} Thus the prechondroblastic cells are homologous to the preosteoblasts of the periosteum of the mandible^{55,61} and react in a similar way to mechanical stimuli.¹⁰

According to Petrovic and Stutzmann,⁶² the retrodiscal pad affects mandibular growth by means of a biomechanic and a vascular component. The biomechanic component of the retrodiscal pad is probably responsible for the posterior condylar growth direction and the supplementary lengthening of the mandible during functional appliance treatment. As a result of piezoelectric and other effects, an increase in negative charges occurs along the

posterior border of the ramus, producing increased periosteal bone formation and reciprocally increased bone resorption on the anterior border.

The signs of ramus remodeling seen in 1 adolescent and 2 young adult patients treated with the Herbst appliance most probably resemble the mentioned processes. However, it remains unclear why only 3 of the 39 investigated patients treated with the Herbst appliance exhibited these signs of ramus remodeling. Unclear is also whether the total disc displacement without reduction seen in 2 of the subjects with ramus remodeling before treatment was a possible cause of the increased ramus remodeling.

Glenoid Fossa Remodeling

Histologic animal studies have shown that the temporal bone of the glenoid fossa adapts to protrusive function^{3,6,10,12,56} through a reversal of the normal growth pattern with bone formation along the anterior border and bone resorption on the posterior border.

Fossa remodeling as visualized in 22 of the 28 TMJs of the young adult subjects with the Herbst appliance and in 36 of the 50 investigated TMJs of adolescents occurred at a later treatment stage than condylar remodeling. A similar delay in temporal bone response to altered mandibular function has been shown histologically in young adult monkeys.^{6,14} In juvenile monkeys, on the other hand, new bone deposition started 2 weeks after appliance placement and ceased after 12 weeks.

An explanation for the delayed MRI visualization of adolescent glenoid fossa remodeling in comparison with the histologic findings in animals might be the difference between the adaptive processes of the temporal bone (periosteal ossification) and the condyle (endochondral ossification). The periosteal ossification is not associated with large increases in water content of the tissue and does not seem to result in a marked change in MRI signal intensity. The bone apposition along the postglenoid spine is thus visualized later in the MRI, at the time when the newly formed bone has consolidated.

Fossa remodeling in both skeletal maturity groups was most intensive at the inferior part of the anterior border of the postglenoid spine leading to an anteclination of the spine. This finding is in concordance with those from animals.^{6,14} The new bone formation seems to be induced by tensile forces of the posterior fibrous tissue of the articular disc transmitted to the periosteum experiments.^{6,14} However, the fossa adaptation in the patients treated with the Herbst appliance was less extensive than in the animals, which may be due to the fact that the size of the postglenoid spine in humans is reduced compared with that of the monkeys.⁶

Effective TMJ Changes

It was revealed that effective TMJ changes in both skeletal maturity groups could be significantly increased during the Herbst treatment period of approximately 8 months when compared with a group of untreated individuals with ideal occlusion (Bolton Standards).³⁶ These findings are in agreement with several other Herbst studies that analyzed the treatment effects on mandibular condyle growth.^{21,23-25,63,64} However, the amount of effective TMJ changes was larger in the adolescent than in the young adult group. This is most likely due to the basically larger mandibular growth rate in the adolescents.⁶⁵

Furthermore, the effective TMJ changes were more horizontally (posterior) than vertically (superior) directed. This has also been shown for condylar growth in prepubertal patients treated with the Herbst appliance⁶³ and in mandibular protrusion experiments in growing monkeys.^{5,9} Woodside et al,¹⁴ on the other hand, found that Herbst appliance treatment only stimulated the condylar growth in the vertical direction.

It might be argued that the effective TMJ changes reflect mainly changes in condylar position than condylar and glenoid fossa remodeling. However, in earlier studies with MRIs in both young adult and adolescent patients treated with the Herbst appliance^{30,31} it could be shown that condylar position was, on the average, unchanged through Herbst treatment.

Patients with severe Class II malocclusion at the end of their growth (R-IJ or R-J),³³ such as those treated in the present study, are usually referred for orthognathic surgery.³² It might be argued that, in the young adult patients, a larger reduction in facial profile convexity may have been achieved by means of orthognathic surgery procedures instead of the Herbst treatment. However, substantial improvements in facial profile convexity through Herbst treatment have been shown for both adolescents and young adults.^{38,66} Furthermore, no difference in facial profile convexity reduction could be shown when comparing patients with headgear-activator and mandibular advancement osteotomy.⁶⁷

Because some mandibular protrusion experiments in adult monkeys suggest the development of TMJ pathologic features and regressive remodeling,^{16,17} although other experiments do not,^{6,12-14} all present patients treated with the Herbst appliance (young adults and adolescents) were screened throughout treatment with respect to any signs and symptoms of TMJ disorder, both clinically and by means of MRI. No negative findings could be recorded in any of the patients. On the contrary, in some patients with pretreatment articular

disk displacements, a reduction could be achieved simultaneously to Class II correction.

CONCLUSION

The increase in mandibular prognathism accomplished by Herbst therapy in both adolescents and young adults seems in particular to be a result of condylar and glenoid fossa remodeling. Because the Herbst appliance is most successful in Class II patients at the end of their growth period and the TMJ in these elderly patients is capable of growth adaptation, the treatment method could be an alternative to orthognathic surgery in borderline skeletal Class II cases, thus reducing both risks and costs for the patient. Finally, MRI renders an excellent opportunity to visualize the TMJ remodeling growth processes.

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