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Temporomandibular joint growth adaptation in Herbst treatment: a prospective magnetic resonance imaging and cephalometric roentgenographic study

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SUMMARY The aim of this investigation was to analyse three possible adaptive TMJ growth processes contributing to the increase in mandibular prognathism accomplished by Herbst appliance therapy: (1) condylar remodelling; (2) glenoid fossa remodelling; and (3) condyle-fossa relationship changes. The subjects were 15 consecutive Class II malocclusions (11 males and four females, aged 11.5–17.5 years) treated with the Herbst appliance for an average period of 7 months. Condylar remodelling, glenoid fossa remodelling, and condyle-fossa relationship changes were analysed by means of magnetic resonance imaging (MRI). From each subject, four MR images were evaluated: before treatment, start of treatment (when the Herbst appliance was placed), during treatment (6–12 weeks after appliance placement), and after treatment (when the appliance was removed). 'Effective condylar growth' (= the sum of condylar remodelling, fossa remodelling, and condyle-fossa relationship changes) was analysed with the aid of pre- and post-treatment lateral cephalometric roentgenograms.

In all 15 subjects, Herbst therapy resulted in an increase in mandibular prognathism. After 6–12 weeks of treatment MRI-signs of condylar remodelling were seen at the posterior-superior border in 29 of the 30 condyles. MRI-signs of glenoid fossa remodelling at the anterior surface of the postglenoid spine were noted in 22 of the joints. Condylar remodelling seemed to precede fossa remodelling. The condyle-fossa relationship was, on average unaffected by Herbst therapy. 'Effective condylar growth' during treatment was, on average, approximately five times larger in the Herbst group than in an untreated group with ideal occlusion (Bolton Standards) and the direction of the growth changes was relatively more horizontal in the treated cases. The results indicate that condylar as well as glenoid fossa remodelling seem to contribute significantly to the increase in mandibular prognathism resulting from Herbst treatment, while condyle-fossa relationship changes are of less importance. MRI renders an excellent opportunity to visualize temporomandibular remodelling growth processes.

Introduction

The Herbst bite jumping appliance (Herbst, 1934) has been shown to be most effective in Class II treatment by increasing mandibular growth (Pancherz, 1979, 1981, 1982; Pancherz and Hägg, 1985). Three adaptative processes in the temporomandibular joint (TMJ) are thought to contribute to the changes of mandibular position: (1) condylar remodelling; (2) glenoid fossa remodelling; and (3) condylar position changes within the fossa.

However, the mechanisms contributing to the TMJ response upon bite jumping with the Herbst appliance are still unknown: on orthopantomograms a double contour on the posterior aspect of the condyle was described in one patient (Bakke and Paulsen, 1989); using computed tomography (CT) double contours could be identified on the posterior-superior part

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Table 1 Herbst appliance treatment of 15 Class II malocclusions. Distribution of the patient material.

Case	Gender	Angle Class	Age at start of treatment (years ^{months})	Amount of initial bite jumping (mm)	Treatment time (months)	Treatment result	Increase (degrees) in mandibular prognathism (S–N–Pg)*	Visibility of condylar remodelling on MRI
1	Female	II:1	17^6	10	10	B	3.5	clear
2	Male	II:1	11^5	6	6	A	0.5	clear
3	Male	II:1	13^0	10	5	B	1.5	clear
4	Male	II:1	11^{11}	10	7	A	3.0	clear
5	Male	II:2	15^1	8	7	B	3.0	poor
6	Male	II:1	12^2	11	9	B	2.5	moderate
7	Male	II:1	13^7	right 2/left 5.5	7	B	1.0	moderate
8	Male	II:1	13^9	5	6	B	2.0	moderate
9	Female	II:1	13^4	5	7	A	0.5	poor
10	Female	II:1	15^1	6	6	B	1.0	moderate
11	Female	II:2	13^9	4	8	A	1.0	clear
12	Male	II:1	12^7	8	8	A	3.0	clear
13	Male	II:1	12^0	11	8	A	3.5	clear
14	Male	II:1	15^4	9	6	B	3.0	clear
15	Male	II:1	12^7	7	7	B	2.5	moderate
Mean			13^6	7.6	7.1		2.1	

A = Class I dental arch relationship.
B = Over-corrected Class I dental arch relationship.
* = in the evaluation of the angle S–N–Pg growth at nasion (N) was considered (Pancherz and Sack, 1990).

of the condyle and the glenoid fossa in single subjects (Paulsen *et al.*, 1995); on TMJ roentgenograms double contours of the anterior surface of the post-glenoid spine have been demonstrated in some patients (Pancherz, 1979; Wieslander, 1984; Decrue and Wieslander, 1990); and using roentgenographic cephalometry in a number of patients an insignificant post-treatment anterior condyle position was found (Pancherz and Stickel, 1989).

Roentgenograms and CT have, however, a limited value for cartilage imaging, which is the main area of interest in the study of TMJ growth adaptation. Magnetic resonance imaging (MRI), on the other hand, is a non-invasive technique which allows a valid and reproducible assessment of articular joint cartilage morphology (Eckstein *et al.*, 1994). Due to its superior sensitivity for detection of unmineralized tissue, MRI can be used to visualize cartilage changes at an early stage (Reuther and Mutschler, 1989).

Using MRI and cephalometric roentgenograms the present study aimed to analyse three possible adaptative TMJ mechanisms responsible for the increase in mandibular prognathism accomplished by Herbst therapy: condylar remodelling, glenoid fossa remodelling, and condylar position changes within the fossa.

Subjects

Of all patients visiting the Department of Orthodontics at the University of Giessen and applying for treatment in 1995, the first 15 subjects (four girls and 11 boys) with a Class II malocclusion in the permanent dentition were selected for this prospective investigation. All patients were treated with a cast splint Herbst appliance (Pancherz, 1995). The mean age of the subjects at start of treatment was 13.5 years. Treatment time was on average 7 months. All subjects were treated to a Class I or over-corrected Class I dental arch relationship. Thereby, mandibular prognathism (SNPg angle) was increased by an average of 2.1 degrees. The characteristics of the individual subjects are given in Table 1.

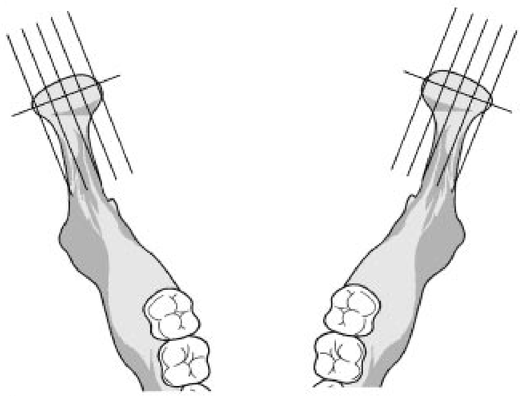

Figure 1 Image plane orientation for the parasagittal MRIs.

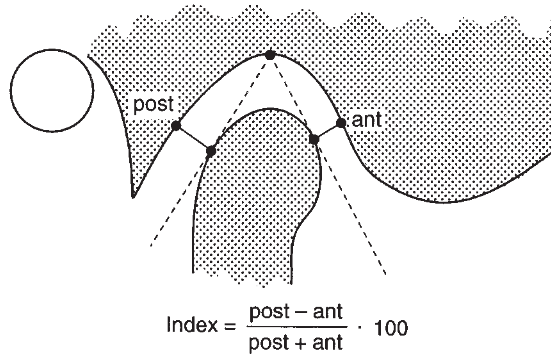

Figure 2 Method for assessment of anterior (ant) and posterior (post) joint spaces (mm).

Methods

Magnetic resonance imaging (MRI)

MRIs of the TMJ were obtained by means of a Magnetom Expert® 1.0 Tesla (Siemens AG, Erlangen, Germany) equipped with TMJ coils for simultaneous imaging of the left and right joints. The MRI protocol included closed mouth parasagittal proton density weighted spin echo sequences (TR 2000/TE 40/Matrix 252 × 256/FOV 150 × 150) and mouth open parasagittal T2-weighted sequences (TR 4500/TE 128/Matrix 230 × 256/FOV 201 × 230) taken perpendicular to the long axis of the condyle (Figure 1). Slice thickness was 3 mm with no interslice gap.

The MRIs were taken at the following treatment stages:

- T_0 — before Herbst treatment (in the mean 28 days before start of treatment);
- T_1 — at start of Herbst treatment, when the appliance was placed (in the mean 6 days after appliance placement);
- T_2 — during Herbst treatment (6–12 weeks after appliance placement);
- T_3 — at end of Herbst treatment, when the appliance was removed (in the mean 4 days after appliance removal).

Closed mouth images before treatment (T_0) and after treatment (T_3) were taken with the teeth in habitual occlusion. At treatment start (T_1) and during treatment (T_2) the closed mouth images were taken with the appliance in place and the teeth in an incisal edge-to-edge position.

The possible remodelling processes of the condyle and glenoid fossa during Herbst therapy were analysed by visual inspection of the MRIs. A quantitative analysis of the remodelling effects of the TMJ would have been valuable. This was attempted by superimposition of the MRIs but proved impossible as slight changes in parasagittal plane orientation occurred between the MRIs from different treatment stages.

In order to assess condylar position changes induced by the appliance an analysis of the anterior and posterior joint spaces in the sagittal plane was performed: the central MRI scans (Figure 1) of both the left and right TMJ from before (T_0) and after (T_3) Herbst treatment were traced and analysed according to the method described by Kamelchuk *et al*. (1996; Figure 2). To eliminate the problem with differences in joint sizes when comparing the individuals a *Joint Space Index* was calculated:

$$\textit{Joint Space Index} = \frac{\text{Post} - \text{Ant}}{\text{Post} + \text{Ant}} \times 100$$

where Post is the posterior joint space and Ant is the anterior joint space.

An Index value of '0' indicates a centric condylar position, a negative value a posterior condylar position and a positive value an anterior condylar position.

Roentgenographic cephalometry

Lateral head films in habitual occlusion were taken before (T_0) and after (T_3) Herbst treatment. The roentgenograms were traced and the 'effective condylar growth' (= the sum of condylar remodelling, glenoid fossa remodelling, and positional changes of the condyle within the fossa) was assessed using a modification of the method described by Creekmore (1967): an arbitrary condylar point (Co) was marked on the pre-treatment head film (T_0) and transferred to the post-treatment head film (T_3) after superimposition of the radiographs on the nasion sella line at sella. For analysis of the 'effective condylar growth' the mandibles of the two head films were superimposed using the anterior contour of the symphysis and the lower mandibular border for orientation. The positional changes of point Co were measured in relation to a reference grid comprising the pre-treatment occlusal line (OL) and the occlusal line perpendicular (OLp) through sella (Figure 3). The following distances were recorded: Co/OL (distance Co to OL) = vertical condylar point position; and Co/OLp (distance Co to OLp) = horizontal condylar point position.

For comparison of the measured growth increments of the Herbst patients with those of untreated subjects with ideal occlusion, the Bolton Standards (Broadbent *et al*., 1975) were used. The annual tracing of the Standards were analysed according to the method described above. In the comparisons, the Standards were age and treatment time related to the individual Herbst cases.

In the cephalometric evaluation no correction for linear magnification (approximately 6 per cent for both the Herbst cases and the Bolton Standards) was made.

Statistical methods

All measurements from the MRIs and cephalometric roentgenograms were performed twice and the mean value was used in the final evaluation. For the different variables the arithmetic mean (Mean), the standard deviation (SD), the maximum (Max) and minimum (Min) were calculated. Student's t-tests were performed to assess the statistical significance of the changes in anterior and posterior joint spaces as well as the 'effective condylar growth' of the Herbst patients in comparison with the Bolton Standards. The statistical significance was determined at the 0.1 and 5 per cent levels of confidence. *P*-values larger than 5 per cent were not considered statistically significant (NS).

Error of the method

For the assessment of the method error, the MRIs and cephalometric roentgenograms of all subjects 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 two measurements of a pair and *n* is the number of subjects. In the analysis of the *Joint Space Index* the method error for the MRIs was 9.1 before treatment and 7.5 after treatment. In the analysis of 'effective' condylar growth changes the method error for horizontal changes (Co/OLp) was 0.8 mm, and for vertical changes (Co/OL) 0.6 mm.

Results

Magnetic resonance imaging (MRI)

Condylar remodelling. At the start of Herbst treatment (T_1) the condyles in the 15 subjects were advanced anteriorly by varying amounts (depending on the degree of mandibular advancement with the Herbst telescope mechanism; Table 1) to become positioned on the articular eminence. After 6 to 12 weeks of therapy (T_2), the condyles in the patients were partially relocated in a posterior direction in the glenoid fossa. At T_2 the posterior-superior region of the condyle showed a distinct area of increased signal intensity (bright area) immediately below the signal-poor zone surrounding the condyle (dark area) in 29 of the 30 investigated TMJs. This was true both in the proton density weighted and in the T2 weighted parasagittal scans. The

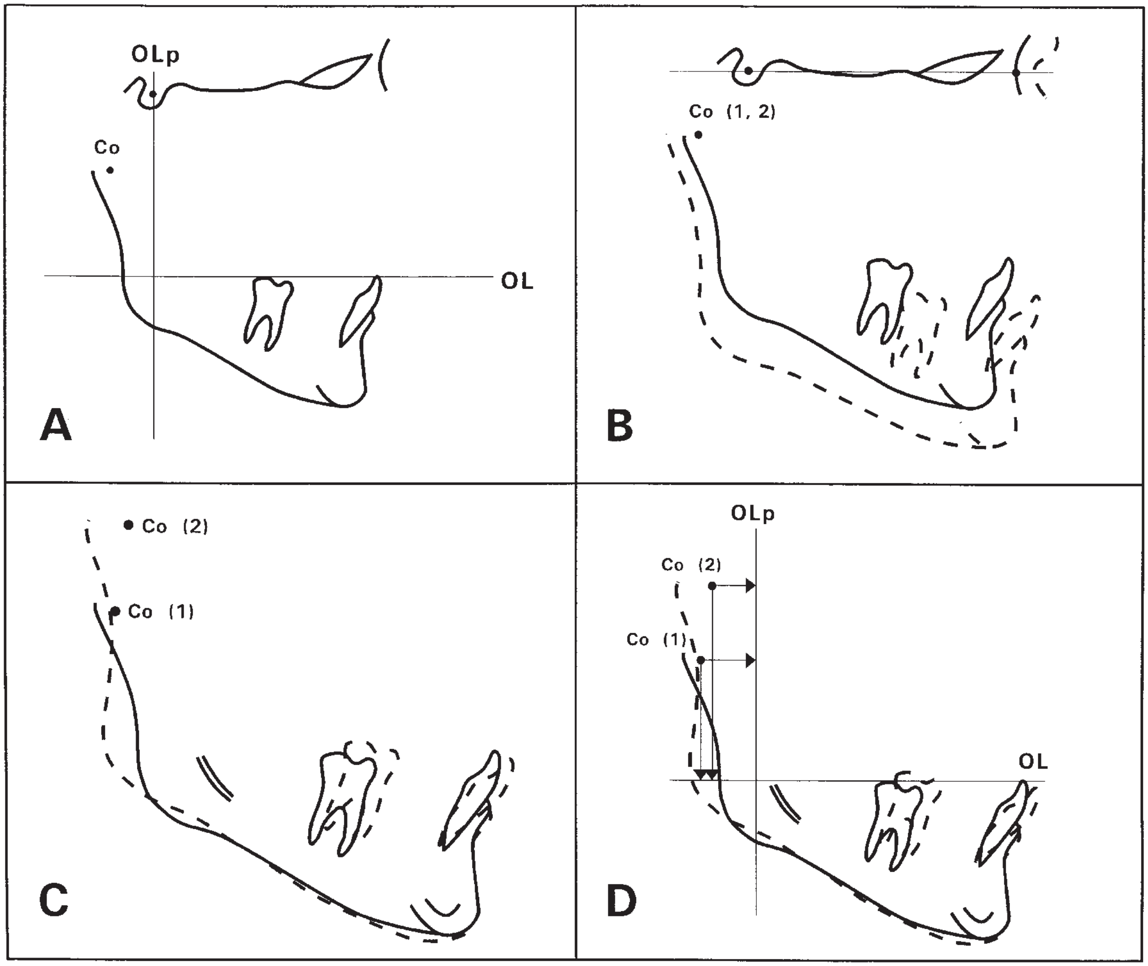

Figure 3 Technique for the evaluation of 'effective condylar growth'. (A) Marking of an arbitrary condylar point (Co) on the pretreatment head film. (B) Transfer of point Co to the post-treatment head film after superimposition of the radiographs on the nasion sella line at sella. (C) Analysis of the 'effective condylar growth' by superimposition of the mandibles of the two head films using the anterior contour of the symphysis and the lower mandibular border for orientation. (D) Measurement of the positional Co changes from pre-treatment (Co1) to post-treatment (Co2) relative to the OL/OLp reference grid.

size and visibility of this zone of increased signal intensity varied between individuals (Table 1, Figures 4–6).

Fossa remodelling (Figure 7). Signs of glenoid fossa remodelling could be visualized in 22 TMJs (11 Herbst patients). In contrast with the signs of condylar remodelling, glenoid fossa changes seemed to develop later in the course of treatment between T_2 (6–12 weeks of treatment) and T_3 (removal of the appliance). The adaptive processes were located on the anterior aspect of the post-glenoid spine in all cases. Most of the remodelling took place at the inferior part of the spine and decreased towards the top of the fossa leading to an anteclination of the post-glenoid spine in comparison with the pre-treatment images. The amount of adaptation of the glenoid fossa was smaller than the remodelling processes of the condyle. The MRI appearance of the

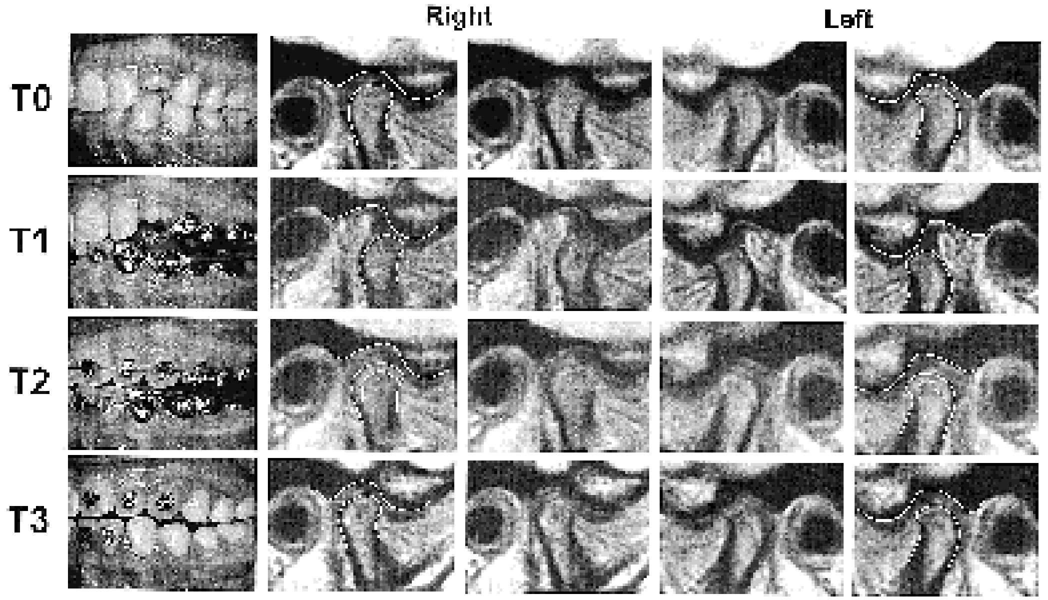

Figure 4 Case No. 11: a girl aged 13 years 9 months treated with the Herbst appliance. The intra-oral photographs, the proton density-weighted parasagittal MRIs of the left and right TMJ, and the corresponding tracings of the TMJ area from the different treatment stages are shown: before treatment (T_0), at start of treatment (T_1), at 7 weeks of treatment (T_2), and after treatment (T_3). The outline of the condyle and the glenoid fossa as well as the appositional condylar area are marked on the tracings.

glenoid fossa remodelling on the MRIs differed between individuals; in 10 subjects the anteclination of the post-glenoid spine could be detected on the proton density-weighted parasagittal MRIs; in five of these subjects additional double contours of the post-glenoid spine could be seen on the T2 weighted parasagittal MRIs, but in one subject signs of glenoid fossa remodelling could only be seen on the T2 weighted MRIs.

Condyle-fossa relationship changes. For the 15 subjects examined the before and after treatment *Joint Space Indices* are given in Figures 8 and 9. None of the condyles was ideally centred in the fossa (Index = 0). A tendency for anterior positioning of the condyles could be seen in most subjects both pre- and post-treatment. The average change of the Index during treatment was not significant: 1.7 (SD 23.6) for the right and 1.6 (SD 28.3) for the left TMJ. This means that condylar position was, on average, unaffected by Herbst treatment. However, a large individual variation existed.

Roentgenographic cephalometry

'Effective condylar growth'. The 'effective condylar growth' in the Herbst and the Bolton groups is given in Table 2 and Figure 10. In comparison with the Bolton group the amount of 'effective condylar growth' in the Herbst group was on average six times larger ($P < 0.001$) in the horizontal and four times larger ($P < 0.001$) in the vertical direction. Furthermore, in 11 of the 15 Herbst cases the direction of 'effective condylar growth' was relatively more horizontal when compared with the Bolton Standards. One case (Case 12) exhibited the same growth direction as the Bolton Standards, while three cases (Cases 6, 10, and 13) showed a slightly more vertical growth direction.

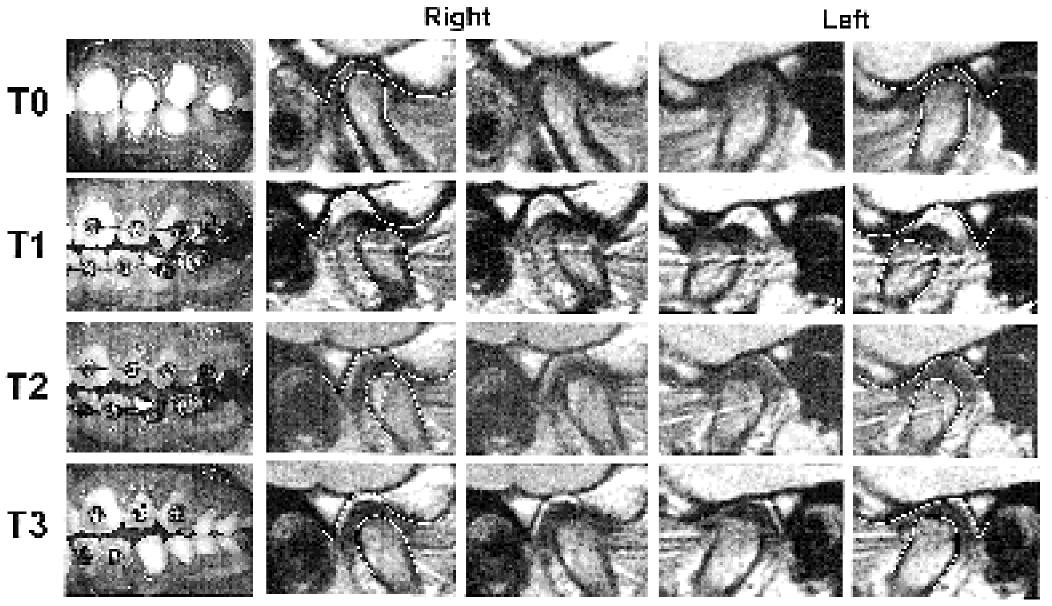

Figure 5 Case No. 13: a 12-year-old boy treated with the Herbst appliance. The intra-oral photographs, the proton density-weighted parasagittal MRIs of the left and right TMJ, and the corresponding tracings of the TMJ area from the different treatment stages are shown: before treatment (T_0), at start of treatment (T_1), at 11 weeks of treatment (T_2) and after treatment (T_3). The outline of the condyle and the glenoid fossa, as well as the appositional condylar area are marked on the tracings. The streak artifact seen on the images at T_1, T_2, and T_3 are caused by the metal of the Herbst splints and the brackets.

Discussion

Especially for the MRI section it would have been desirable to have a suitable control group, but for ethical reasons this was not possible. However, it should be pointed out that MRI changes such as those seen in the Herbst patients have never been observed in MRIs of orthodontically-untreated subjects.

Condylar remodelling

Different theories have been discussed with respect to the mechanism by which the condylar cartilage responds to an altered functional position of the condyle: (1) alteration in the function of the superior head of the lateral pterygoid muscle (Petrovic, 1972; McNamara, 1973); and (2) alterations in the functional loading of the condyle (Kantomaa and Hall, 1988) resulting in changes of the intracellular cAMP (Bourret and Rodan, 1976) and Ca^{2+} (Ingervall *et al.*, 1972) concentrations as biochemical signal transducers or pressure induced changes in the electric potential of the cartilage as a bioelectric signal (Dannhauer *et al.*, 1990).

Histological studies in animals (Breitner, 1930; Charlier *et al.*, 1969; Petrovic *et al.*, 1975, 1981; Stöckli and Willert, 1971; McNamara and Carlson, 1979; McNamara *et al.*, 1975, 1982) show that an adaptive response in the form of considerable hyperplasia of the prechondroblastic-chondroblastic area of the posterior and posterior-superior border of the condyle takes place following anterior mandibular repositioning. These adaptations reach their maximum at 6 weeks of active treatment with an increased thickness of the subarticular condylar cartilage layer which is three to four times larger than in controls (McNamara and Carlson, 1979). However, large inter-individual differences in tissue reaction have been noted.

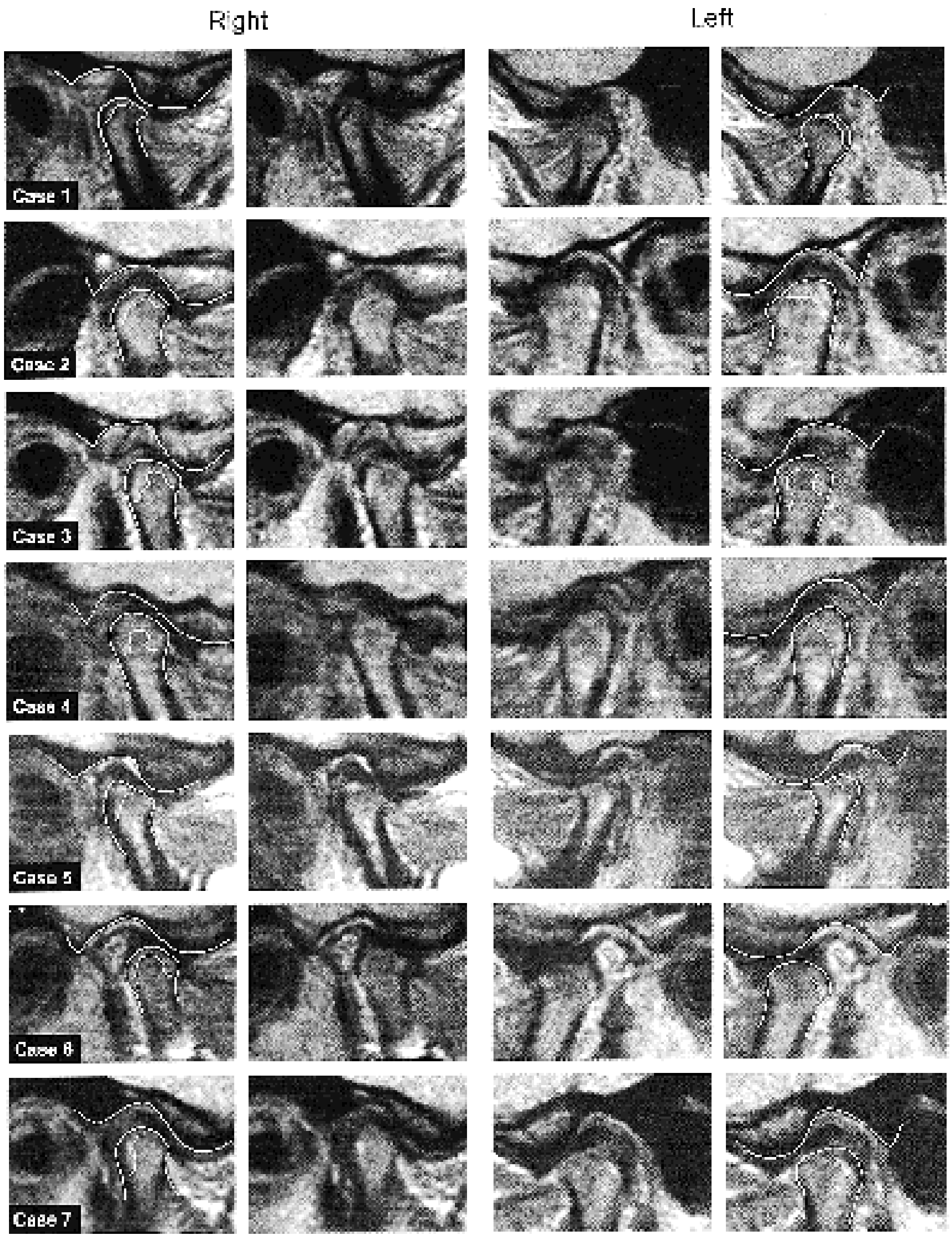

Figure 6 Condylar remodelling in 13 Herbst patients (cases 11 and 13 are presented in detail in Figures 4 and 5) as visualized on the parasagittal MRIs at T_2 (after 6–12 weeks of treatment). The MRIs of the left and right TMJ, and the corresponding tracings of the TMJ area are shown. The outline of the condyle and the glenoid fossa, as well as the appositional condylar area are marked on the tracings.

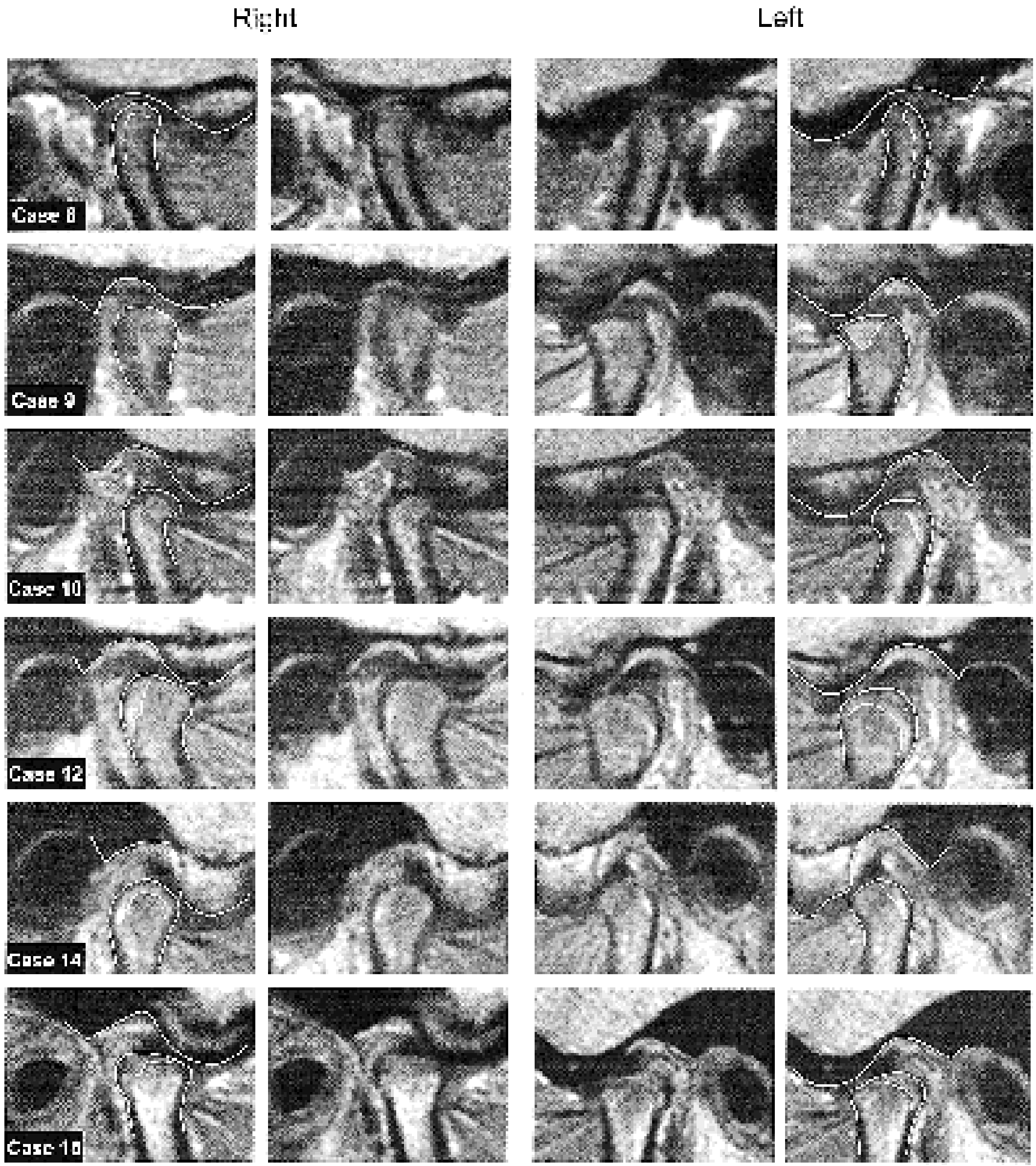

Figure 6 (Continued).

In proton density-weighted MRIs 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*, while tissues with a low proton density have a low signal and appear *dark* on the MRI. The proton density weighted MRIs of the Herbst patients taken at 6–12 weeks of treatment show an area of increased signal intensity (*bright* area) at the posterior–superior aspect of the condyle. The size and visibility of this area exhibit large inter-individual variation (Figures 4–6). Unlike histological

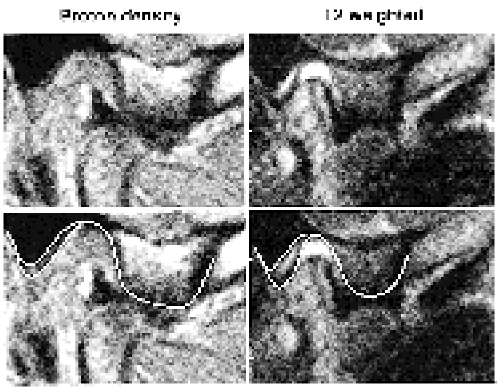

Figure 7 Fossa remodelling in a Herbst patient (case 14) as visualized in the proton density weighted and T2-weighted parasagittal MRIs. The outline of the glenoid fossa and the appositional area on the anterior aspect of the post-glenoid spine are marked on the tracings.

sections, however, MRIs do not allow a specific histological differentiation.

The normal histology of the mandibular condyle shows different histologic layers: the articular, proliferative, and upper and lower hypertrophic layers. Cell size and cell diameter as well as the amount of extracellular matrix per cell increase from the top of the articular layer to the lower hypertrophic layer. In monkeys it has been shown, that during mandibular condylar growth, cartilage matrix production exceeds chondrocyte enlargement (Bosshardt-Luehrs and Luder, 1991). The volume of cartilage matrix depends to a considerable degree on its extensive water content. In water, hydrogen is very susceptible to the effects of the magnetic field in MRI due to the high electronegativity of the oxygen. Therefore, if an intermediate signal on the proton density weighted images and a clearly increased signal on the T2-weighted images, as in the Herbst patients, is seen (bright area) there could be an increase in water content of the tissue. This possibly resembles the histologically proven hyperplasia of the prechondroblastic-chondroblastic area (McNamara and Carlson, 1979) and, thus, represents an area of active condylar growth. This hypothesis is underlined by the fact that changes in the MRI signals of the Herbst patients at T_2 (6–12 weeks of treatment) correspond in time to the changes reported in the histologic animal studies (McNamara and Carlson, 1979).

Fossa remodelling

Animal studies have shown that the temporal bone of the glenoid fossa adapts to protrusive function (Breitner, 1930; Stöckli and Willert, 1971; McNamara and Carlson, 1979; Hinton and

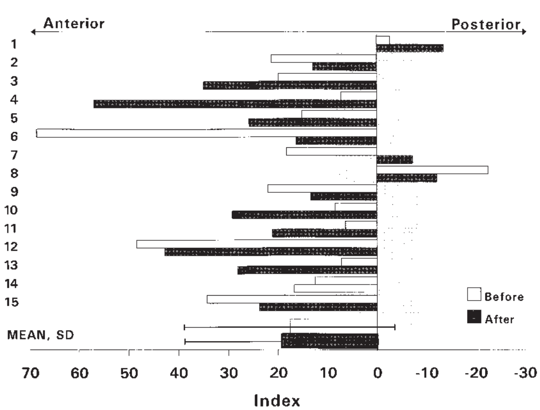

Figure 8 The Joint Space Index of the *right* TMJ in 15 Herbst patients (cases 1–15) before and after treatment. The method error for the registrations is shown as a grey shaded area. A positive value implies an anterior condylar position in the glenoid fossa, while a negative value indicates a posterior condylar position.

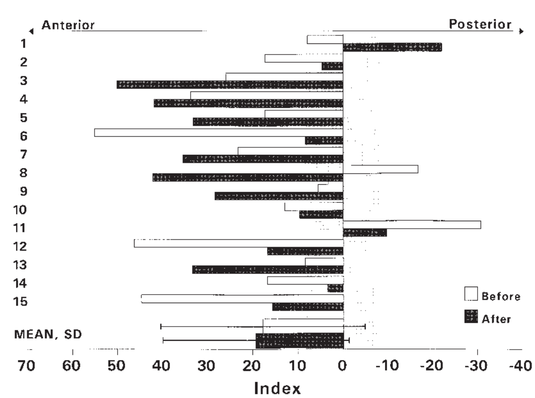

Figure 9 The Joint Space Index of the *left* TMJ in 15 Herbst patients (cases 1–15) before and after treatment. The method error for the registrations is shown as a grey shaded area. A positive value implies an anterior condylar position in the glenoid fossa, while a negative value indicates a posterior condylar position.

Table 2 'Effective condylar growth' (mm) in 15 Class II malocclusions treated with the Herbst appliance and in the age and treatment time related Bolton Standards. The horizontal (Co/OLp) and vertical (Co/OL) condylar growth components are given.

Case	Horizontal growth Herbst Co/OLp (mm)	Vertical growth Herbst Co/OL (mm)	Horizontal growth Bolton Standards Co/OLp (mm)	Vertical growth Bolton Standards Co/OL (mm)	Group difference (Horizontal growth) Co/OLp (mm)	Group difference (Vertical growth) Co/OL (mm)
1	2.3	4.0	0.4	2.1	1.9	1.9
2	1.8	2.3	0.8	1.5	1.0	0.8
3	3.0	4.3	0.0	1.3	3.0	3.0
4	4.5	4.5	1.1	1.3	3.4	3.3
5	5.0	7.0	0.0	1.1	5.0	5.8
6	4.5	6.5	1.5	1.5	3.0	5.0
7	1.8	5.0	0.1	1.8	1.7	3.3
8	2.8	4.5	0.1	1.5	2.6	3.0
9	0.3	4.0	0.0	1.8	0.3	2.3
10	–0.3	3.8	0.0	1.0	–0.3	2.8
11	2.3	3.8	0.2	2.0	2.0	1.8
12	5.3	11.0	0.8	1.6	4.4	9.4
13	6.5	8.0	1.3	1.3	5.2	6.7
14	1.5	7.8	0.0	1.0	1.5	6.8
15	3.8	4.8	0.8	1.3	2.9	3.4
Mean	3.0	5.4	0.5	1.5	2.5***	4.0***
SD	1.9	2.2	0.5	0.3	1.6	2.3
Max	6.5	11.0	1.5	2.1	5.2	9.4
Min	–0.3	2.3	0.0	1.0	–0.3	0.8

*** $P < 0.001$.

McNamara, 1984; Woodside *et al*., 1987) through a reversal of the normal growth pattern with bone formation along the anterior border and bone resorption on the posterior border.

Glenoid fossa remodelling could be visualized in 11 of the 15 Herbst patients, but at later treatment stages (between T_2 and T_3) than condylar remodelling (T_2). This finding is in agreement with the results of Woodside *et al*., (1987) who reported a greater adaptive response of the monkey temporal bone in the 12-week than in the 6-week animals. A similar delay in temporal bone response to altered mandibular function was shown by Hinton and McNamara (1984) in young adult monkeys. 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 visualization of the adaptive response of glenoid fossa remodelling 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 result in a marked change in MR signal intensity. Therefore, the bone apposition along the post-glenoid spine is visualized later in the MRI, at the time when the newly-formed bone has consolidated.

The anteclination of the post-glenoid spine found during Herbst treatment resembles the findings in animal experiments in which bone apposition was most pronounced in the inferior part of the spine, decreasing towards the top of the fossa (Hinton and McNamara, 1984; Woodside *et al*., 1987).

Furthermore, the area of new bone formation along the anterior border of the post-glenoid spine appeared to be located in the primary attachment area of the posterior fibrous tissue of the articular disc (Hinton and McNamara, 1984; Woodside *et al*., 1987). Therefore, the temporal bone response has been associated with an increase in tensile forces transmitted to the

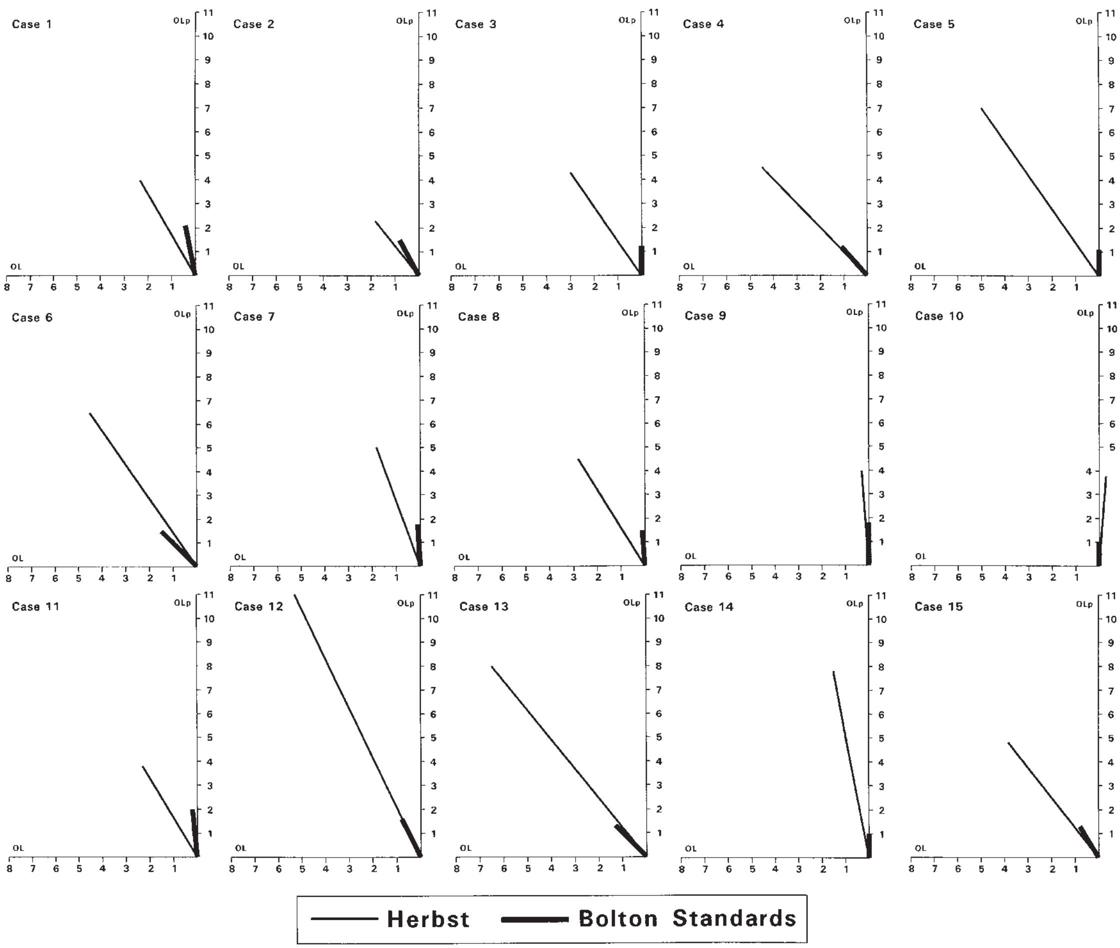

Figure 10 'Effective condylar growth' (mm) in 15 Herbst patients (cases 1–15) after 5–10 months of treatment. The age and treatment time related 'effective condylar growth' of the Bolton Standards is given. The OL/OLp reference grid (see Method) is shown.

periosteum of the post-glenoid spine from the superior stratum of the bilaminar zone.

The decreased amount of adaptation of the temporal bone in the Herbst patients compared with that seen in animal experiments (Hinton and McNamara, 1984; Woodside *et al.*, 1987) may be due to the smaller size of the post-glenoid spine in humans.

Condyle-fossa relationship changes

The clinical significance of the size of joint space remains controversial, as the importance of a decreased or increased joint space is unknown. This is especially the case as no control patients were available. Prior to treatment, the condyles of the Herbst patients were, on average, found to be anteriorly positioned, which is a deviation from ideal concentricity that has been described for Class II division 1 patients (Pullinger *et al.*, 1987). Post-treatment, the average condylar position was insignificantly more anterior than pre-treatment—an observation that has also been made by evaluating lateral head films of Herbst patients (Pancherz and Stickel, 1989). Furthermore, these findings coincide with those of Woodside *et al*. (1987) who, in mandibular protrusion experiments in monkeys, found a proliferation of the posterior part of the articular disc which appeared to fill the space created by condylar displacement thus leading to an anteriorly eccentric condyle position at the end of treatment. Analogous findings have also been reported by Vargervik and Harvold (1985) in activator patients.

'Effective condylar growth'

It was revealed that 'effective condylar growth' could be significantly increased during the Herbst treatment period of 7 months when compared with a group of untreated individuals with ideal occlusion (Bolton Standards). These findings are in agreement with several other Herbst studies analysing the treatment effects on mandibular condyle growth (Pancherz, 1979, 1982; Pancherz and Hägg, 1985; Wieslander, 1984; Pancherz and Littmann, 1989). Furthermore, during the treatment period 'effective condylar growth' was more horizontally (posterior) than vertically (superior) directed, which is in agreement with the results of Elgoyhen *et al*. (1972), McNamara *et al*. (1975), and Pancherz and Littmann (1989). Woodside *et al*. (1987), on the other hand, found that Herbst appliance treatment only stimulated condylar growth in a vertical direction. After removal of the protrusive appliances both in Herbst patients (Pancherz and Littmann, 1989) and in animals (McNamara *et al*., 1975; McNamara and Bryan, 1987) condylar growth direction becomes more vertical, similar to the growth direction found in the Bolton Standards and in untreated growing rhesus monkeys (Elgoyhen *et al*., 1972; McNamara *et al*., 1975).

Conclusions

The increase in mandibular prognathism accomplished by Herbst therapy seems in particular to be a result of condylar and glenoid fossa remodelling, while condyle-fossa relationship changes are of less importance. MRI renders an excellent opportunity to visualize the TMJ remodelling growth processes.

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