

Morphological changes of the TMJ condyles of 100 patients treated with the Herbst appliance in the period of puberty to adulthood: A long-term radiographic study

Hans Ulrik Paulsen

Department of Orthodontics, Copenhagen Municipal Dental Health Service, Denmark

SUMMARY One hundred consecutive patients were treated with the Herbst appliance in the period of puberty to adulthood. The orthopaedic effects on the morphology of the condyles were described from orthopantomographic and transpharyngeal radiographs. The orthopaedic treatment effect was, in most cases, visible as a change in morphology of the condyle, a double contour in the distocranial part of the condyle and sometimes also at the distal surface of the ramus. In patients at the peak of puberty, the double contour was distinct for a short time. In patients in late puberty, the double contour could be seen several months after treatment. At adulthood, males showed, in most cases, double contours, while females showed in most cases nearly unchanged condyles. When double contours were seen, these persisted for a few months to several years after Herbst treatment. The newly formed bone was stable and no TMJ problems were observed. The change in morphology and the double contour of the condyle can be interpreted as bone modelling. The newly formed bone on the posterior part of the condyle can be explained as a response to hypertrophic chondrocytes, and that on the posterior part of the ramus as a response of resting osteoblasts to mechanically induced changes in the condyle (adaptive bone growth). In two cases, remodelling resorption was found in the anterior part of the condyle after Herbst treatment, again as a sign of adaptation to changed mechanical influence. In both cases, later refilling with bone was registered during the remodelling process. The biomechanical effect of Herbst treatment on the mandible is also analogous with an impeded matrix rotation combined with relocation of the mandible.

Introduction

Wieslander (1984) and Decrue and Wieslander (1990) have described the TMJ (temporo-mandibular joint) before puberty (double contours in the roof of the fossa), and Pancherz (1979, 1982), the effect around puberty (increased condylar growth during treatment), and they have carefully followed the effect and stability of the Herbst treatment. Hansen *et al.* (1990) pointed out that the condyle position seems to be unaffected by treatment, even if the mandible is displaced in an anterior-inferior direction at the start of therapy. The normal condyle position seen at follow-up 7.5 years after Herbst treatment was probably achieved by increased condylar growth during treatment and/or remodelling of the articular fossa, as

described by Wieslander (1984) and Pancherz (1979, 1982), and in monkey studies by Stöckli and Willert (1971), McNamara (1980, 1987) and Woodside *et al.* (1987).

Remodelling of the TMJ condyles in late puberty and in late adolescence has been reported in two cases by Bakke and Paulsen (1989) and Paulsen *et al.* (1995).

The aim of this study was qualitatively to describe the changes in morphology of TMJ condyles in 100 patients treated with the Herbst appliance in the period of puberty to adulthood, i.e. growth modification of TMJ condyles.

Subjects and methods

The Herbst sample consisted of 100 consecutive

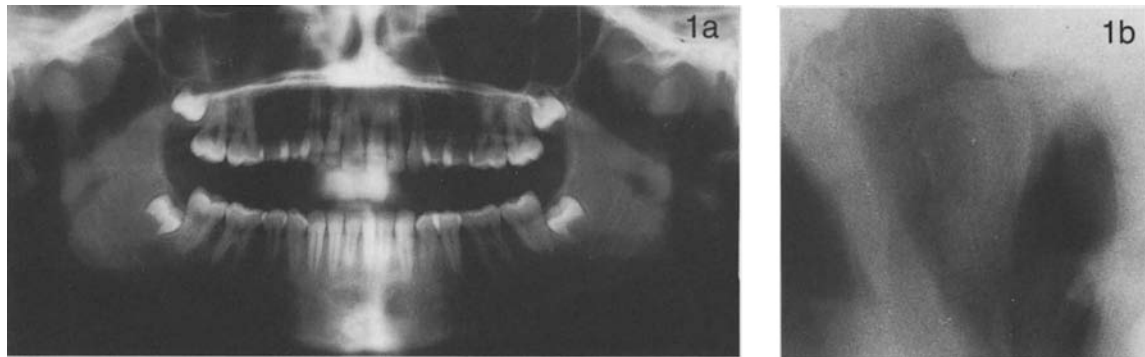


Figure 1 (a) Representative orthopantomograph illustrating the position of the condylar process with the incisors biting in an edge-to-edge contact on a 1 cm thick block. (b) Representative transpharyngeal radiograph of the right condylar process taken from the incisura mandibular on the left side of the face with the incisors biting in an edge-to-edge contact on a 2 cm thick block.

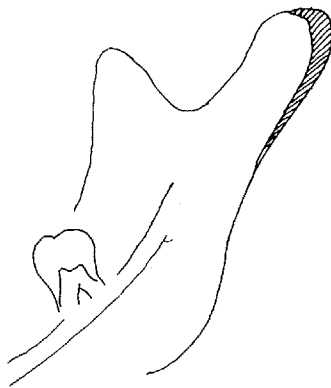


Figure 2 Diagrammatic drawing indicating the extent of orthopaedic treatment effects on the condyle and, on occasions, also on the distal border of the ramus as a change in length of the condyle in a distocranial direction.

patients (64 girls and 36 boys) with extreme Angle Class II malocclusions, late in DS3M1–DS4M2 (Björk *et al.*, 1964). Morphological analysis showed relative retrognathic mandibles. There were no symptoms or signs of cranio-mandibular disorders. The sample was selected from a sample of 1091 orthodontic patients (576 girls and 515 boys).

Treatment

The Herbst appliance was inserted as described by Bakke and Paulsen (1989) and Paulsen *et al.* (1995). In patients with a midline discrepancy and a difference in the amount of distal molar occlusion (asymmetry of the mandible or cranial base) this was normalized during treatment. All

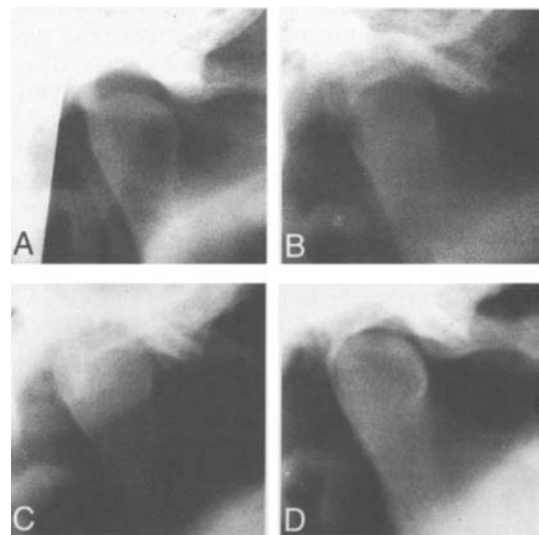


Figure 3 Radiographs showing the effect on the morphology of the right condylar process in a boy with a rapid skeletal turnover treated with the Herbst appliance during the pubertal peak. (A) Pre-treatment. (B) Ten months of treatment. Post-treatment: (C) 4 months, (D) 2 years. Note the change in shape of the cranio-posterior part of the condylar process (B) and later normalization of the morphology of the condyle (C and D). Skeletal maturity assessed according to Helm *et al.* (1971) A: MP₃cap, B: DP₃u, C: MP₃u, D: MP₃u. Height measured without shoes to the nearest 0.5 cm, A: 162.0, B: 174.5, C: 174.5, D: 179.0.

patients were treated to normal occlusion. Orthopantomographs, transpharyngeal radiographs, body stature height, radiographs of hands, plaster models, and radiographs of the face in profile were collected before and

Table 1 Case distribution.

	Chronological age								Total
	10-11	11-12	12-13	13-14	14-15	15-16	16-17	17-18	
Girls	2	7	13	22	12	5	2	1	64
Boys		1	4	9	12	9	1		36
Total	2	8	17	31	24	14	3	1	100

Table 2 Case distribution.

	Skeletal maturity*								Total
	10-11	11-12	12-13	13-14	14-15	15-16	16-17	17-18	
Girls, numbers		1	2	49	12				64
Boys, numbers			2	1	5	24	4		36
Total		1	4	50	17	24	4		100

*Assessed according to skeletal maturity and prediction of adult height (TW2 method), Tanner *et al.* (1983).

Table 3 Case distribution.

	Skeletal maturity*					Total
	MP ₃ =	MP ₃ cap	DP ₃ u	MP ₃ u	Ru	
Girls	1	25	17	18	3	64
Boys	6	23	6	1	0	36
Total	7	48	23	19	3	100

*Assessed according to Helm *et al.* (1971).

Table 4 Case distribution, skeletal maturity.

	Body growth*				Total
	Pre-peak	Peak	Post-peak	Adulthood	
Girls		1	53	10	64
Boys	6		29	1	36
Total	6	1	82	11	100

*Assessed according to differences in body height, measured without shoes to the nearest 0.5 cm.

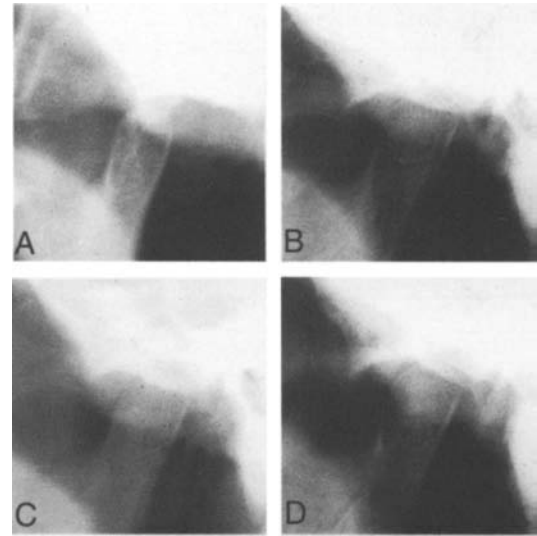
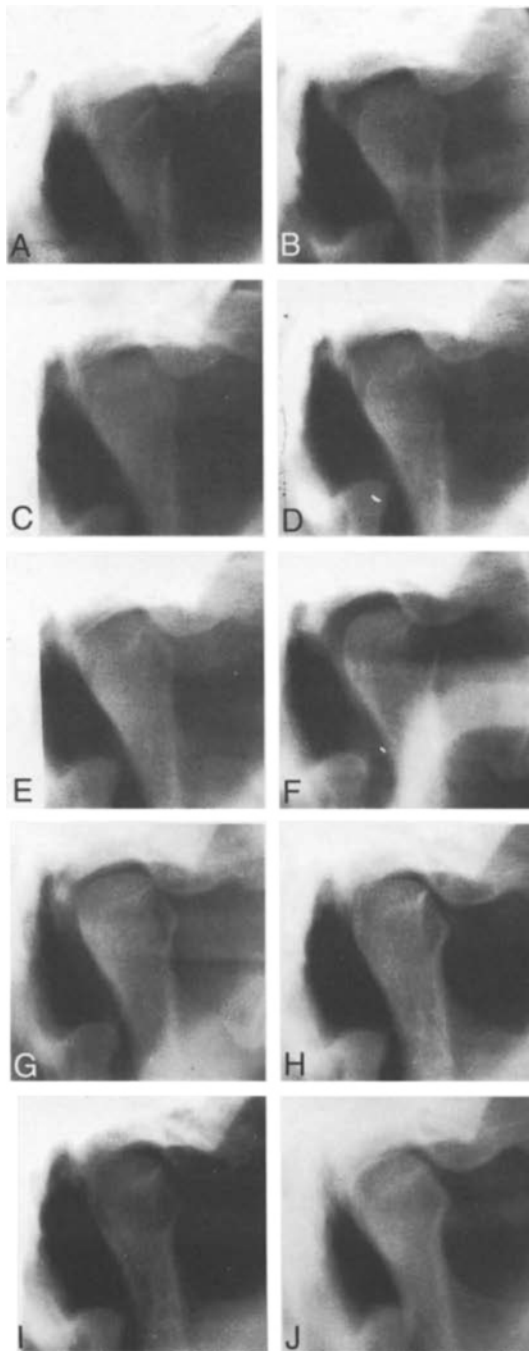


Figure 5 Radiographs showing the effect on the morphology of the left condylar process in a boy treated with the Herbst appliance before the pubertal peak. (A) Pre-treatment. Active treatment: (B) 3 months and (C) 4 months. (D) Seven months post-treatment. Note the change in shape of the cranioposterior part of the condylar process and ramus and the two cortical layers (double contour) during treatment (B and C). Skeletal maturity assessed according to Helm *et al.* (1971), A: MP₃=, B: MP₃=, C: MP₃=, D: MP₃cap. Height measured without shoes to the nearest 0.5 cm, A: 153.5, C: 159.0, D: 170.0.

Figure 4 Radiographs showing the effect on the morphology of the right condylar process in a girl with a slow skeletal turnover treated with the Herbst appliance after the pubertal peak. (A) Pre-treatment. Active treatment: (B) 2 months, (C) 4 months and (D) 6 months. Post-treatment: (E) 8 months, (F) 12 months, (G) 18 months, (H) 2½ years, (I) 3½ years and (J) 4½ years. Note the change in shape of the cranioposterior part of the condylar process and two cortical layers (double contour) during treatment (B–D). Post-treatment. The change in morphology of the condylar process is stable and two cortical layers (double contour) can be recognized (E–J). Skeletal maturity assessed according to Helm *et al.* (1971), A: DP_{3u}, B: DP_{3u}, C: PP_{3u}, D: MP_{3u}, E: MP_{3u}, F: MP_{3u}, G: MP_{3u}, H: MP_{3u}, I: Ru, J: Ru. Height measured without shoes to the nearest 0.5 cm, A: 173.0, D: 173.5, E: 173.5, F: 175.0, G: 175.0, H: 176.0, I: 176.5, J: 176.5.

after Herbst treatment and yearly thereafter. Treatment time for boys: M: 11⁶ SD: 1.29, for girls: M: 10⁸ SD: 1.21. The length of treatment time was to ensure a firm premolar occlusion. Orthopantomograms and transpharyngeal

radiographs were also taken during Herbst treatment. The material was collected in order to evaluate the treatment effect and stability, and to intervene in the event of any adverse side-effects. Treatment effects and stability of the condyles in relation to sex and maturity were followed 5 years after treatment, or at least until growth had ceased.

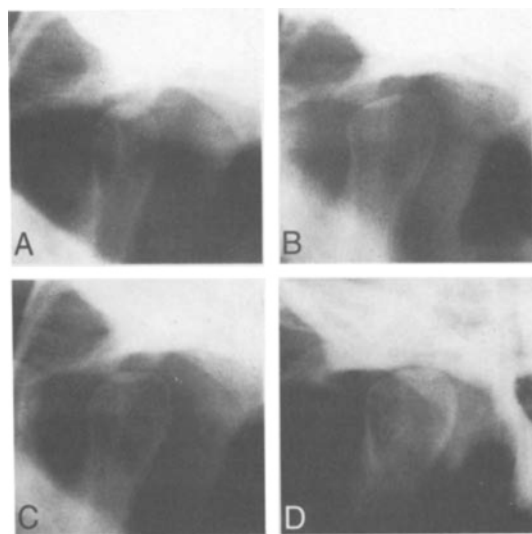


Figure 6 Radiographs showing the effect on the morphology of the left condylar process in a girl treated with the Herbst appliance after the pubertal peak. (A) Pre-treatment. (B) Six months of treatment. Post-treatment: (C) 3 months and (D) 2 years. Note the change in shape of the cranioposterior part of the condylar process and two cortical layers (double contour) during treatment (B). Post-treatment the change in morphology is stable but the two cortical layers (double contour) are blurred (C) and blotted out (D). Skeletal maturity assessed according to Helm *et al.* (1971), A: MP_{3cap}, B: DP_{3u}, C: MP_{3u}, D: Ru. Height measured without shoes to the nearest 0.5 cm, A: 162.5, B: 167.0, C: 168.0, D: 169.5.

Recordings

Orthopaedic effects on the morphology of the condyles were investigated from orthopantomographic and transpharyngeal radiographs. The quality of the radiographs is illustrated in Figure 1(a,b). The morphological effect was assessed qualitatively, comparing the radiographs before, during and after Herbst treatment (Figure 2). Chronological age, skeletal age (TW2 method) (Tanner *et al.*, 1983) modified for the Danish population (Helm, 1979; Altermann and Schnack, 1980), skeletal maturity (Helm *et al.*, 1971) and growth rate in stature height were used to determine the patient's skeletal age (Tables 1, 2, 3 and 4). The various methods were used to show the great variability in patient age compared with different treatment decisions. The TMJ was followed until growth had ceased.

Orthopantomograms were obtained with

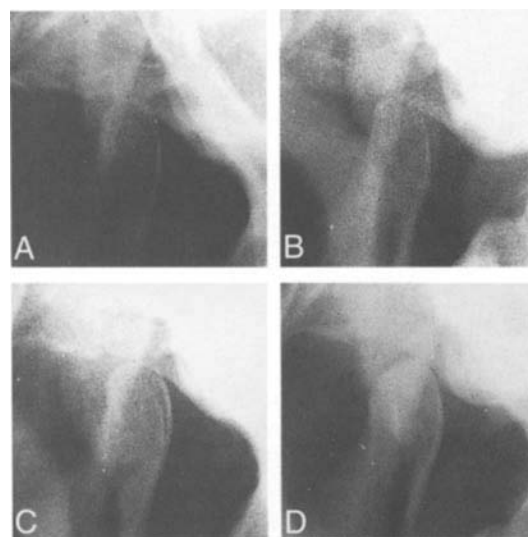


Figure 7 Radiographs showing the effect on the morphology of the right condylar process in a female treated with the Herbst appliance at the end of puberty. (A) Pre-treatment. (B) Three months of treatment. Post-treatment: (C) 1 year, (D) 2½ years. Note the change in shape of the cranioposterior part of the condylar process and two cortical layers (B). During treatment the inner contour appeared to be more radiopaque than the outer contour; 1 year after treatment the outer contour was more radiopaque than the inner contour (C). Two and a half years post-treatment the change in morphology is stable but no double contour can be seen (D). Skeletal maturity assessed according to Helm *et al.* (1971), A: MP_{3u}, B: MP_{3u}, C: Ru, D: Ru. Height measured without shoes to the nearest 0.5 cm, A: 167.0, B: 167.5, C: 167.0, D: 167.5.

a Siemens Orthopan 5 (Siemens, Munich, Germany) with the incisors in an edge-to-edge contact biting on a 1 cm thick block just before and after Herbst treatment. Transpharyngeal radiographs were obtained with a Siemens Heliodent 70KV (Siemens, Munich, Germany).

Results

The orthopaedic treatment effect was, in most cases, visible as a change in length and morphology of the condyle in a distocranial direction (Figure 3), as a double contour in a distocranial part of the condyle (Figure 4), and sometimes as a double contour at the distal surface of the ramus (Figure 5). The double contour was generally most distinct 2–6 months after insertion of the Herbst appliance.

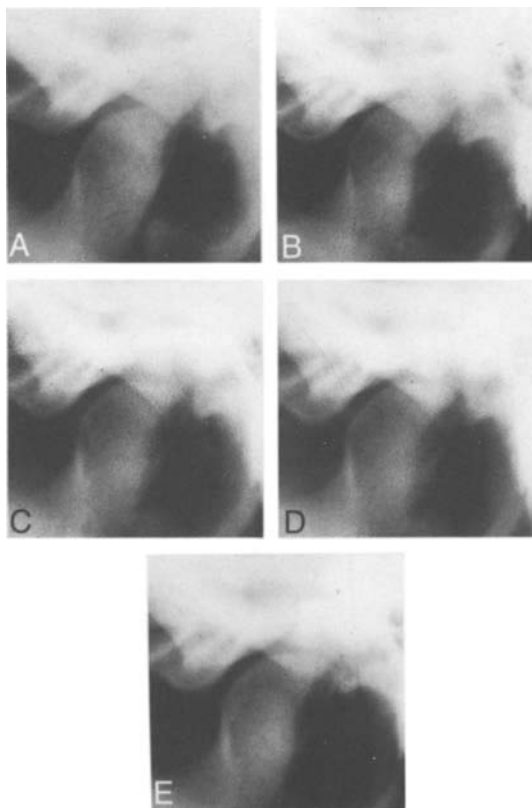


Figure 8 Radiographs showing the effect on the morphology of the left condylar process in a female treated with the Herbst appliance at the end of puberty. (A) Pre-treatment. (B) Treatment for 15 months. Post-treatment: (C) 1 year, (D) 2 years, (E) 3 years. Note the almost unchanged shape of the condylar process. Skeletal maturity assessed according to Helm *et al.* (1971), A: DP_{3u}, B: MP_{3u}, C: MP_{3u}, D: MP_{3u}, E: Ru. Height measured without shoes to the nearest 0.5 cm, A: 162.0, B: 171.0, C: 171.0, D: 171.0, E: 172.0.

In patients at the peak of puberty (peak height velocity of growth, PHV) the double contour was distinct for a shorter time (Figure 6). In patients in late puberty (PHV), the double contours could usually be seen for several months after treatment (Figure 7). One girl in late puberty showed almost unchanged condyles (Figure 8).

Males showed, in most cases, double contours which could usually be seen for a few months to several years after treatment. Females at adulthood showed almost unchanged condyles. If double contours were found, they could be seen for several years (Figure 9).

Where midline discrepancies and differences in

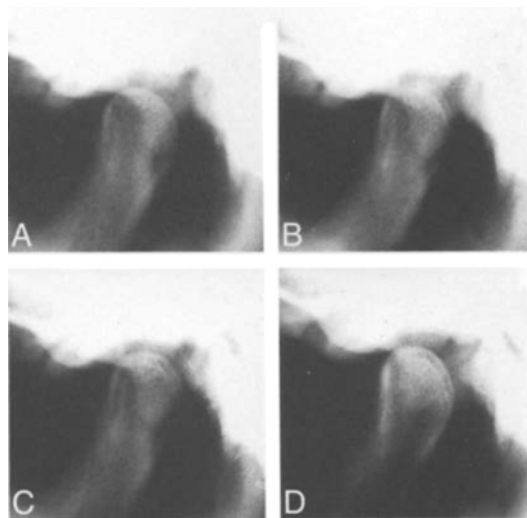


Figure 9 Radiographs showing the effect on the morphology of the left condylar process in a female treated with the Herbst appliance at adulthood. (A) Pre-treatment. (B) Active treatment over 8 months. Post-treatment: (C) 1 year and (D) 2 years. Note the change in shape of the cranioposterior part of the condylar process and two cortical layers (B–D). During treatment the inner contour appeared to be more radiopaque than the outer contour (B). One year after treatment the outer contour was more radiopaque than the inner contour (C), and 2 years post-treatment the outer contour is heavy and the inner weak (D). Skeletal maturity assessed according to Helm *et al.* (1971), A: MP_{3u}, B: MP_{3u}, C: Ru, D: Ru. Height measured without shoes to the nearest 0.5 cm, A: 172.0, B: 172.0, C: 171.5, D: 171.5.

the amount of distal molar occlusion occurred these were normalized during treatment, and the condyle growth differed in amount and direction (Figures 10 and 11).

In younger patients, opposite effects were registered on the morphology of the condyle during and after Herbst treatment: during Herbst treatment the morphology changed in a distocranial direction; after Herbst treatment, the morphology of the condyle was re-established from the new position to the appearance before Herbst treatment (Figure 12).

One patient showed remodelling resorption of the cortical and spongy bone in the mesio-cranial aspect of the condyle and formation of new bone in the distocranial region of the condyle during Herbst treatment, and a further patient showed the same remodelling resorption after treatment. The resorption of the bone surface was refilled and covered by a layer of

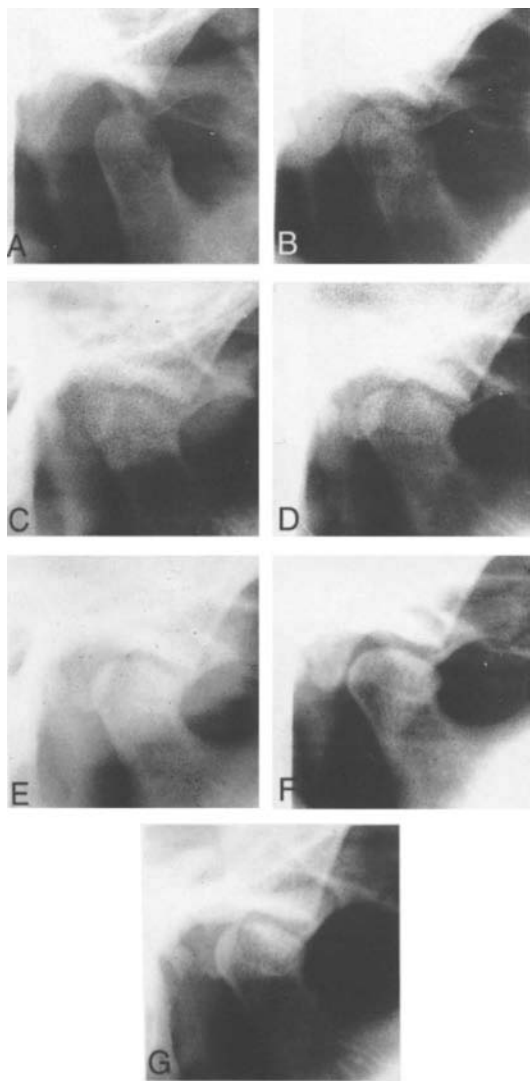


Figure 10 Radiographs showing the effect on the morphology of the right condylar process in a girl treated with the Herbst appliance after the pubertal peak. (A) Pre-treatment. (B) Treatment for a period of 6 months. Post-treatment: (C) 7 months, (D) 1½ years, (E) 2½ years, (F) 3½ years, (G) 4½ years. Note the change in shape of the cranioposterior part of the condylar process in a sagittal direction and the two cortical layers (B). The remodelling processes with bone resorption and apposition can be followed and the double contour can be seen (C–G). The morphology of the condyle is normalized (G). Skeletal maturity assessed according to Helm *et al.* (1971), A: MP₃cap, B: DP₃u, C: MP₃u, D: MP₃u, E: MP₃u, F: MP₃u, G: Ru. Height measured without shoes to the nearest 0.5 cm, A: 161.5, C: 168.0, D: 171.0, E: 171.5, F: 172.0, G: 173.0. (Same patient as Figure 11.)

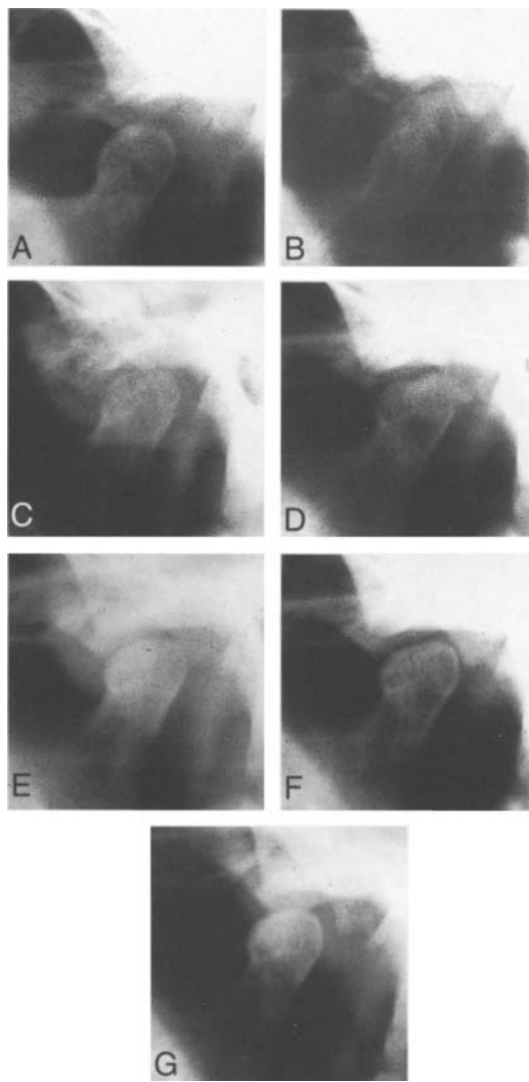


Figure 11 Radiographs showing the effect on the morphology of the left condylar process in a girl treated with the Herbst appliance after the peak of puberty. (A) Pre-treatment. (B) Six months of treatment. Post-treatment: (C) 7 months, (D) 1½ years, (E) 2½ years, (F) 3½ years, (G) 4½ years. Note the change in shape of the cranioposterior part of the condylar process in a vertical direction and two cortical layers (B). The remodelling processes can be followed and the double contour can be seen (C–G). The morphology of the condyles is normalized (G). Skeletal maturity assessed according to Helm *et al.* (1971), A: MP₃cap, B: DP₃u, C: MP₃u, D: MP₃u, E: MP₃u, F: MP₃u, G: Ru. Height measured without shoes to the nearest 0.5 cm, A: 161.5, C: 168.0, D: 171.0, E: 171.5, F: 172.0, G: 173.0 cm. (Same patient as Figure 10.)

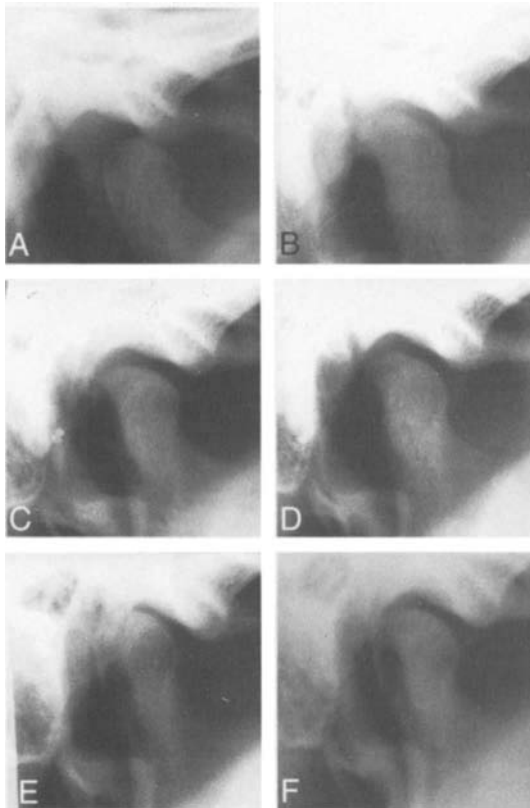


Figure 12 Radiographs showing the effect on the morphology of the right condylar process in a girl treated with the Herbst appliance at the pubertal peak. (A) Pre-treatment. (B) Six months of treatment. Post-treatment: (C) 9 months, (D) 1½ years, (E) 3 years, (F) 4 years. Note the change in shape of the cranio-posterior part of the condylar process in a sagittal direction (B). After treatment normal vertical growth of the condyle 'normalizes' the shape of the condyle (C and D). The final normal morphology is stable as skeletal growth has ceased (E and F). Skeletal maturity assessed according to Helm *et al.* (1971), A: MP₃cap, B: MP₃cap, C: DP₃u, D: DP₃u, E: Ru, F: Ru. Height measured without shoes to the nearest 0.5 cm, A: 148.5, B: 157.5, C: 158.5, D: 161.0, E: 164.0, F: 164.0.

corticalis (Figure 13). The newly formed bone was stable, and no TMJ problems were observed radiographically (Figure 14).

Discussion

Adaptive bone growth in the TMJ condyle due to mechanical usage has previously been shown by Bakke and Paulsen (1989) and by Paulsen *et al.* (1995) in a case from the sample with CT scanning and radiographs during treatment.

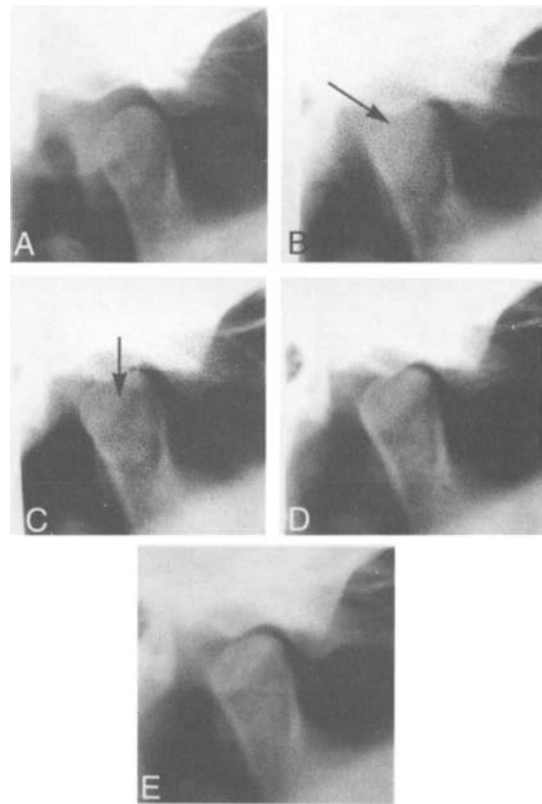


Figure 13 Radiographs showing the effect on the morphology of the right condylar process in a girl treated with the Herbst appliance after the pubertal peak. (A) Pre-treatment. (B) Six months treatment. Post-treatment: (C) 1 year, (D) 2 years, (E) 3 years. Note the change in shape of the cranio-posterior part of the condylar process in a sagittal direction (B). After treatment the condylar morphology normalizes during further vertical condylar growth (C). The condylar morphology is stable (D and E). Skeletal maturity assessed according to Helm *et al.* (1971), A: MP₃cap, B: DP₃u, C: MP₃u, D: MP₃u, E: Ru. Height measured without shoes to the nearest 0.5 cm, A: 165.5, B: 168.0, C: 168.0, D: 169.0, E: 169.0.

Condylar cartilage is considered to have four different zones: fibrous connective tissue, proliferation, hyaline cartilage, with randomly distributed hypertrophic chondrocytes, and endochondral ossification (Enlow, 1990).

The 'design' and 'redesign' of bone involves three different processes: bone growth (i.e. enchondral growth), modelling (i.e. endesmal growth) and remodelling. Bone's structural adaptations to mechanical usage have been widely described by Frost (1963, 1990a,b,c,d). In

this study, the change in morphology and the double contour of the condyle can be interpreted as bone modelling adapted from changes in the stress-strain direction and magnitude primarily affecting the hypertrophic chondrocytes to produce increased matrix. This is later converted to bone matrix which mineralizes.

The change in morphology and the double contour of the distal surface of the ramus can be interpreted as bone modelling adapted from the resting osteoblasts covered by periosteum.

Owing to new, adaptive bone deposition on an existing surface (Durkin *et al.*, 1969, 1971; Durkin, 1972), all other parts of the structure undergo relative positional shifts, and adaptive bone remodelling will adjust the shape and size of the area to the new relationship and in that way eliminate the double contour. Selective resorption and apposition processes functionally model and remodel the area in conformity with form and function, as described by Moffet *et al.* (1964). Landmarks and vestiges of former contours and growth levels will remain (cortical drift), and this record permits a reconstruction of the developmental history in any particular area, as described by Enlow (1990). Information which initiates the remodelling process is considered to be the second messengers, described by Sandy and Farndale (1991).

Information which initiates the biomechanically induced remodelling process is considered to be contained within the various soft tissues, which act as a functional matrix to control bone growth. The growth in the condyle is considered to be adaptive in nature and the primary function of the condylar cartilage is to provide enough growth to enable the condyle to remain in contact with the articular fossa, while the mandible is being carried down as a result of forces exerted by the surrounding soft tissues. Relocation and remodelling will change the shape, size and biomechanical aspects to coincide with functional requirements (Moss, 1969; Moss and Salentijn, 1969; Enlow, 1990; Rakosi *et al.*, 1993).

Age difference in bone reaction can be explained as a difference in the speed of the turnover process, the amount of hypertrophic chondroblasts, and resting osteoblasts. This newly

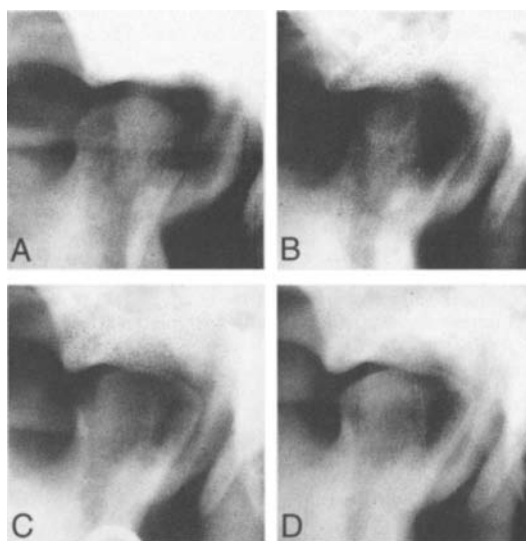
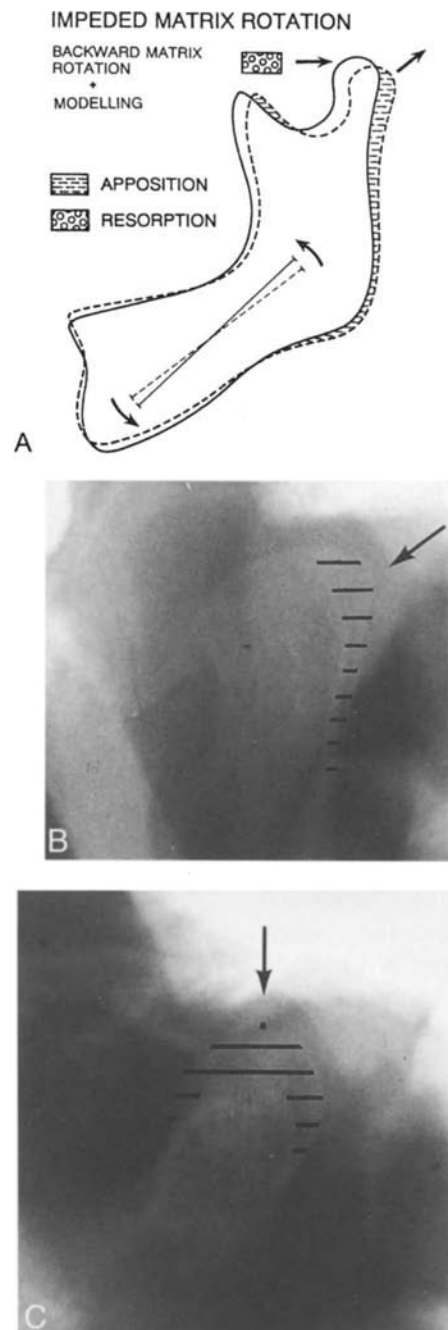


Figure 14 Radiographs showing the effect on the morphology of the left condylar process in a boy treated with the Herbst appliance at the pubertal peak. (A) Pre-treatment (B) Six months treatment. Post-treatment: (C) 2½ years, (D) 4 years. Note the change in shape of the cranioposterior part of the condylar process in a sagittal direction and remodelling resorption of the cortical and spongy bone in the mesiocranial part of the condyle (B). The resorption cavities are refilled and covered by a new layer of corticalis (C), and condylar morphology re-established (D and E). Skeletal maturity assessed according to Helm *et al.* (1971), A: MP₃cap, B: MP₃cap, C: MP₃u, D: Ru. Height measured without shoes to the nearest 0.5 cm, A: 167.5, B: 172.5, C: 181.0, D: 181.0.

formed bone is woven bone which has to be replaced with normal lamellar bone by the remodelling process. Each remodelling process is initiated by activation (A) by which osteoblastic lineage cells start to secrete collagenase which removes the thin layer of unmineralized bone typical of a resting bone surface. This exposes the mineralized bone underneath to the multinucleated, mobile osteoclasts. During osteoclastic bone resorption (R), Howship's lacunae can be excavated. A short reversal phase, where the cement line is formed, follows, and then bone formation (F) normally begins. At the termination of the remodelling process, the bone surface is covered by non-mineralized bone and a layer of flat lining cells. The bone is in this way converted into a resting surface and is again covered by a thin layer of unmineralized bone (Mosekilde,

Figure 15 (A) Sketch of impeded matrix rotation of a mandible with original anterior rotation. The axis of the corpus changes its inclination in space in a backward direction (opposite to the effect in a mandible with original backward rotation). This effect is initiated by the Herbst biomechanics and the growth direction of the condylar process is changed in a distocranial direction, because of induced cellular activity in the fibrous cartilage and the periosteal tissue, i.e. growth modifications. In a few cases a similar resorption is induced in the mesiocranial direction. The bone is remodelled in a compensatory fashion to the new position, which depends on the bone turnover. Radiographs showing (B) adaptive growth of the condyle and the ramus in a cranioposterior direction, mostly in a sagittal direction, and (C) adaptive growth of the condyle in a cranioposterior direction, mostly in a vertical direction.



1992). This ARF sequence in bone remodelling was first described by Frost in 1969.

In two cases pronounced resorption of the anterior part of the condyle, following Herbst treatment or during later repair with bone, was observed during the modelling process (modelling drift). One of the cases showed this effect during Herbst treatment (Figure 13), and the other case after Herbst treatment, again as a sign of adaptation to changed mechanical influence. In both cases, later refilling with bone was registered during the remodelling process.

Long-term effects of the Herbst appliance with special reference to the TMJ have been shown by Hansen *et al.* (1990) in cases treated before puberty. However, biomechanical factors that result in changes of the functional activity of TMJs can modify the growth of the structures, especially of the cartilage. In growing individuals, modelling and remodelling are biological mechanisms that serve to maintain the balance between articular form and function, i.e. growth adaptation and growth modification. As normal bone growth related to maturity and sex is also current after Herbst treatment, normal morphology of the condyle is therefore re-established in younger patients (Figure 12). In adulthood, when the growth function of the condylar cartilage is diminished, modelling and remodelling are considered to be the most important mechanisms that maintain functional balance (Frost, 1995). The effect of Herbst treatment in adulthood shows that the morphology of the condyle may no longer return to its original size and shape after unloading.

The biomechanical effect of Herbst treatment

on the mandible is also analogous with the changes in matrix rotation of the mandible as described by Björk and Skieller (1983) and Björk (1991), combined with relocation of the mandible. The treatment effect can be explained from a principal sketch of impeded matrix

rotation (Figure 15A), combined with relocation of the condyle (Figure 15B,C). This effect of Herbst treatment has been shown by Paulsen *et al.* (1995: Figures 2 and 3). However, different amounts of growth direction in the condyles were seen in patients where a midline discrepancy was normalized during Herbst treatment. This biomechanically initiated difference in growth of the condyles (Figures 10 and 11) illustrates that the amount and direction of growth of contralateral condyles can be changed selectively during Herbst treatment. Thus, for the first time it has been shown that impeded matrix rotation of the mandible can be biomechanically initiated (modelling) and changed with different effect in contralateral condyles. A similar growth modification effect of TMJ condyles during Herbst treatment has been shown in an implant study of a child with hemifacial microsomia treated with the Herbst appliance (Sarnäs *et al.*, 1982). This knowledge can be of great value in the treatment of facial asymmetry, as the largest individual asymmetry has been located in the mandible (Holsko, 1967).

The total Herbst effect can, in selected cases, present a biological alternative to orthodontic-surgical treatment (Bakke and Paulsen, 1989). However, the ability to induce remodelling in late puberty in some girls was minimal with condyles seemingly unchanged. This can be due to the fact that biomechanically induced modelling and remodelling of TMJ condyles cannot occur without a potential growth of the cartilage, i.e. hypertrophic chondrocytes in the fibrocartilage.

Conclusion

The newly formed bone on the posterior part of the condyle can be explained as a response to hypertrophic chondrocytes, and the newly formed bone on the posterior part of the ramus to a response from the resting osteoblasts to mechanically induced changes in the fibrocartilage and the bone surface (adaptive bone growth).

The clinical consequences of the induced changes were accelerated growth of the condyles and a change in the direction of the condyles during Herbst treatment, in most cases in a more sagittal direction. Condylar modelling was

selective in amount and direction in the left and right condyles. The consequence of this was normalization of midline discrepancy and differences in the amount of distal molar occlusion when the Herbst appliance was adjusted into the normal midline. The effects on the condyles seem, on average, less pronounced in girls than in boys, and age and maturity also lessened the effect. This will be described in a future publication, mainly based on cephalometric measurements. The long-term effects were stable, with no TMJ problems and newly formed bone was observed.

Normal bone growth related to maturity and sex was continued after Herbst treatment. Growth direction and morphology of the condyle were therefore re-established in younger subjects. However, the effect of Herbst treatment in adulthood showed that the morphology of the condyle may no longer return to its original size and shape after unloading.

The biomechanical effect of Herbst treatment on the mandible is also analogous with an impeded matrix rotation combined with relocation of the mandible.

The described biomechanically induced modelling and remodelling of TMJ condyles cannot occur without a potential growth of the cartilage, i.e. hypertrophic chondrocytes are still present in the fibrocartilage. This aspect will be elucidated in a future study.

Address for correspondence

Hans Ulrik Paulsen
Department of Orthodontics
Copenhagen Municipal Dental Health Service
Peder Lykke School
Brydes Allé 25
2300 Copenhagen S, Denmark

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