Influences of vertical occlusal discrepancies on condylar responses and craniofacial growth in growing rats

Hiroki Sugiyama, DDS; Kayou Lee, DDS; Shinji Imoto, DDS; Akiko Sasaki, DDS; Toshitsugu Kawata, DDS, PhD; Kazunori Yamaguchi, DDS, PhD; Kazuo Tanne, DDS, PhD

Abstract: The present study was conducted to investigate the influence of vertical occlusal discrepancies on condylar remodeling and the subsequent craniofacial growth in growing rats. Thirty 4-week-old male Wistar strain rats were used. A 1-mm-thick metal plate was bonded onto the occlusal surface of the maxillary molars to increase posterior dentoalveolar height. During the early phase of the experiment, the thickness of the proliferative and maturative/hypertrophic zones in the anterior and superior portions of the condyle was significantly smaller in the experimental group than in the controls. The number of TRAP-positive cells was significantly greater in the experimental group than in the controls. At the end of the experiment, decreased ramus height and a large gonial angle were found in the experimental group. Changes in the intra-articular environment associated with vertical occlusal discrepancies may influence condylar and craniofacial growth in growing individuals, although some adaptive response of the condyle may be induced if growth potential remains.

Key Words: Vertical discrepancy, Intra-articular derangement, Condylar cartilage, Craniofacial growth, Rat

The influence of occlusal discrepancy, either horizontal or vertical, on craniofacial growth and morphogenesis is of great interest to orthodontists. Previous studies have demonstrated that changes in mandibular function may have substantial effects on the condylar responses and craniofacial growth.[1-4]

Temporomandibular disorders (TMD), meanwhile, have recently become a greater concern in the field of dentistry.[5-8] Etiologic and clinical studies have suggested various causes for TMD, indicating that it is multifactorial in nature. Among these causes are occlusal and skeletal discrepancies and the relevant mandibular or condylar displacement, both of which are assumed to induce biological disturbances in the TMJ space. These are speculated to have some relationship to the onset of TMJ internal derangement with or without condylar deformity. With these considerations in mind, morphologic and functional changes in the craniofacial region have been studied with special reference to the TMJ components, demonstrating that mandibular growth is influenced by biologic and mechanical factors.[9-12] However, there has been controversy about whether or not the condyle has the potential for adaptive growth and remodeling in response to alterations in the intra-articular environment.

The purpose of this study was to reveal, by means of histochemical and morphometric techniques, condylar responses and craniofacial growth in relation to vertical occlusal discrepancy produced by increasing the posterior dentoalveolar heights in growing rats.

Materials and methods

Thirty 4-week-old male Wistar strain rats were used in this study. The rats were divided equally into experimental and control groups.

Author Address
Dr. H. Sugiyama
Department of Orthodontics
Hiroshima University School of Dentistry,
1-2-3 Kasumi, Minami-Ku, Hiroshima 734-8553, Japan

Hiroki Sugiyama, assistant professor, Department of Orthodontics, Hiroshima University School of Dentistry, Hiroshima, Japan.

Kayou Lee, graduate student, Department of Orthodontics, Hiroshima University School of Dentistry, Hiroshima, Japan.

Shinji Imoto, graduate student, Department of Orthodontics, Hiroshima University School of Dentistry, Hiroshima, Japan.

Akiko Sasaki, graduate student, Department of Orthodontics, Hiroshima University School of Dentistry, Hiroshima, Japan.

Toshitsugu Kawata, assistant professor, Department of Orthodontics, Hiroshima University School of Dentistry, Hiroshima, Japan.

Kazunori Yamaguchi, associate professor, Department of Orthodontics, Hiroshima University School of Dentistry, Hiroshima, Japan.

Kazuo Tanne, professor and chairman, Department of Orthodontics, Hiroshima University School of Dentistry, Hiroshima, Japan.

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Under general anesthesia with sodium pentobarbital, a 1-mm-thick metal plate with a metal mesh base was bonded onto the occlusal surfaces of the upper first molars of the experimental animals using composite resin to create postero-inferior displacement of the mandible or occlusal discrepancy in the vertical direction. Body weight was measured every week during the experiment.

Five rats in each group were sacrificed at three experimental stages, 1, 2, and 4 weeks after initiation of the experiment. Rats were sacrificed using an overdose of sodium pentobarbital and a left ventricular perfusion with 4% neutral buffered formalin.

Lateral cephalograms were taken of all the rats using a rat and mouse cephalometer (RM-50, Asahi Roentgen Industry Co, Kyoto, Japan). The animal's head was fixed firmly with a pair of ear rods oriented vertically to the median sagittal plane. The cephalogram was taken using dental occlusal film (DF-50, Eastman Kodak, Rochester, NY) at 6 mA and 25~35 Kvp with an exposure time of 3.0 seconds. The distances from the median sagittal plane of the rat to the X-ray tube and the film were 250 mm and 25 mm, respectively. Cephalograms were scanned using an image scanner (GT-9000, Epson, Tokyo, Japan) and enlarged five times. Cephalometric analysis was performed on a Macintosh computer (Macintosh Quadra 800, Apple Japan Inc, Tokyo, Japan) according to the modified method of Kiliaridis et al.[13] Landmarks and measurement items were established for the present study, as depicted in Figure 1.

For histological and histochemical examinations, the head of each animal was dissected, kept in 2% neutral buffered formalin at 4ºC for 24 hours, and decalcified with 0.25 M EDTA at 4ºC for about 2 weeks. After demineralization, the temporomandibular joints were embedded in paraffin, and the right and left condyles were cut into serial frontal and sagittal sections of 6 μm.

Every fifth section was stained with tartrate-resistant acid phosphatase (TRAP), and the remaining sections were stained with hematoxylin-eosin (H-E). The H-E stained sections were examined microscopically for histologic changes. The articular cartilage layer was divided into the fibrous (articular), proliferative (chondrogenic), maturative/hypertrophic (cartilaginous), and erosion zones. Five sagittal sections around the

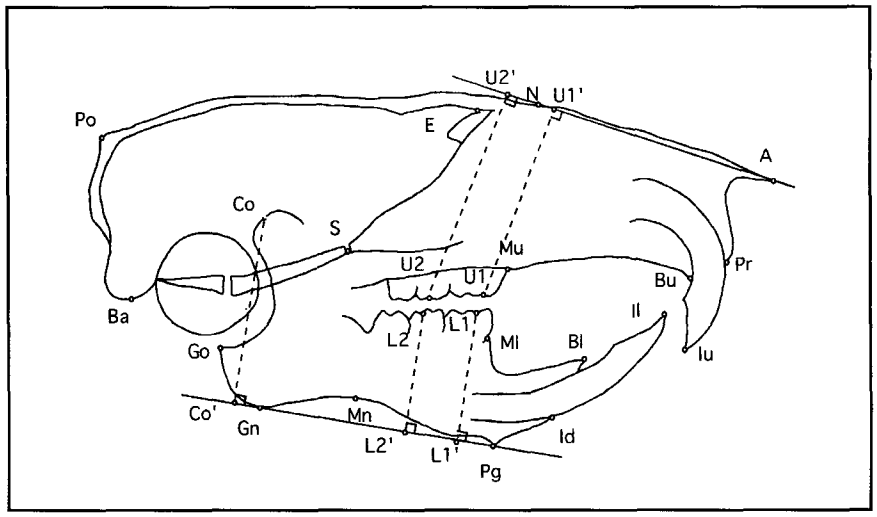

Figure 1
Landmarks and measurement items used for the cephalometric analyses

Po	Posteriormost point on cranial vault
N	Point on the nasofrontal suture
A	Anteriormost point on nasal bone
E	Intersection between frontal bone and most superior-anterior point of the posterior limit of the ethmoid bone
S	Intersection between posterior border of basisphenoid and the tympanic bulla
Ba	Most posterior and inferior point of occipital condyle
Pr	Most inferior and and anterior point on alveolar process of premaxilla
Bu	Point on premaxilla between jawbone and lingual surface of upper incisors
Iu	Most prominent point between incisal edges of upper incisors
Mu	Point on intersection between maxillary bone and mesial surface of upper first molar
U1	Point on mesial occlusal fossa of upper first molar
U1'	Crossing point on A-N perpendicular to A-N from U1
U2	Point on distal occlusal fossa of upper second molar
U2'	Crossing point on A-N perpendicular to A-N from U2
II	Most prominent point between incisal edges of lower incisors
Id	Most inferior and anterior point on alveolar process of mandible
Pg	Point on most inferior contour of lower border of mandible, adjacent to incisors
Mn	Point in deepest part of antegonial notch curvature
Gn	Point on most inferior contour of angular process of mandible
Go	Most posterior point of angular process of mandible
Co	Most posterosuperior point of condylar process
Co'	Crossing point on Pg-Gn perpendicular to Pg-Gn from Co
MI	Point on intersection between the mandibular alveolar bone and mesial surface of first molar
BI	Point on intersection between lingual surface of lower incisors and anteriormost part of lingual alveolar bone
L2	Point on distal occlusal fossa of lower second molar
L1'	Crossing point on Pg-Gn perpendicular to Pg-Gn from L1
L2'	Crossing point on Pg-Gn perpendicular to Pg-Gn from L2

mesiolateral center of the mandibular condyle were selected. According to the method described by McNamara and Carlson,[3] the thickness of each zone was measured perpendicularly to the articular surface for the anterior, superior, and posterior portions of the condylar cartilage on the photomicrographs of these sections (Figure 2). Histochemical staining with TRAP was made according to the method of Cole and Walters,[14] and counterstaining was done with hematoxylin. TRAP staining was used to identify osteoclasts and chondroclasts as well as their precursors[15,16] in the erosion zone of the condylar cartilage (Figure 3). Five frontal sections were selected from each of the anterior, superior, and posterior portions of the whole condyle. The number of TRAP-positive multinucleate cells adjacent to the hypertrophic cartilage layer was determined.

Prior to statistical treatment of these data, handling errors for the cephalometric and histologic measurements were estimated using double recordings of replicated X-ray films and photomicrographs of 10 rats, according to Dahlberg's double determination method.[17] The maximum errors of cephalometric measurements, performed on the lateral cephalograms with 5x magnification, were 0.99 mm and 1.32 degrees for the linear and angular measurements, respectively. The value for histologic measurement was 7.76 μm. It is confirmed from these preliminary findings that the reliability and reproducibility of these methods are acceptable.

The cephalometric and histologic data were subjected to statistical analysis. First, the variances in these values between the experimental and control groups were examined by use of an *F*-test. Then, the differences in cephalometric and histologic measurements between these two groups were evaluated statistically with a Student's *t*-test.

Results

Body weight

The body weight of rats in the experimental and control groups increased continuously with similar incremental change. No significant differences in body weight in either group were found during the entire experimental period (Table 1).

Morphometric findings for the craniofacial skeleton

Means and standard deviations for the linear and angular measurements are shown for both the experimental and control groups in Tables 2 and 3, respectively.

For all the experimental periods, no significant differences in the shape and size of the neurocranium and total skull were found between the experimental and control groups.

Significant differences in gonial angle (CoGo/MnId) and convexity of the angular process (CoGo/GoPg) were found between 5-week-old experimental and control rats, whereas no remarkable differences in skeletal dimensions were found between the two groups. For the dentoalveolar dimensions, meanwhile, significant differences were found between the experimental and control groups. The amount of eruption of the lower first molars (L1-L1′) was significantly smaller and the length of the upper incisors (Pr-Iu) was significantly larger in the experimental group than in the controls. Greater lingual inclination of the upper incisors (IuE/SE, PrIu/MuBu) was also found in the experimental animals.

For the 6-week-old experimental group, a significant downward rotation of the upper viscerocranium was found in comparison with the controls, as noted by a larger angle between the palatal plane and anterior cranial base (MuBu/SE). The mandible in the 6-week-old experimental group presented a larger gonial angle (CoGo/MnId, CoGo/GnPg) and a less convex angular process (CoGo/GoPg), both of which differed significantly from controls. The amount of eruption of the upper first and second molars (U1-U1′, U2-U2′) and the length of the angular process (Go-Mn) were significantly smaller in the experimental group than in the controls.

For the 8-week-old rats, ramus height (Co-Co′) and the lengths of mandibular body (Go-Pg) and alveolar bone (Ml-Bl) were significantly smaller in the experimental group than in the controls. Differences in the angular measurements between the two groups were simi-

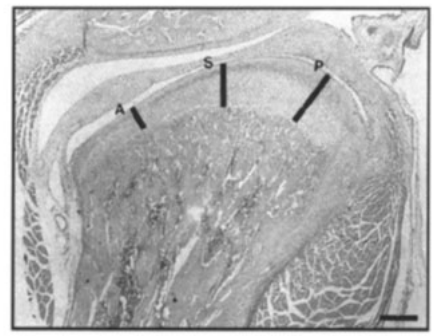

Figure 2
Thickness of the condylar cartilage, measured perpendicularly to the articular surface for anterior (A), superior (S), and posterior (P) portions of the condyle. Bar= 200 μm

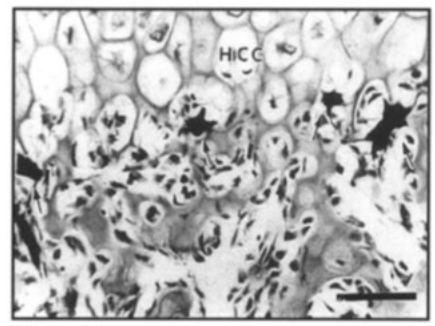

Figure 3
TRAP-positive cells in the erosion zone of the condylar cartilage layer. The multinucleated cells (arrows) stained positive with TRAP are detected adjacent to hypertrophic cartilage cells (HCC). Bar=25 μm

Table 1
Changes in body weight during the experiment

Groups	Experimental periods (weeks) 0	1	2	3	4
Experimental	86.8±7.8	129.4± 9.5	191.1±15.4	241.4±18.6	292.1±23.1
Control	86.4±6.4	145.0±13.6	196.0± 9.0	246.1± 8.8	306.8±13.

(unit: gr, Mean± SD, n=5)
No significant differences were found between two groups for all the experimental periods.

Table 2
Thickness of the condylar cartilage in the experimental and control groups

	1 week				2 weeks				4 weeks			
	Exp.		Cont.		Exp.		Cont.		Exp.		Cont.	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Anterior region												
Fibrous zone	22.5	7.4	37.0	11.6*	19.4	1.4	29.6	2.8**	27.0	7.6	28.6	3.7
Proliferative zone	29.2	5.7	44.4	7.9**	26.2	7.6	37.2	4.7*	29.0	3.1	34.2	4.5
Maturative/hypertrophic	147.5	21.9	173.6	14.5*	116.4	9.4	154.6	5.9**	103.8	9.3	105.4	19.5
Total	199.3	31.1	255.0	24.0**	162.0	12.4	221.4	8.9**	159.8	11.4	168.2	18.4
Superior region												
Fibrous zone	37.2	5.8	43.2	6.2	35.2	5.1	39.8	7.6	43.4	9.2	51.8	6.1
Proliferative zone	57.3	3.6	60.0	4.0	39.2	11.3	48.0	8.6	37.2	5.8	44.6	7.3
Maturative/hypertrophic	211.1	13.5	269.2	16.2**	197.0	16.7	259.2	12.3**	201.2	9.7	211.0	22.9
Total	305.6	18.8	372.4	18.4**	271.4	33.1	347.0	24.8**	281.8	12.3	307.4	28.3
Posterior region												
Fibrous zone	46.7	11.8	62.0	9.1**	39.0	9.3	53.6	15.3	56.8	8.7	65.4	6.5
Proliferative zone	78.7	17.5	106.6	13.9**	62.6	10.2	77.2	16.2	85.2	18.1	79.2	22.3
Maturative/hypertrophic	327.6	36.4	313.6	23.2	319.6	15.7	310.6	7.1	331.2	22.1	243.4	28.6*
Total	452.9	47.3	482.2	46.1	421.2	26.8	441.4	14.4	473.2	34.5	388.0	50.3**

*$p<0.05$, **$p<0.01$ (Unit:μm)

lar to those of the 6-week-old group.

Histologic findings

Figure 4 shows photomicrographs of the condyles in the experimental and control animals. In both groups, several zones were clearly distinguished as fibrous, proliferative, maturative, and hypertrophic zones.

In the anterior portion of the condyle in the 5-week-old experimental group, the cartilage cells in the hypertrophic zone were arranged irregularly and exhibited less hypertrophy than in the controls. The control group, meanwhile, exhibited a typical cartilaginous structure consisting of clear zones of proliferation, hypertrophy, and ossification (Figure 4A-B). In the 8-week-old experimental group, the cartilage layers were almost similar to those of the controls (Figure 4C-D).

Thickness of the cartilage layers

In the control group, no remarkable changes were found in the thickness of the fibrous zone, while the proliferative and maturative/hypertrophic zones were getting thinner through the entire experimental period. The thickness of each zone was greatest in the posterior portion and smallest in the anterior portion of the condyle.

For the anterior portion of the condyle, the thickness of each zone was significantly smaller in the 5-week-old experimental group than in the controls. The thickness of the maturative/hypertrophic zone and the total thickness of the superior portion was also significantly smaller in the 6-week-old experimental group than in the controls, whereas no significant differences were found between the two groups of 8-week-old rats. The thicknesses of the fibrous and proliferative zones in the posterior portion of the condyle were significantly smaller in the 5-week-old experimental group than in the controls, whereas the thickness of maturative/hypertrophic zone and the total thickness were significantly larger in the experimental group than in the controls at the end of the experiment (Table 4).

Number of TRAP-positive cells

Changes in the number of TRAP-positive cells adjacent to the hypertrophic cartilage layer are shown in Figures 5 to 7. In the control group, the number of TRAP-positive cells

Table 3
Linear values of cephalometric measurement

	1 week				2 weeks				4 weeks			
	Exp.		Cont.		Exp.		Cont.		Exp.		Cont.	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Total skull												
Po-A	211.4	4.8	211.4	3.4	222.1	2.5	219.4	3.6	234.3	2.7	239.2	1.9
Neurocranium Po-E	124.5	3.8	126.2	1.7	127.1	2.9	130.4	3.2	133.2	2.8	134.8	2.2
Po-Ba	47.4	2.2	49.8	1.5	52.8	2.5	53.1	1.0	54.2	2.1	55.8	1.7
Upper viscerocranium												
N-A	73.5	2.5	73.0	2.4	78.1	1.8	76.5	1.6	86.7	1.5	88.6	2.6
A-Pr	19.5	1.5	21.3	2.0	23.0	2.0	24.5	2.0	26.2	1.8	27.3	1.5
Mu-Bu	56.2	2.2	55.3	0.8	60.7	1.6	59.3	0.7	65.1	1.7	65.6	1.0
Pr-Iu	38.7	2.9	34.5	2.4*	38.0	2.5	36.4	0.6	37.6	1.3	39.0	1.2
U1-U1'	53.8	2.5	55.7	1.0	57.0	0.5	61.0	0.7**	61.0	1.6	64.3	1.6*
U2-U2'	57.3	2.1	58.8	0.3	60.0	1.1	64.3	0.9**	65.8	1.1	68.2	1.3*
Mandible												
Go-Mn	41.3	0.4	42.7	1.5	46.8	1.7	50.4	2.7*	54.1	2.7	58.0	1.7*
MI-BI	28.0	0.7	28.1	0.6	28.4	1.2	28.7	1.2	30.4	1.0	33.0	0.9**
Co-Gn	48.9	1.8	47.0	1.0	53.3	1.6	52.8	1.9	57.8	1.1	60.7	1.8*
Co-Co'	46.5	1.6	45.9	1.0	51.3	1.2	52.0	2.0	56.5	1.8	59.4	1.9*
Co-Pg	97.4	2.5	95.4	2.0	103.4	1.6	100.6	2.7	109.9	1.6	109.1	2.9
Go-Pg	85.8	2.4	84.9	2.9	93.3	2.9	93.4	3.6	96.4	2.3	100.8	3.6*
Il-Id	54.7	2.5	53.6	2.2	56.1	3.2	55.2	3.9	61.8	1.5	60.0	3.3
L1-L1'	31.7	0.6	34.7	0.4**	33.6	1.3	36.0	1.5**	36.2	1.2	41.2	1.3**
L2-L2'	32.8	0.9	34.1	0.8	34.5	0.3	35.7	1.5	37.2	1.9	40.9	1.3**

*$p<0.05$; **$p<0.01$ (Unit:mm)

Table 4
Angular values of cephalometric measurement

	1 week				2 weeks				4 weeks			
	Exp.		Cont.		Exp.		Cont.		Exp.		Cont.	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Neurocranium												
PoE/SE	41.3	2.6	42.9	1.9	43.2	1.3	42.4	3.4	41.7	1.0	44.8	2.1
PoBa/PoE	90.0	1.9	89.1	1.1	84.8	5.3	84.7	2.5	78.8	2.0	81.5	1.3
Upper viscerocranium												
AN/SE	117.3	2.1	117.3	3.2	115.3	1.3	117.6	2.6	115.4	1.5	114.2	1.2
Related to neurocranium												
PrE/SE	108.1	3.0	107.1	1.9	105.7	1.4	106.1	2.6	105.1	1.3	104.0	1.4
BuE/SE	95.6	1.6	96.3	2.2	95.0	1.0	95.3	2.0	95.6	0.3	94.5	1.4
IuE/SE	84.7	1.4	86.6	2.0*	84.8	1.4	85.4	1.8	86.2	0.4	84.5	1.3
MuBu/SE	49.4	2.2	47.7	2.2	51.5	1.3	47.7	3.3*	50.8	0.4	48.5	2.0
MuPr/SE	37.2	2.3	38.0	1.9	41.3	1.6	39.4	3.4	42.4	1.4	43.5	2.0
U1U2/SE	48.8	3.0	49.3	3.0	51.6	3.0	48.6	3.4	46.7	2.3	49.9	2.1
Upper viscerocranium												
BuE/U1U2	35.6	2.6	33.9	1.9	33.3	2.9	36.1	2.1	37.7	2.1	35.1	3.2
PrIu/U1U2	107.0	4.3	107.7	2.5	110.3	3.8	111.7	2.3	114.5	3.3	114.7	3.1
PrIu/MuBu	106.4	2.9	109.4	1.7*	110.5	3.1	112.6	1.0	110.4	1.9	112.3	1.9
Mandible CoGo/MnId	90.6	2.7	86.9	2.7*	84.3	1.7	79.5	2.2**	88.5	2.2	77.9	2.7**
CoGo/GnPg	90.7	3.3	88.6	2.3	85.8	1.8	81.0	1.8**	88.3	1.9	79.8	3.2**
CoGo/GoPg	97.5	3.2	93.9	1.5*	90.0	2.2	86.7	1.3*	93.9	1.5	85.3	2.5**
GoMn/MnId	172.7	1.8	174.4	2.7	177.1	2.3	175.0	2.1	176.5	2.2	174.0	0.9
GnMn/MnPg	162.7	2.6	163.5	1.1	162.3	2.3	162.6	1.1	159.9	1.4	159.0	1.7
L1L2/GnPg	3.8	2.4	2.4	1.0	3.1	3.2	1.5	1.4	3.0	2.3	1.7	1.4
MIBI/IdII	46.4	3.5	46.5	3.8	46.5	2.7	48.2	1.9	48.3	3.2	52.5	2.8*

*$p<0.05$; **$p<0.01$ (Unit:degrees)

decreased gradually for all the portions of condyle through the entire experimental period. In the 5-week-old experimental animals, the numbers of TRAP-positive cells in the anterior and superior portions were significantly greater than in the controls, whereas the number in the posterior portion was almost similar to the controls. In the 8-week-old animals, no significant differences in numbers were found between the experimental and control groups for the anterior and superior portions. However, the number of TRAP-positive cells at the posterior portion was significantly greater in the experimental group than in the controls.

Discussion

For growing patients with small and/or distally-positioned mandibles, growth acceleration of the mandible is of great significance in clinical orthodontics. However, some patients with vertical discrepancies of the occlusion and maxillomandibular relationship may exhibit less forward and/or more downward growth of the mandible. For this reason, it may be assumed that condylar and mandibular growth is affected by the vertical discrepancy, which is expressed as an increase in the posterior dentoalveolar heights. Furthermore, experienced orthodontists note that TMJ internal derangement with degenerative changes may be relevant to such morphologic characteristics of the mandible as steep mandibular plane and short ramus height.[18-20] It is thus of great importance to elucidate the association between occlusion-induced displacement of the mandible and condylar responses, noting cartilaginous and bony changes of the condyle in particular. With these considerations, this study was designed to reveal, by means of morphometric and histochemical techniques, craniofacial

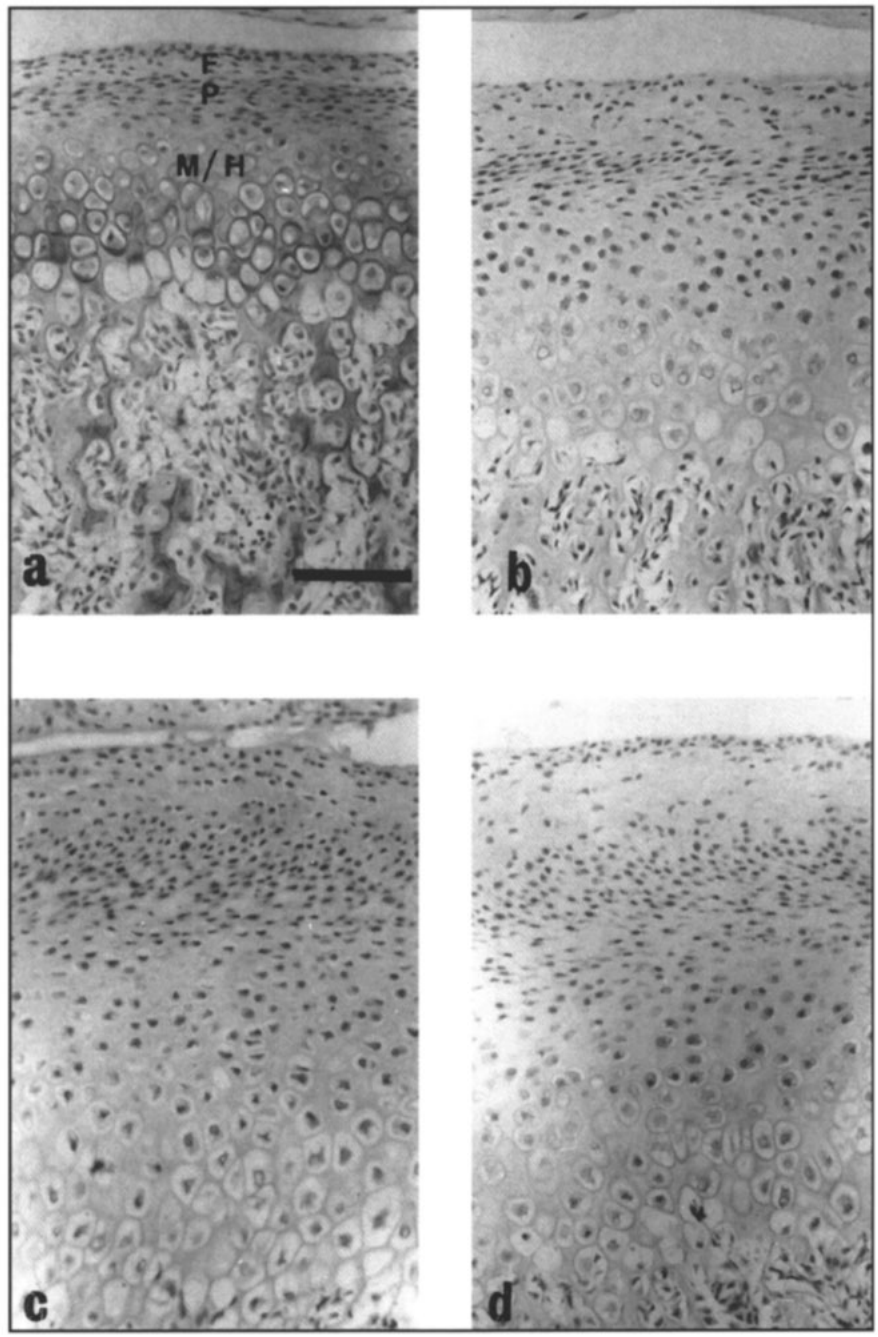

Figure 4
Sagittal sections for the anterior and posterior portions of the mandibular condyle. a-b: anterior portion 1 week after beginning of experiment; c-d: posterior portion 4 weeks after beginning of experiment. a,c: experimental group; b,d: control group. (H-E) bar; 100 μm. F=fibrous zone, P= proliferative zone, MH= maturative/hypertrophic zone. Bar= 50 μm.

growth and condylar responses to vertical occlusal discrepancy produced by increasing the posterior dentoalveolar heights in growing rats. In experimental animals, the appliance produced translation of the condyle toward the articular eminence with a posteroinferior rotation of the entire mandible. At this new mandibular position, anterior and superior joint spaces in the condyle were reduced, while posterior joint space was increased. The articular cartilage of rats is similar to that of humans in the histological structures, although some differences in morphology have been documented.[21] Rats, in general, exhibit fewer differences in genetic factors between individuals,[22,23] and it is much easier to obtain large numbers of rats for studies. With these considerations, the Wistar strain rats were used in this experiment.

Histologic findings derived from this study may demonstrate that mechanical stresses on the condyle induced by changing the intra-articular environment influence the release of cells from the proliferating cell pool in the condylar cartilage and resorption of the hypertrophic cartilage. This assumption was also verified by changes in the thickness of the proliferative and hypertrophic zones and the number of TRAP-positive cells in the experimental animals.

Various studies have shown that responses of the condylar cartilage may be altered by changes in the biological and biomechanical environment in the TMJ space.[1-4,8-13] This adaptive response has also been confirmed in previous studies. Yamamoto[11] created an increase in the unilateral occlusal vertical dimension in the rat mandible and reported that the occlusal discrepancy produced thinning of the condylar cartilage as a result of the reduced size of articular chondrocytes and the decrease in the cartilage matrix. Findings were similar in the present study, although there were differences in the simulated occlusal discrepancy and unilateral and bilateral occlusal imbalances. Similar changes were demonstrated in rats when the incisors were trimmed or removed,[2] and when the mandible was displaced anteriorly and inferiorly by an inclined plane bonded on the incisors.[3] These studies may thus support the present findings in terms of condylar remodeling related to external loading on the condyle.

On the other hand, Sim et al.[24] reported increases in the prechondroblastic and chondroblastic layers in the mandibular condyle after an increase in the vertical dimension through the use of a tooth-borne intraoral appliance in adult monkeys. In an adult rabbit study,[25] an increase in the volume of the experimental condylar cartilage also demonstrated by raising the vertical dimension of the occlusion. These different findings, observed in rats and other animals, may be attributed to differences in species, age of subjects,[21] and magnitude of mandibular displacement due to variations in appliances used for different animals.[3]

In a biomechanical study with finite element analysis, Tanne and associates[26] investigated stresses in the TMJ during clenching associated with skeletal discrepancies in the vertical direction, as represented in a three-dimensional TMJ model. They noted that mechanical stresses increased for the condyle with larger gonial and mandibular plane angles. In the present study, remodeling of the condylar cartilage was examined in young rats with inferior and posterior displacement of the mandible. Initially, the experimental animals showed a large number of chondroclasts just below the hypertrophic cell layer. For this reason,

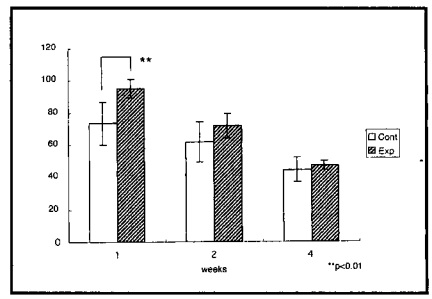

Figure 5
The number of TRAP-positive cells adjacent to hypertrophic cartilage cells for the anterior portion of mandibular condyle.

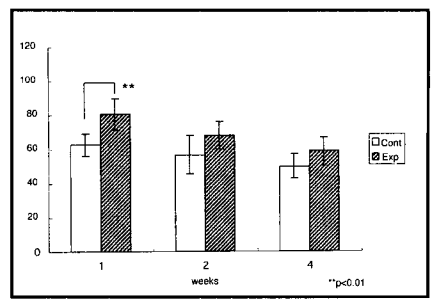

Figure 6
The number of TRAP-positive cells adjacent to hypertrophic cartilage cells for the superior portion of mandibular condyle.

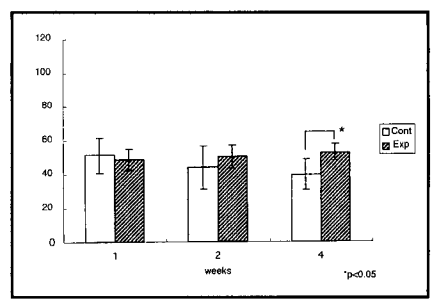

Figure 7
The number of TRAP-positive cells adjacent to hypertrophic cartilage cells for the posterior portion of mandibular condyle.

it may be suggested that TMJ loading was increased in a certain area by occlusal and skeletal discrepancies and resulted in alteration of the thickness of the cartilage layer and the number of chondroclasts in the experimental animals.

An interesting revelation was that differences in histologic findings were observed for the anterior, su-

perior, and posterior portions of the condyle in experimental animals. It may be speculated that stresses for each portion of the condyle were varied by mandibular displacement, as demonstrated in the preceding analytical study.[26] Condylar stresses are determined not only by the magnitude of TMJ loading, but also by the area of loading. Changes in the anteroposterior relationship of the condyle and glenoid fossa imply the possibility that local pressure increases as the contact area between dentitions decreases, even if with the magnitude of total loading does not change. Changes in proliferative cells and chondroclasts in response to altered functional conditions are assumed to be temporary, and the growth rate of the condyle may approach normal if the growth potential remains under functional equilibrium.

Morphometric analysis with lateral cephalograms demonstrated that vertical occlusal discrepancy substantially influenced craniofacial growth, mandibular growth in particular, and the resultant morphology in growing rats. Remarkable changes in ramus height and gonial angle were found in the experimental group, whereas no significant differences in size of the total skull and neurocranium were found between experimental and control groups.

The neurocranium, in general, exhibits a type of growth common to the nervous system and is highly relevant to growth of the brain. It is well known that the rat mandible and cerebral cranium reach about 75% and 93%, respectively, of the mature size 1 month after birth.[27] It is assumed, therefore, that the influences of masticatory function were not substantially expressed in this experiment.

On the other hand, it has been documented that mandibular growth is highly influenced by occlusal[28-30] and functinal[13,31] discrepancies in growing animals. These findings suggest substantial influences of muscular function on mandibular growth, which was documented in the literature as a functional matrix theory by Moss.[32] McNamara investigated the influence of increases in the vertical dimension on craniofacial adaptations in growing rhesus monkeys.[30] He demonstrated that the amount of vertical growth at the condylar head was decreased by moderate bite opening and that bone resorption was induced around the gonial angle by severe bite opening. In addition, significant adaptation was revealed in the maxillary region, where the normal downward displacement was decreased and the anterior displacement was accelerated. The differences in the present findings from the previous study may be attributed to differences in the animals used and/or the magnitude and direction of mandibular displacement created by occlusal appliances.

In rats, the interocclusal distance at the mandibular resting position is approximately 1 mm.[33] Since the influences of occlusal discrepancy, created by increased posterior dentoalveolar height of 1 mm, may be assumed to be negligible for the masseter muscles,[34] the present results emphasize a substantial effect of mechanical stimuli to the TMJ components, the condyle in particular, on condylar remodeling and mandibular growth rather than that of muscular function.

Tissue reactions in different animals may not be identical to those in humans. However, the present results suggest that condylar remodeling should be focused on as one of the possible tissue reactions leading to the correction of various condylar deformities. Future studies are anticipated for clarifying condylar responses to mechanical changes in actual force levels generated on the dentition by occlusal and skeletal discrepancies. In such a case, various types of forces of controlled magnitude, direction, and duration should be taken into consideration. These approaches would provide a better understanding of the influences of vertical discrepancy on the nature of craniofacial growth.

Conclusion

This study was conducted to investigate condylar responses to a malocclusion artificially induced by increasing the occlusal vertical dimension in young rats. Early in the experimental period, the animals showed thinner proliferative and hypertrophic layers with a larger number of chondroclasts positively stained with TRAP just below the hypertrophic chondrocyte layer. At the end of experimental period, clockwise rotation of the maxilla and a large gonial angle were found in the experimental group.

From these findings, it is suggested that changes in the condylar environment associated with vertical occlusal discrepancies influence condylar and craniofacial growth, although some adaptive response of the condyle may be expected if the growth potential remains.

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