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The Effect of Continuous Bite-Jumping in Adult Rats: A Morphological Study

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ABSTRACT

The aim of this study was to determine the mandibular morphology before, during, and after bite-jumping in nongrowing species. Fifty-two adult female Sprague-Dawley rats were divided into four experimental groups and four control groups. The experimental groups were fitted with fixed bite-jumping devices that protruded the mandible. The animals were sacrificed on days 3, 14, 30, and 60. Right halves of the mandible were harvested and freed of soft tissue. Digital pictures were obtained in a standardized manner. Selected linear and angular measurements were made. There were no morphological differences between the controls and experimental group on days 3 and 14. The length of condylar process increased significantly on day 30 and remained so on day 60 in the experimental group. The angulation of the condylar process was significantly affected because of increased apposition of bone in the middle and especially the posterior parts of the condyle. Thus, bite-jumping of the mandible in adult rats affects the size and angulation of the condylar process because of differential apposition of bone on the condylar head.

KEY WORDS: Functional appliance therapy, Mandibular advancement, Nongrowing species.

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INTRODUCTION Return to TOC

The concept of the bite-jumping orthodontic device was introduced to correct Class II malocclusion in young patients more than 100 years ago.[1] Numerous designs of removable and fixed devices have been presented over the years but the potential treatment effect on mandibular growth still is widely disputed.[2–4] However, continuous bite-jumping with fixed functional appliance had been documented to have an immediate effect on mandibular growth, whereas the effect of removable functional appliance is uncertain.[2,5–7] Continuous bite-jumping in young adult patients with Class II malocclusion resulted in remodeling of the temporomandibular joint, as assessed by MRI and forward positioning of the mandible.[8,9] To investigate the possibility of growth modification in nongrowing species, nonhuman-primate models had been developed for advancement of the mandible,[10–14] but an accordance result was hard to get from these experiments. Some reports showed that there were signs of remodeling of condyle and glenoid fossa,[11,12,14] whereas others revealed that such an adaptive response to forward mandibular positioning diminished with the increase in age of the species.[10,13] Petrovic et al[15] produced sagittal deviation using the postural hyperpropulsor on male rats from the age of 48 to 180 days, which resulted in greater length of mandible than that of control. Experiments of continuous bite-jumping in young rats resulted in enhanced mandibular growth and remodeling of the glenoid fossa.[16,17] By raising the bite in rats, Buchner[18] concluded that growth still occurred in the condyles at 12–18 months of age, and the growth modification was made possible by the persistence of chondrogenic cells.

The growth of condyle and glenoid fossa of growing rats could be enhanced by bite-jumping appliances.[16,17,19,20] TMJ growth is regulated by factors endogenously expressed by cells in the condyles,[21] as well as in glenoid fossa.[19] Forward mandibular positioning led to a change in the biophysical environment of TMJ that led to the release of key regulatory factors that enhanced condylar growth.[17] Because these factors were endogenously expressed by cells in the condyles and glenoid fossa in response to mechanical strain, a similar effect might occur in adult rats, regardless of their growth status.

The present study was designed to investigate the morphological changes in the condyles and the mandibles to continuous forward mandibular positioning in adult species.

MATERIALS AND METHODS Return to TOC

This experiment was approved by the Committee on the Use of Live Animals in Teaching and Research of the University of Hong Kong (CULATER 586-01).

The bite-jumping appliance used in this study was a modification of the one developed for young rats in a previous study.[16] In this study, to ensure a continuous forward advancement in adult rats, besides the incline bite plane inserted on the upper incisors, a lower crown with an anterior incline plane was also bonded to the lower incisors (Figure 1 A). The appliance resulted in a vertical displacement of 1–2 mm and an anterior advancement of 4 mm; the amount of displacement was checked by X-ray (Figure 1 B). A series of appliances were duplicated using Probase Cold (Ivoclar Vivadent, Liechtenstein), which was transparent, so the interrelationship of upper and lower incisors could be checked when the appliance was tried on the species (Figure 1A).

Fifty-two 120-day-old nongrowing[22] female Sprague-Dawley rats were included in this study. The species were randomly allotted into four experimental groups with nine rats each and four control groups with four rats each. The appliances were fitted under anesthesia (10% ketamine and 2% xylazine, 2:1, 0.1 ml/100 gm). Light curing Panavia F (Kuraray Medical Inc, Okayama, Japan) was used as bonding material to provide enough retention for the appliance. The species were kept in standardized condition with artificial light and water ad libitum. To minimize the influence of diet on experiment results,[23–25] all the rats were provided with ground rat chow (Laboratory Rodent Chow 5010, PMI Feeds Inc., St. Louis, USA) instead of normal pellets from 90 days of age (ie, 30 days before fitting the appliances). The weight of all rats was recorded from the age of 120 days, initially every day during the first week and thereafter once a week.

Experimental and corresponding control group of rats were sacrificed after 3, 14, 30, and 60 days by an intraperitoneal injection of 20% dorminal (200 mg/ml pentobarbital sodium, Alfasan Woerden, The Netherlands). The heads of animals were carefully dissected along the middle sagittal plane. Right halves of mandibles were harvested and freed of soft tissue after fixation for gross morphological analysis.

Digital pictures of the lateral view of the right mandibles of the rats were taken using a true color video camera (JVC TK-1281 EG) to allow for the angular and linear measurements except that of the width (Q-R) and length (C-D) of the condylar head, which were measured directly using a vernier caliper. The mandible was mounted at 90° angle at a fixed distance from the digital camera. To increase the accuracy of the quantification of small morphological changes, the images were enlarged to two times the original size and were traced using selected landmarks, distance, and angles [23,26,27] (Figure 2; Table 1).

Measurement was evaluated by two independent recordings of measurements, which were performed at an interval of four weeks. Hypothesis testing indicated no significant difference between the two registrations. The error of measurement was calculated with Dahlberg's formula[28]:

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

where *d* represents the difference between two registrations and *n* is the number of duplicate registrations. Ten species were randomly selected for the evaluation of method error. Table 3 lists the size of method error.

The statistic analysis was processed with SPSS for Windows (Release 11.0.0, standard version, SPSS Inc., Chicago, USA) for one-way ANOVA with Bonferroni multiple comparisons test.

RESULTS Return to TOC

Body weight

The body weight of the experimental species was reduced after the insertion of the appliance. The reduction in weight was about 10% and remained on that level until the second week. In week 3, the weight of the experimental group increased close to its original value (Figure 3).

Linear and angular measurements

There was no significant change in mandibular morphology in the control group during the whole observation period or in the experimental group on days 3 and 14 (Table 2). The length of mandibular base (A-B) and the distance between the reference point on the most anterior surface of the condyle (C) and the mandibular plane (GH) remained the same in both groups throughout the observation period.

On day 30, the length of the condylar process (B-F) as well as the dependent mandibular length (A-F) had increased significantly and remained so day 60.

The condylar length (C-D) and width (Q-R) had increased significantly on day 30, but only the length of the condyle remained larger than that of control on day 60. The distance from the anterior point of the condylar head (C) to the mandibular plane (GH) remained unchanged on days 30 and 60, whereas the distance from the posterior part of the condylar head (D) to the mandibular plane (GH) was reduced. This affected the distance between the midpoint of the condylar surface (F) to the mandibular plane (GH). The change of position of the reference point F affected the angle BF/GH, which was significantly reduced.

Change of condyle

Besides the changes in size and angle shown above, the appearance of the condyle surface was also changed. In the control, the surface of the condyle looked more like a bone (Figure 4A). On the contrary, the surface of the condyle on days 30 and 60 of the experimental groups showed a translucence, especially in the posterior part (Figure 4B), indicating formation of cartilage.

DISCUSSION Return to TOC

In the present study, a fixed bite-jumping device was used to create continuous mandibular advancement in adult rats for 60 days, and the changes in mandibular morphology were studied at different time points. The results showed that continuous bite-jumping in adult rats resulted in marked increase of the length of the condylar process after 30 days (Table 2). Because the apposition of bone was differential and did not occur on the anterior surface of the condylar head but only on the posterior and superior surfaces, the size as well as the shape of the condylar head were affected, which was also supported by the reduction of the angle of the condylar process to the mandibular plane. The changes registered on day 30 remained so on day 60 except for the width of the condyle that went back to the original size. This showed that the period of bite-jumping has to be sufficiently long to affect the mandible and that when the treatment period is extended it did not result in further significant treatment effect with constant amount of bite-jumping (Table 2). However, the treatment period has to be of a certain duration to allow permanent effect.[29]

Results of the present study also showed that the shape of the condyle could be changed after fitting bite-jumping appliances in adult rats. Our results demonstrated that condyles of the experimental group animals were elongated. Because the distance from point C to the mandibular plane (GH) was stable and the distance from point F and D to GH was reduced during the experimental period (Table 2), the longitudinal growth of the condyle was thus due to increased bone apposition in the posterior part of the condyle and superior part of the condylar head, which was verified by the increase in the distance B-F (Table 2).

Additional evidence of bone remodeling of the condyle was the change of appearance in the surface of the condyle. Because of aging, the cartilage layer becomes very thin in older rats than in young species.[30–32] This may be the reason why the surface of condyles in the control groups looked more like a bone (Figure 4A), whereas the surface of the condyle on days 30 and 60 in the experimental groups became translucent (Figure 4B). The reason for this change may be the regeneration of the cartilage in the condyle surface. Bite-jumping appliances can improve proliferation of mesenchymal cells in the condylar cartilage in young rats.[33] The same mechanism may also exist in adult species. When more mesenchymal cells transform into chondrocytes, there will be more bone formation in the condyle.[21] Thus, mandibular advancement could also stimulate the adaptive growth of the condyle in adult rats. This finding does not support previous experimental results where it was reported that adult monkeys lost the ability for condylar remodeling.[10,13] The possible reason may be that the stage of dentition could not reflect the exact chronological age of experimental monkeys. The results also showed that the width of the condyle became significantly larger on day 30 in the experimental group, and the value was reduced on day 60. A possible explanation may be the quick bone remodeling in the transverse direction of the condyle.

The morphological changes of the condyle were also confirmed by the change of the condylar process angle (BF/GH), which was reduced by 8.9° and 12.5°, respectively, on days 30 and 60 (Table 2). The significant increment of condylar process length (B-F) was found at the same time point. Because the increment of condylar process length was small compared with the change in angle, the direction of condylar relocation was also due to the morphological changes of condylar head. As mentioned above, new bone apposition was mainly located in the posterior part of the condyle; therefore, point F would “shift” posteriorly and then the condylar process looked more inclined than did the control (Figure 5A,B). Because there was no increase in the length of the mandibular base (A-B), the remodeling of the condyle ultimately resulted in the increase in mandibular length (A-F). This finding supports the opinion that the length of mandible is not entirely predetermined by genetic factors.[15,34]

CONCLUSIONS Return to TOC

The present study demonstrated that adaptive morphological changes could be achieved by 30-day continuous mandibular advancement in adult rats. Because of the new bone apposition in the posterior condylar head, the angulation of the condylar process was significantly affected, as well as the length of mandible and condylar process.

ACKNOWLEDGMENTS

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TABLE 1. Definition of Landmarks, Linear, and Angular Measurements

Variables	Definition
Landmarks	
A	The most anterior point of the lingual alveolar bone
B	The midpoint of mandibular foramen
C	The most anterior point of condyle
D	The most inferior (posterior) point of condyle
E	The middle of point C and D
F	Intersection point of B-E extension line and outer contour of condyle
G	Posterior-inferior point of attachment of digastric muscle
H	The most inferior point of lower border of angular process
Q	The outmost point of ventral contour of condyle
R	The outmost point of dorsal contour of condyle
BF	Condylar process axis
GH	Mandibular plane
Linear measurement (mm)	
B-F	The length of condylar process
A-F	Mandibular length
A-B	Length of mandibular base
C-D	Length of condyle
Q-R	Width of condyle
C-GH	The distance from point C to GH line
F-GH	The distance from point F to GH line
D-GH	The distance from point D to GH line
Angular measurement (°)	
BF/GH	Angle of condylar process axis to mandibular plane

TABLE 2. Values of Linear and Angular Measurements of Mandibular Morphology (Mean ± SD) in Experimental and Control Groups in Different Time Points[a]

	3 Days			14 Days		
	Experiment	Control	Difference	Experiment	Control	Difference
Linear measurement (mm)						
B-F	6.17 ± 0.25	6.19 ± 0.28	−0.02 ns	6.04 ± 0.26	5.84 ± 0.44	0.2 ns
A-F	26.22 ± 0.53	26.59 ± 0.34	−0.37 ns	26.09 ± 0.62	26.23 ± 0.58	−0.14 ns
A-B	21.05 ± 0.84	21.58 ± 0.10	−0.53 ns	21.02 ± 0.44	21.46 ± 0.17	−0.44 ns
C-D	3.59 ± 0.24	3.61 ± 0.17	−0.02 ns	3.67 ± 0.16	3.58 ± 0.20	0.09 ns
Q-R	1.70 ± 0.13	1.63 ± 0.06	0.07 ns	1.74 ± 0.12	1.58 ± 0.10	0.16 ns
C-GH	10.99 ± 0.20	11.47 ± 0.22	−0.48 ns	11.19 ± 0.66	11.36 ± 0.39	−0.17 ns
F-GH	10.66 ± 0.43	10.79 ± 0.23	−0.13 ns	10.69 ± 0.52	10.55 ± 0.30	0.14 ns
D-GH	8.77 ± 0.39	8.98 ± 0.15	−0.21 ns	8.80 ± 0.40	8.80 ± 0.21	0.00 ns
Angular measurement (°)						
BF/GH	33.22 ± 3.92	32.50 ± 1.00	0.70 ns	31.83 ± 1.64	32.50 ± 1.73	−0.67 ns

[a] * $P < .05$; ** $P < .01$; *** $P < .001$ (experiment vs control); ns, not significant.

TABLE 2. Extended

30 Days			60 Days		
Experiment	Control	Difference	Experiment	Control	Difference
6.55 ± 0.33	6.04 ± 0.06	0.51***	6.54 ± 0.22	5.93 ± 0.18	0.61***
27.82 ± 0.65	26.15 ± 0.27	1.67***	27.78 ± 0.38	26.32 ± 0.06	1.46***
21.54 ± 0.60	21.47 ± 0.66	0.07 ns	21.63 ± 0.32	21.54 ± 0.06	0.09 ns
4.28 ± 0.25	3.54 ± 0.06	0.74***	4.21 ± 0.08	3.57 ± 0.06	0.64***
1.95 ± 0.14	1.67 ± 0.03	0.28***	1.75 ± 0.08	1.63 ± 0.05	0.12 ns
11.34 ± 0.51	11.37 ± 0.03	−0.03 ns	11.02 ± 0.36	11.47 ± 0.13	−0.45 ns
9.90 ± 0.45	10.65 ± 0.12	−0.75 ns	9.61 ± 0.29	10.57 ± 0.23	−0.96**
8.00 ± 0.52	8.78 ± 0.19	−0.78*	7.89 ± 0.21	8.96 ± 0.19	−1.07***
24.89 ± 2.52	33.75 ± 1.50	−8.86***	19.28 ± 1.79	31.75 ± 2.50	−12.47***

TABLE 3. The Size of Method Error (Me) in the Measurements

Measurements	Me
Linear measurement (mm)	
B-F	0.15
A-F	0.17
A-B	0.19
C-D	0.11
Q-R	0.12
C-GH	0.17
F-GH	0.19
D-GH	0.21
Angular measurement (°)	
BF/GH	1.32

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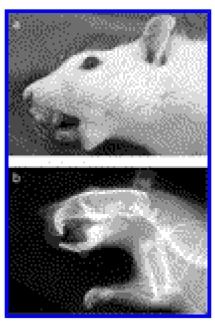
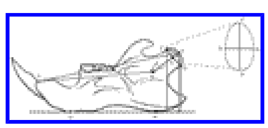


Click on thumbnail for full-sized image.

FIGURE 1. (A) Lateral view and (B) the radiograph after appliance fitting showed the vertical and anterior displacement of mandible



Click on thumbnail for full-sized image.

FIGURE 2. Illustration of landmarks, linear and angular measurements (for definitions see Table 1)

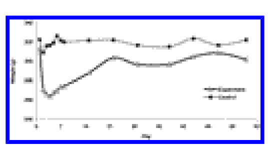


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FIGURE 3. The change of weight of the control and experimental groups after bite-jumping appliance fitting over the 60-day period

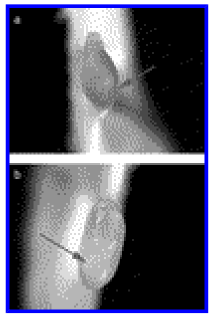

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FIGURE 4. Photograph showed the appearance of condylar surface in (A) the control and (B) the experimental groups on day 60. Note the change of appearance, especially the posterior part of condyle (arrow showed)

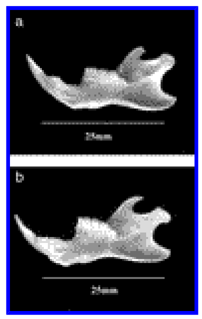

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FIGURE 5. Photograph showed the morphology of the right mandible of (A) the control and (B) the experimental groups on day 60.

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