

Effect of a modified Herbst appliance on maxillofacial morphology

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We examined morphological and functional changes induced with the use of a modified Herbst appliance which is used to promote condylar cartilage growth, and thereby induce forward remodeling of the glenoid fossa. The study included 7 females between 18.0 to 20.6 years of age with an average of 18.8 years who had Angle Class II malocclusion and an ANB angle between 5.3 and 7.5 degrees with an average of 6.4 degrees. The treatment time with the appliance was 8 months. Lateral cephalometric radiographs and computed tomography images were taken to evaluate morphological changes. Electromyographic activity of the masseter and temporalis muscles was recorded with surface electrodes.

Angle Class II treatment with a modified Herbst appliance was accompanied by both skeletal and dental changes. The results suggest that anteroinferior movement of the condyles in the glenoid fossa with Herbst treatment leads to a combination of condylar growth and glenoid fossa remodeling. (J Osaka Dent Univ 2015 ; 49(1) : 105–114)

Key words : Herbst appliance ; Late growth ; Temporomandibular joint ; Physiological mandibular rest position ; Neuromuscular concept

INTRODUCTION

Cases of skeletal maxillary protrusion can be classified into those in which there is overgrowth of the maxilla and those in which there is undergrowth of the mandible. At the time of treatment for skeletal maxillary protrusion with mandible undergrowth during the growth period, functional appliances are often used to stimulate forward growth or remodeling of the temporomandibular joint region.^{1–4} However, it is difficult to stimulate forward growth of the mandible during the period from late adolescence to adulthood. During this time orthodontic treatment is usually in the form of either surgical orthodontics or distoclination of the maxillary incisors.¹

Functional appliances used during the growth period include the Fränkel (FR-2), the twin block, the bionator, and Herbst appliances.⁵ Although almost all of these are removable, among them, the Herbst appliance is a fixed type. The Herbst appliance was introduced by Emil Herbst⁶ for the purpose of stimulating protrusive growth in an underdeveloped mandible.

McNamara⁷ performed experiments in growing monkeys, and in recent years, Pancherz *et al.*^{8,9} published clinical reports on the subject. Since the Herbst appliance is a fixed Angle Class II improvement device, effective treatment does not require cooperation of the patient.^{10,11} We studied the influence of the modified Herbst appliance¹² on late mandible growth and development in subjects who had completed growth.

MATERIALS AND METHODS

Materials

The experimental subjects were 7 females (the H Group) between 18.0 to 20.6 years of age with an average of 18.8 years who had Angle Class II malocclusion and an ANB angle between 5.3 and 7.5 degrees with an average of 6.4 degrees. They were thought to have completed their vigorous growth and development, as defined by the hand-wrist radiographic stage R-J. The control group consisted of 7 females (the N Group) between 19.1 to 22.6 years of age with an average of 20.5 years who had an ANB angle between 5.1 and 7.7 degrees with an average of 6.4 degrees,

whose hand-wrist radiographic stage was R-J. This study was approved by the Ethics Committee of Osaka Dental University (Approval No.23416).

Placement of the appliance

The H Group was treated with a multi-bracket appliance prior to placement of the Herbst appliance. A jaw function examination was done using the K7 Evaluation System EX (Myo-Tronics, Kent, WA, USA) 5.7 to 6.3 months later, with an average of 6 months. The jaw function examination evaluated the middle of the left masseter muscle (LMM), the middle of the right masseter muscle (RMM), the front of the left temporalis anterior (LTA) region and the right temporalis anterior (RTA) region. Measurements were made at rest and at the maximal intercuspal position. The maximal mouth opening and the limit of lateral mandibular movement were determined, as well as the mandibular rest position.^{13, 14} In order to relax the subject's muscles, the low frequency myomonitor (Myo-Tronics) was used to stimulate the trigeminal and facial ner-

ves, relieving tension in all the muscles. After the subject's jaw muscles had been relaxed, the habitual mandibular rest position was recorded, and the endogenous rest position was established as the physiological mandibular rest position (Fig. 1).¹⁴

Based on the above jaw function data, the modified Herbst appliance¹² was placed so that the mandible was in the physiological occlusion position (Fig. 2). In accordance with the Dischinger¹⁵ report, the appliance was placed for 8 months.

Methods

For the H Group, lateral cephalometric radiographs were exposed and temporomandibular joint cone beam computed tomography (CBCT) images were obtained before treatment, 4 months after treatment, 8 months after treatment (at removal), and then 4 months after removal, and the results were analyzed.^{16, 17} The jaw function examination was done 4 months after removal and the changes from before placement of the appliance were determined and analyzed. Also, lateral cephalometric radiographs were obtained one year after the initial examination of the N Group and analyzed. Calculations were done using a spreadsheet.

Angle and distance measurements were calculated on the cephalograms for the maxillofacial morphology (Fig. 3). Calculations were done for the mean and standard deviation of the values to investigate whether or not there were any significant differences between the H and N Groups. The Student's t-test was applied

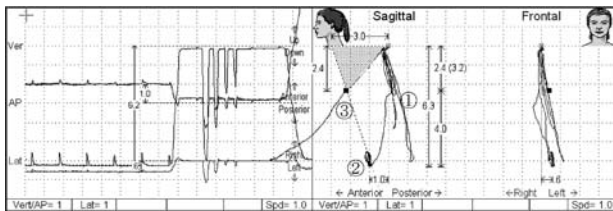


Fig. 1 Positions relating to the oral environment. ①Mandibular rest position, ②Physiological mandibular rest position, and ③ Physiological occlusion position.

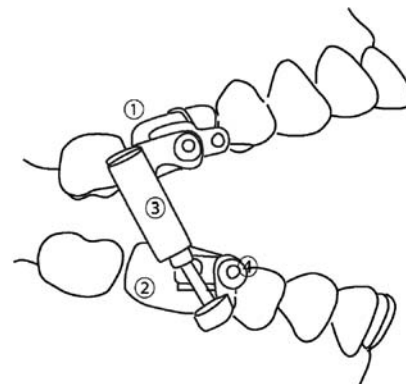


Fig. 2 The modified Herbst appliance. ①Band for the maxillary first molar, ②Band for the mandible first molar, ③Telescoping rod, and ④Screw.

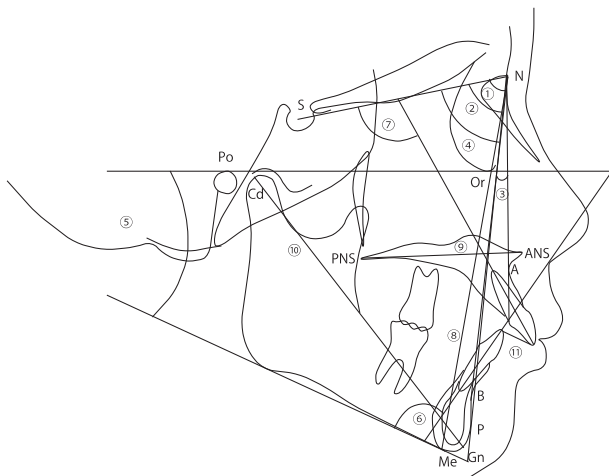


Fig. 3 Measurement points on the lateral radiographic cephalogram. ①SNA, ②SNB, ③ANB, ④SNP, ⑤FMA, ⑥IMPA, ⑦U 1 to SN, ⑧N-Me, ⑨ANS-PNS, ⑩Cd-Gn, and ⑪Overjet.

at a significance level of 1%.

An arm type X-ray CT diagnosis device (Asahi Roentgen, Kyoto, Japan) was utilized for CBCT imaging of the temporomandibular joint region. Coordinate axes were established in order to standardize the imaging conditions for this study. The Frankfort horizontal plane, which extends from the superior margins of the bilateral external auditory meatus to the left orbitale, was employed as the x-axis. The perpendicular plane passing through the midpoint of the line running through the medial angles of the bilateral eyes was defined as the median sagittal plane and was used as the y-axis. Finally, a third plane running perpendicular to the other two whose superior border passes through both orbitales, was defined as the orbital

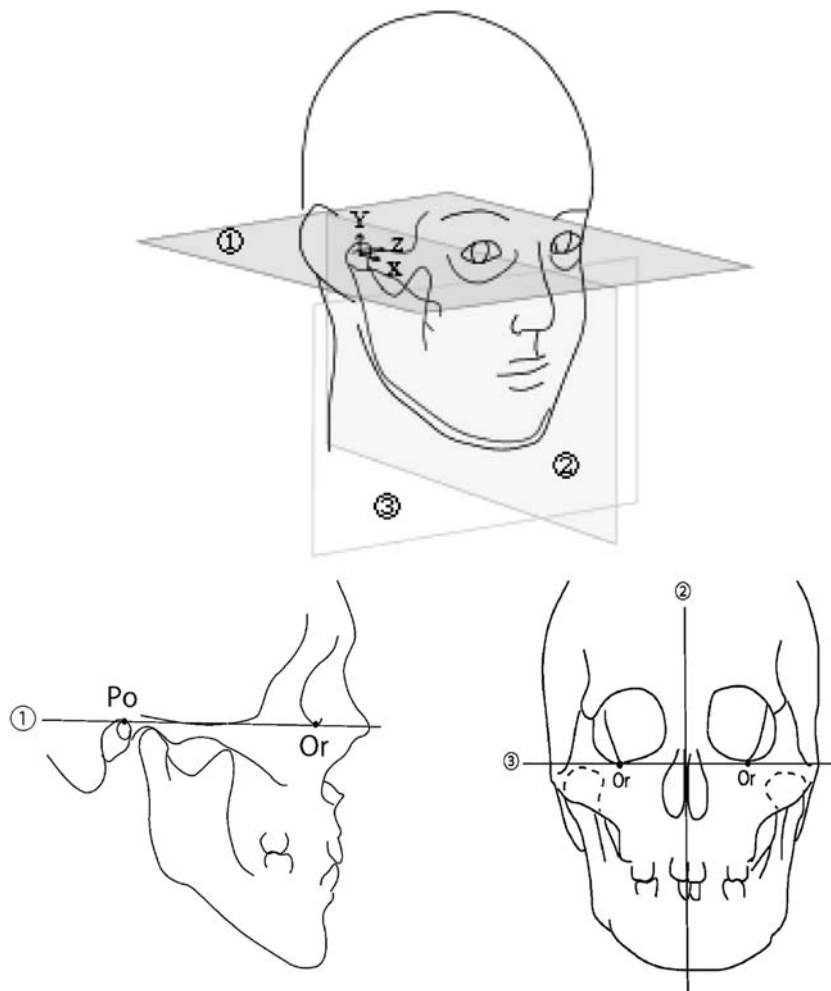


Fig. 4 Axis of coordinates. ①Frankfort horizontal plane (x-axis), ②Median sagittal plane (y-axis), and ③Orbital plane (z-axis).

plane and used as the z-axis (Fig. 4).¹⁸ Each subject was placed in a sitting position parallel to the x-axis with their head perpendicular to the y-axis. Ear rods, a chin rest, and a head belt were used to hold their head in place.

We obtained measurements from 10 females ranging in age from 22 to 25 to confirm that the imaging conditions had been standardized appropriately. The image that showed the broadest diameter of the inside of the condyle was selected from the z-axis images of the condyle. The z-axis measurements were made of the distance between line A, which runs parallel to the y-axis and contacts the outermost side of the condyle, and line B, which passes through the outermost side of the temporal bone (Fig. 5).¹⁹ Similarly, distance measurements were made on the maxilla and the mandible between line C, which links the

deepest point of the glenoid fossa with the lowest point of the meatus, and line D, which passes through the highest point of the external auditory meatus (Fig. 6).¹⁹ The above measurements were compared with those obtained on CBCT one year later. Since there was no significant difference at the 1% level, it was determined that the imaging conditions were standardized.

After confirming this, in order to make comparisons of the position of the temporomandibular joint before and after placement of the appliance, measurements for the H Group were made of the distance between the condyle and the glenoid fossa. First, the z-axis image on which the external diameter of the condyle was broadest was selected, and distance “a” was established as the point between the top of the condyle and

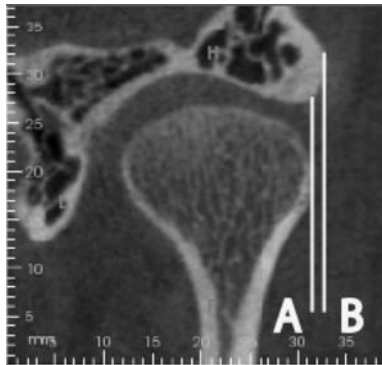


Fig. 5 Reference lines on the temporomandibular joint. A : Contact with the outermost side of the condyle, and B : Line through the outermost side of the temporal bone.

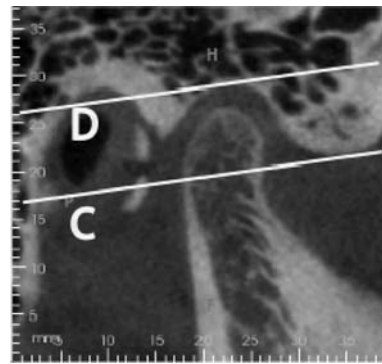


Fig. 6 Reference lines on the temporomandibular joint. C : Line connecting the deepest point of the glenoid fossa with the lowest point of the meatus, and D : Line through the highest point of the external auditory meatus and parallel to C.

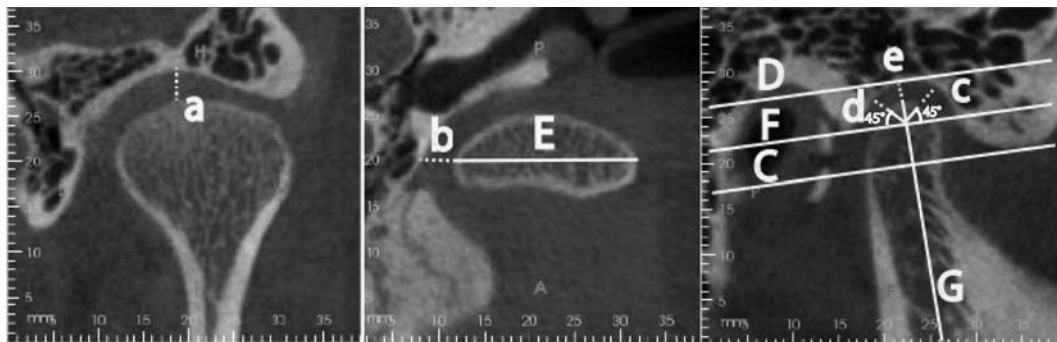


Fig. 7 Reference lines on the temporomandibular joint. E : Largest diameter of the condyle, F : Line through the center of the external auditory meatus and parallel to C, G : Perpendicular line from the midpoint of F in the condyle, and a, b, c, d, e : Distances between the condyle and the glenoid fossa.

the deepest point of the glenoid fossa. The image with the broadest diameter of the condyle was selected from the x-axis images, and this diameter was designated as line E.

The distance between the edge of line E and the temporal bone of the skull was designated as distance "b". Among the y-axis images, the line that passes through the center of the external auditory meatus and runs parallel to lines C and D was designated as line F. The perpendicular line that runs through the midpoint of line F in the condyle was designated as line G. Then, the distances between where line F bisects line G and the glenoid fossa were designated as "c" and "d". The distance between the summit of the condyle along line G to the deepest part of the glenoid fossa was designated as distance "e." These five points were established as the distances between the condyle and the glenoid fossa (Fig. 7).

During the examination of jaw function, the significance of the differences between the mean and standard deviation values obtained prior to treatment and those acquired after treatment was determined using the Student's t-test, with the significance level set at 5%.

RESULTS

Lateral cephalometric radiographs

In the H Group, the SNB angle increased an average of 1.6 degrees, the SNP angle an average of 1.8 de-

grees, the Cd-Gn distance an average of 3.5 mm, and the ANB angle an average of 1.8 degrees, while the Overjet decreased an average of 3.6 mm. In all items, significant differences ($p < 0.01$) were noted in comparison with the N Group in SNB, ANB, SNP, Cd-Gn and Overjet (Table 1).

Temporomandibular joint region CBCT

Even though the physiologic occlusal position was established, analyses based on CBCT did not find any significant differences in the position of the temporomandibular joint before placement of the appliance and after its removal (Table 2).

Investigation of jaw function

When comparing the muscle action potential with the mandible at rest, it was found that the potential difference was lower after removal of the appliance than prior to its placement. When the action potential at the time of clenching in centric occlusion was compared, although there was a wide variation in this value before placement of the appliance, after its removal this variation disappeared and the measurements became more uniform. Even in the context of limited mandibular movement, it was noted that the balance of the locus between the increase in maximum opening and the limit of lateral movement of the mandible had also improved (Table 3).

Table 1 Lateral cephalometric measurements

	H group (n = 7)				N group (n = 7)			Significance
	Before placement	After removal	Four months after removal	Change Before / After	Before	After	Change Before / After	
①SNA (degrees)	82.2 ± 3.4	82.3 ± 3.3	82.3 ± 3.3	0.1	80.8 ± 3.1	80.9 ± 3.1	0.1	—
②SNB (degrees)	76.0 ± 3.9	77.7 ± 3.7	77.7 ± 3.7	1.6	74.4 ± 3.8	74.3 ± 3.9	-0.1	*
③ANB (degrees)	6.4 ± 1.1	4.6 ± 1.1	4.6 ± 1.1	-1.8	6.4 ± 1.3	6.3 ± 1.2	-0.1	*
④SNP (degrees)	76.3 ± 3.9	78.5 ± 3.9	78.5 ± 3.9	1.8	75.1 ± 3.6	74.9 ± 3.8	-0.3	*
⑤FMA (degrees)	27.1 ± 4.3	28.0 ± 4.1	27.1 ± 4.1	0.1	28.6 ± 3.3	27.5 ± 4.3	1.1	—
⑥IMPA (degrees)	96.3 ± 9.3	99.1 ± 5.9	98.4 ± 6.4	2.1	96.8 ± 3.6	98.9 ± 5.4	2.1	—
⑦U1-SN (degrees)	102.6 ± 5.3	100.7 ± 6.5	101.1 ± 4.8	-1.4	97.4 ± 5.4	96.0 ± 5.4	1.4	—
⑧N-Me (mm)	128.4 ± 5.3	129.3 ± 5.4	128.2 ± 5.1	-0.2	127.6 ± 7.6	127.9 ± 7.5	0.3	—
⑨ANS-PNS (mm)	53.1 ± 4.0	53.1 ± 4.0	53.1 ± 4.0	-0.1	50.6 ± 3.3	50.6 ± 3.3	0	—
⑩Cd-Gn (mm)	117.1 ± 7.7	120.5 ± 7.5	120.6 ± 7.6	3.5	114.6 ± 5.1	114.6 ± 5.0	0.3	*
⑪Overjet (mm)	6.6 ± 1.3	3.0 ± 1.2	3.0 ± 0.5	-3.6	3.9 ± 1.0	3.9 ± 1.3	0	*

Mean ± SD, * $p < 0.01$.

Table 2 Distance between the condyle and glenoid fossa

	Parameter	Before placement	After removal	Change Before / After	Significance
Right (mm)	a	3.95 ± 2.0	3.85 ± 2.0	0.1	–
	b	2.77 ± 0.6	2.78 ± 0.6	–0.01	–
	c	2.93 ± 0.7	3.04 ± 0.7	–0.11	–
	d	2.09 ± 0.5	2.05 ± 0.5	0.1	–
	e	3.45 ± 0.9	3.38 ± 1.1	0.07	–
Left (mm)	a	5.0 ± 1.9	5.5 ± 0.6	0	–
	b	3.1 ± 0.8	3.1 ± 0.1	0	–
	c	3.01 ± 0.5	2.94 ± 0.7	0.07	–
	d	2.28 ± 0.3	2.21 ± 0.7	0.07	–
	e	2.94 ± 0.8	2.94 ± 0.8	0	–

n = 7, *p < 0.01.

Table 3 Jaw function examination

	Parameter	Before placement	After removal	Change Before / After	Significance
At rest (μ V)	LTA	1.95 ± 0.8	1.11 ± 0.6	0.84	**
	LMM	1.6 ± 0.5	1.19 ± 0.5	0.41	–
	RMM	1.32 ± 0.4	1.13 ± 0.6	0.19	–
	RTA	1.87 ± 0.8	0.91 ± 0.6	0.96	**
Maximum clenching (μ V)	LTA	98.6 ± 24	112 ± 26	–13.4	–
	LMM	126.9 ± 38	155.4 ± 38	–28.5	–
	RMM	125.7 ± 14	140.6 ± 21	–14.9	–
	RTA	79.1 ± 25	87.9 ± 19	–8.8	–
Maximum opening (mm)		40.0 ± 4.9	42.0 ± 3.3	–2	**
Limit of lateral movement (mm)	Front	10.5 ± 3.7	8.57 ± 4.0	1.93	–
	Back	20.7 ± 8.0	21.7 ± 6.4	–1	–
	Right	4.77 ± 1.8	7.06 ± 2.3	–2.29	–
	Left	6.19 ± 1.9	6.77 ± 2.0	–0.58	–

**p < 0.05.

DISCUSSION

Late growth

Analytic methods of growth and development include the categories of annual change of chronological age, dental age, skeletal age, and cervical vertebrae age. All of these are utilized in the growth forecast of the individual subjects.^{20–22} In the context of orthodontic therapy, the carpal maturity level, which is closely related to individual growth and development, is often used as the basis for assessment. There are numerous epiphyses in this region, it is easy to take hand-wrist radiographs, radiation exposure is low, and it is considered a highly reliable method even for comparison of such elements as cervical vertebrae age.²³ In

the prediction method for maxillary and mandibular growth by Sato *et al.*²⁴, it was reported that the standard female skeletal Cd-Gn growth rate peak is reached at around the age of 11 years, and that the growth increase between the ages of 14 and 17 years is 2.4 mm. The same value between 16 and 17 years is less than or equal to 1 mm.

In this study, the skeletal maturity stages of the middle phalanx of the third finger (MP 3) was divided into the four stages of MP 3-E, MP 3-F, MP 3-FG and MP 3-G, while the radius (R) was divided into the four stages of R-H, R-I, R-IJ and R-J, in accordance with the reports of Helm²⁵, Hägg²⁶, Tanner²⁷ and Sato^{28,29}. According to Sato³⁰, the radial epiphyseal nucleus reaches full maturity during stage J (which occurs af-

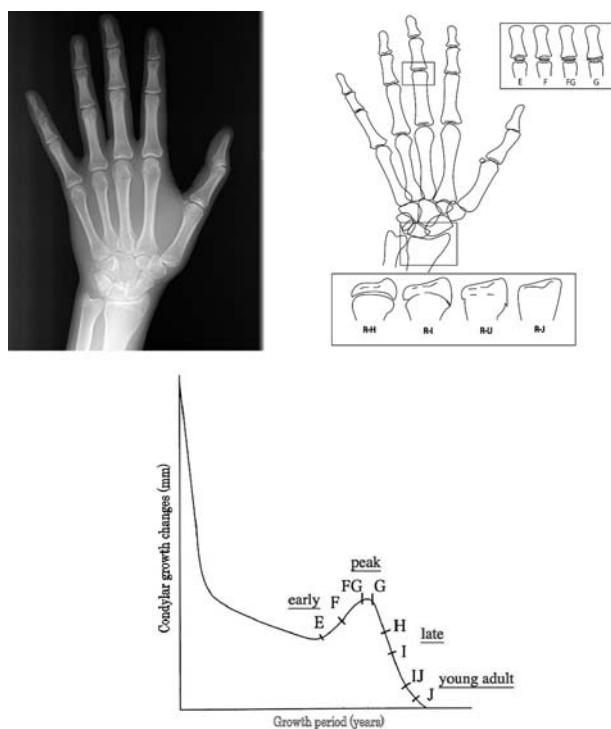


Fig. 8 Evaluation of carpal maturity. E through G are the stage of early adolescence, while young adulthood is defined by stage IJ or J.

ter the age of 16), when the epiphysis fuses with its metaphysis; therefore, little growth or development is thought to occur beyond this point (Fig. 8).

Our assessment of lateral cephalometric radiographs showed only a slight increase of only 0.3 mm for the distance Cd-Gn in the N Group. This indicates the same growth rate at the stage R-J found in the report of Sato *et al.* Even viewed from this standpoint, the 3.5 mm of growth observed in the H group was not considered to represent late growth, but rather to be caused by placement of the appliance.

Temporomandibular joint region CBCT

Because lateral cephalometric radiographs only allow two-dimensional analyses, three-dimensional methods³¹ have recently been used to grasp the changes in facial form associated with hard tissues. In the case of the CBCT, it has been reported³² that use of the three-dimensional image is superior to other methods in image reproduction and measurement precision. However, it was necessary in this study for us to es-

tablish new conditions of imaging and axis coordinates to quantitatively measure changes in the position of the condyle of temporomandibular joint sections.

During the CBCT-based assessments of the changes in the position of the condyle, it was found that placement of the appliance had guided the condyle into a more protrusive position. However, even after removal of the appliance, a physiological occlusal position was maintained. In addition, the condyle returned to its position in the center of the glenoid fossa; thus, no significant difference in the positional relationship between the temporomandibular joint and the glenoid fossa was detected before and after treatment. As a result, it was determined that the glenoid fossa and condyle had undergone remodeling.

Results

The appliance

The Herbst appliance is a large miniscope device connecting the maxillary first molars and the mandibular first premolars. Although it is not often used in Japan, it has been reported⁶ that it is a common treatment in America and Europe. However, in recent years a modified Herbst appliance that causes less discomfort has received more publicity than those reported by Corcoran *et al.*¹² and Dischinger.³³ The modified Herbst appliance is more comfortable because it only connects the maxillary first molar and the mandibular first molar. Because the telescoping rod that connects the maxilla and mandible is short, it also relieves the labial tipping that is a reaction to the horizontal component. Also, it is only one-half the size of the conventional Herbst appliance.^{34,35} Since it is in the posterior region of the mouth, it does not cause pain in the orbicularis oris, and the telescoping rod screws do not irritate the buccal mucosa.

The bionator is a functional appliance often utilized^{5,36} for treatment of Angle Class II malocclusion accompanied by mandibular retrusion, in the same manner as the Herbst appliance. It is removable, and recommended for use during the pubertal growth spurt.³⁶ Although good results can be obtained during the growth period with a removable appliance, it is difficult to obtain the same sort of results in young adults

with a removable appliance in the same length of time. Since, utilization in tandem with a multi-bracket appliance during active treatment is troublesome, the treatment period may be prolonged. Because the Herbst appliance is a fixed type device, it does not require the cooperation of the patient. Because it seems like a good treatment for use in tandem with general orthodontic therapy, we decided to utilize it for this study.

Measurement results

Voudoris *et al.*^{37,38} reported that in patients with protruding mandibles, the guidance of the mandible with a conventional Herbst appliance results in growth of the mandibular body through condylar remodeling and the suppression of maxillary growth, leading to distocclusion of the maxillary teeth and mesial inclination of the mandibular teeth. We found significant differences in the mandibular body length between the H and N Groups. Placement of the functional Herbst appliance guides the mandible into a new position in the sagittal plane. It has been reported³⁹ that changes in the intercuspal position created by an appliance may be reversed or result in a dual bite, unless the position of the temporomandibular joint and the position of the muscles are stabilized. This may give rise to temporomandibular joint syndrome.

Neuromuscular concept

Kawamura⁴⁰ studied the neuromuscular concept, which clarifies the role of the periodontal membrane, the temporomandibular joint and muscle sensory receptors, as well as stimulation to the central nervous system and mandibular movements. Subsequently, through development of the mandibular movement measurement appliance and the electromyogram, it has become possible to kinetically and chronologically grasp mandibular movements.⁴¹ Jankelson⁴¹ premised that it is not possible to reproduce a physiological mandibular position without removing such elements as occlusal disharmony and emotional stress because of abnormal muscular activity or muscle atrophy. He advocated establishment of the occlusal position by utilization of the myomonitor.

The physiological mandibular position is a condition

in which there exists a 1.0 to 2.0 mm interocclusal clearance in the mandibular rest position for the benefit of the occlusion.⁴² This is based on the positional relationship between the articular disk on the rear slope of the mandibular tubercle and the mandibular condyle.⁴² In addition, when such interocclusal clearance is present, the jaw muscles are considered to be in functional balance.⁴² Whilst changes in occlusion and the temporomandibular joint occur with age, it is thought that the physiological condition of the jaw muscles can be restored through appropriate treatment.⁴² Since cases of malocclusion combined with functional disorders of the mandible are quite common, it is considered necessary to achieve a functional balance between the muscles involved in occlusion.⁴³

In this study, jaw function examinations were conducted to identify patients whose mandibular rest position differed from their physiological mandibular rest position. The modified Herbst appliance was used to guide the mandible in the sagittal plane and to achieve a physiological occlusal position in order to shift the position of the condyle within the glenoid fossa in the sagittal plane. Since the distance between the condyle and the glenoid fossa is increased when the condyle is shifted anteroinferiorly, such changes give rise to remodeling of the glenoid fossa and condyle. We found that it is possible to encourage mandibular growth using a fixed functional appliance during the late growth period.

In this study, we obtained lower resting muscle action potential index values than those reported in previous studies (LTA : 2.8 μ V, LMM : 2.0 μ V, RMM : 2.0 μ V, RTA : 2.8 μ V),⁴¹ and it appeared that the muscles were in a more relaxed state after removal of the appliance. Since CT confirmed that the relationship between the condyle and the glenoid fossa observed after removal of the appliance was similar to that seen when the appliance was placed, our results agree with the conventional neuromuscular concept theory. In our examination of jaw function, we demonstrated that the mandible protruded to a greater extent in the physiological mandibular rest position than it did in the mandibular rest position observed prior to placement of the appliance, indicating that the physiological ma-

mandibular rest position and the mandibular rest position were the same after removal of the appliance. Based on this result, we think that it is necessary to take account of occlusion, the position of the temporomandibular joint, and the jaw muscles to obtain optimal results during Herbst treatment. Our method resulted in minimal reversal of the new mandibular position, showed very little evidence of a dual bite, and alleviated the burden on the temporomandibular joint.

CONCLUSION

We studied how treatment with the modified Herbst appliance in females during late growth influenced maxillofacial morphology. The results suggest that this appliance is effective for patients in the latter part of their growth period.

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