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Kinetic Analysis of Facial Soft Tissue with Twin Block during Mandibular Movement

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The aim of this study was to elucidate dynamic state of the kinetics of facial soft tissue affected by use of a Twin Block appliance (TB). The subjects were 10 adult males (mean 25.4±3.1 years old) with Class II division 1 malocclusion (Class II group) and 10 adult males (22.7±10.2 years) with Class I malocclusion (Class I group). Individual TB appliances were prepared by registering the construction bite vertically after being raised by 2 mm at the incisors. The mandible was advanced stepwise to 4 protruding positions of 0, 2, 4, and 6 mm, as well as 3 dimensional positions noted by 18 markers, whose coordinates were converted from 3 forehead points determined in the directions of the x, y, and z axes using an optical motion capture system. For the task, tapping at 2 Hz was performed. The movement distance of the upper lip in the transverse direction was significantly less in the Class II group without an appliance than in the Class I group without an appliance. In contrast, that of the upper lip in the longitudinal and vertical directions was significantly greater in the Class II group at the 4-mm protruding position than in the Class II group without an appliance. Our results show that the motor function of the upper lip may be restored with use of a TB appliance.

Key words : kinetic analysis, soft tissue, twin block

Introduction

A Twin Block appliance (TB)[1], used for the treatment of Class II division 1 malocclusion, is an orthodontic appliance with two plates each for dentition, whose usage allows near normal movements of the tongue, lips, and mandible during speaking and eating. This functional mechanism causes a maximum growth reaction of the mandible[2], and produces favorable therapeutic results such as improvement in the maxillomandibular relation in the anteroposterior direction[3] and soft tissue of the lateral facial profile[4,5].

The amount of construction bite in the longitudinal direction attained by use of TB is generally set so as not to exceed 70% of the longitudinal distance between that at the centric position and that at the maximum anterior position, with a maximum of 10 mm from the incisal edge. For advancement that exceeds the above-mentioned levels, reports have been made regarding progressive activation[6], as well as comparisons of the effects of advancement between a single-step procedure, in which mandible were advanced once, and a stepwise procedure, in which mandible were advanced stepwise by 2 mm at a time[7,8].

A motion capture system enables kinetic analysis of facial soft tissue by use of multiple

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measurement points on the face[9]. Thus far, no report has been made on the optimum amount of construction bite based on kinetic analysis of the face. In the present study, for the purpose of elucidating the optimum amount of construction bite during mandibular movement with use of TB, facial soft tissue kinetics were examined using a motion capture system.

Subjects and Methods

2.1. Subjects

Twenty adult male subjects were selected for the study and divided into 2 groups : 10 with Angle Class II division 1 malocclusion (mean age 25.4±3.1, range 20.8-29 years) and 10 with Class I malocclusion (mean age 22.7±10.2, range 24.2-37.8 years). These subjects were selected from patients with Class I or II malocclusion, who had a bilaterally symmetric dental arch with a midline deviation within 2 mm, and no missing teeth (excluding the third molar), without premature contact, without history of temporomandibular arthrosis, or orthodontic treatment experience. In addition, they fulfilled the following criteria :

2.1.1. Patients with Class II div. 1 malocclusion

a. Angle Class II at the bilateral molars

b. Arch length discrepancy of -4 to 0 mm

c. Overbite of +4 mm or greater and overjet of +4 mm or greater

d. Possible to register a construction bite

2.1.2. Patients with Class I malocclusion

a. Angle Class I malocclusion at the bilateral molars

b. Arch length discrepancy of -4 to 0 mm

c. Overbite and overjet within normal ranges

Data were collected after obtaining approval from the ethical committee of the Ohu university and informed consent of the subjects.

2.2. Measurements

2.2.1. Optical motion capture system

For the measurements, we used the optical motion capture system VICON MX (VICON, Oxford, UK), which can track minute movements of facial soft tissue. The subjects were instructed to keep a natural head posture while in a sitting position on a chair placed at the center of the floor in a motion analysis room and fix their visual point toward a single point as much as possible during the time of measurement. This system is frequently used for analyses of bodily motion with computer graphics and enables synchronous analysis of measurements taken at multiple points on maxillofacial soft tissue. Further, the head of the subject does not need to be secured and movements of the markers on the soft tissue can be tracked noncontact[9].

For measurement, twelve MX40 high-speed cameras (VICON, OXFORD, UK), 4 mobile and 8 stationary types, were used. Four of the cameras were set at positions from the center of the floor of the motion analysis room. The sampling rate was set at 160 Hz.

For determining the position of each camera and coordination system of the measured space, a calibration frame with a cubic lattice set at a fixed distance was placed in the center of the floor of the motion analysis room. The center of the floor of the motion analysis room was set at the point of origin of the measured space by static calibration of photographs taken by each camera. The reference axes were expressed as follow. The x axis in the right direction was positive, the y axis in the anterior direction was positive, and the z axis in an upward direction was positive. Since the measured space was limited to maxillofacial soft tissue, dynamic calibration of the space was performed using a frame for which the distance was set in advance.

To track the movement of the soft tissue, we used reflective hemispherical markers (VICON, Oxford, UK) sized 3 mm in diameter, which were considered to attain a more favorable

Table 1 Accuracy test (mm).

	x axis	y axis	z axis
Mean of the differences of actual measurements	0.276±0.182	0.388±0.134	0.290±0.211
Standard error	0.008	0.006	0.009

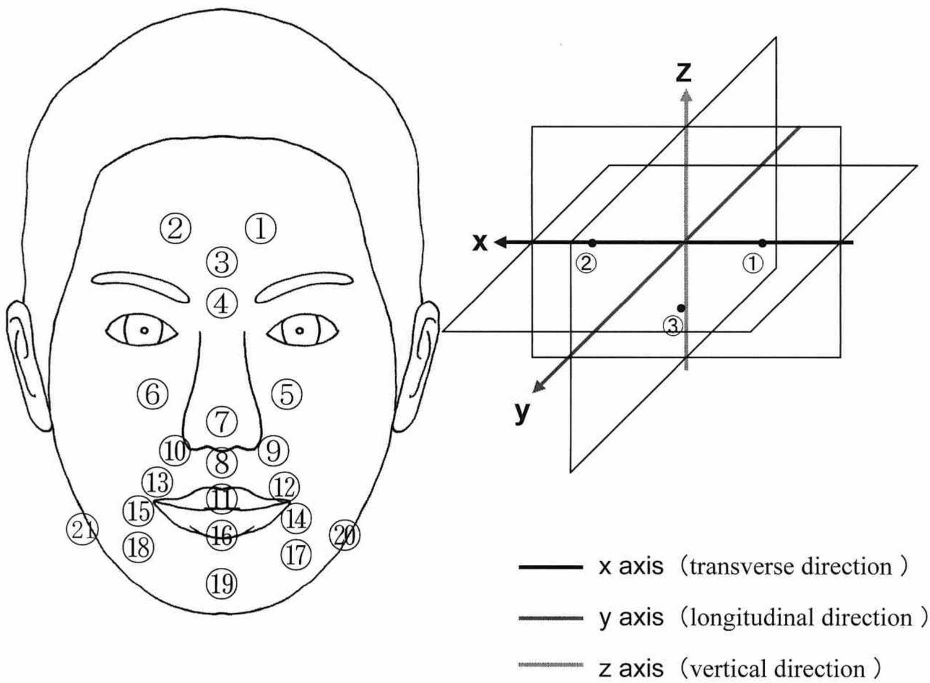

Fig. 1 Facial landmarks and coordination system

attachment than the spherical type.

2.2.2. Accuracy test

Two of the hemispherical markers were adhered to a digital caliper (Mitutoyo, Tokyo, minimum scale 0.01 mm, instrumental error ±0.02mm). The actual measurement values obtained by adjusting the distance between the two markers from 0 mm to 150 mm by 50 mm in a transverse direction (x axis), longitudinal direction (y axis), and vertical direction (z axis) in the motion analysis room, along with values obtained by the motion capture system (sampling rate 160 Hz, 2 second intervals), were determined. The mean difference between the actual measurement value and value obtained with the system ranged from +0.276 to +0.388, with a standard error of +0.006 to +0.009, which demonstrated a high level of precision (Table 1).

2.3. Setting of measurement points and coordination system

Using the points for body measurement reported by Martin[10], the following measurement points were set : (1, 2) bilateral frontal eminences, (3) midpoint between the metopion and glabella, (4) glabella, (5, 6) bilateral orbitals, (7) spinode of the nose, (8) subnasal point, (9, 10) bilateral nosewing points, (11) upper lip point, (12, 13) midpoints between the bilateral nosewing points and angular nodal points, (14, 15) bilateral angular nodal points, (16) lower lip point, (17, 18) bilateral subangular points, (19) pogonion

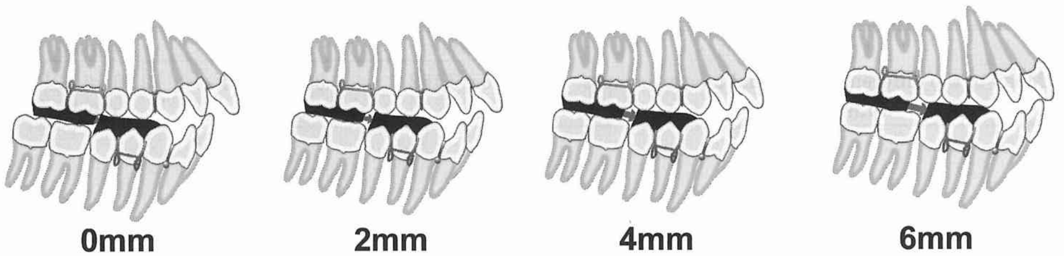

Fig. 2 Distance of mandible advancement

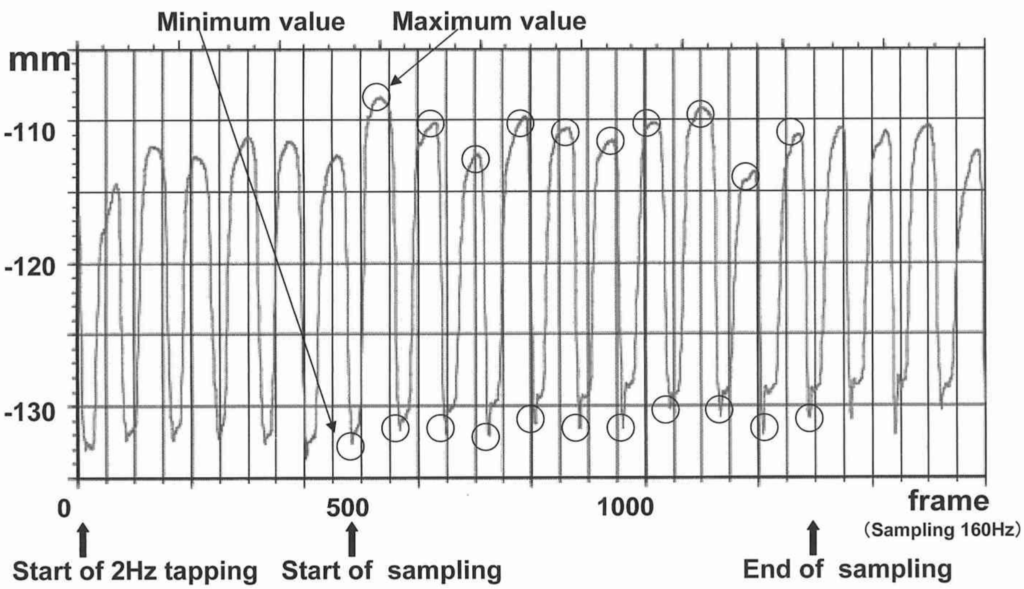

Fig. 3 Tapping task and data collection

of the soft tissue, and (20, 21) bilateral gonions (Figure 1). The hemispherical reflective markers were adhered using double-faced tape.

For the coordinate system, after recording the position of each marker on the x, y, and z axes of the camera coordinates, the origin of which was the center of the floor, the coordinates were converted as follows. The x axis (positive in the right hand direction) passed through the bilateral frontal eminence (1, 2), and the z axis (positive in the upper direction) passed through the midpoint between the metopion and glabella (3), which were vertical to the x and y axes (positive in the anterior direction), and vertical to the x and z axes. Then, the 3-dimensional positions of 18 points below the glabella of the facial soft tissue (4) were expressed as time-series data (sampling rate 160 Hz) (Fig. 1).

2.4. Setting of construction bite and preparation of Twin Block appliance

Impressions of the upper and lower dental arches were taken. By using the bite taken with a Pro-jet bite gauge (Great Lakes, N.Y., USA, amount of occlusal elevation 2 mm), a working model was formed and mounted on an articulator (FKO split post-fix Zeter,

Table 2 Comparison between the Class I and Class II groups without a TB.

Facial landmarks	No.	Direction	Class I group			Class II group			significance
			median	inter-quartile range	average	median	inter-ruartile range	average	
Left orbital	5	x	0.298	0.178	0.328	0.154	0.125	0.177	* *
Right orbital	6	x	0.342	0.292	0.375	0.154	0.123	0.164	* *
		y	0.638	0.591	0.714	0.316	0.311	0.322	* *
Spinode of the nose	7	x	0.467	0.391	0.567	0.269	0.190	0.305	*
Subnasal point	8	x	0.672	0.350	0.690	0.301	0.213	0.295	* *
Right nosewing point	10	y	0.771	0.596	0.880	0.431	0.264	0.374	* *
Upper lip point	11	x	0.677	0.605	0.868	0.273	0.241	0.324	* *
Left angular nodal point	14	x	2.437	1.449	2.702	2.037	1.049	2.200	*
Right angular nodal point	15	x	2.074	1.907	2.383	1.146	1.070	1.511	*
Right subangular point	18	x	1.318	1.744	2.201	0.485	0.553	0.752	*
Left gonion	20	x	1.182	0.691	1.195	0.729	0.371	0.676	*
Right gonion	21	x	1.485	1.152	1.509	0.341	0.510	0.456	* *

*$P<0.05$, **$P<0.01$

Dentauram, Ispringen, Germany). Base plates were then prepared for the maxillamandible, to which occlusal bite blocks were attached. The inclined plane provided to the occlusal bite blocks at the second premolar or deciduous molar was set at 70° to the occlusal plane. A screw 10 mm in length was incorporated into the occlusal bite block so that the upper was parallel to the occlusal plane, in order to adjust the amount of mandibular advancement precisely (Figure 2). The movement distance of the screw was measured using a digital caliper minimum scale (Mitutoyo, Kawasaki, Kanagawa, JAPAN).

2.5. Task

For the task, tapping at 2 Hz for 10 seconds was performed by the subjects with Class II malocclusion (Class II group) with and without TB, while the subjects with Class I malocclusion (Class I group) without TB performed the same task with a 20-second rest period. The task was repeated 3 times. For the Class II group with TB, tapping was performed with the mandibular position vertically elevated by 2 mm and longitudinally protruded positions of 0, 2, 4, and 6 mm. The rhythm for tapping was kept by an electronic metronome (YAMAHA, ME-300, Tokyo, JAPAN).

2.6. Data analysis

Three-dimensional coordinate data from each measuring point on the maxillofacial soft tissue were collected in the data station. Then, 21 markers were labeled on the workstation for reproducing the 3-dimensional position of each. For data analysis, software (Workstation, VICON, Oxford, UK) and a personal computer (Precision 370, DELL, Texas, USA) were used. The maximum and minimum values for 10 tapping tasks from around 480 frames to 1280 frames, when tapping motion became stabilized, were recorded (Figure 3). For markers of each facial landmarks, the mean movement distances in the directions of the x, y, and z axes were calculated.

2.7. Statistical analysis

The results of the Class I group without TB and Class II group without TB were compared using a Mann-Whitney U-test, while Dunnett's test was used for comparing the Class II group with TB at the protruding positions of 0, 2, 4 and 6 mm with those without TB as a control. Regression analysis was performed between the overjet and mean movement distance in the direction of the x, y, and z axes by the 18 points on the face. For statistical analysis,

Table 3 Comparison at protruding positions of stepwise advancement

Measuring points	No.	Direction	without a TB (control)	0mm	2mm	4mm	6mm
			mean±SD	mean±SD	mean±SD	mean±SD	mean±SD
Right orbital	6	x	0.164±0.067	0.180±0.055	0.189±0.073	0.413±0.269*	0.280±0.117
		y	0.322±0.184	0.501±0.376	0.606±0.416	0.741±0.371	0.903±0.801*
Spinode of the nose	7	y	0.327±0.227	0.534±0.451	0.626±0.520	0.584±0.394	1.092±1.005*
Subnasal point	8	y	0.514±0.283	0.541±0.437	0.772±0.516	0.741±0.361	1.186±0.956*
Right nosewing point	10	y	0.373±0.139	0.560±0.482	0.690±0.517	0.646±0.402	1.091±1.094*
Upper lip point	11	y	0.474±0.244	0.621±0.419	0.796±0.473	1.329±0.690*	1.110±1.008
		z	0.506±0.505	0.680±0.504	0.696±0.581	1.121±0.313*	0.684±0.720
Left angular nodal point	14	x	2.200±0.591	1.827±0.615	1.652±0.470	1.498±0.612*	1.329±0.530**
Right angular nodal point	15	y	3.575±0.769	2.292±0.879*	2.223±0.869*	3.003±1.361	2.270±1.451*
Left subangular points	17	x	1.677±0.867	1.421±1.020	0.867±0.419*	0.870±0.576*	0.965±0.322
		y	5.800±1.994	3.702±1.882	3.292±1.538*	5.014±2.789	4.159±2.169

*P<0.05, **P<0.01

software (SPSS 14. OJ, SPSS, Tokyo, JAPAN) and a personal computer (Vectra VE, Hewlett Packard, Clifornia, USA) were used.

Results

3.1. Movement distance of facial soft tissue in subjects without TB

Movement distance in the transverse direction in the Class II group without TB was significantly less at the left orbital point, right orbital point, spinode of the nose, subnasal point, upper lip point, left angular nodal point, right angular nodal point, right subangular point, left gonion, and right gonion, as compared to those of the Class I group (Table 2). Further, movement distance in the longitudinal direction in the Class II group was significantly less at the right orbital point and right nosewing point than those in the Class I group. No statistically significant differences were observed for the other points, including in the vertical direction.

3.2. Mean movement distance of facial soft tissue at the time of mandibular advancement

In a comparison of the Class II group with and without TB, subjects with TB showed significantly greater movement distance in the transverse direction at the right orbital point when the mandible was advanced by 4 mm. When the mandible was advanced by 6 mm, the movement distance in the longitudinal direction of the Class II group with TB was significantly greater at the right orbital point, spinode of the nose, subnasal point, and right nosewing point. At the upper lip point, the movement distance in the longitudinal and vertical direction was significantly greater when mandibular was advanced by 4 mm. The movement distance at the left angular nodal point was significantly less in the transverse direction when the mandible was advanced by 4 and 6 mm. Further, movement distance at the right angular nodal point was significantly smaller in the longitudinal direction when the mandible was advanced by 0, 2, and 6 mm. At the left subangular point, the movement distance was significantly less in the transverse direction when the mandible was advanced by 2 and 4 mm, and in the longitudinal direction when the mandible was advanced by 2 mm. As for the other points, no statistically significant differences were observed (Table 3).

3.3 Regression analysis

Regression analysis of overjet and mean longitudinal and vertical movement distance at 18 points on the face showed a negative correlation (correlation coefficient -0.656,

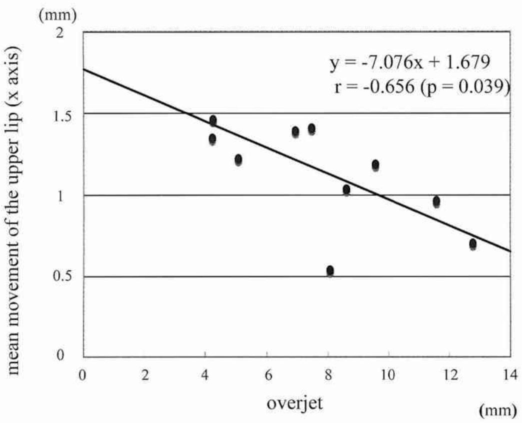

Figure 4 Class II group with the mandible at the 4-mm protruding position in the direction of the X axis. Relationship between the mean movement of the upper lip with TBA and overjet without a TB.

p=0.039) with the upper lip point in the direction of the x axis when the mandible was protruded by 4 mm (Figure 4).

Discussion

Increases in overjet and overbite in patients with Class II division 1 malocclusion make lip closure difficult and produce a compensatory function in the perioral muscles when fulfilling the physiological functions of mastication, swallowing, respiration, and pronunciation. This condition induces habitual thrusting of the lower lip between the anterior teeth of the maxilla and mandible, an adynamic upper lip due to hypofunction of the orbicular muscle of the mouth, and excessive tension in the muscles in the lower lip and chin. For muscular function around the mouth, the following causes have been noted : low labial pressure of the upper lip[11], short longitudinal movement distance of the upper lip[12], the maxillary incisor to Frankfort horizontal angle was related to the upper lip closing force[13] and relationship between the angle of inclination of the lower anterior teeth and activity of the orbicular muscle[14]. It is considered that inactivity of the orbicular muscle including the upper lip might be one of the causes of malocclusion[15].

Sakaguchi *et al.* reported that changes in the midline region of the upper lip during mastication mainly consisted of motor components in the vertical direction, with few lateral components[15]. In the present study, the amount of movement was a meaningful difference was not recognized statistically at the subnasal point and upper lip point in the longitudinal and vertical directions in the Class II group without TB and the Class I group. However, movement distance in the transverse direction was significantly smaller in the Class II group. This might indicate hypofunction of the upper lip in the Class II subjects.

In a comparison between the Class II group with and without TB, the amount of movement was greater at the subnasal point in the longitudinal direction in those with TB, as well as at the upper lip point in the longitudinal and vertical directions when the mandible was advanced by 4 mm. It was considered that the activity of the orbicular muscle of the upper lip might be improved in the longitudinal and vertical directions by occlusal elevation and mandibular advancement with use of TB, even with a simple movement such as tapping, which temporarily activated and improved the motor function of the upper lip in the present subjects. At the right angular nodal point and in the right subangular point, the movement distance in the transverse direction was significantly smaller in the Class II group without TB than in the Class I group.

In subjects with normal occlusion, movement in the angular nodal region consisted of a larger lateral component as compared to the longitudinal component. The course of the muscles arranged radially from the angle of the mouth at the center might have an effect on the movement around the angular nodal points[16]. In the present study, the Class II group without TB showed less transverse movement at the bilateral angular nodal points and right subangular point than the Class I group without TB, which suggested a dysfunction at the angular nodal point toward the transverse direction point in the Class II group.

At the angular nodal point, the movement distance decreased on the right side in the longitudinal direction and on the left side in the lateral direction when the mandible was advanced. We considered that the movement distance in the longitudinal and transverse direction was decreased as the buccinator muscle, elevator muscle of the upper lip, depressor muscle of the lower lip, and risorius muscle, which are major muscle parts of the orbicular muscle, were elongated, as the tapping task was performed by raising the occlusion with the appliance and protruding the mandible.

At the lower lip point and pogonion of the soft tissue, no significant differences were observed among the Class I group without TB, Class II group without TB, and Class II group when the mandible was advanced stepwise. It was speculated that since the movement was a simple tapping task in which lip closure was not requested for Class II malocclusion subjects, the movement did not exert any effect on the muscular movement of the lower lip and chin, even when the mandible was advanced forward.

On the basis of our findings, we considered that the function in the upper lip would be improved in Class II patients when the mandible is advanced by 4 mm. Iwahashi *et al.* reported that the muscular function of the lips could not be restored even by changing the overjet experimentally with use of a dummy in the upper anterior teeth in patients with lip closure failure[17]. However, their experimental procedure was different from ours, in that overjet was reduced by advancing the mandible. Nakamura *et al.* carried out an experiment in which healthy adult males with a TB performed tapping, and reported that the surface temperature of the soft tissue in the philtrum elevated when the mandible was advanced by 2 and 4 mm[18]. In the present study, the Class II group, in which the amount of movement in the transverse direction was small at the upper lip, showed increased movement in the vertical and longitudinal direction when the mandible was advanced by 4 mm. Thus, the function of the upper lip might be increased at the time of mandibular advancement by 4 mm.

Regression analysis of the mean movement distance in the vertical direction at the upper lip point when the mandible was advanced by 4 mm and overjet without TB revealed a negative correlation (r=-0.656). This suggested that as the overjet increased, the movement distance in the vertical direction became smaller. In the present study, the overjet in the Class II group was 8.25±3.6 mm and the 4mm advancement of the mandible was equivalent to approximately 50%. In regard to the activated amount of construction bite, it has been reported that stepwise advancement using a screw was effective[19] no difference in the effect was observed between a 3-mm advancement and 5 to 6 mm of advancement[20] and the amount should not exceed 70% of the maximum amount of forward movement[21]. The results of the present study were similar to those findings. Accordingly, since the amount of upper lip movement increased in subjects with Class II division 1 malocclusion when the mandible was advanced by 4 mm, it is suggested that 4 mm of advancement is an appropriate amount for a construction bite.

Conclusion

The amount of movement of the upper lip was smaller in the transverse direction in subjects with Class II division 1 malocclusion than in those with Class I malocclusion. However, the amount of movement increased in the vertical and longitudinal direction when the mandible was advanced by 4 mm. Therefore, the motor function of the upper lip may be restored with use of a twin block appliance.

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