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Brain Activity after Wearing a Twin Block Appliance

Satoshi YOSHINAGA, Masakuni HIROSE
Shinji NAKAMURA and Toshihiko HIMURO

To investigate the effects of mandibular advancement with a twin block appliance (TBA) on brain activity in the prefrontal cortex during gum chewing in Class Ⅱ division 1 malocclusion. The study group consisted of 20 males (25.1±3.0 years old), who were divided into 10 Class Ⅰ individual normal occlusion subjects with a favorable facial morphology and 10 Class Ⅱ div. 1 malocclusion subjects with retruded mandible. Brain activity in the prefrontal cortex was measured using near-infrared spectroscopy (NIRS). Without wearing a TBA, we found that the concentration of oxygenated hemoglobin (O_2Hb) in the left prefrontal cortex was significantly lower in the Class Ⅱ group than in the Class Ⅰ group. In both groups, the concentration of O_2Hb in the right prefrontal cortex was significantly elevated when a TBA was used at the 0-mm protruding position as compared to when a TBA was not used. No statistically significant differences were observed between the groups with a TBA at the 0-mm protruding position. There was no increase in O_2Hb concentration in the Class Ⅱ group when the mandible was advanced stepwise to the 8-mm protruding position with a TBA. In contrast, VAS (visual analog scale) scores, used for rating the level of discomfort, increased in accordance with the increase in mandibular advancement. Our results suggest that measurement of brain activity in the prefrontal cortex by NIRS might be useful for monitoring discomfort when masticating with a TBA.

Key words : prefrontal cortex, Twin block appliance, emotion, mandibular advancement, NIRS

INTRODUCTION

Class Ⅱ div. 1 malocclusion[1] generally arises from mandibular bradyauxesis and causes narrowing of the upper tooth row, deep overbite, and excessive overjet[2~5]. Orthodontic treatments for the condition include bite jumping, mandibular advancement, and lateral expansion. A twin block appliance (TBA)[6,7] is an orthodontic appliance that exerts three-dimensional control over the upper and lower jaws. It has been shown to be effective for treatment of Class Ⅱ div. 1 malocclusion, and has been used for patients in the growth period as well as young adults. A TBA guides the lower jaw forward for chewing movement, which facilitates growth of the articular process. However, the appliance can cause discomfort, as it forcefully advances the lower jaw and exerts stress on mandibular movement immediately after fitting.

The prefrontal cortex is the high-order nerve center involved in thinking, behavior control, and decision making, and is also involved in the perception of pleasant and unpleasant feelings. Davidson *et al*[8]. found that a pleasant feeling

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奥羽大学歯学部成長発育歯学講座歯科矯正学分野
（指導：氷室利彦教授）

Division of Orthodontics and Dentofacial Orthopedics, Department of Oral Growth and Development, Ohu University School of Dentistry
(Director : Prof. Toshihiko HIMURO)

enhanced EEG activity in the left hemisphere, while an unpleasant feeling elevated activity in the right hemisphere. In a study that utilized fMRI, Ueda *et al*[9]. reported that pleasant stimuli induced activation of the left prefrontal cortex and unpleasant stimuli induced that of the right prefrontal cortex. Morinaga *et al*[10]. clarified those findings using NIRS and noted that elevation of oxygenated hemoglobin levels in the right prefrontal cortex might be related to an uneasy feeling in subjects prior to measurements. These findings strongly suggest that pleasant feelings are associated with brain activity in the left prefrontal cortex and unpleasant feelings with that in the right prefrontal cortex[8~12].

Brain activity is generally determined on the basis EEG findings for the action potential of nerve cells. Such neuron activity activates energy metabolism, and secondarily increases the regional cerebral blood flow that supplies glucose and oxygen to the brain. Therefore, measurement of regional changes in hemoglobin levels by optical topography provides an important index for clarifying the site where cerebral function is activated[13]. For brain activity induced by mastication, it has been shown that gum chewing activates that in the prefrontal cortex[14,15]. NIRS represented by optical topography is non-restrictive and different from fMRI and PET, as it can be used to determine brain activity during mastication movement without being affected by the masticatory muscles[16].

For the present study, we designed an experimental plan based on the following hypotheses : (1) unpleasant feelings caused by TBA fitting elevates brain activity in the right prefrontal cortex and (2) an increase in the amount of mandibular advancement elevates brain activity in the right prefrontal cortex. For the purpose of elucidating the actual condition of the unpleasant feelings caused by TBA fitting in patients undergoing orthodontic treatment, we determined the level of oxygenated hemoglobin in blood flow in the prefrontal cortex using optical topography to investigate whether it could be a useful index. Thereafter, we attempted to clarify brain activity in the prefrontal cortex that is involved with pleasant and unpleasant feelings in patients with Class II malocclusion, immediately after TBA fitting and during gum-chewing while the lower jaw was advanced stepwise to protruding positions.

MATERIALS & METHODS

1. Subjects

The subjects were 20 male students [25.1±3.0 years old (mean±SD)] of our university. They were divided into 2 groups ; the Class II group consisting of 10 students (24.9±4.3 years) who demonstrated mandibular retrusion (Class II div. 1) in a facial features examination (Regan-Berston Analysis[17]) and the Class I group consisting of 10 students (25.3±1.1 years) who had characteristic normal occlusion and balanced facial features. The Class II group had an overjet of +11.1±4.2 mm, while that in the Class I group was +1.9±0.5 mm, which were significantly different ($p<0.01$). All subjects were right-handed. The study was performed under the approval of the Ethical Review Board of Ohu University after obtaining informed consent from the subjects.

2. Preparation of TBA

A construction bite for each subject was registered by setting the vertical dimension between the central incisors of the upper and lower jaws at 2 mm, and the longitudinal dimension at 0 mm using a Pro-Jet Bite Jigs kit (Great Lakes Co., N.Y., USA). Thus, the occlusion was raised by about 3-5 mm at the molars.7 Cast models of the upper and lower jaws were attached to an articulator (FKO Split post-fix zetor, Dentauram Co., Ispringen,

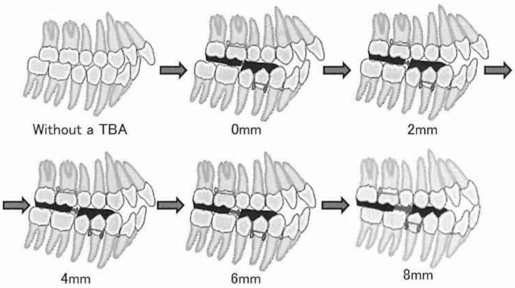

Fig. 1 Setting of mandibular advancement

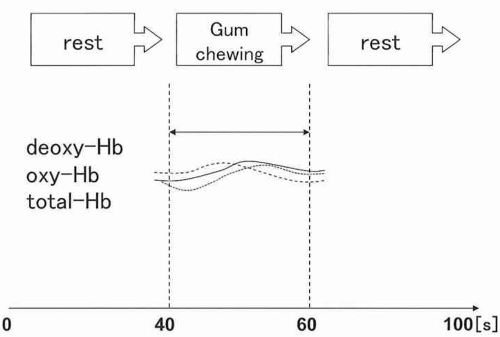

Fig. 2 Task and mesurement

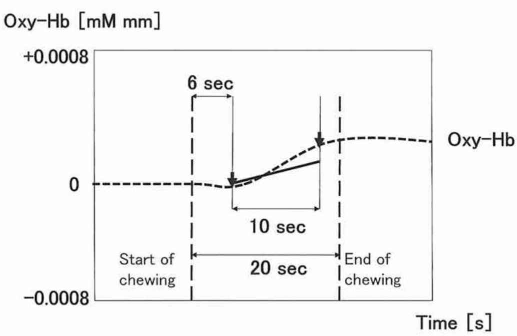

Fig. 3 Analysis

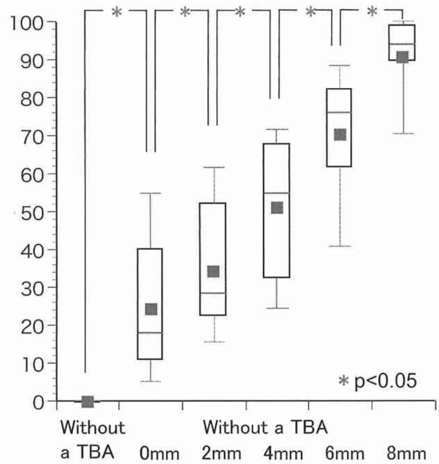

Fig. 4 Introspective report using a VAS score in the Class Ⅱ group.

The intensity of unpleasant feelings while gum chewing without a TBA and with a TBA with mandibular advancement of 0, 2, 4, 6, and 8 mm were rated using a VAS, and the results were examined with Friedman's χ^2 r-test.

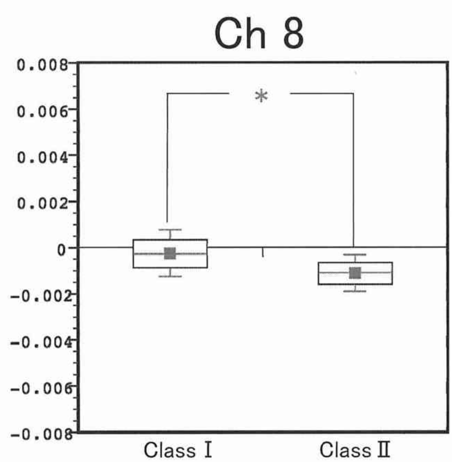

Fig. 5 Comparison of brain activity during gum-chewing between the Class I and Class Ⅱ groups without a TBA (P<0.05).

Germany) using a Pro-jet bite gauge. A stainless steel screw was incorporated into the block of appliance for the upper jaw, making it in parallel with the occlusal plane, as a mechanism to precisely adjust the amount of mandibular advancement.

3. Experimental procedure

The subjects were fitted with a probe cap for measuring cerebral activity and instructed to maintain a restful sitting posture, then chewed gum softened by chewing in advance. In the Class I group, the levels of oxygenated hemoglobin, considered to provide an index of brain activity in the prefrontal cortex, were measured over time under the conditions of with and without a TBA. In the Class Ⅱ group, those

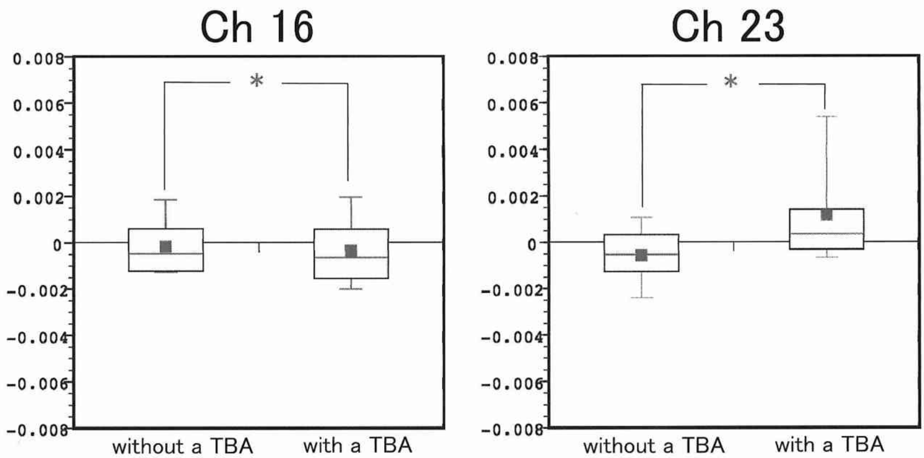

Fig. 6 Brain activity during gum-chewing in the Class I group (P<0.05).
To determine differences between with and without a TBA, a Wilcoxon t-test was used for data from each of the 24 channels.

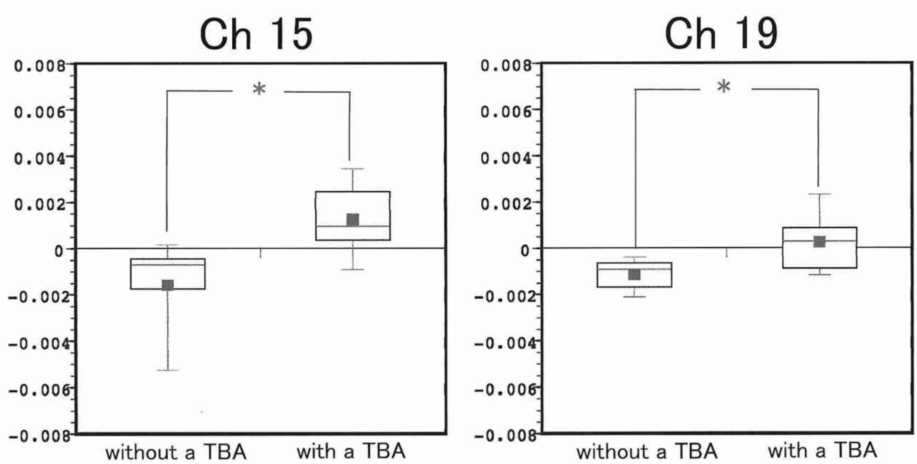

Fig. 7 Multiple comparisons of brain activity during gum-chewing in the Class II group (P<0.05).
To determine differences between without a TBA and with a TBA set at 0 mm of advancement, a Wilcoxon t-test was used.

levels were determined under the following 6 conditions : without a TBA, and with a TBA with the mandibular advancement set at 0, 2, 4, 6 and 8 mm (Fig. 1). For setting the amount of construction bite, a digimatic caliper (Mitsutoyo Co., Kanagawa, Japan) with a minimum indication of 0.01 mm and instrumental error of ±0.02 mm was employed.

After beginning the measurment, the subject was asked to keep the lower jaw at rest for 40 seconds, then to begin the gum chewing task for 20 seconds and rest again for 40 seconds, after which the measurment was completed (Fig. 2). For the task, the subjects were instructed to chew in a uniform rhythm, but freely under each condition. Before changing the condition, a 5-minute rest period was provided.

4. Investigation of unpleasant feelings and related sites using a visual analog scale (VAS)

As shown in the figure below, the left edge of a 10-cm VAS was designated as "no unpleasant feeling" and the right edge as "strong unpleasant feeling". The subjects were instructed to note the intensity of any unpleasant feeling they had on the 10-cm VAS and also note the site for each condition.

5. Measurement of cerebral activity during gum chewing task

For measuring brain activity, optical topography equipment (Hitachi Medico ETG-100, Tokyo, Japan) was used. Optical topography utilizes the optical absorption properties of Oxy-Hb and Deoxy-Hb. It is a non-invasive cerebral function measuring system that uses near-infrared light at 2 wave lengths, 720 and 820 nm. It has relatively high biological permeability to detect changes in the levels of Oxy-Hb, Deoxy-Hb, and Total-Hb in cerebral tissue, and at the same time creates a two-dimensional picture of cortical activity at minimum 0.1-second intervals using multi-channel optical measurements.

To determine the levels of Oxy-Hb in the prefrontal cortex, which is involved in pleasant and unpleasant feelings, an optical fiber cap with 12 probes on one side (illumination-detection distance 30 mm, 24 channels) was attached to the frontal region of each subject. The room temperature was set at 25±1℃. For measuring brain activity using near-infrared light, the region equivalent to the prefrontal cortex was identified in accordance with International Procedure 10-20.

6. Data analysis

There was an approximately 6-second time-lag before any change in neuron activity was reflected as a change in cerebral blood flow[18], thus the gradient of the primary line obtained from the linearized curve of the waveform for the 10-second period beginning from 6 seconds after the start of gum chewing under each condition was used to indicate the changes in Oxy-Hb levels (Fig. 3). Blood flow was measured at 12 points on each side, for a total of 24 sites. For the gradient of the waveform of the Oxy-Hb levels, a positive sign (+) was used to indicate an increase and a negative sign (-) to indicate a decrease.

To determine differences between with and without a TBA in the Class I group, a Wilcoxon t-test was used for data from each of the 24 channels. For determining differences among subjects with and without a TBA in the Class I and II groups, a Mann-Whitney U-test was used for data from each of the 24 channels. To determine differences between without a TBA and with a TBA set at 0 mm of advancement in the Class II group, a Wilcoxon t-test was used. In addition, for examining the differences among the 5 positions of 0, 2, 4, 6, and 8 mm of mandibular advancement, a Friedman's χ^2 r-test was used. For comparing VAS scores in the Class II group without a TBA and with a TBA at 0, 2, 4, 6, and 8 mm of advancement, a Friedman's χ^2 r-test was used. For all statistical analyses, the SPSS statistical analysis software package (SPSS 16.0J, SPSS Co., Tokyo) was employed.

RESULTS

1. VAS measurement

The intensity of unpleasant feelings while gum chewing without a TBA and with a TBA with mandibular advancement of 0, 2, 4, 6, and 8 mm were rated using a VAS, and the results were examined with Friedman's χ^2 r-test. The VAS ratings for unpleasant feelings became significantly higher ($p<0.05$) as mandibular advancement increased (Fig. 4), indicating that mandibular advancement causes discomfort.

2. Measurement of prefrontal cortex activity

1) Effects of TBA fitting on pleasant and unpleasant feelings

The Class II group without a TBA showed a significantly lower ($p<0.05$) level of Oxy-Hb than the Class I group without a TBA (median,

$-1.1x10^{-3}$; interquartile range, $1.0x10^{-3}$) at channel 8 in the left hemisphere, which is considered to be the area of the prefrontal cortex related to pleasant and unpleasant feelings ($p<0.05$) (Fig. 5). There were no significant differences observed between the groups without a TBA at any of the other channels.

In the Class I group, the levels at channels 16 (median : $-9.3x10^{-4}$, interquartile range : $2.2x10^{-3}$) and 23 (median $3.6x10^{-4}$, interquartile range : $2.5x10^{-3}$) with a TBA were compared with those obtained without a TBA at channels 16 (median : $-2.4x10^{-4}$, interquartile range : $2.5x10^{-3}$) and 23 (median : $-8.0x10^{-4}$, interquartile range : $2.2x10^{-3}$), which showed that the levels were significantly elevated with a TBA ($p<0.05$) (Fig. 6).

In the Class II group, the levels of Oxy-Hb at channels 15 (median : $9.7x10^{-4}$, interquartile range : $2.5x10^{-3}$) and 19 (median : $3.0x10^{-4}$, interquartile range : $2.1x10^{-3}$), which are considered to represent the area of unpleasant feelings in the prefrontal cortex, in subjects with a TBA were compared with those obtained without a TBA at channels 15 (median : $-6.9x10^{-4}$, interquartile range : $1.8x10^{-3}$) and 19 (median : $-8.9x10^{-4}$, interquartile range : $1.2x10^{-3}$), which again showed that the levels were significantly elevated with a TBA ($p<0.05$) (Fig. 7).

In contrast, a comparison between the Class I group and Class II group with a TBA at 0 mm of mandibular advancement found no significant differences for any of the channels between the groups. These findings indicate that a TBA can cause unpleasant feelings.

2) Effects of amount mandibular advancement on pleasant and unpleasant feelings

Under the 5 conditions of mandibular advancement with a TBA (0, 2, 4, 6, and 8 mm), the levels were measured and the results examined using Friedman's χ^2 r-test. However, no significant differences were observed among the various conditions, indicating that mandibular advancement with a TBA does not exacerbate unpleasant feelings.

DISCUSSION

In the present study, the Oxy-Hb levels in subjects with a TBA were elevated after attachment of the appliance in both the Class I and Class II groups, though significant differences were observed only for channels in the right hemisphere. Maeda and Fukumi[19] studied healthy subjects whose bite was raised by 3, 5, and 7 mm with a mouthpiece and reported that brain activity was elevated most in those with 5-mm bite jumping. In the present study, the bite was raised from 3-5 mm at the molars when a TBA was fitted. Accordingly, we speculated that brain activity was most enhanced following those adjustments. However, brain activity was significantly elevated only in the right prefrontal cortex. It has been shown that brain activity in the right hemisphere reflects unpleasant feelings[8~12]. Accordingly, we considered that the elevation in brain activity just after TBA fitting reflects the unpleasant feelings induced by gum chewing with an advanced bite. Moreover, there were no significant differences between the Class I and Class II groups with a TBA for any of the recorded channels. We speculated that this was because the unpleasant feelings had already manifested after TBS fitting in both groups.

In the Class II group, the lower jaw was advanced to 5 positions (0, 2, 4, 6, and 8 mm) with a TBA. Analysis using Friedman's χ^2 r-test showed no statistically significant differences among those settings, which suggested that the unpleasant feeling induced by bite jumping is not increased by greater amounts of mandibular advancement. These results agree with the findings of Hashimoto *et al*[20]., who observed no significant brain activity with mandibular advancement up to 67% of the most protruded position with an intraoral appliance used for sleep apnea.

Using a VAS, we examined the differences among the 6 conditions with a TBA and the condition without a TBA using Friedman's χ^2 r-test. The subjects wearing a TBA noted that the unpleasant feelings became significantly greater as the mandible was advanced. Interestingly, brain activity in the prefrontal cortex, considered to reflect unpleasant feelings, did not increase with mandibular advancement, while the VAS results increased with mandibular advancement. Accordingly, it is considered that the TBA fitting itself induced unpleasant feeling and affected the VAS results.

Aggarwal *et al*[21]. longitudinally analyzed electromyogram findings for up to 6 months after TBA fitting and concluded that it was strongly likely that sagittal rearrangement of a retrograded mandible in a Class II div. 1 patient will occur within about 3 months after the start of treatment using a functional appliance. Pancherz *et al*[22]. also reported that dysfunction of the masseter muscle based on EMG analysis was observed for the first 3 months after fitting of a Herbst appliance, a fixed-type appliance used to facilitate mandibular growth in patients with bradyauxesis, and that it took 6 months to recover the level after fitting. We consider that results obtained in the present study regarding the increase of unpleasant feelings for 1 month after TBA fitting are consistent with those previous findings.

Nakajo *et al*[23]. found a significant difference in the prefrontal cortex and parietal association areas with tapping for mandibular guidance to a protruded position, which was greater than that seen with bite raising. Moreover, Nakamura *et al*[24]. monitored brain activity in the primary motor area when the mandible was advanced to a protruded position by TBA fitting and speculated that such fitting exerts stress on mandibular movement. In the present study, we considered that the effect of chewing movement on the modified mandibular position also affected the motor area of the brain that controls muscular activity and the sensory area involved in the sense of discomfort associated with fitting of the appliance.

CONCLUSION

Our findings clarified that it is possible to measure unpleasant feelings associated with TBA fitting by determining blood Oxy-Hb levels in the prefrontal cortex. We found that mandibular advancement did not increase unpleasant feelings, though discomfort was induced at the time of TBA fitting. It is suggested that monitoring unpleasant feelings in patients fitting with TBA is clinically useful.

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著者への連絡先：吉永　聡，(〒963-8611)郡山市富田町字三角堂31-1　奥羽大学歯学部成長発育歯学講座歯科矯正学分野
Reprint requests : Satoshi YOSHINAGA, Division of Orthodontics and Dentofacial Orthopedics, Department of Oral Growth and Development, Ohu University School of Dentistry
31-1 Misumido, Tomita, Koriyama, 963-8611, Japan