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Original article

Effect of occlusal support by implant prostheses on brain function

Naoko Okamoto DMD

Department of Removable Prosthodontics, Tsurumi University School of Dental Medicine, 2-1-3 Tsurumi Tsurumi-ku, Yokohama, Kanagawa 230-8501, Japan

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Abstract

Purpose: The present study was carried out to identify how gum chewing with and without occlusal support by implant prostheses affects brain function as well as chewing function.

Methods: Twenty-four subjects rehabilitated with implant-supported fixed prostheses were evaluated. An electroencephalograph (EEG) (ESA-Pro) and mandibular kinesiograph (Bio PAK®) wear used to measure brain function and chewing function, respectively, before and after gum chewing with and without an implant superstructure. Based on brain function estimated by the $D\alpha$ values derived from measurement data, the subjects were divided into the normal region group (including the sub-normal region group) ($n = 15$; $D\alpha \geq 0.952$) and the impaired region group ($n = 9$; $D\alpha < 0.952$). All the data were statistically analyzed using the Wilcoxon test ($\alpha = 0.05$).

Results: Brain function in the normal region group showed no change after gum chewing, whether or not an implant superstructure was in place ($p > 0.05$). However, brain function in the impaired region group showed significant improvement after gum chewing ($p < 0.05$). Seven of 9 subjects using an implant superstructure in impaired region group indicated an increase or no change in brain function compared to the results without an implant superstructure. In the impaired region group, there was a high positive correlation between brain function and masticatory movement ($\gamma = 0.75$).

Conclusions: Subjects in the impaired region group revealed a strong positive correlation between brain function and masticatory movement, indicating that occlusal support by implant-supported fixed prostheses has the potential to enhance brain function.

Keywords: Occlusal support; Implant prostheses; Brain function; Chewing function

1. Introduction

The advent of a "super-aging" society and the increased incidence of dementia pose a serious threat to the Japanese society [1]. The loss of teeth is one of the risk factors for Alzheimer's disease [2,3]. A number of researchers have studied the association among oral health, dementia and the whole body [4–8]. In particular, it was found that elderly people aged 70–80 years with fewer missing teeth and greater ability to chew not only had better quality of life (QOL) and activity levels but also exhibited greater motor, visual, and hearing abilities [9].

Hara et al. [10] noted that the distribution of potentials generated in the surface layer of the cerebral cortex differs between healthy individuals and patients with Alzheimer's disease. Based on this observation, they developed the Diagnosis Method of Neuronal Dysfunction (DIMENSION), an analytical tool that quantitatively estimates synaptic/neuronal dysfunction based on scalp-derived α waves. DIMENSION is a highly sensitive tool that can directly measure neuronal cortical activity without exposing patients to invasive procedures. Because measurements can be taken in a short time, it is useful for dynamically evaluating brain function activity immediately before and after changes in oral function.

Kimura et al. used DIMENSION to examine the effects of art therapy on patients with Alzheimer's disease as well as healthy individuals who had been diagnosed with neither Alzheimer's disease nor any other brain disorders. Art therapy contributed to activating brain function in healthy individuals who had not been diagnosed with either Alzheimer's disease or any other brain disorders but whose brain function had been in the impaired region prior to the therapy [11]. However, when all healthy individuals, including those whose brain function had been in the normal region, were examined together, no improvement in brain function could be observed.

Morokuma [12] examined the efficacy of complete denture adjustment and reported that the activation of brain function

E-mail address: okamoto-naoko@tsurumi-u.ac.jp.

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Table 1
Subjects characteristics. Places where dental prostheses, are applied, method used to fix the superstructure in place, types and numbers of implants. F: female, M: male, S: screw retain, C: cement retain, BM: Brånemark system, NR: nobel replace, ITI: Straumann, N: normal region group, and I: impaired region group.

Subjects	Age	Gender	Prosthesis sites	Retention	Type and numbers of implant		Eichner classification	*Dα*
1	57	F	36, 37	C	BM	2	B-1	N
2	63	F	36, 37	S	NR	2	B-1	I
3	75	M	36, 37	S	NR	2	B-2	I
4	59	M	35, 36, 46	C	NR	3	B-2	N
5	61	F	45, 46, 47	S	BM	3	B-1	N
6	77	F	35, 36, 37	S	ITI	3	B-1	N
7	40	F	35, 36, 37	S	BM	3	B-2	I
8	67	F	45, 46, 47	C	BM	3	B-3	N
9	60	F	45, 46, 47	C	NR	2	B-2	I
10	67	M	35, 36, 46, 47	S	BM	4	B-2	N
11	64	F	34, 35, 36, 37	S	NR	3	B-2	N
12	62	F	44, 45, 46, 47	S	BM	2	B-1	N
13	65	M	36, 37, 46, 47	S	NR	4	B-3	N
14	74	F	12, 13, 14, 15, 16	C	NR	3	B-2	N
15	81	F	15, 16, 17, 26, 27	C	ITI	5	B-2	N
16	65	M	36, 37, 45, 46, 47	C	NR	5	B-2	N
17	52	F	35, 36, 37, 45, 46, 47	C	BM	4	B-2	I
18	74	F	35, 36, 37, 45, 46, 47	S	ITI	5	B-2	I
19	71	F	11, 12, 21, 24, 25, 26, 27	S	NR	4	B-3	I
20	51	F	14, 15, 16, 17, 25, 26, 27	S	ITI	5	B-3	I
21	63	F	23, 24, 26, 27, 45, 46, 47	C	NR, BM	4, 3	B-4	N
22	75	M	11, 21, 22, 23, 24, 25, 26, 27	C	NR	6	B-3	I
23	85	F	34, 35, 36, 43, 44, 45, 46, 47	C	ITI	6	B-4	I
24	60	M	34, 35, 36, 37, 44, 45, 46, 47	C	NR	6	B-4	N

Subjects characteristics. Places where dental prostheses, are applied, method used to fix the superstructure in place, types and numbers of implants. F: female, M: male, S: screw retain, C: cement retain, BM: Brånemark System, NR: Nobel Replace, ITI: Straumann, N: Normal region group, I: Impaired region group.

was observed immediately after the treatment. Shibuya [13] compared brain function in partial denture wearers in the maintenance stage with and without the denture in place and reported that their brain function positively correlated with the occlusal contact area and occlusal force. These findings suggested that wearing a plate denture promotes normal chewing and activates brain function [5].

Implant treatment has recently become a prosthodontic treatment option for missing teeth. Rehabilitation of oral function by an implant-supported prosthesis can restore jaw and oral functions to a dentate jaw to their previous level or even better [14–18]. Because osseointegration cannot restore the periodontal membrane, the stimulus delivered to the trigeminal nerve via the periodontal membrane decreases. However, Yan et al. [19] claim that clenching improves brain function in edentulous patients wearing dentures or implant superstructures. Furthermore, Kimoto [20] examined healthy dentulous individuals, individuals with an implant superstructure-placed partial denture, and complete denture wearers while they were chewing gum and found a similarity in brain activation patterns between the individuals with an implant superstructure and healthy dentulous individuals.

Mastication is regulated by the basal ganglia, limbic system, thalamus, and cerebral cortex. It is also closely linked with the mastication center, deglutition center, and respiratory center. In particular, the hypothalamus is deeply involved in learning, memory, emotion, and sleep [21–23]. Inhibition of masticatory movement linked with the mastication center and deglutition center can cause a sudden deterioration of brain function.

Using imaging techniques such as MRI to statically capture changes in brain function induced by the implant superstructure, it was demonstrated that the implant superstructure does activate brain function [19,20]. However, no study has attempted to analyze changes in the occlusal supporting zone by removing or attaching the implant superstructure in the same subjects and then dynamically capturing brain function activity immediately before and after gum chewing. It is therefore not yet clear how changes in chewing function brought about by implant prostheses can affect brain function.

The present study targeted individuals who first received treatment with implant-supported fixed prostheses and subsequently entered the maintenance stage. Subjects were divided into the normal region group and the impaired region group according to their brain function. The changes in chewing function with and without the implant superstructure were subsequently analyzed to determine whether or not changes in the occlusal supporting zone affect brain activity.

2. Materials and methods

2.1. Subjects

Twenty-four individuals (7 males and 17 females, ages 40–85 years, the average age being 65.3 ± 10.2) who had received implant-supported fixed prostheses to restore occlusal support at

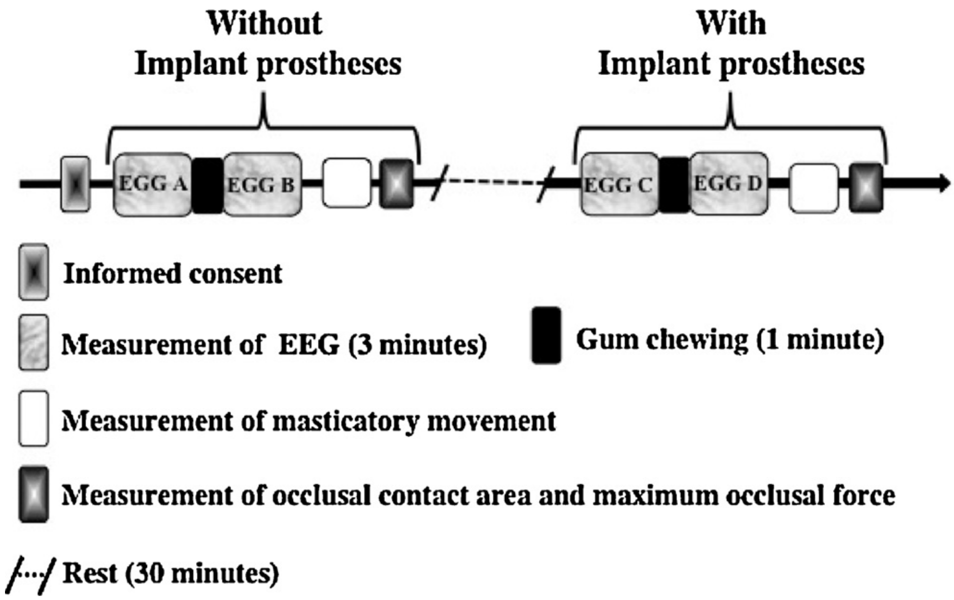

Fig. 1. Time schedule.

Tsurumi University Dental Hospital and subsequently entered the maintenance stage participated in this study. The locations of the prostheses, retention system, types and numbers of implants are shown for each patient in Table 1. Of these prostheses, 12 were the screw-retained type and 12 were the cement-retained type. The cement-retained type of implant superstructure was fixed in place with temporary cement so that it could be easily removed or attached by the dentists. Only individuals who had never had brain disorders such as cerebral infarction and who had never been diagnosed with any form of dementia such as Alzheimer's disease were included in the present study.

2.2. Measurement procedure

All the subjects were fully informed of and consented to the research methods, which had been approved by the ethics committee of Tsurumi University School of Dental Medicine (approval number: 305, August 31, 2005). The measurements were performed using the following procedure: Brain function was measured immediately before and after gum chewing with the implant superstructure removed. The occlusal contact area, maximum occlusal force, and masticatory movement were measured after gum chewing. After a 30 min break, the same measurements were performed with the implant superstructure was fixed in place (Fig. 1).

2.3. Measuring brain function

2.3.1. EEG measurement equipment

EEG measurement equipment ESA-Pro (Brain Functions Laboratory Inc., Kanagawa, Japan) as well as a helmet with paste-less electrodes (Brain Functions Laboratory Inc.) were used to evaluate brain function. Brain function was measured in the shield room by a dentist trained in electroencephalography (Fig. 2). The analysis was carried out at a sampling frequency of 200 Hz using digital filters HPF (1.6 Hz, 12 dB/oct), LPF (60 Hz, 12 dB/oct), and HUM (50 Hz, 2D). The paste-less electrodes were arregiond on the helmet according to the international 10–20 system. A 21-channel scalp EEG was performed with the reference electrodes placed on both earlobes. During the measurement, the subjects were seated comfortably at rest with their eyes closed. After making sure

Fig. 2. Electroencephalographic measurement in the semi-anechoic room. Measurements were performed while the subjects were seated in a resting position with their eyes closed.

that the EEG activities detected from all electrodes were stable, the EEG was recorded several times for 3 min each time.

First, brain function immediately before and after gum chewing was measured with the implant superstructure removed. After a 30 min break, measurements were taken again before and after gum chewing with the implant superstructure in place. The measurements were thus taken four times per patient for 3 min each time (EEG A: measurement taken before gum chewing, with the implant superstructure removed; EEG B: measurement taken after gum chewing with the implant superstructure removed; EEG C: measurement taken before gum chewing with the implant superstructure in place; EEG D: measurement taken after gum chewing with the implant superstructure in place). The recorded EEG data were transferred to the electroencephalogram analysis center of Brain Functions Laboratory Inc., where the DIMENSION analysis was carried out to estimate mean alpha dipolarity ($D\alpha$) as a parameter of dipolarity. In the DIMENSION analysis, an ideal potential distribution of α waves, which indicates stable neuronal activity, is defined as $D\alpha = 1$. The $D\alpha$ value decreases as the brain function deteriorates. $D\alpha$ can distinguish that early stages of Alzheimer's disease can be discriminated from normal aging using measures of cortical neuronal impairment. Musha et al. [24] defined $D\alpha \geq 0.952$ (accuracy: ± 0.005) as the normal region and the sub-normal region, which can be used as a reference point for distinguishing patients in the normal region from those in the impaired region. Similarly, in the present study, subjects whose $D\alpha$ was 0.952 or greater were included in the normal region group while the remaining ones were included in the impaired region group to analyze their chewing function.

2.4. Measuring masticatory movement

Bio PAK® (YOSHIDA Dental Trade Distribution Co. Ltd., Tokyo, Japan) and its analysis software were used to measure masticatory movement. A sensor array was set such that the side arms were parallel to the floor surface. A magnet (13 mm × 6 mm × 4 mm) was retained on the lower central incisors so that it was aligned with the center of the sensor array. The subjects were asked to chew on a 4-g gummy candy and then swallow it whenever they preferred. This process was repeated three times to obtain a measurement. The chewing cycle consisted of opening, closing, and occlusal phases. The 10th to 19th strokes, starting from the beginning of the masticatory movement, were included in the chewing cycle time measurement to evaluate the stability of mandibular movement [25–27]. The coefficient of variation of masticatory movement was calculated for the three measurements taken from all the subjects with the implant superstructure removed, as well as for the other three measurements taken with the implant superstructure in place.

2.5. Measuring the occlusal contact area and maximum occlusal force

After measuring the masticatory movement, the occlusal contact area and maximum occlusal force were measured using Dental Prescale Occluzer FPD-705 (GC, Tokyo, Japan) and

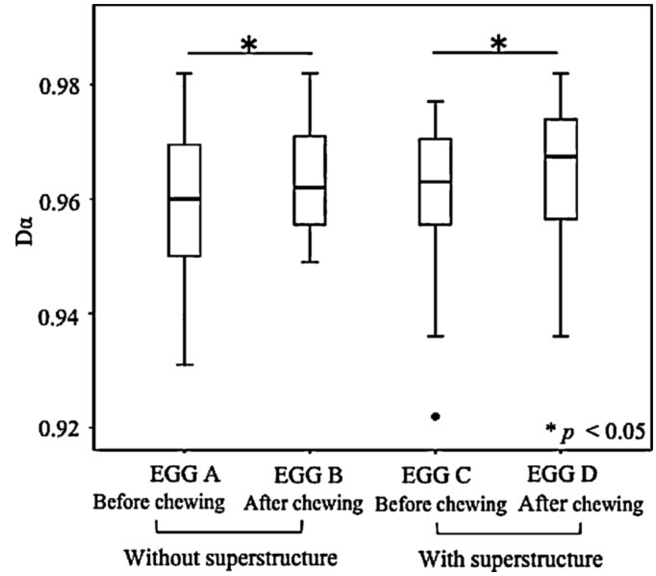

Fig. 3. Comparison of brain function in the entire sample ($n = 24$).

Dental Prescale 50H (without wax) (GC, Tokyo, Japan). The measurements were taken with and without the implant superstructure in place. The Frankfurt plane of the subject's head was first aligned parallel to the floor. The operator pulled the subject's lips away from the teeth and had the subject bite down to check if the subject could bite with ease. The subject was subsequently instructed to bite as hard as possible in central occlusion for 3 s [12,13,28,29].

2.6. Statistical analysis

The Wilcoxon test was used to statistically analyze the brain function, masticatory movement, occlusal contact area, and maximum occlusal force with and without the implant superstructure ($\alpha = 0.05$). Spearman's rank correlation coefficients were calculated for the entire sample as well as for the normal region group and the impaired region group to estimate how brain function may correlate with masticatory movement, occlusal contact area, and maximum occlusal force.

3. Results

3.1. Brain function

The evaluation of $D\alpha$ of the entire sample ($n = 24$) revealed that EEG B exhibited significantly higher $D\alpha$ than EEG A, and that EEG D exhibited significantly higher $D\alpha$ than EEG C ($p < 0.05$). However, no significant differences were observed between EEG A and EEG C, and between EEG B and EEG D ($p > 0.05$) (Fig. 3). Based on the $D\alpha$ value estimated from EEG A, the subjects fell either into the normal region group ($D\alpha \geq 0.952$) or the impaired region group ($D\alpha < 0.952$). As a result, 15 subjects (5 males, 10 females, average age being 66.2 ± 6.9 years) were assigned to the normal region group and 9 subjects (2 males, 7 females, average age being 63.9 ± 14.5 years) were assigned to the impaired region group. In the

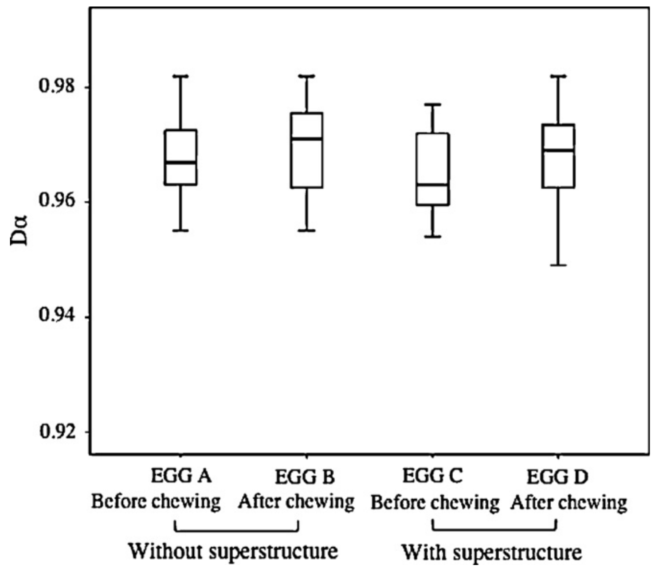

Fig. 4. Comparison of brain function in the normal region group ($n = 15$).

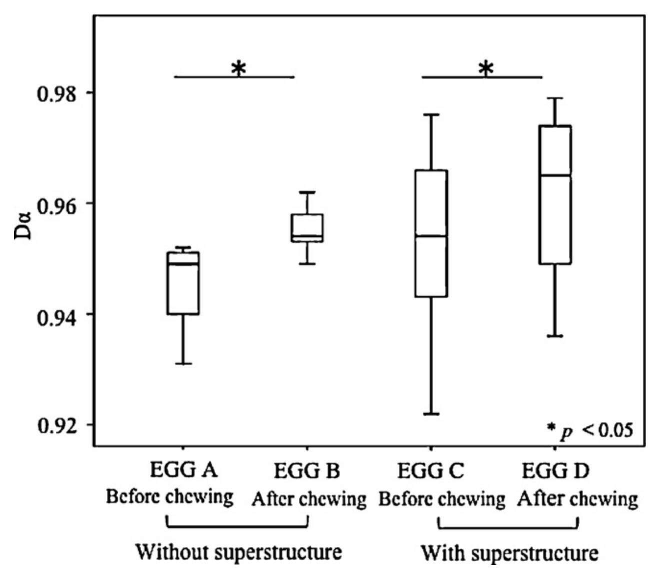

Fig. 5. Comparison of brain function in the impaired region group ($n = 9$).

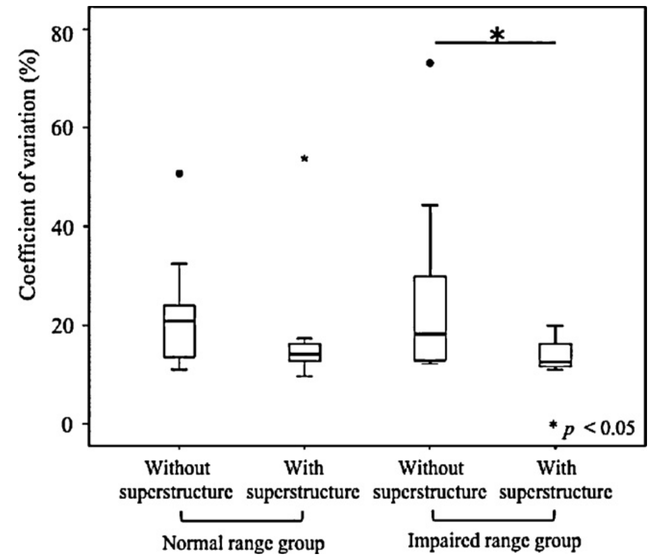

Fig. 6. Comparison of masticatory movement the normal region group ($n = 15$) and the impaired region group ($n = 9$).

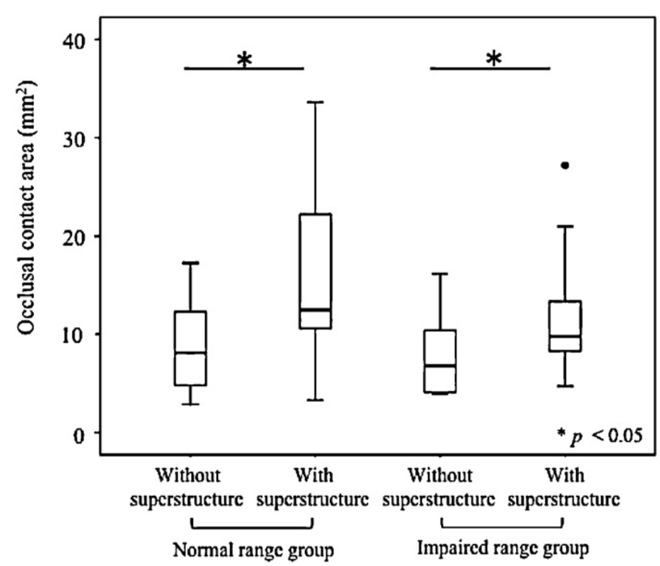

Fig. 7. Comparison of occlusal contact area the normal region group ($n = 15$) and the impaired region group ($n = 9$).

normal region group ($n = 15$), no significant change in $D\alpha$ values was observed between EEG A and EEG B, or between EEG C and EEG D ($p > 0.05$) (Fig. 4). In contrast, in the impaired region group ($n = 9$), a significant increase was observed in $D\alpha$ values after gum chewing (i.e., a significant difference was observed between EEG A and EEG B, and between EEG C and EEG D) ($p < 0.05$), but no significant difference was observed in the $D\alpha$ values between EEG A and EEG C or between EEG B and EEG D ($p > 0.05$). Note that the $D\alpha$ values of EEG C (0.953) and D (0.961) were greater than 0.952 (Fig. 5). The evaluation of brain function in the entire sample as well as in the normal region group revealed little change in the $D\alpha$ value whether or not the implant superstructure was placed. However, 5 of 15 subjects in the normal region group and 7 of 9 subjects in the normal and impaired region groups with an implant superstructure indicated an increase or no change of brain function compared to the state without the implant superstructure. The evaluation of brain function in the impaired region group revealed an increasing trend in the $D\alpha$ value when the implant superstructure was in place compared to when it was removed although no significant difference was detected (Figs. 4 and 5).

3.2. Masticatory movement

In the normal region group, the coefficient of variation of masticatory movement did not significantly change with or without the implant superstructure ($p > 0.05$). In contrast, in the impaired region group, a significant decrease was observed in the coefficient of variation of masticatory movement when the implant superstructure was placed compared to when it was removed ($p < 0.05$) (Fig. 6). This finding suggests that the

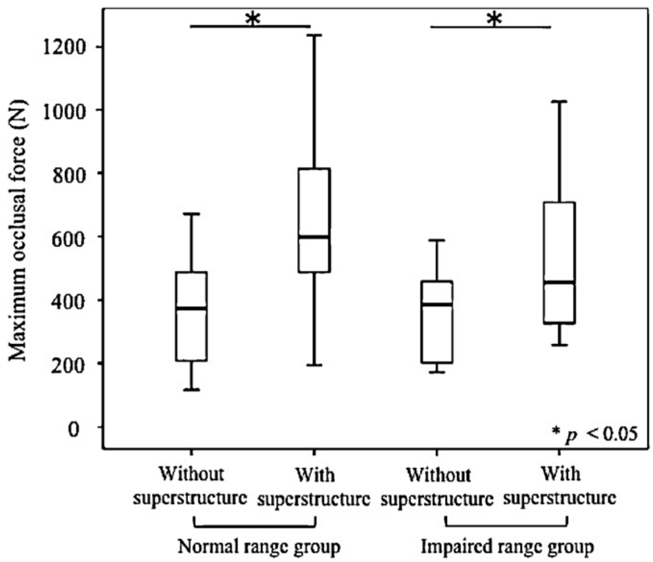

Fig. 8. Comparison of maximum occlusal force the normal region group ($n = 15$) and the impaired region group ($n = 9$)..

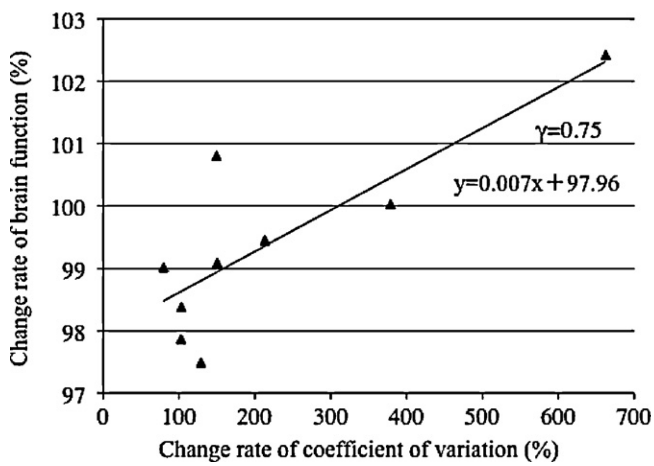

Fig. 9. The impaired region group ($n = 9$). Correlation between brain function and masticatory movement.

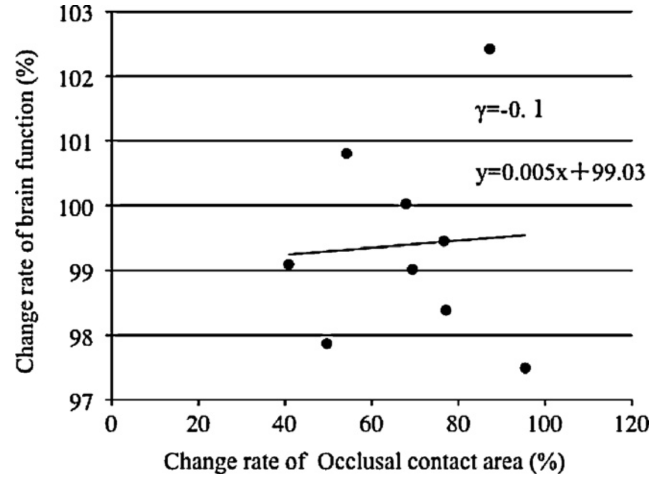

Fig. 10. The impaired region group ($n = 9$). Correlation between brain function and occlusal contact area.

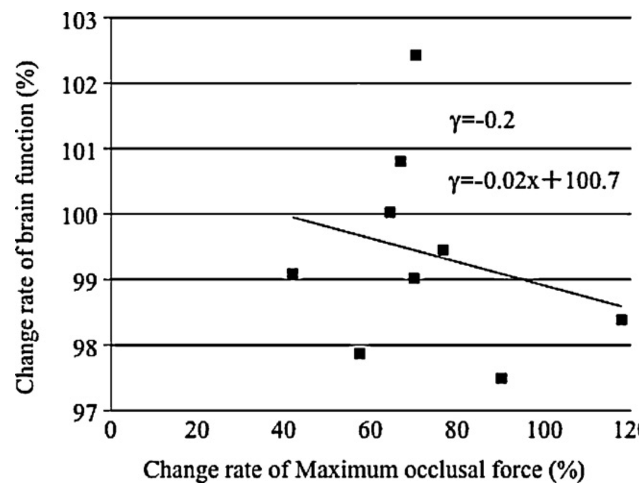

Fig. 11. The impaired region group ($n = 9$). Correlation between brain function and maximum occlusal force.

subjects in this group were able to chew more smoothly with the implant superstructure in place.

3.3. Occlusal contact area and maximum occlusal force

In both the normal region group and the impaired region group, the occlusal contact area (mm^2) was significantly larger when the implant superstructure was placed, compared to when it was removed ($p < 0.05$) (Fig. 7). In both the normal region group and the impaired region group, the maximum occlusal force (N) was significantly greater when the implant superstructure was in place, compared to when it was removed ($p < 0.05$) (Fig. 8).

3.4. Correlation between factors

The evaluation of brain functions should correlate with masticatory movement, occlusal contact area, and maximum occlusal force in the impaired region group subjects whose brain function showed significant improvement between brain function and masticatory movement ($\gamma = 0.75$) ($Y = 0.007X + 97.96$) (Fig. 9). However, no clear correlation was found between brain function and occlusal contact area, or between brain function and maximum occlusal force in the same group ($\gamma = -0.1$, $\gamma = -0.2$) (Figs. 10 and 11). In the normal region group, brain function did not clearly correlate with masticatory movement, occlusal contact area, or maximum occlusal force ($\gamma = -0.025$, $\gamma = -0.114$, $\gamma = 0.048$).

4. Discussion

Previous reports state that the use of implant superstructures contributes to activating brain function [19,20]. Because the implant superstructure does not have periodontal mechanoreceptors, any occlusion-related sensory and kinetic information is believed to be transmitted to the brain via receptors in the periosteum, temporomandibular joint, masticatory muscles, and oral mucosa [19]. According to Kimoto [20], occlusal restoration by means of implant-supported prostheses activates almost the same part of the brain that is stimulated during chewing with natural teeth. This finding indicates the possibility that changes in the brain function of healthy dentulous individuals can be estimated by evaluating the brain function and chewing function of patients treated with implant-supported prostheses while they remove or replace the implant superstructure.

In many of the previous studies using DIMENSION, the analysis was performed with the subjects divided into the normal region group and the impaired region group [11,30–32]. The reason for using this testing method is that brain stimulation affects brain activity in the individuals belonging to the impaired region group whose brain function has deteriorated, but the same stimulation does not affect brain activity in the individuals in the normal region group who have healthy brain function.

Measuring EEG and then performing DIMENSION analysis allow brain function to be captured dynamically. However, brain function can potentially be affected by many factors surrounding the subject, including his/her living environment, hospital visits, conversation with an attending physician, or treatment administered. For this reason, there were concerns prior to performing the present experiment regarding the circadian variability of EEG and the potential effect of measurement sequence on brain function. A preliminary experiment conducted to address these concerns showed that the effect of stimulation dies off in 30 min. Thus, in the present study, a 30 min interval was taken between measurements performed under various conditions.

Kimura et al. [11] used DIMENSION in their study and found increased brain activity in healthy individuals whose brain function had been in the impaired region prior to treatment; however, they did not find a definite sign of increased brain activity in the entire healthy sample, which included individuals in both the normal and impaired region groups. In the present study, however, increased brain activity was found in the entire sample in spite of the fact that 15 out of 24 subjects had normal brain function prior to the prosthodontic treatment. According to Hirai and Koshino [22], when people chew, they sense the taste as well as the hardness of the food so that they can adjust the chewing force. Masticatory stimulation travels from the masticatory muscles to the trigeminal nerve and then to the hypothalamus [33]. This control mechanism, which is believed to involve a wide area of the brain, is unique and quite different from the control mechanisms involved in the movements of the arms and legs. For this reason, it is estimated that gum chewing may be more effective in stimulating brain activity than treatment such as art therapy [11,32]. Although the change in brain function after gum chewing did not reach statistical significance in the normal region group, it did in the impaired region group. Similarly, although the change in masticatory movement after implant superstructure placement did not reach statistical significance in the normal region group, implant superstructure placement did lead to a significant stabilization of masticatory movement in the impaired region group. In both the normal region and the impaired region groups, a significant increase in the occlusal contact area and maximum occlusal force was observed after implant superstructure placement. Furthermore, a strong correlation was found between brain function and masticatory movement. On the other hand, little correlation was found between brain function and occlusal contact area, or between brain function and maximum occlusal force. Naturally, the occlusal contact area increases after implant superstructure placement. Increased maximum occlusal force implies that there is increased sensory information coming from the temporomandibular joint and masticatory muscles [33].

A decreased coefficient of variation of masticatory movement, which is evidence of improved chewing ability, also implies that the neural mechanisms of the mastication center, deglutition center, and respiratory center are controlled smoothly and that the voluntary movement, reflexes, and α–γ coupling mechanism of the muscles related to mastication and swallowing have improved. These findings suggest that improved masticatory movement may be the greatest contributor to improved brain function. On the other hand, previous studies suggest that the brain activation pattern in users of implant-supported prostheses resembles that in healthy dentulous individuals [19,20]. This observation means that the inhibition of masticatory movement can lead to brain function deterioration even in healthy dentulous individuals.

Shibuya reported that there were high correlations between brain function and occlusal contact area, and brain function and occlusal force [13]. These correlations were not detected in the present study, although the correlation between brain function and mandibular movement was observed. Thus, the stability of mandibular movement would strongly affect brain function while increasing the occlusal contact area and occlusal force through the use of an implant superstructure.

5. Conclusions

Subjects who received an implant-supported fixed prosthesis and subsequently entered the maintenance stage were studied to examine how the placement or removal of the implant superstructure and the resulting loss or restoration of occlusal support affects brain function and chewing function after gum-chewing. The following observations were made:

1. Twenty-four subjects were divided into the normal region group (15 subjects, $D\alpha \geq 0.952$) and the impaired region group (9 subjects, $D\alpha < 0.952$) based on the $D\alpha$ value.
2. In the normal region group, no significant increase was found in brain function after gum chewing both with and without an implant superstructure ($p > 0.05$). However, a significant increase in brain function was observed after gum chewing in the impaired region group ($p < 0.05$).
3. The occlusal contact area and the maximum occlusal force significantly increased in both the normal region and impaired region groups when the implant superstructure was in place ($p < 0.05$).
4. There was no significant difference in the coefficient of variation of masticatory movement between the conditions

with and without an implant superstructure in the normal region group ($p > 0.05$). In contrast, the masticatory movement was more stable in the impaired group ($p < 0.05$).
5. Although there was a strong positive correlation between brain function and masticatory movement with and without an implant superstructure in the impaired region group ($\gamma = 0.75$), no correlation was found in the normal region group.
6. Five of 15 subjects (33%) showed an increase or no change in brain function by creating an occlusal supporting area by the implant superstructure; the results for 7 of 9 subjects (78%) in the impaired region group were the same.

These findings suggest that establishing an occlusal support area with an implant-supported prosthesis has the potential to enhance brain function.

Acknowledgments

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