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Association between near occlusal contact areas and mixing ability

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SUMMARY This study investigated the relationship between occlusal contact and near contact areas defined by clenching intensity using electromyograms (EMGs) and mixing ability assessed with colour-changeable chewing gum. Participants comprised 44 dentate adults (24 men, 20 women) with a mean age of 28·2 ± 6·8 years. Silicone material was used to measure the occlusal contact and near contact areas (the area of each type of tooth, the total area of the first molar and second molar, the second premolar to the second molar and the first premolar to the second molar) defined by clenching intensity at 10% maximum voluntary contraction (MVC). Colour-changeable chewing gum was used to assess mixing ability. A colorimeter was used to measure colour changes, and the calculated colour difference (Δ*E*) was used as a measure of mixing ability. Correlation analysis of Δ*E* and occlusal contact and near contact areas revealed a significant positive correlation of 0·47 at 0–160 μm thicknesses of the silicone registration material of the second molar (*P* < 0·01). The near contact area with a thickness up to 200 μm was correlated with mixing ability, with the correlation strengthening as the interocclusal distance increased up to 160 μm. Notably, occlusal contact and near contact areas of the second molar were strongly correlated with mixing ability in dentate adults.

KEYWORDS: mastication, occlusal contact, near contact, mixing ability, chewing gum, electromyography

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Background

Many factors are known to influence masticatory performance, such as age, gender, loss and restoration of post-canine teeth, jaw muscle activity, occlusal contact area, bite force and salivary flow (1). As factors related to occlusal contact, number of teeth present (2), number of occluding pairs of teeth (3), total occlusal surface (4) and occlusal contact area (5–11) have been reported to influence masticatory performance. Occlusal contact is especially crucial for efficient mastication (12), and the occlusal contact area of the premolars and molars is important for dentate adults (13). Masticatory performance is thought to be associated with not only occlusal contact area, but also the near contact area close to the contact area (9–11).

A variety of methods have been used to measure occlusal contact, such as occlusal strips or silk, three-dimensional (3D) occlusal examination (14) or examinations using articulating paper, the Dental Prescale system (5–7), and the Black Silicone-image analysing device system (15). Examinations with the Dental Prescale system or Black Silicone-image analysing device system and 3D occlusal examinations can quantitatively measure the occlusal contact area, but the Dental Prescale system and Black Silicone-image analysing device system cannot measure the near contact area. Although the complicated, 3D occlusal examination likely measures the near contact area,

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there are no studies on the near contact area. Recently, a new device has been developed that can measure the near contact area to a thickness of 200 μm or less (16).

Some studies have found an association between comminution ability using silicone test food and occlusal contact and near contact areas measured with subjects clenching firmly based only on oral instruction (9–11). Test foods, as well as peanuts and other natural food products, are widely used to assess the comminution ability as part of masticatory performance (13, 17). Mastication consists of not only comminution but also mixing of food. This ability to mix food is called mixing ability, and methods for measuring it use gum or wax cubes as test materials (17, 18). Previous studies (9–11) have shown an association between the comminution ability and occlusal contact and near contact areas, but the relationship with mixing ability remains unclear. Because clenching intensity was not defined using electromyograms (EMGs) in these previous studies, measurements of occlusal contact and near contact areas are not necessarily reproducible (19).

We therefore investigated the relationship in dentate adults between occlusal contact areas and near contact areas of 0–200 μm thickness while defining clenching intensity using EMGs and assessing mixing ability with colour-changeable chewing gum.

Methods

Subjects

Participants comprised 44 dentate adults (24 men, 20 women) with a mean age of 28·2 ± 6·8 years. Inclusion criteria were not having any diseased teeth such as caries or periodontal disease and no missing teeth, excluding third molars. Exclusion criteria were having either temporomandibular disorder or xerostomia.

Measurement of occlusal contact and near contact areas

Silicone material (Blue silicone*) was used to measure the occlusal contact area. EMGs were recorded with an EMG measurement device (EMG Master†) simultaneously as the Blue silicone registration was taken. EMG signals were sampled at 1000 samples/s, amplified 1000 times and filtered with a 5-Hz high-pass filter and 1-kHz low-pass filter. Clenching intensity was controlled using the EMGs. EMGs of the masseter muscle on the preferred side were measured using surface electrodes (Duotrode electrodes‡). First, participants clenched in the maximum intercuspal position, and the maximum voluntary contraction (MVC) was recorded. Next, silicone material was placed on the occlusal surface of the dental arch, and the participant was instructed to bite down on the silicone material for 90 s, while trying to reach the value (10% MVC) displayed on the screen as visual feedback. The tolerance level was ±3% MVC, and if 10% MVC exceeded the tolerance level, the silicone registration test was conducted again. The hardened silicone material was trimmed to be parallel with the occlusal plane.

The silicone material was set in an occlusal analytic device (BITE EYE BE-I*). The silicone material was measured at the side of preferred chewing, and the occlusal contact area of each type of tooth from the first premolar to the second molar, the first premolar (FP), second premolar (SP), first molar (FM) and the second molar (SM), and the total area of the FP–SM, SP–SM and FM–SM were measured for silicone material thicknesses of 0–200, 0–160, 0–100 and 0–50 μm, which were then used as the values for assessing the occlusal contact and near contact areas (Fig. 1). In this study, the occlusal contact with a thickness of 50 μm or less is defined as 'occlusal contact' and the occlusal contact with a thickness of 100, 160 and 200 μm or less is defined as 'near occlusal contact'.

Colour measurement of test item

Mixing ability was assessed using colour-changeable chewing gum (Masticatory Performance Evaluating Gum XYLITOL§) according to the method described by Komagamine *et al.* (20, 21). Measurements were carried out once. Participants rinsed their mouth with water for 15 s prior to measurement and chewed the gum 60 times. To ensure the gum contacted the teeth

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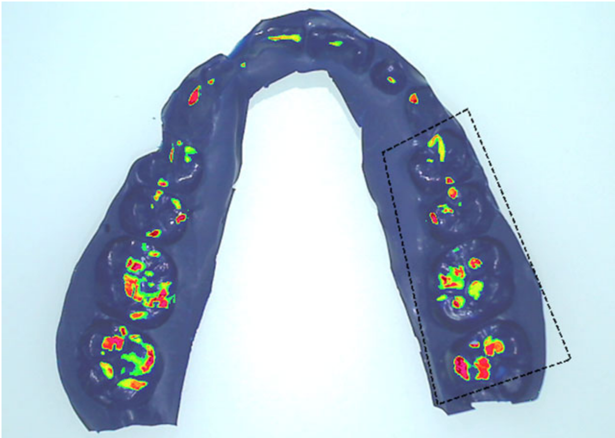

Fig. 1. Analysed Blue silicone showing the occlusal contact and near contact areas with thicknesses of 50 μm or less (red), 51–100 μm (orange), 101–160 μm (yellow) and 161–200 μm (green).

with each chew, participants were instructed to chew freely without a set rhythm on the side with which they normally chew food. To determine the preferred side, participants were asked which side they chew with more. Participants who answered with the right or left side were instructed to use only that side when chewing. Those that did not know were instructed to chew with one side only, and the side used was considered their preferred side.

Mixing ability was measured immediately after mastication. A colorimeter (CR-13[¶]) was used to measure the colour in five spots: the centre and four spots 3 mm above, below, to the left, and to the right of the centre spot. These were used for the CIELAB colour system. This system expresses colour in 3D coordinates with an L axis, a axis and b axis; a^* and b^* represent the hue and saturation, and L^* represents the lightness. The mean L^*, a^*, b^* values were determined for the five spots, and the distance (ΔE) of the two colours from the mean in the colour space was calculated with the following formula.

$$\Delta E = [(L^* - 72 \cdot 3)^2 + (a^* + 14 \cdot 9)^2 + (b^* - 33 \cdot 0)^2]^{1/2}$$

The L^*, a^*, b^* values prior to mastication were 72·3, −14·9 and 33·0, respectively. ΔE was measured from the colour change in the gum and was used to assess mixing ability.

Table 1. Mean values and standard deviations for occlusal contact and near contact areas (mm^2), (N = 44)

Types of teeth	Near contact area 0–200 μm	0–160 μm	0–100 μm	Contact area 0–50 μm
FP–SM	35·3 ± 13·8	28·3 ± 12·0	19·5 ± 9·4	13·1 ± 7·2
SP–SM	31·9 ± 13·0	25·5 ± 11·3	17·6 ± 8·8	11·9 ± 6·8
FM–SM	27·3 ± 11·3	22·0 ± 9·6	15·1 ± 7·5	10·3 ± 5·9
SM	14·3 ± 7·4	11·9 ± 6·6	8·4 ± 4·9	5·7 ± 3·8
FM	13·0 ± 6·0	10·1 ± 5·0	6·7 ± 4·2	4·5 ± 3·3
SP	4·5 ± 4·1	4·3 ± 3·7	2·5 ± 2·5	1·6 ± 1·6
FM	3·5 ± 2·5	2·8 ± 2·0	1·9 ± 1·6	1·2 ± 1·2

FP, first premolar SP, second premolar FM, first molar SM, second molar.

Statistical analysis

The relationship between ΔE and occlusal contact and near contact areas was assessed using Pearson's correlation coefficients. Statistical software (JMP8.0**) was used for statistical analysis. The level of significance was 0·05.

Results

The mean and standard deviation for ΔE was 45·5 ± 4·8. Table 1 shows the means and standard deviations for the occlusal contact and near contact areas for FP, SP, FM and SM with silicone material thicknesses of 0–200, 0–160, 0–100 and 0–50 μm and the total area of the FP–SM, SP–SM and FM–SM occlusal contact and near contact areas. Table 2 shows the results of correlation analysis between ΔE and occlusal contact and near contact areas as a total of FP–SM, SP–SM and FM–SM with silicone material thicknesses of 0–200, 0–160, 0–100 and 0–50 μm. According to correlation analysis, the highest correlation coefficient was between ΔE and occlusal contact and near contact areas of SM for all silicone material thicknesses. The correlation coefficient between ΔE and occlusal contact and near contact areas up to a thickness of 160 μm was 0·47 ($P < 0·01$). A significant correlation was also observed with the occlusal con-

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Table 2. Correlation coefficients, confidence interval (CI), and P-value between ΔE and occlusal contact and near contact areas, ($N = 44$)

Types of teeth	Near contact area 0–200 μm	0–160 μm	0–100 μm	Contact area 0–50 μm
FP–SM				
r	0·38	0·39	0·37	0·29
95% CI	[0·09, 0·61]	[0·11, 0·62]	[0·08, 0·60]	[−0·01, 0·54]
P	0·01*	0·01*	0·01*	0·05
SP–SM				
r	0·43	0·44	0·40	0·32
95% CI	[0·15, 0·65]	[0·16, 0·65]	[0·11, 0·62]	[0·02, 0·56]
P	<0·01*	<0·01*	<0·01*	0·04*
FM–SM				
r	0·42	0·44	0·39	0·29
95% CI	[0·14, 0·64]	[0·16, 0·65]	[0·11, 0·62]	[−0·01, 0·54]
P	<0·01*	<0·01*	0·01*	0·06
SM				
r	0·45	0·47	0·44	0·34
95% CI	[0·18, 0·66]	[0·20, 0·67]	[0·17, 0·65]	[0·05, 0·58]
P	<0·01*	<0·01*	<0·01*	0·03*
FM				
r	0·24	0·23	0·18	0·12
95% CI	[−0·07, 0·50]	[−0·08, 0·49]	[−0·12, 0·45]	[−0·18, 0·40]
P	0·12	0·14	0·24	0·43
SP				
r	0·20	0·17	0·23	0·30
95% CI	[−0·10, 0·47]	[−0·14, 0·44]	[−0·07, 0·50]	[0·01, 0·55]
P	0·19	0·28	0·13	0·05*
FP				
r	−0·15	−0·12	−0·03	−0·03
95% CI	[−0·43, 0·15]	[−0·40, 0·19]	[−0·33, 0·27]	[−0·32, 0·27]
P	0·32	0·45	0·84	0·87

*$P < 0{\cdot}05$.

tact and near contact areas of FM–SM, SP–SM and FP–SM which all include the SM.

Discussion

We observed a correlation between mixing ability and occlusal contact and near contact areas up to a thickness of 200 μm. Moreover, the correlation strengthened with increasing near contact area at thicknesses from 50 to 160 μm. This indicates that mixing ability is strongly correlated with the near contact area at a thickness of up to 160 μm. Previous studies have also confirmed a correlation between comminution ability using silicone test food and occlusal contact and near contact areas (9–11). Owens *et al.* (9) demonstrated a correlation with silicone material thicknesses of 50–350 μm, with the correlation coefficient gradually increasing until peaking at 250 μm. Lujan *et al.* (10) reported that the correlation coefficient was the same for areas from 0–50 to 0–200 μm thicknesses and comminution ability, and that, although it decreased at higher thicknesses, occlusal contact and near contact areas correlated with comminution ability for the thicknesses of 0–500 μm. A commonality among these studies is that comminution ability was related not only to occlusal contact, but also to near contact area. On the other hand, compared to comminution ability using a silicone test food, mixing ability has been shown to be associated with occlusal contact and near contact areas at only a distance up to 160 μm. This may indicate the difficulty of mixing with contact areas of a large interocclusal distance exceeding 200 μm.

The results of the present study showed a correlation between ΔE and the area of SM among the different types of teeth. Correlations were also observed between ΔE and the area covering FP, SP, FM and SM and, the area covering SP, FM and SM and the area covering FM and SM. This suggests that the area covering SM relates to mixing ability. Owens *et al.* (9) found a relationship between comminution ability and area covering FP, SP and FM up to a thickness of 350 μm. However, their study did not examine the contact area for SM. This suggests that mixing ability differs from comminution ability using a silicone test food in that the most distal teeth are strongly correlated with masticatory performance. As a characteristic of the occlusal contact area of second molars, the occlusal contact area has been reported to increase moving towards the back from the first premolar to the second molar (22). Moreover, occlusal contact area in the molar region has been shown to increase with higher clenching intensity (23, 24). These studies suggest that the occlusal contact area of the second molars tends to increase with higher clenching force. A reason for this may be the presence of periodontal and other soft tissue between tooth and bone or because it is easier to apply force to the molar region through the hinge movement of the temporomandibular joint and the positional relationship of the molars. Consequently, there may be a tendency for the second molars to become displaced, increasing the area of the second molars during intercuspation so that more food can be mixed. This may result in a stronger relationship between occlusal contact and near contact areas of the second molar and mixing ability.

It is clear from this study that the molars contribute more to the mixing of the gum than the premolars. Manly *et al.* (25) revealed that the loss of molars leads to the functional decline of masticatory performance. As the gum is not chewed with just one pair of teeth, it is easier to mix with the molars than the premolars because of the size of the occlusal contact area. Occlusal contact and near contact areas of the molars are correlated with mixing ability.

None of the studies of the relationship between masticatory performance and occlusal contact and near contact areas have examined occlusal contact and near contact areas by clenching intensity using EMGs. Studies on the relationship between masticatory performance using a silicone test food and occlusal contact and near contact areas did not use EMGs and only used oral instruction to define the criteria for clenching intensity (9–11). Clenching intensity controlled using EMGs has been shown to have a higher reproducibility than clenching intensity left only to the subjective sensations of participants (19). Using EMGs to define the criteria for clenching intensity, we were able to calculate a reproducible occlusal contact area controlled by the amount of muscle activity.

A benefit of using Blue silicone is that it enables evaluation of a wider near contact area. Methods of measuring the occlusal contact area with the Dental Prescale system or Black Silicone-image analysing device system (5, 23) can only assess contact regions with a thickness of up to 50 μm. Methods using silicone usually involve illuminating the silicone material and examining differences in light transmission to measure the area. Blue silicone offers greater light transmission than conventional registration materials and can thus be used to calculate wide near contact areas of thicknesses up to 200 μm. However, a drawback of Blue silicone is its long hardening time. Regarding the setting of clenching intensity, a study on the differences in reproducibility with clenching intensity controlled using EMG found that reproducibility was low when set by 10% MVC (23, 24). However, setting a high MVC raises the concern that subjects may have difficulty clenching for the long hardening time. For the present study, we therefore used a low clench intensity of 10% MVC.

We focused on mixing ability in the present study. The relationship between reproducible occlusal contact and near contact areas using EMGs and masticatory performance with silicone test food or natural food product remains unclear. In addition, as we examined dentate adults, no studies have yet been conducted on the correlation between masticatory performance and occlusal contact and near contact areas of dentures in denture wearers. The size of the near contact area varies significantly with the type of occlusion, such as full balanced occlusion or lingualised occlusion. Further studies are needed to examine the relationship between masticatory performance and differences in occlusal contact and near contact areas with the type of occlusion.

Conclusion

In dentate adults, the near contact areas of thicknesses up to 200 μm were correlated with mixing ability, with the correlation strengthening as the interocclusal distance increased up to 160 μm. In particular, the occlusal contact and near contact areas of the second molar were strongly correlated with mixing ability.

Acknowledgment

The Ethics Committee at Tokyo Medical and Dental University approved the study protocols (#844), which conformed to the principles described in the World Medical Association Declaration of Helsinki (2002), and all participants provided written, informed consent before enrolment in the study.

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Conflict of interest

No conflicts of interest are declared.

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