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Thermography-Measured Facial Temperature Affects Masticatory Ability

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ABSTRACT

Introduction: *Facial skin temperature has been shown to increase during chewing. There have been few reports regarding changes in skin temperature as measured by thermography, a method suggested for screening and evaluation of diseases to assess masticatory ability. In the present study, we assessed whether increases in facial skin temperatures during gum chewing differed on the basis of masticatory ability.*

Methods: *Sixty healthy young women were enrolled in this study. Skin temperatures of the right and left sides of the face were measured by thermography in a room with a temperature of 25°C, before and after chewing; chewing was performed at a speed of 1 chew per second, for 5, 10, and 15 minutes. Facial skin temperatures were expressed as area ratio (%), averaged between sides, per 1°C (from 30°C to 36°C). Additionally, we calculated the weighted average efficiency (°C). We classified subjects into high and low groups based on the amount of sugar elution by the chewing gum method, which was used as index of masticatory ability.*

Results: *The area ratio at 32°C or 33°C was greater in the low group, whereas the area ratio at 33°C and 34°C was greater in the high group. In both groups, the skin temperature after 5 minutes of chewing was significantly higher than that at 0 minutes. However, the skin temperature in the low group was significantly lower than that in the high group after both 10 and 15 minutes of chewing.*

Conclusion: *These results revealed that individuals with low mastication ability exhibited lower skin temperature due to chewing than individuals with high mastication ability. Moreover, the measurement of facial skin temperature by thermography might be useful for assessment of masticatory ability.*

Keywords

Facial skin temperature, Young women, Sugar elution amount, Thermal analysis, Mastication.

Introduction

Mastication is the movement of the stomatognathic system and is caused by contraction and extension of the masticatory muscles. Recently, the importance of mastication has been reconsidered among clinicians. Low mastication frequency due to dietary habits might cause reduction in insulin sensitivity, diet-induced thermogenesis, immune function, motor function, and activities of daily living; concurrently, it may promote osteoporosis and obesity [1-3]. Accordingly, good masticatory ability is considered to be important for prevention of various diseases and maintenance of health. To maintain good masticatory ability, it is important to determine the current masticatory ability.

There are various methods to evaluate masticatory ability and function, such as chewing of color-changing gum [4,5], gummy jelly [6], and peanuts [7,8], as well as the use of a questionnaire [9] and electromyography [10]. Measurement of muscle temperature is another method used for evaluation of masticatory ability. Because thermogenesis occurs due to the activity of masticatory muscles, masticatory ability can be evaluated by measurement of muscle temperature.

Measurements of muscle temperature are classified into measurements of deep temperature and those of skin temperature. A deep thermometer is necessary to measure deep temperature in the oral cavity, and this is regarded as a limitation that interferes

with chewing, because several sensors with cords must be attached directly to the measurement location [11,12], and the apparatus is considerably large. Conversely, the use of thermography can only obtain thermal measurements from the skin surface; however, because it does not require sensors, measurement can easily be performed and the subject can perform mastication as usual [13]. There have been several studies of skin temperature measured in this manner. However, although the skin temperature has increased due to gum chewing in most studies, each study has used unique calculation and measurement methods. For example, a study using temperature measurement of the central portion of the masseter muscle showed increased temperature due to gum chewing [14,15], whereas another study used the average value of skin temperature at 4 locations on the face and neck [16]; a third study used the dimensions of areas, which was higher by a certain temperature than the reference temperature set for each individual [17]. Therefore, we examined the use of a method to more precisely quantify facial skin temperature in a more reproducible manner [18]. However, our previous study did not clarify whether skin temperature reflects masticatory ability. In the present study, we aimed to clarify whether masticatory ability is reflected by an increase in facial skin temperature during gum chewing.

Methods

Subjects

Ethical approval was obtained from the Research Ethics Committee of Nagoya Bunri University (No. 40), and the study was conducted in accordance with the principles expressed in the Declaration of Helsinki. Subjects were informed of the experimental procedures and purpose of the study prior to providing written consent to participate. Sixty female college students (19-22 years old) were recruited for this study from Nagoya Bunri University in Japan from 2015 to 2018. Inclusion criteria for study were young adults with no symptoms of jaw dysfunction and no history of lifestyle-related diseases. The measurements (physical condition, mastication ability and photographing of the face by thermography) were performed at the laboratory of Nagoya Bunri University. Also, each subject performed all measurements on the same day.

Physical condition

The subjects underwent physical measurements. Height was measured by using a YL-65S (YAGAMI Inc.). Body weight and percent body fat were measured by a body composition analyzer (InBody 70, InBody Japan, Inc.), and body mass index (BMI) was calculated based on the acquired measurements.

Facial skin temperature by thermography

In this study, we acquired thermal images of facial skin by thermography and calculated the area ratio per 1ºC, as well as its weighted average efficiency [18].

The skin temperatures of the right and left facial sides were measured with Thermo GEAR G100 (Nippon Avionics Co.). The Thermo GEAR has a measurement temperature range of -40°C to 500°C and a temperature resolution of 0.06°C at 30°C. The number of detected pixels is 320(H) × 240(V) pixels; one pixel is 1.8 mm^2 at a distance of 1 m from the Thermo GEAR.

Measurement was performed at 9:00 am on the same day as the other measurement, and the room temperature was maintained at 25°C. Subjects were asked to not wear makeup; they used medical caps to contain their hair, in order to expose the measurement region. We asked subjects not to speak for 5 minutes before measurement, and to remain in a resting state. Thereafter, each subject chewed one piece of dental xylitol gum (Lotte Co.) at a rate of one chew per second for 15 minutes [19]. Before chewing (0 minutes), as well as after chewing for 5, 10, and 15 minutes, the left and right sides of the face were photographed with the Thermo GEAR. The distance between the Thermo GEAR and the subjects was 1.2 m.

The photographed images were processed by InfReC Thermography Studio software, attached to the Thermo GEAR, as well as ImageJ image processing software (NIH, Bethesda, MD, USA) [20,21]. The area ratio (%) per 1°C during each chewing period (5, 10, and 15 minutes) was obtained. First, using the InfReC Thermography Studio, seven thermal images with different display temperature ranges were created from one raw thermal image. The display range was from 30.0°C, 31.0°C, 32.0°C, 33.0°C, 34.0°C, 35.0°C, and 36.0°C to 37.0°C. That is, seven thermal images in which the lower limit was increased by 1 degree without changing the upper limit of the range were made from one original image. Secondly, these images contained unused regions, such as the neck and top of the head; therefore, we linked these seven images with the "Image to stack" function of ImageJ and retrieved only the face region, while simultaneously comparing the thermal image with the corresponding visible light image. The face side region was the section surrounded by the cap, ears, lower jaw, and the line from chin to nose and the forehead. This region was designated as the reference area.

Thirdly, we adjusted the color of each of the seven thermal images with the "Color Threshold" function, and the area of the face side region was calculated with the "Wand tool" and "Measure" functions. Then, the area per degree in one side of face was calculated by subtraction of each area. For example, "area of 30.0°C to 37.0°C" – "area of 31.0°C to 37.0°C" = "area of 30°C." In order to eliminate individual differences in facial area, the area ratio was calculated by dividing the area of each temperature by the reference area. Finally, the same analysis was performed on the other face side image, and the average of the area ratios on the left and right at the same time was used as the "area ratio (%)."

In addition, to perform statistical processing, the "weighted average efficiency (°C)" of the skin temperature was obtained by calculation of the sum of the skin temperature and "area ratio (%)" at each chewing time, as shown in the following formula.

Weighted average efficiency (°C) = [30 (°C) × area ratio at 30°C (%) /100] + [31 (°C) × area ratio at 31°C (%) /100] + [32 (°C) × area ratio at 32°C (%) /100] + [33 (°C) × area ratio at 33°C (%) /100] + [34 (°C) × area ratio at 34°C (%) /100] + [35 (°C) × area

ratio at 35°C (%) /100] + [36 (°C) × area ratio at 36°C (%) /100].

Mastication ability

The amount of sugar elution in the gum was used to measure masticatory ability [22]. Each subject chewed one piece of xylitol gum 40 times; the gum was weighed before and after chewing, and the difference was regarded as the amount of sugar elution. In this study, we did not ask the subjects to restrict chewing to a particular side of the mouth, and the subjects chewed with their preferred rhythm and strength. Based on prior research regarding female university students [22], subjects with <0.66 g of sugar elution were classified in the group with low masticatory ability (low group), and those with ≥ 0.66 g were classified in the group with high ability (high group).

Statistical Analysis

Values are expressed as mean ± standard deviation. All data analyses were conducted using Prism version 5.01 (GraphPad Software Inc.), and P values < 0.05 were considered to be statistically significant. The results of physical condition assessments were compared by using the Mann-Whitney U test. Comparisons of facial skin temperature with respect to masticatory ability and chewing time were conducted by using Bonferroni post hoc tests after two-way repeated measures ANOVA.

Results

As a result of evaluating the mastication ability by the amount of sugar elution, the young female subjects were 36 in the low group (0.55 ± 0.09 g) and 24 in the high group (0.76 ± 0.06 g).

The subjects' physical conditions are summarized in Table 1. There was no difference between the low and high groups in age, height, body weight, BMI, or body fat percentage (P > 0.05 for each).

	Low group	High group
Number of subjects	36	24
Age (years)	20.5 ± 0.7	20.7 ± 0.8
Height (cm)	158.7 ± 5.4	157.8 ± 4.0
Body weight (kg)	53.7 ± 7.9	50.9 ± 5.1
Body mass index (kg/m^2)	21.3 ± 3.2	20.5 ± 2.1
Body fat percentage (%)	29.9 ± 6.4	27.2 ± 5.0

Table 1: Physical conditions.
Values are means ± SD. There were no significant differences.

Figure 1 shows the area ratio of each skin temperature separated on the basis of chewing time in each masticatory ability group. For all chewing times in both groups, the area ratio at 36°C was ≤ 2%. In the low group, the area ratios at 32°C and 33°C were large, whereas the area ratio at 35°C was small. In the high group, the area ratios at 33°C and 34°C were large, whereas the area ratios at 30°C and 31°C were small.

Figure 2 shows the comparison of the weighted average efficiencies of the low and high groups. Notably, no interaction (Masticatory ability × Time) was observed between the low and high groups (P = 0.217). In the low group, the skin temperature was 32.37 ± 0.72°C at 0 minutes of chewing, 32.53 ± 0.68°C at 5 minutes, 32.58 ± 0.68°C at 10 minutes, and 32.60 ± 0.68°C at 15 minutes. Significant temperature increases were observed at 5, 10, and 15 minutes of chewing, compared to 0 minutes of chewing (P < 0.05, P < 0.01 and P < 0.001, respectively). However, no significant differences were found among 5, 10, and 15 minutes. In the high group, the skin temperature was 32.78 ± 0.78°C at 0 minutes of chewing, 33.01 ± 0.76°C at 5 minutes, 33.11 ± 0.75°C at 10 minutes, and 33.16 ± 0.73°C at 15 minutes. Similar to the findings in the low group, significant temperature increases were observed in the high group at 5, 10, and 15 minutes of chewing, compared to 0 minutes (P < 0.05, P < 0.001 and P < 0.001, respectively). Moreover, no significant differences were found among 5, 10, and 15 minutes. However, at 10 and 15 minutes of chewing, skin temperature was significantly higher in the high group than in the low group (P < 0.05 for each).

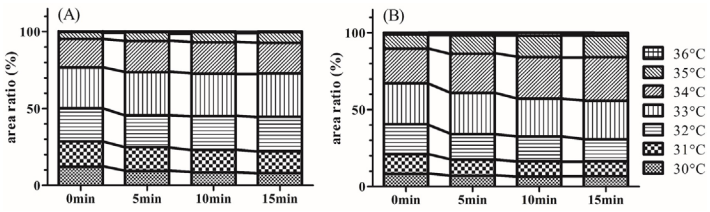

Figure 1: Area ratio of each skin temperature, separated on the basis of chewing time, in each masticatory ability group. (A) Low group. (B) High group.

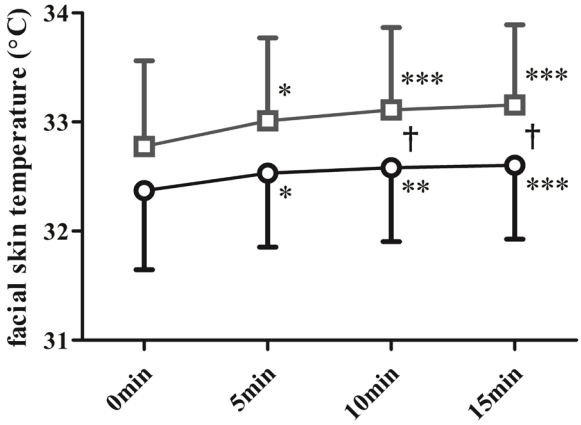

Figure 2: Skin temperature calculated by weighted average efficiency between masticatory groups.
Circles (○) and squares (□) indicate low and high masticatory ability groups, respectively.
Values are mean ± standard deviation. The standard deviation bars are only shown on one side.
Notably, there are no interactions (Masticatory ability × Time).
* = p < 0.05; ** = p < 0.01; *** = p < 0.001 in comparison with 0 minutes of each group, as determined by Bonferroni post hoc tests following two-way ANOVA.
† = p < 0.05 between low and high groups for the same chewing time, as determined by Bonferroni post hoc tests following two-way ANOVA.

Discussion

This study used thermography to measure changes in facial skin temperature while chewing gum, and determined the relationship

of these changes with masticatory ability. Notably, when chewing for more than 10 minutes, skin temperatures in the high group were significantly higher than those in the low group (Figure 2). This is likely because skin temperature rose during the period between 5 and 10 minutes of chewing in the high group, whereas there was no clear change in the low group. People with high masticatory ability exhibit good chewing habits, so masticatory muscles were well-maintained. Therefore, skin temperature might have risen because of strong chewing for 10 minutes. Subjects with low ability typically did not exhibit good chewing habits, so they experienced fatigue upon chewing for > 5 minutes. Additionally, they may not have been chewing solely by vertical movement of the jaw.

Thermography has been recommended to be used in various fields of medicine. For example, thermal images have been used to assess autonomic nervous function in patients with vertigo [23], patients with poor circulation due to cold [24], and those with craniomandibular disorders [25]. In a previous study, we found that adults with low and delayed insulin secretion had low facial skin temperature during chewing [18]. There have been reports that thermal images to identify diseases of the oral system [16,26,27]. Thermography is used as a screening approach for influenza and SARS infection at the airport; however, in research and medical practice, the measurement of skin temperature by thermography is rarely used. We suspect that this is due to the difficulty of digitizing the resulting images. When using general measurement instruments, numerical values from the instruments are reported. Because thermography involves thermal images with a range of temperatures, individuals may demonstrate different temperature data. For example, Woźniak et al. [16] assumed the temperature to be the region surrounded by a circle with a diameter of 1 cm from the image; here, we experienced difficulty in reproducibly enclosing the region at ≥ 1 cm. Therefore, we devised a method to obtain the area ratio of the temperature and the resultant weighted average efficiency.

Regarding image analysis, ImageJ software was used. A wide range of commercial image analysis software is available; however, this type of software is expensive and thus cannot be used in our laboratory. However, since we described an image analysis method using free software, we think that it will be easy for many clinicians and researcher to use.

Regarding the selection of the measurement region, although the temperature of the masseter muscle might be most closely related to mastication, temporal muscle and mimetic muscles, such as orbicularis oris, were also used for chewing. Woźniak et al. [16] used a portion of the temporal muscle; therefore, the present study calculated the skin temperature across the lateral portion of the face. The masseter muscle moves directly during chewing; this may have contributed to the lack of a significant difference in temperature between the low and high groups in the present study. Moreover, because the temporal muscle also moves indirectly during chewing, temperature differences might easily arise upon measurement of the temperature of the whole face [16,26,28]. Additionally, there are preferred and non-preferred chewing sides; however, this study did not evaluate differences between the sides (the average of left and right sides was used). In the future, we will clarify differences between chewing sides and measurement regions. Regarding the area ratio, areas per 1°C were used for calculation; thus, the area ratio of 30°C was actually the ratio of ≥ 30°C, relative to < 30°C. Technically, this parameter could be calculated per 0.5°C or 0.1°C, and the accuracy of the weighted average efficiency would increase. However, because data processing would be increased by 2-fold or 10-fold, calculation per 1°C was the maximum accuracy that could be achieved.

The amount of eluted sugar was used to evaluate masticatory ability. Although each evaluation method involves advantages and disadvantages, a notable disadvantage of the current method might be the influence of the volume of saliva. However, the influence of chewing force was shown to be stronger than the saliva volume when using this method [29]; thus, it is generally used as a method to evaluate masticatory ability. Additionally, we chose this method because it enabled immediate measurement with a minimal amount of equipment.

This study had the following limitations: subjects were only young females, skin temperatures were calculated by averaging the left and right sides of the face, and masticatory ability was evaluated by the amount of sugar elution. In the future, adding men and other age groups to the subject may lead to showing the reference value of skin temperature, accuracy and problems for evaluation of mastication ability by facial skin temperature.

In this study, we performed thermal image analysis, which was more quantitative and reproducible than prior methods. In addition, we revealed that individuals with high masticatory ability exhibited higher facial skin temperature when chewing gum than those with lower masticatory ability. Finally, we expect that this study and the included methods can contribute to further thermography research and usage in a variety of medical fields.

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Clinical Trial Registry or Grant Details

Since this study is not a clinical trial, no clinical study registration has been made, but the ethics committee was obtained. Ethical approval was obtained from the Research Ethics Committee of Nagoya Bunri University. The authors have no conflicts of interest directly relevant to the content of this article.

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