Mastication and Bone Density of Young Women and the Relationship with Tolerance to Exercise -Analysis with thermography and a Bicycle Ergometer-

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Abstract

Introduction: Chewing well is linked to preventing obesity and lowering the risk of type-2 diabetes and the importance of mastication is recognized. In the field of dentistry, there have been numerous reports on the relationship between bite and tolerance to exercise. However due to the lack of reports relating to mastication and tolerance to exercise we aim to clarify the relationship between mastication and tolerance to exercise and bone density.

Method: 23 healthy young females (21.3 ± 0.4 years old) without a history of exercise had their habitual non-masticatory side determined by finding the main occluding area using stopping. The facial skin temperature at rest on the habitual non-masticatory side was measured using thermography and the area was multiplied by that temperature for each 1℃ and totaled. Each participant was placed in either the high or low chewing efficiency group depending on the average of that value. Tolerance to exercise was determined by a bicycle ergometer and exhaled gas analysis while ultrasound was used to determine bone density, and the 2 groups were compared.

Results: The bone density, peak oxygen consumption per 1kg of body weight and minute volume of ventilation from 5 minutes before the end of exercising to end of exercising were each considerably small in the low chewing efficiency group compared to the high chewing efficiency group.

Conclusion: The facial skin temperature was measured using thermography to give masticatory muscle activity when at rest as chewing efficiency and was confirmed to have a relationship with exercise tolerance. Chewing efficiency can be determined using thermography. Also, a relationship was confirmed between chewing efficiency and bone density, and since there is a relationship between bone density and heart pump functionality through mastication in eating habits and exercise habits, we reconfirmed the importance of mastication.

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.

Keywords
Bone Density, Ergometer, Mastication, Thermography, Young women.

Introduction
In recent years in Japan, there is a concern that chewing is insufficient due to skipping breakfast or consuming soft foods due to the westernization of the diet. Mastication has a wide range of uses such as promoting growth of facial bones, promoting digestion or appetite regulation through endocrine exacerbation, regulating health by promoting the excretion of saliva, and brain activity [1]. Further, in cohort studies the stronger chewing group have a reduced risk of developing type 2 diabetes compared to the weaker chewing group [2], and chewing well is linked to preventing obesity [3,4], so the importance of mastication is verified.
The Cardiopulmonary Exercise Test (CPX) that uses exhaled gas analysis is one method of determining athletic ability. Combining knowledge gained from CPX, highly repeatable and objective information on the overall health of an individual can be obtained [5,6]. Previous studies on the use of CPX in medicine include standards for determining heart transplants for heart failure [7], determining severity [8], relation with prognosis on the life of a healthy person [9], relation with prognosis on the life of patients with heart disease [10]. Similar studies in sports science are on training using the anaerobic threshold (AT) [11], and in studies in dentistry on the relation between the state of occlusion and athletic ability [12,13]. In each field, there are many reports of the main test subjects in studies using CPX being junior or senior high school students and they report on the relationship between occlusion and athletic ability. However, studies on the relationship between mastication and athletic ability are few in number. Also, since there is a prevalence of osteoporosis in females, compared to males [14,15], this study targets young females and examines gradual load on CPX using a bicycle ergometer and measures bone density in addition to chewing efficiency obtained from thermography of masticatory muscle activity. The aim is to clarify the relationship between chewing efficiency and tolerance to exercise and bone density in young females.

Methods
Participants
Twenty-three healthy female university students with no history of exercise (age: 21.3 ± 0.4: average ± standard deviation) were enrolled in the study with informed consent. This study received authorization, based on the Helsinki Declaration, from the Nagoya Bunri University Ethics Council (No. 44).

Facial skin temperature measurement method
The method was used according to Takahashi et al. [16,17]. Namely, facial skin temperature measurements were taken on the left and right side of the face when at rest using the infrared thermography camera, Thermo GEAR G100 (Nippon Avionics Co., Ltd.). Using the analysis software, InfReC Analyzer NS9500 (Nippon Avionics Co., Ltd.), the number of pixels (area) in each image that corresponded to a change in loc between 30-36°C were counted for each temperature and corrected for a standard facial surface area. Each temperature was multiplied by this correction value and then summed to obtain the normal skin temperature for each participant.

Determining the habitual masticatory side
Stopping was used in accordance with the method to determine the main occluding area [18]. According to Tochikura et al. [19], there is a difference in functionality between the main masticatory side and the non-main masticatory side when biting, and they reported that the strength, stability of motion and chewing efficiency were higher in the main masticatory side than the non-masticatory side. From this we consider that the habitual non-masticatory side has weaker functionality and that there is a large difference in chewing efficiency for that side, therefore this study analyzed the habitual non-masticatory side.

Exercise load
The Bicycle ergometer 75 XLII (Combi Corporation) was used. The linear incremental load exercise used here is an exercise load method proposed by Whipp et al. [20], wherein the exercise difficulty is linearly increased. It is safe and the necessary data can be obtained in a short time and is widely used in the field of respiratory physiology. Previous studies used loads of 12.5 W every 30 s [21], 10 W or 20 W every 1 min. [22,23], 25 W every 2 min [24], and 25W every 3 min [25]. Since the subjects in this study have no experience with exercise, we began at 70 pedal revolutions per minute at 20 W and increased in 10 W increments every 3 min, and continued until either 30 min had elapsed or the rate of 70 pedal revolutions per minute could not be maintained. During the exercise, the exhaled breath was collected and analyzed using the breath-by-breath method with the exhaled gas analyzer VO2000 (S&ME Inc.). Furthermore, the heartbeat was continuously measured during the exercise using the simple cardiometer A360 (Polar Japan).

Bone density measurements
Quantitative ultrasound (QUS) was used. QUS is used to diagnose osteoporosis, as there is a correlation with the bone density measured via dual-energy X-ray absorptiometry (DXA) [26,27]. The speed of sound (SOS) (m/s) and transmission index (TI) through the calcaneus were measured using the ultrasonic bone density evaluation equipment AOS-100 (Hitachi Aroka Medical Inc.) and the bone density was obtained as the osteosonic index (OSI) from the following equation [28,29].

\[ OSI = TI \times SOS^2 \]

Statistical processing
The participants were placed in the low group (L-group) or high group (H-group) based on the average normal skin temperature on their habitual non-masticatory side, and the Mann-Whitney U test, with the statistical significance set to 5%, was run on SPSS statistical processing software (IBM).

Results
Participants
Table 1 shows the physical condition of the participants. Thirteen were in the L-group and 10 in the H-group. There was no significant difference in any of the age, height, weight, BMI or body mass percentage between the groups.

<table>
<thead>
<tr>
<th>Masticatory group</th>
<th>n</th>
<th>Age (year)</th>
<th>Body height (cm)</th>
<th>Body weight (kg)</th>
<th>Body Mass Index (BMI) (kg/m²)</th>
<th>Body fat (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low (L)</td>
<td>13</td>
<td>21.2 ± 0.7</td>
<td>157.9 ± 3.7</td>
<td>53.7 ± 7.9</td>
<td>21.5 ± 3.1</td>
<td>30.8 ± 5.9</td>
</tr>
<tr>
<td></td>
<td></td>
<td>n.s.</td>
<td>n.s.</td>
<td>n.s.</td>
<td>n.s.</td>
<td>n.s.</td>
</tr>
<tr>
<td>High (H)</td>
<td>10</td>
<td>21.2 ± 0.4</td>
<td>155.8 ± 4.7</td>
<td>57.2 ± 10.5</td>
<td>23.6 ± 4.5</td>
<td>31.4 ± 8.6</td>
</tr>
<tr>
<td></td>
<td></td>
<td>n.s.</td>
<td>n.s.</td>
<td>n.s.</td>
<td>n.s.</td>
<td>n.s.</td>
</tr>
<tr>
<td>Total</td>
<td>23</td>
<td>21.3 ± 0.4</td>
<td>157.0 ± 4.2</td>
<td>55.2 ± 9.1</td>
<td>22.4 ± 3.8</td>
<td>31.1 ± 7.0</td>
</tr>
</tbody>
</table>

Table 1: Clinical characteristics of the 23 subjects. The data are expressed as the mean ± standard deviation (SD).
There were no significant differences in clinical characteristics.

**Bone density**

Table 2 shows the measured results for bone density. They were 2.568 ± 0.262 (×10⁻⁰⁶) for the L-group and 2.776 ± 0.251 (×10⁻⁰⁶) for the H-group, with the L-group being significantly lower (p=0.036).

<table>
<thead>
<tr>
<th>Masticatory group</th>
<th>n</th>
<th>Bone density (×10⁻⁰⁶)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low (L)</td>
<td>13</td>
<td>2.568 ± 0.262</td>
</tr>
<tr>
<td>High (H)</td>
<td>10</td>
<td>2.776 ± 0.251</td>
</tr>
<tr>
<td>Total</td>
<td>23</td>
<td>2.659 ± 0.273</td>
</tr>
</tbody>
</table>

Table 2: Bone density value of the 23 subjects.

The data are expressed as the mean ± standard deviation (SD). *: p < 0.05. There were significant difference in Bone density (p=0.036).

**Peak oxygen consumption per 1kg of body mass**

Table 3 shows the results for peak oxygen consumption per 1kg of body mass (peak VO₂/kg). They were 28.79 ± 8.10mL/kg/min for the L-group and 35.41 ± 6.20mL/kg/min for the H-group, with the L-group being significantly lower (p=0.036).

<table>
<thead>
<tr>
<th>Masticatory group</th>
<th>n</th>
<th>Peak oxygen consumption per 1kg of body weight (mL/kg/min)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low (L)</td>
<td>13</td>
<td>28.79 ± 8.10</td>
</tr>
<tr>
<td>High (H)</td>
<td>10</td>
<td>35.41 ± 6.20</td>
</tr>
<tr>
<td>Total</td>
<td>23</td>
<td>31.67 ± 7.92</td>
</tr>
</tbody>
</table>

Table 3: Peak oxygen consumption per 1kg of body weight value of the 23 subjects.

The data are expressed as the mean ± standard deviation (SD). *: p < 0.05. There were significant difference in Peak oxygen consumption per 1kg of body weight (p=0.036).

**Minute ventilation**

Table 4 shows the results for minute ventilation (VE). At 5 min before the end of the exercise, the L-group was 32.98 ± 13.20L/min and the H-group was 53.55 ± 15.98L/min (p=0.002), at 4 min before, the L-group was 37.80 ± 10.06L/min and the H-group was 52.52 ± 15.23L/min (p=0.030), at 3 min before, the L-group was 34.82 ± 10.98L/min and the H-group was 52.71 ± 18.68L/min (p=0.010), at 2 min before, the L-group was 32.75 ± 16.02L/min and the H-group was 56.65 ± 16.49L/min (p=0.003), at 1 min before, the L-group was 38.79 ± 14.27L/min and the H-group was 58.69 ± 18.23L/min (p=0.008), and at the end of the exercise, the L-group was 32.35 ± 10.91L/min and the H-group was 57.33 ± 19.06L/min (p=0.001), and in all cases the L-group was significantly lower.

<table>
<thead>
<tr>
<th>Masticatory group</th>
<th>n</th>
<th>Before the end of exercising</th>
<th>End of exercising</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>5 minutes</td>
<td>4 minutes</td>
</tr>
<tr>
<td>Low (L)</td>
<td>13</td>
<td>32.98 ± 13.20</td>
<td>37.80 ± 10.06</td>
</tr>
<tr>
<td>High (H)</td>
<td>10</td>
<td>53.55 ± 15.98</td>
<td>52.52 ± 15.23</td>
</tr>
<tr>
<td>Total</td>
<td>23</td>
<td>41.92 ± 17.55</td>
<td>44.20 ± 14.34</td>
</tr>
</tbody>
</table>

Table 4: Minute volume of ventilation value (L/min) of the 23 subjects.

The data are expressed as the mean ± standard deviation (SD). *: p < 0.05, **: p < 0.01. There were significant differences in 5 minutes before the end of exercising (p=0.002), 4 minutes before the end of exercising (p=0.030), 3 minutes before the end of exercising (p=0.010), 2 minutes before the end of exercising (p=0.003), 1 minute before the end of exercising (p=0.008) and end of exercising (p=0.001).

Discussion

**Measurement of facial skin temperature using thermography and chewing efficiency**

This study evaluated chewing efficiency from facial skin temperature using thermography. General methods for evaluating chewing efficiency include having the participant chew on chewing gum [30], colour changing gum [31], gummi drops [32], peanuts [33], or raw rice [34]. However, these methods involve numerous factors such as occlusion, masticatory muscles, salivary output, and mixing ability with saliva (tongue movement). Electromyography [35] can also be used, however small variations in the positioning of the sensor can lead to differences in results. A previous study by Berry et al. [36], thermography was used to measure the facial skin temperature distribution during mastication, and the facial surface temperature was shown to vary with chewing.

Tsuchiya et al. [37] measured the facial temperature distribution when the participant was chewing gum and compared the spread of high temperature regions from before and after chewing. The sum of the corrected surface area multiplied by the respective temperature used in this study is considered a more comprehensive and finer evaluation of facial skin temperature due to masticatory muscle movement than in previous studies.

**Determining the habitual masticatory side**

This study used to stop to determine the main occluding area and hence determine the habitual masticatory side. Christensen et al. [38] and Kazazoglu et al. [39] had participants chew gum and observed the chewing stroke to determine the habitual masticatory side. Also, Pond et al. [40] and Delport et al. [41] set the habitual masticatory side to be that on which the first stroke of the masticatory movement and reported that there was a correlation between the first stroke of the masticatory movement and the side used in continual chewing. Therefore, the current study considered it reasonable to use stopping to determine the main occluding area and hence determine the habitual masticatory side.
Mastication and bone density
The results of this study determined that the bone density was considerably lower in the group with lower chewing efficiency than in the other group. In previous studies, Teraoka et al. [42] examined bone density and chewing efficiency in elder people and confirmed a relationship between bone densities and chewing efficiency in elder males yet found no significant difference with the elderly females and reported a strong influence due to aging. Iwasaki et al. [43] investigated the occlusal force and physical strength along with bone density of the calcaneus of female junior college students and stated that it is possible to increase bone density through using exercises to strengthen occlusal force. Mitsuki et al. [44] analyzed the relevance of calcaneus bone density and occlusal support, and confirmed a relationship between a decrease in the calcaneus bone density and loss of occlusal support. Occlusal force is one factor in setting chewing efficiency [45] and mastication is suggested as an influence on bone density.

Mastication and athletic ability
This study confirmed a relationship between mastication and athletic ability. In a previous study, Iwasaki et al. [46] investigated the relationship between occlusal force and physical strength in sportsmen, and reported a significant positive correlation between occlusal force and grip strength and back strength. Ishiyama [47] investigated the relationship between occlusal force and the physical fitness test of the Japanese Ministry of Education and Science of healthy young females, and reported that for participants with occlusal force greater than 45kgf had stronger grip strength, could stand on one leg with their eyes closed for longer and better full body endurance that those with a grip force up to 45kgf. From these reports, we can infer that there is a close relationship between occlusal force, upper and lower limb strength, and full body endurance.

There are also reports similar to this study that investigate the relationship between mastication and athletic ability. Ono et al. [48] investigated the relationship between masticatory force and physical test results of elementary school students, and reported that compared to the low masticatory force group, the high masticatory force group has significantly better scores for grip strength, seated toe touching stretch, 20m shuttle run and 50m dash. Iwasaki et al. [49] investigated the relationship between chewing ability and length of time standing on one leg in elderly participants, and reported a significant relationship between poor chewing ability and not being able to stand on one leg for more than 30s. Johnson et al. [50] reported on confirming a significant positive correlation between occlusal force, grip strength and back strength due to the direct proportionality of masticatory and limb muscle growth. From the above, occlusion and chewing ability can be inferred to have a close correlation with athletic ability, and suggests that mastication influences tolerance to exercise. This study confirmed a correlation between mastication and grip strength, as mentioned in previous studies. Grip strength reflects full body strength around the lower limb strength [51] and as the period of inactivity increases, atrophy progresses and muscle strength decreases [52]. The participants in this study had no history of exercise, and showed a decreasing trend in full body strength including grip strength. Since the strength of the masticatory muscles decreased slightly from chewing motions, we could not confirm a relation with grip strength, and this required further study.

Research limitations
The participants in this study were young females with no history of exercise and different results can be expected for different genders, ages, and exercise history.

Conclusion
Facial skin temperature was measured with thermography, and a relationship was confirmed between tolerance to exercise and chewing efficiency from masticatory muscle activity at rest. Therefore, thermography can be used to determine chewing efficiency. Furthermore, a correlation was confirmed between chewing efficiency and bone density and the importance of mastication was reconfirmed from the correlation of bone density and heart pumping ability with mastication through eating and exercise habits. Here the masticatory muscle activity on the habitual non-masticatory side was used, yet further study is required to investigate the relationship between tolerance to exercise and chewing efficiency from masticatory muscle activity on the habitual masticatory side.

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