Original Article

Development of a Novel Chewing Counter with a Bone Conduction Sound System

Keisuke NISHIGAWA[1), Yoshizo MATSUKA[2), Shogo MINAGI[3)

Keywords : mastication, chewing counter, bone conduction sound, electromyogram

Abstract :

Purpose: The purpose of this research was to develop a novel method to quantitatively evaluate chewing features during daily meal events.

Methods: An occlusal tooth contact sensor with a bone conduction sound system was used as a chewing counter, and surface electromyography of the masseter muscle and a previously used chewing counter (bitescan) were also used to evaluate the validity of the novel chewing counter. The number of chewing cycles and other chewing features were recorded in 10 adult volunteers while eating lunch.

Results: The average number of chewing cycles was 541, the mean duration of chewing was 11.0 minutes, and the chewing speed was 51.3 cycles/minute.

Conclusion: The chewing features measured with the novel method exhibited good consistency with the other chewing counting methods.

1. Introduction

Previous research evaluating mastication was mainly concerned with indicators of masticatory efficiency[1-3). Questionnaires about masticatable diets and sieving tests for masticatory efficiency are examples of direct examination of masticatory function. Assessment of maximum occlusal force, measurement of the rhythm of chewing cycles, and evaluation of occlusal contacts in the interocclusal position are examples of indirect examination of masticatory function. Most of those direct and indirect examination methods aim to evaluate the quality of masticatory efficiency. More recently, the comprehensive effects of mastication have been investigated in interdisciplinary studies; for example, relating to obesity prevention, improvement of cognitive function, and the general health of the elderly patient[4-6). To clarify these potential effects of mastication, quantitative evaluation is required.

This study introduces a novel chewing counter that uses a bone conduction sound (BCS) system. Surface electromyography (EMG) recordings of the masticatory muscles and a previously used chewing counter bitescan (Sharp Corp, Osaka, Japan) were also used to evaluate the validity of the novel chewing counter. Chewing indices, such as number of chewing cycles, duration of chewing, and speed of the chewing cycle, were recorded during the lunchtime of 10 adult volunteers.

2. Materials and Methods

An occlusal tooth contact sensor with a bone conduction sound system was used as the chewing counter. Surface EMG of the masseter muscle and a previously used chewing counter bitescan were also used.

The occlusal tooth contact sensor consisted of a microphone (ECM-TL3, Sony Corp, Tokyo, Japan) attached to the

[1) Department of Oral Health Sciences, Faculty of Health and Welfare, Tokushima Bunri University
[2) Department of Stomatognathic Function and Occlusal Reconstruction, Institute of Biomedical Sciences, Tokushima University Graduate School
[3) Department of Occlusal and Oral Functional Rehabilitation, Faculty of Medicine, Dentistry and Pharmaceutical Sciences, Institute of Academic and Research, Okayama University

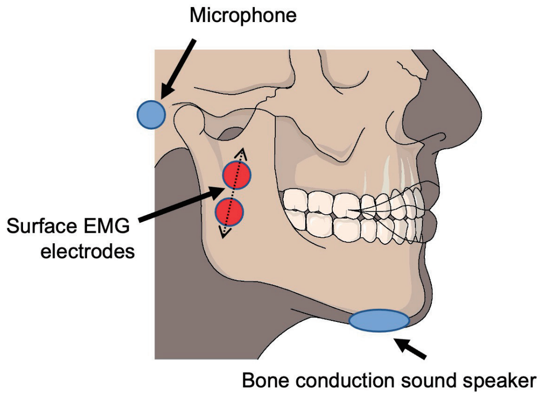

Fig. 1 Arrangement of sensors for the bone conduction sound system and the electromyography electrodes.

external ear and a bone conduction sound speaker (DE-8297, Design Factory, Tokyo, Japan) attached to the chin. The bone conduction sound signal from the speaker was detected at the microphone. Because this signal spread from the mandibular bone to the maxillary bone, the intensity of the signal increased with occlusal contact (Figure 1, 2). Since our previous study revealed that sine wave with 630 Hz frequency is the most suitable signal for detecting occlusal contact, this signal was played back by the bone conduction sound speaker. Then bandpass filter with the same frequency was also applied for the recorded sound by the microphone[7]. The bone conduction sound signal was recorded and played back with an iPod touch (Apple Inc, CA, USA).

A wireless EMG logger II (Unique Medical Co Ltd, Tokyo, Japan) was used to measure the surface EMG of the masseter muscle. Two electrocardiogram (ECG) electrodes Inspad S (Japan Medicalnext Co Ltd, Osaka, Japan) were attached to the skin surface over the unilateral masseter muscle. The electrodes were placed along the muscle fiber direction with 30 mm distance between the centers of the electrodes. The reference electrode was attached to the forehead of the subject and a bipolar read of the EMG signal was performed. Before attaching the electrodes, the skin surface of the subject was cleaned with skin preparation gel skinPure (Nihon Koden Corp, Tokyo, Japan).

The bitescan chewing counter is a miniature ear-mounted device for monitoring chewing action during the day. This device detects chewing activity from vibrations of the skin of the auricle[8, 9]. The chewing activity was recorded with a smartphone application connected by Bluetooth.

The number of chewing cycles and other features were recorded during the lunchtime of 10 adult volunteers (10 female, average age 22.0 ± 0.22 years). All subjects were asked to eat lunch at the laboratory with the sensor units attached. The food was selected by the subjects themselves.

Fig. 2 Scene of the experiment during taking lunch with the bone conduction sound system and other sensors. Below left; Bone conduction sound speaker that attached to chin, right; microphone attached to the external ear that detect detects BCS signal.

To synchronize signals from the sensor units, the subjects were also asked to clench three times at the beginning and conclusion of the meal. The computer program MATLAB (MathWorks Inc., MA, USA) was used to analyze the bone conduction sounds and EMG signals. The duration of chewing, the number of chewing cycles, and the speed of the chewing cycle were recorded. The same parameters were also recorded by the bitescan application which was installed on a smartphone AQUOS Sense3 (Sharp Corp, Osaka, Japan).

Bartlet test was used to confirm the null hypothesis that the results of those three kinds of chewing counting methos have equal variances. Then One-way analysis of variance was used to evaluate differences in the chewing features between the three chewing counting methods. Statistical analyses were performed with Statcel4 (oms-publication, Tokyo, Japan)

This research was approved by the Research Ethics Committee of Tokushima Bunri University (No. H29-5).

3. Results

Figure 3 shows an example of the surface EMG signal of the masseter muscle and the bone conduction sound signal. Simultaneous elevations of these two signals are shown over a 10-second period. The duration of chewing time was measured from the start to the finish of the lunchtime meal for each subject. The number of chewing cycles was recorded as the number of peak elevations of the EMG and the bone conduction sound signals independently. The speed of the chewing cycle was calculated by dividing the duration of

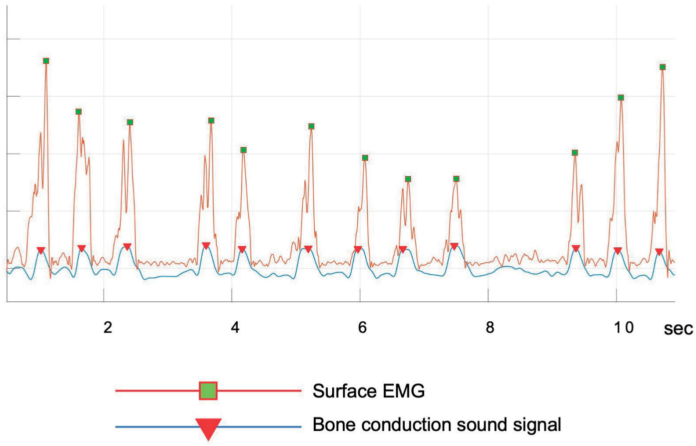

Fig. 3 Example of the surface electromyography signal of the masseter muscle and the bone conduction sound signal. Simultaneous elevations of these two signals are observed.

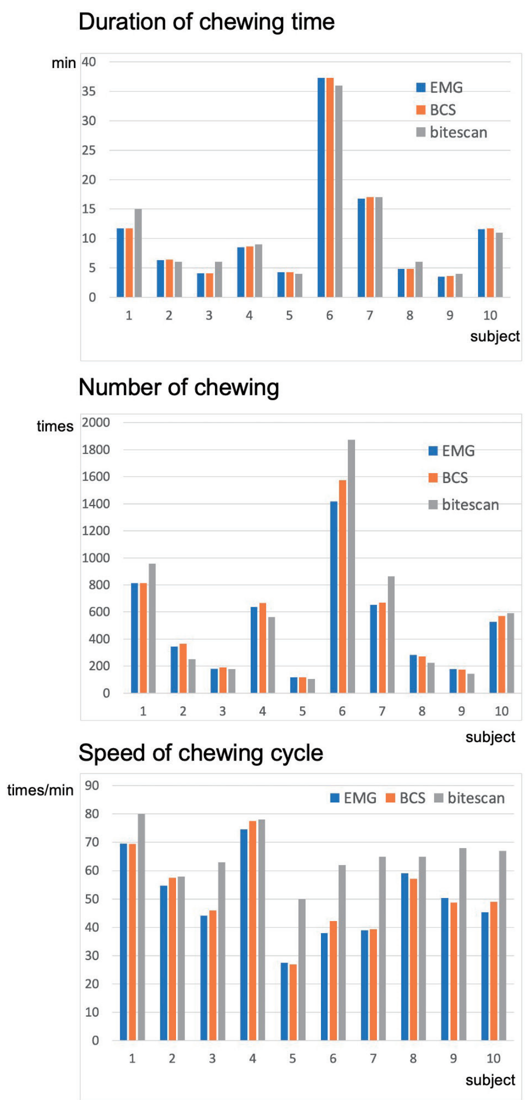

Fig. 4 Bar graphs for the duration of chewing, the number of chewing cycles, and speed of the chewing cycle of 10 subjects measured with three chewing counting methods.

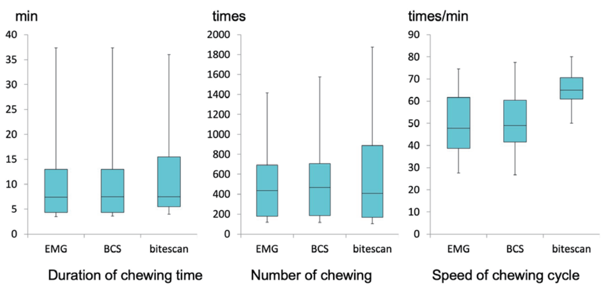

Fig. 5 Boxplots with interquartile for the duration of chewing, the number of chewing cycles, and speed of the chewing cycle of 10 subjects measured with three chewing counting methods. The speed of the chewing cycle was higher when measured with the bitescan device than the other two methods.

chewing by the number of chewing cycles.

Figure 4 and 5 show the bar graphs and the boxplots with interquartile for the duration of chewing, the number of chewing cycles, and the speed of the chewing cycle for the three chewing counting methods. The results for the duration of chewing and the number of chewing cycles did not differ between the three chewing counting methods. However, the speed of the chewing cycle was higher when measured with the bitescan device than the other two methods.

Bartlet test exhibited equal variances in three groups of chewing counting methods for chewing duration, number and speed (Table 1). One-way analysis of variance did not find any significant differences in the results for the duration of chewing and the number of chewing cycles, but revealed significant differences in the results of the speed of the chewing cycle (Table 2).

Table 1 Comparisons of the variance in the results of three chewing counting methods (EMG, BCS, bitescan) were performed with Bartlet test. Since no significant p-value were found, those three group resuls have equal variances.

	χ-squared	df	p-value
Duration of chewing time	0.028	2	0.986
Number of chewing	1.004	2	0.605
Speed of chewing cycle	2.635	2	0.268

Table 2 Comparison of the chewing features detected using three chewing counting methods (one-way ANOVA test). Speed of chewing cycle exhibited significant difference among the results of three chewing counting methods (EMG, BCS, bitescan)

	df	Mean square	F	p-value
Duration of chewing time	2	0.7770	1.279	0.303
Number of chewing	2	9014.4	1.084	0.359
Speed of chewing cycle	2	736.78	27.17	0.000*

The average results for the new chewing counting method with a bone conduction sound system for the 10 subjects were 11.0 ± 10.2 minutes for the duration of chewing, 541 ± 437 for the number of chewing cycles, and 51.3 ± 14.7 cycles/minute for the speed of the chewing cycle.

4. Discussion

In this study, the bitescan device exhibited a significantly faster chewing cycle speed than the other two methods. Because the bitescan application uses the chewing period (i.e., the duration from intake to swallowing food) to calculate the chewing cycle, the definition of this parameter was not identical to the other two methods. All three chewing counting methods recorded almost the same results for the duration of chewing and the number of chewing cycles, indicating that all are valid methods for evaluating chewing features.

Substantial individual differences between subjects were noted in the duration of chewing and the number of chewing cycles. These differences seem to be related to the personality of the subject, as well as the food selected for lunch by the subject. The speed of the chewing cycle also exhibited individual differences between subjects, but these differences were less marked.

Although all subjects of this research belong to the same gender and the same age group, the duration and number of chewing exhibited large individual differences. This finding indicates that mastication is the eating action with large individual variety. As we mentioned in introduction, mastication may have comprehensive effects on general health[4-6]. To clarify those comprehensive effects of mastication, individual observation of the chewing action with handy and reliable method will be required. Since the new chewing counter with a bone conduction sound system is consisted with only common audio products, and also exhibits same level of reliability with EMG and bitescan, this new chewing counter can be the useful tool for individual evaluation of mastication.

5. Conclusions

The number of chewing cycles and other chewing features were recorded during the lunchtime meal of 10 adult volunteers. An occlusal tooth contact sensor with a bone conduction sound system, surface EMG of the masseter muscle, and a bitescan device were used as chewing counters. The average duration of the lunchtime meal was 11.0 ± 10.2 minutes, the average number of chewing cycles was 541 ± 437, and the average speed of the chewing cycle was 51.3 ± 14.7 times/minutes. These findings confirm the validity of the novel chewing counter that uses a bone conduction sound system.

Conflicts of interest

There are no conflicts of interest to declare.

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