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Evaluation of masticatory performance by motion capture analysis of jaw movement

Running title: Motion capture analysis of mastication

Masaaki Imaoka[1], Kentaro Okuno[2], Ryuichiro Kobuchi[2], Taro Inoue[2], Kazuya Takahashi[2]

[1]Departmet of Geriatric Dentistry, Osaka Dental University Graduate School of Dentistry, Hirakata-shi, Osaka, Japan

[2]Department of Geriatric Dentistry, Osaka Dental University, Hirakata-shi, Osaka, Japan

Corresponding author

Kentaro Okuno, Department of Geriatric Dentistry, Osaka Dental University, Hirakata-shi, Osaka 573-1121, Japan

Email: okuno-kentaro-ig@alumni.osaka-u.ac.jp

Authors' contributions

Masaaki Imaoka designed the study, contributed to the collection and analysis of data, and wrote the initial draft of the manuscript. Kentaro Okuno designed the study, contributed to the collection, analysis, and interpretation of data, and assisted in the preparation of the manuscript. All other authors have contributed to data interpretation, and critically reviewed the manuscript. All authors approved the final version of the manuscript.

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Abstract

Background: The assessment of masticatory performance (MP) is conducted in hospitals, but is difficult to perform in nursing facilities that lack specialists in dysphagia. To determine the appropriate food form in nursing practice, a simple method of evaluating the MP should be developed.

Objective: The purpose of this study was to investigate motion parameters that influence MP by motion capture analysis of maxillofacial movement on chewing gummy jelly in healthy adults.

Methods: The subjects were 50 healthy adults. The state of chewing gummy jelly was photographed using a high-speed camera. Simultaneously, we evaluated the amount of glucose extracted (AGE) obtained with gummy jelly as a reference value for MP. The subjects were divided into two groups: normal and low masticatory groups (NG and LG, respectively) based on the AGE. The cycle of mastication was classified into 3 phases: closing phase (CP), transition phase (TP), and opening phase (OP) through motion capture analysis of the video photographed. Parameters of jaw movement, and their associations with the AGE were examined.

Results: The transition phase ratio (TR), and opening phase ratio (OR) were correlated with the AGE. Furthermore, the TR in the NG was significantly higher than in the LG, whereas the OR was significantly lower than in the LG. The age, TR, and Opening velocity were significant independent variables.

Conclusion: Motion capture technology facilitated the analysis of jaw movement. The results suggested that MP can be evaluated by analyzing the ratios of TP and OP.

Keywords

masticatory performance, motion capture, high-speed camera, jaw movement, long-term care, gummy jelly

1 INTRODUCTION

The oral functions, such as mastication and swallowing, decrease with aging[1], and oral hypofunction is associated with systemic motor hypofunction[2], a poor nutritional status[3], and an increase in the mortality rate in the older adults[4–6]. Dementia[7] and cerebrovascular diseases[8] cause masticatory/swallowing dysfunction, and dysphagia leads to long-term nursing or an increase in readmission[9]. Furthermore, it was reported that the morbidity rate of dysphagia was 60% in older adults admitted to a nursing facility[10]; the management of dysphagia is an issue in nursing practice. The selection of an inadequate food form causes aspiration[11]; therefore, it is important to provide an appropriate food form in accordance with individual swallowing functions. Swallowing-function-evaluating methods include videoendoscopic evaluation of swallowing (VE)[12], swallowing videofluorography (VF)[13], and observation of care recipients' diet by a meal round in cooperation with physicians or dentists[14]. Among the swallowing functions, masticatory performance is particularly important for determining the food form.

For masticatory performance (MP) assessment, methods with silicone impression materials[15], chewing gum[16,17], paraffin wax[18], or gummy jelly[19–22] are used. These methods are conducted in hospitals, but are difficult to perform in-nursing facilities that lack specialists in dysphagia. To determine the appropriate food form in nursing practice, a simple method of evaluating the swallowing function should be developed. Among MP assessment methods that are currently used in clinical practice, measurement of the amount of glucose extracted (AGE) after chewing gummy jelly facilitates quantitative, objective MP measurement[20,21]. However, the chewing time is established as 20 seconds, and the chewed gummy jelly must be spat out without swallowing it; due to these conditions, patients who can follow instructions must be selected, and it is difficult to adopt this method in nursing practice. The purpose of this study was to establish a method of MP assessment through motion capture for mandibular movement on meals as a simpler MP assessment method that is available for anyone. We investigated which motion parameter influences MP by motion capture analysis of maxillofacial movement on chewing gummy jelly in healthy adults.

2 METHODS

2.1 Subjects

The subjects were 50 healthy adults (24 males, 26 females) selected from students belonging to Osaka Dental University and clinical fellows at Osaka Dental University Hospital, with a mean age of 25.4 ± 2.7 years. The inclusion criteria were: (1) the absence of systemic or masticatory abnormalities, and (2) having a dentition classified as A1 according to Eichner's classification. Those receiving orthodontic treatment were excluded from the subjects. This study was approved by the ethics committee of Osaka Dental University (Approval No. 110970).

2.2 Collection of basic information

Information (age, sex, medical history, medications, habitual masticatory side) was obtained from the subjects. The body mass index (BMI) was calculated by dividing the body weight by the height squared. Oral examination was conducted by dentists (MI), and the number of residual teeth was evaluated. Wisdom teeth were not included in the number of residual teeth.

2.3 Recording of MP

2.3.1 Test food

As the test food, a column-shaped glucose-containing gummy jelly measuring approximately 14 mm (diameter) x 10 mm (height) and weighing 2.3 g (Glucolum, GC, Tokyo, Japan) was used.

2.3.2 Measurement of MP

The subjects were instructed to initially chew the glucose-containing gummy jelly on the habitual masticatory side and, then, freely for 20 seconds after the start of chewing. However, they were prohibited from swallowing the saliva or gummy jelly on mastication. After mastication, the subjects were instructed to instantly contain 10 mL of distilled water in the oral cavity and spit out all remnants into a cup with a filter. The filtrate concentration of glucose, that is, AGE, was measured using a glucose analyzer (GLUCO SENSOR GS-II, GC, Tokyo, Japan), and used as a quantitative parameter of MP.

Shiga et al. reported that the reference value of AGE on an MP test with gummy jelly was 150 mg/dL[21]. In this study, a group with an AGE of ≥ 150 mg/dL was established as the normal masticatory performance group (NG), and a group with an AGE of < 150 mg/dL as the low masticatory performance group (LG).

2.4 Motion capture analysis of mandibular movement

2.4.1 Motion videography

On the face of each subject, round white stickers measuring 8 mm in diameter as measurement points were attached to the area between the eyebrows and mentum

(Figure 1: A). To the mentum, the sticker was attached by determining the widest contour of the mental protuberance by palpation. Furthermore, the distance between the maximum contours of the left and right wings of the nose was measured using digital calipers (19981, Shinwa Rules Co., Ltd., Niigata, Japan) for calibration on motion capture analysis.

The subjects were instructed to sit on a chair with a backrest of which the height was adjusted so that the bilateral feet might be placed on the ground (Figure 1: B). For motion videography, a high-speed camera (HAS-U2, Ditect, Tokyo, Japan) was used. For motion recording, motion-recording software for Windows (HAS-Xviewer, Ditect, Tokyo, Japan) was used. Videography was initiated 2 seconds before making a sign to start chewing, and the subjects were instructed to freely chew the gummy jelly for 20 seconds. At the same time as making a sign to complete chewing, recording was stopped. Under the following conditions, videography was conducted: resolution, 800*600 (ppi); frame rate, 200 (frame per second: fps); and shutter speed, 1/200 (s). The subjects were instructed to look at the camera during videography.

2.4.2 Analysis of motions

The video taken was analyzed using motion analysis software for Windows (Dipp-motion V2D, Ditect, Tokyo, Japan). On the software, motions at the measurement points marked on the face were traced (Figure 1: C).

A point between the eyebrows was established as the origin of measurement. Regarding the opening direction of mandibular movement, that is, downward direction, as the positive direction of the vertical component, the moving distance and velocity of the vertical component of the mentum were analyzed. The point at which the coordinate value of the mentum reached a maximum was regarded as the maximum opening point. The cycle from the maximum opening point to the point immediately before the next maximum opening point was regarded as a masticatory cycle. Of one masticatory cycle, the point with a mental velocity of $\geq$ -8 mm/s was regarded as the stop-starting point, starting from a mental velocity of < -8 mm/s. Subsequently, the point immediately before the mental velocity reached $\geq$ 8 mm/s was regarded as the stop-completing point. The period from the maximum opening point to the stop-starting point was defined as the closing phase (CP), and that from the stop-completing point to the point immediately before the next maximum opening point as the opening phase (OP). Furthermore, the period from the stop-completing point to the stop-starting point, that is, the period of transition from closing to opening, was defined as the transition phase (TP). When the mental velocity returned to a range of -8 to 8 mm/s within 0.075 seconds despite its deviation from this range during the TP, the deviation period was included in the TP (Figure 2).

In one cycle, 8 parameters of jaw movement were calculated: the distance of a transition route [Closing distance (CD), Opening distance (OD)], cycle time (CT), ratio of each phase to cycle time [Closing phase ratio (CR), Transition phase ratio (TR), Opening phase ratio (OR)], transition velocity [Closing velocity (CV), Opening velocity (OV)]. The absolute value of transition distance in each phase was used as the measured value. The OV was recorded as a positive value, and the CV as a negative value. The 10^{th} to 19^{th} cycles of mastication (total: 10 cycles) were analyzed using the mean values of respective parameters in the 10 cycles as variables.

2.5 Statistical analysis

The data were analyzed using software for statistical analysis, SPSS Statistics 22 (IBM, Chicago, IL, USA). A p-value of 0.05 was regarded as significant.

2.5.1 Correlation matrix table

The correlation coefficients of the AGE and 8 parameters of jaw movement were calculated. Using the Shapiro-Wilk test, normality was tested. As a result, a normal distribution was observed. To calculate correlation coefficients among variables: AGE, CD, OD, CR, TR, and OR, Pearson's correlation coefficient was used. To calculate correlation coefficients involving any of variables, such as CT, CV, and OV, which were not normally distributed, Spearman's correlation coefficient was used.

2.5.2 Comparison between the two groups (NG and LG)

The age, sex, body mass index (BMI), number of teeth, AGE, and 8 parameters of jaw movement were compared between the two groups, NG and LG. To examine the association between classification into the two groups and sex, the chi-square independence test was used. Next, the normality of each sample classified into the two groups was investigated using the Shapiro-Wilk test. As the number of teeth, CD, OD, CR, TR, and OR were normally distributed, the mean [standard deviation (SD)] was calculated, and the t-test or Welch's t-test was conducted to examine differences in the mean between the two groups. Concerning the age, BMI, AGE, CT, CV, and OV, both or either sample in the two groups was not normally distributed; therefore, the median (interquartile range) was calculated, and the Mann-Whitney U-test was conducted to examine differences in the center of distribution between the two groups.

2.5.3 Multiple logistic regression analysis

To investigate variables in which MP is involved in the normal masticatory group (NG) or low masticatory group (LG), multiple logistic analysis was performed using NG and LG as dependent variables. Considering multicollinearity based on the correlation matrix table, multiple logistic regression analysis with the backward selection method was conducted using the age, sex, OD, CT, TR, OR, and OV as independent variables.

3 RESULTS

3.1 Basic information and parameters of jaw movement

The basic information on each subject, as well as the mean±SD of the jaw movement parameters, are shown in Table 1. The mean BMI was 21.3 ± 2.7. The mean number of teeth was 27.5 ± 1.1. The mean AGE was 185.1 ± 42.9 mg/dL.

3.2 Correlation

We examined the association between MP and each parameter of jaw movement. MP was correlated with the CT ($r = -0.30$, $p < 0.05$), TR ($r = 0.42$, $P < 0.01$), OR ($r = -0.55$, $p < 0.05$), and OV ($r = 0.31$, $p < 0.05$) (Table 2).

3.3 Comparison between the two groups (NG and LG)

The data were compared between the two groups, NG and LG, using the t-test, Welch's t-test, or Mann-Whitney U-test (Table 3). The AGE in the LG was significantly lower than in the NG (199.9 (180.8-216.0) vs. 140.0 (124.8-141.8) mg/dL, respectively, $p = 0.000$). The TR in the LG was significantly lower than in the NG (36.6 ± 6.7 vs. 28.4 ± 8.5 %, respectively, $p = 0.005$). The OR in the LG was significantly higher than in the NG (28.0 ± 4.6 vs. 33.5 ± 5.0 %, respectively, $p = 0.001$). There were no significant differences in the age, sex, BMI, number of teeth, CD, OD, CT, CR, CV, or OV between the two groups.

3.4 Multiple logistic regression analysis

We analyzed which variable influences classification into the NG/LG using multiple logistic regression analysis. Using the backward selection method, as selected variables, the age (OR: 0.48, 95%CI: 0.25-0.94), TR (OR: 0.83, 95%CI: 0.73-0.95), and OV (OR: 0.90, 95%CI: 0.83-0.98) were extracted as significant independent variables. The chi-square test showed significant differences ($p < 0.01$), and the Hosmer-Lemeshow test did not show any significant differences ($p = 0.09$). We could not conclude that the results of analysis were not matching. The percentage of correct classifications was 88.0% (Table 4).

4 DISCUSSION

In this study, we analyzed the parameters of jaw movement motion capture analysis of jaw movement on chewing the gummy jelly at a point on the mandibular skin using a high-speed camera, and examined variables related to MP. We investigated the relationships parameters of jaw movement and AGE, which is reference value of MP. It was correlated with the CT, TR, OR, and OV. Furthermore, multiple logistic regression analysis was conducted using the MP level (normal or low) as a dependent variable. As a result, the age, TR, and OV were extracted as significant independent variables. This is the first study in which the influence of the time ratio to the masticatory cycle on MP was clarified by motion capture analysis of jaw movement on mastication.

The masticatory cycle is classified into 3 phases: closing, occlusal, and opening phases[17,18,22]. In this study, the masticatory cycle could also be classified into 3 phases by motion capture analysis at a point on the mandibular skin. Various studies reported the relationship between jaw movement and MP, but, in these studies, motions were recorded using a three-dimensional jaw movement-measuring system[15,17,18,22]. The use of this system is not simple from the viewpoint of instrument procurement or usage. If mandibular movement monitoring at only a single point on the skin with this system facilitates MP assessment, mealtime MP assessment may contribute to the determination of food form.

Based on the correlation matrix table, the OV and TR were significantly positive correlation with AGE (OV, $r = 0.31$, $p < 0.05$ and TR, $r = 0.42$, $p < 0.01$). The CT and OR were significantly negative correlation with AGE (CT, $r = -0.30$, $p < 0.05$ and OR, $r = -0.55$, $p < 0.01$).

The CT is a surrogate parameter of the frequency of mastication. Uesugi[22] and Yoshida[18] et al. also reported that there was a correlation between the CT and MP. In this study, the frequency of mastication per time may also have increased with a reduction in the CT, improving MP.

The TP is a period between closing and opening. This may correspond to the occlusal phase of the masticatory cycle. Uesugi[22], Komagamine[17], and Yoshida[18] et al. reported that there was no correlation between the occlusion time and MP. On the other hand, in this study, we investigated the relationship of MP with the ratio of the standardized time of each phase to the cycle time. The TR was high, suggesting a prolonged time for opposing teeth to occlude and crush foods. This may have led to the finding that there was a positive correlation between the ratio of TP and MP.

The OP may be a preparatory period for next mastication movement. There was a negative correlation between the AGE and OR. The TR can be increased by reducing the OR. Therefore, as described above, the masticatory efficiency may be improved by reducing the OR. Furthermore, the correlation between the ratio of CP+TP and MP is inversely related to that between the ratio of OP and MP; therefore, the plus/minus sign-reversed coefficient is used as the correlation coefficient. Briefly, MP may improve with a longer CP+TP period.

On the other hand, when focusing on the CP alone, there was no correlation between the MP and CR. Inoue[23] et al. reported that blockage of sensation of the periodontal membrane through amputation of the maxillary or inferior alveolar nerves, which control the periodontal membrane, reduced closing activities on mastication based on the results of an animal experiment. Furthermore, another study indicated that a forced added to the molar periodontal membrane during mastication-like movement on cerebral cortex stimulation in anesthetized animals increased jaw-closing musculature activities[24]. Such a series of reflex is termed “periodontal-masseteric reflex”[25], and jaw movement on closing may be caused by reflex. This study involved healthy adults without abnormalities in mastication, and the closing reflex may have uniformly and correctly occurred during jaw movement on closing, with no marked difference, thus contributing to the finding that there was no correlation. Although opening movement has an aspect of reflex on mastication, the opening reflex is strongly suppressed under non-noxious stimuli, such as routine mastication[26,27]. Opening movement may depend on the mode of each subject’s jaw movement, dentition, state of occlusion, and factors, such as habits.

In accordance with a report published by Shiga et al.[21], the subjects were divided into two groups: normal and low MP groups (NG and LG, respectively), establishing an AGE of 150 mg/dL as the cut-off value. In this study, there were significant differences in the TR (36.6 ± 6.7 vs. 28.4 ± 8.5%, respectively, $p = 0.005$) and OR (28.0 ± 4.6 vs. 33.5 ± 5.0%, respectively, $p = 0.001$), as parameters of jaw movement, between the NG and LG. This suggests that the TR and OR are significant parameters for evaluating whether MP is normal. On the other hand, there was no difference in the CR between the two groups; there may be no marked differences in the closing time among healthy adults, and this parameter may not closely be associated with MP.

We analyzed which variable influences classification into the NG/LG using multiple logistic regression analysis. As selected variables, the age (OR: 0.48, 95%CI: 0.25-0.94), TR (OR: 0.83, 98% CI: 0.73-0.95), and OV (OR: 0.90, 95%CI: 0.83-0.98) were extracted as significant independent variables. The TR was extracted as a significant variable even on multiple logistic regression analysis. The TR may be a period during which foods are actually crushed, and a high TR means that much time is spent chewing in a cycle of masticatory movement. This may have contributed to the extraction of the TR as a significant independent variable. Among the parameters of jaw movement, the OV was extracted as another significant independent variable. The OR may reduce with a high OV. However, based on the correlation matrix table, there was no correlation between the OR and OV. On the other hand, there was a correlation between the OV and OD. When the OV is high, the OD may increase. To improve MP, the OP time must be shortened. In other words, if the OD can be reduced and the OV can be accelerated, the OP time may be shortened, improving MP. Possibly due to such a factor, the OV was extracted as an independent variable. Among the parameters other than jaw movement, age was extracted as an independent variable. Miyaura[28] et al. reported that the occlusal force and occlusal contact area reached a peak at approximately 30 years of age. Several studies indicated that there was an association between the maximum occlusal force and MP[15,29], and that there was an association between the occlusal contact area and MP[15,30].

The subjects of this study had natural dentition, with a mean age of 25.4±2.7 years. The age was extracted as a significant independent variable possibly due to the presence of subjects aged approximately 30 years at which the occlusal force and occlusal contact area reach a peak. It is necessary to conduct a similar study involving late middle-aged and older adults subjects and examine the association between the results in wide range of age groups and MP.

In this study, we analyzed the vertical component of jaw movement from a measurement point attached to the mentum, and investigated its association with MP. Jaw movement functions vertically and horizontally on mastication. A study reported an association between horizontal movement and MP[31]. In the future, the association between horizontal movement and MP must also be investigated through motion capture. Furthermore, another study indicated the association between lip closure and MP[32]; therefore, we will analyze lip motions using the system adopted in this study to investigate their association with MP.

Previous studies investigated the association between the parameters of jaw movement obtained using a three-dimensional jaw-movement-measuring system and MP, and reported that there was an association between the mandibular transition distance and MP[15,18,22]. In this study, there was no relationship between the mandibular transition distance and MP. At the dermal measurement points used in this study, jaw movement was two-dimensionally analyzed, and this may have contributed to the finding that there was no correlation. On the other hand, the cycle of mastication from closing to opening could be evaluated using this system. This study showed that the CR, TR, and OR influenced MP. If MP can be evaluated based on rough motions, such as closing, stop, and opening, but not based on the detailed motions of jaw movement, a camera that facilitates high-speed videography, such as a high-speed camera, may not be necessary, and analysis of jaw movement during mastication with a smart phone camera may facilitate MP assessment. If the development of smart phone applications from a series of protocol makes it possible for anyone to evaluate MP simply, it may be helpful for the determination of a food form appropriate for nursing facility users' MP. In the future, it may be necessary to perform analysis using this system in older adults subjects or those with various diseases.

5 CONCLUSIONS

Jaw movement could be analyzed motion capture analysis of jaw movement at a point on the mandibular skin. There was a relationship between jaw movement and the MP value measured with a gummy jelly, suggesting that MP can be evaluated by analyzing the ratio of TP, in which opposing teeth may occlude each other, between closing and opening and the ratio of OP, which may be a preparatory period for next mastication movement.

Conflicts of Interest

We have nothing to declare for this study.

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Tables

TABLE 1 Basic information on the subjects and parameters of jaw movement

Variable	n=50
Age (y)	25.4 ± 2.7
Female (%)	52.0
BMI (kg/m^2)	21.3 ± 2.7
Number of teeth	27.5 ± 1.1
AGE (mg/dL)	185.1 ± 42.9
CD (mm)	6.1 ± 2.3
OD (mm)	5.7 ± 2.3
CT (ms)	597.6 ± 100.1
CR (%)	36.1 ± 6.8
TR (%)	34.6 ± 8.9
OR (%)	29.3 ± 5.3
CV (mm/s)	-27.1 ± 11.1
OV (mm/s)	37.1 ± 16.9

Note: Data are given as mean ± SD.
Abbreviations: BMI, body mass index; AGE, amount of glucose extracted; CD, closing distance; OD, opening distance; CT, cycle time; CR, closing phase ratio; TR, transition phase ratio; OR, opening phase ratio; CV, closing velocity; OV, opening velocity.

TABLE 2 Correlation matrix table between AGE and each parameter of jaw movement

n = 50	AGE	CD	OD	CT	CR	TR	OR	CV	OV
AGE†	1								
CD†	-0.01	1							
OD†	0	0.98**	1						
CT‡	-0.30*	-0.29*	-0.27	1					
CR†	-0.12	0.59**	0.59**	-0.25	1				
TR†	0.42**	-0.50**	-0.51**	0.11	-0.81**	1			
OR†	-0.55**	0.08	0.10	0.25	0.07	-0.65**	1		
CV‡	-0.23	-0.83**	-0.82**	0.56**	-0.21	0.18	0.07	1	
OV‡	0.31*	0.63**	0.62**	-0.53**	0.35*	-0.21	-0.17	-0.69**	1

Note: Concerning correlation coefficients, Pearson's correlation coefficient was used for variables that follow a normal distribution, and Spearman's correlation coefficient for items including variables that do not follow a normal distribution.
Abbreviations: AGE, amount of glucose extracted; CD, closing distance; OD, opening distance; CT, cycle time; CR, closing phase ratio; TR, transition phase ratio; OR, opening phase ratio; CV, closing velocity; OV, opening velocity.
† Variables that follow a normal distribution
‡ Variables that do not follow a normal distribution
*$p < 0.05$, **$p < 0.01$

TABLE 3 Comparison of AGE and each parameter of jaw movement between the two groups (NG, LG)

Variable	NG (n=38)	LG (n=12)	p-value
Age, years median (IQR)†	25.5 (24.0 - 27.0)	24.5 (23.0 - 25.0)	0.057
Female, n %‡	47.4	66.7	0.243
BMI, kg/m^2 median (IQR)†	20.9 (19.0 - 22.6)	21.4 (20.6 - 23.2)	0.388
Number of teeth, mean (SD)§	27.6 (1.0)	27.4 (1.2)	0.711
AGE, mg / dL median (IQR)†	199.0 (180.8 - 216.0)	140.0 (124.8 - 141.8)	0.000
CD, mm mean (SD)§	6.2 (2.4)	5.9 (1.6)	0.687
OD, mm mean (SD)§	5.8 (2.4)	5.6 (1.7)	0.775
CT, ms median (IQR)†	569.3 (533.6 - 629.8)	637.3 (565.8 - 695.1)	0.075
CR, % mean (SD)§	35.4 (6.7)	38.0 (6.6)	0.252
TR, % mean (SD)§	36.6 (8.0)	28.4 (8.5)	0.005
OR, % mean (SD)§	28.0 (4.6)	33.5 (5.0)	0.001
CV, mm / s median (IQR)†	-26.1 (-34.9 - (-21.9))	-22.1 (-24.1 - (-18.2))	0.093
OV, mm / s median (IQR)†	33.6 (27.5 - 52.3)	30.7 (22.9 - 34.4)	0.156

Abbreviations: AGE, amount of glucose extracted; NG, normal masticatory performance group; LG, low masticatory performance grope; BMI, body mass index; CD, closing distance; OD, opening distance; CT, cycle time; CR, closing phase ratio; TR, transition phase ratio; OR, opening phase ratio; CV, closing velocity; OV, opening velocity.

†Mann-Witney U test

‡Chi-square test

§t test

TABLE 4 Multiple logistic analysis regarding variables that influence classification into the NG and LG groups

Variable	β	se	Wald	OR	95％ CI	p-value
Age	-0.73	0.34	4.60	0.48	(0.25-0.94)	0.032
TR	-0.19	0.07	7.44	0.83	(0.73-0.95)	0.006
OV	-0.10	0.05	5.33	0.90	(0.83-0.98)	0.021
(Intercept)	26.56					0.011

Abbreviations: NG, normal masticatory performance group; LG, low masticatory performance group; TR, transition phase ratio; OV, opening velocity.

Chi-square test, $p < 0.01$

Hosumer Lemeshow test, p= 0.09

The percentage of correct classifications, 88.0%

Figure legends

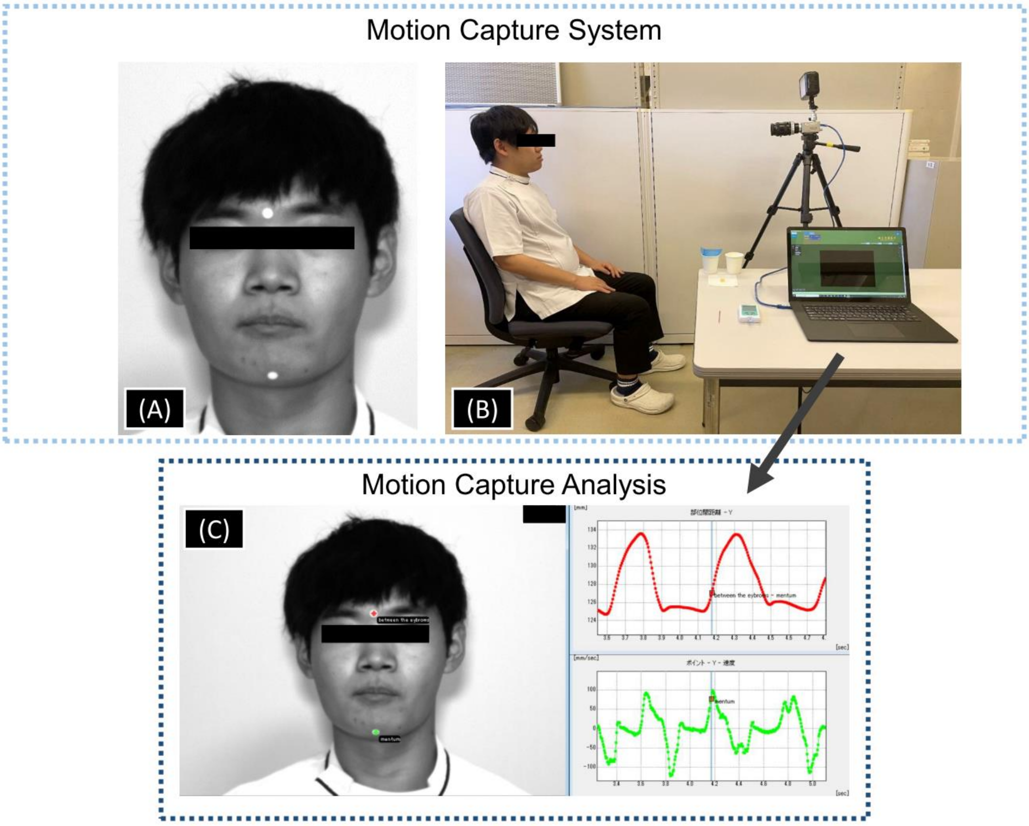

FIGURE 1 Motion capture system and motion capture analysis of jaw movement

(A), As measurement points of jaw movement, round white stickers were attached to the area between the eyebrows and mentum. (B), The state of chewing the gummy jelly was photographed using a high-speed camera. (C), Motions at a measurement point of the mentum were traced using a Dipp-motion V2D system, and vertical motions were analyzed.

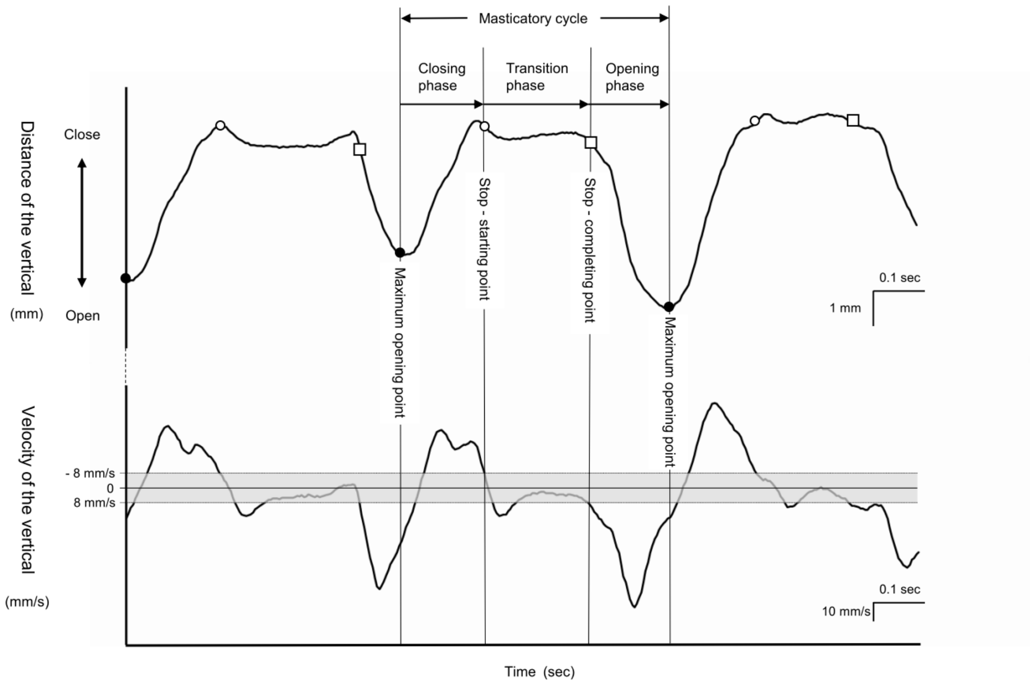

FIGURE 2 Analysis of jaw motions

The point at which the coordinate value of the mentum reached a maximum was regarded as the maximum opening point. The cycle from the maximum opening point to the point immediately before the next maximum opening point was regarded as a masticatory cycle. Of one masticatory cycle, the point with a mental velocity of ≥ -8 mm/s was regarded as the stop-starting point, starting from a mental velocity of < -8 mm/s. Subsequently, the point immediately before the mental velocity reached ≥ 8 mm/s was regarded as the stop-completing point. The period from the maximum opening point to the stop-starting point was classified as the closing phase (CP), that from the stop-starting point to the stop-completing point as the transition phase (TP), and that from the stop-completing point to the point immediately before the next maximum opening point as the opening phase (OP). When the mental velocity returned to a range of -8 to 8 mm/s within 0.075 seconds despite its deviation from this range during the TP, the deviation period was included in the TP.