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Original Article

Head movements in the occlusal phase of mastication

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It has been recognized that mandibular movements evoke head movements during jaw tapping. However there have been only a few studies that investigated the aspects of head movements during mastication. The objective of this study was to demonstrate the hypothesis that the head moves actively in mastication in order to achieve effective destruction of a food bolus. Head and mandibular movements during gum, gummi candies and kelp chewing among nine adult volunteers have been recorded as time series data with a three-dimensional motion capture system and the vertical components of the movements have been analyzed. To focus on occlusal phase of mastication, the following parameters have been examined: time lag of the head movements at the beginning of occlusal phase, perpendicular velocity of the head at the beginning of the phase of occlusion, and average velocity of the head during occlusal phase. The results showed that the head moved downward in mastication and the velocity of the head movements increased in the order of gum, gummi candies and kelp chewing. There is a possibility that the elasticity of a food bolus affects the activity of head movements, and the kinetic energy was increased to achieve effective destruction of a food bolus.

Key words: head movements, mastication, human.

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Introduction

Mastication is an indispensable activity for human beings to maintain their lives. To better understand the mechanism of mastication would be of great value for the clinical dentistry.

It has been suggested that mastication is a functional movement induced by the pattern generators in the brain stem[1,2]. It has been generally accepted that not only the mandible but also the head-neck region cooperatively moves in jaw open-close movement. There are some reports on factors that affect the activity of the head-neck musculature in mandibular movements[3-7]. What has been mainly examined in these reports is the head movements during jaw-tapping, however, the aspect of the head movements during mastication is scarcely known and there seems to be little agreement on how the head movements occurs.

The characteristics of head and mandibular movements during gum, gummi candies and kelp chewing have been recorded and analyzed using a three-dimensional motion capture system, which gives little restriction to head and mandibular movements. Our hypothesis is that the head moves actively in mastication to achieve effective destruction of a food bolus. What is concerned with crushing of a bolus is occlusal phase of mastication, from the intervention of a food

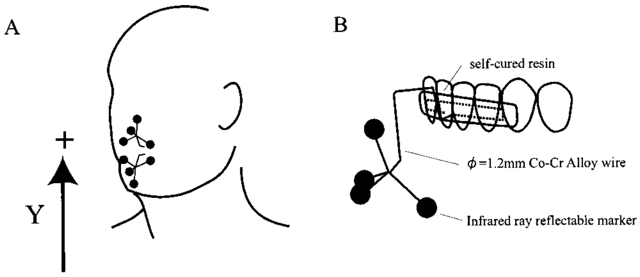


Figure 1. Schematic drawing of measurement system
A: Positions of markers
The measurement space was decided to be about 0.3 m × 0.3 m × 0.3 m and the sampling frequency was 50 Hz. Perpendicular direction was set as Y-axis and the positive direction was set as upper relative to subjects.

B: Schematic drawing of attachment
These attachments consisted of 1.2 mm Co-Cr alloy wire and self-cured resin. Markers were bonded to the labial surfaces of upper and lower incisors through a self-made attachment. The attachments were adjusted so as not to interfere with lip motion, intercuspal position, mastication and deglutition.

bolus between the upper and lower teeth to the disocclusion of the upper and lower dentition. It is short but meaningful period during mastication because it is the only phase to transmit occlusal forces to a bolus and teeth in the whole masticatory movement. Therefore, the analysis was focused on the occlusal phase of mastication in this study.

The purpose of this study was to test our hypothesis by analyzing the dynamic aspects of head movements at the occlusal phase of mastication.

Materials and Methods

Subjects

Nine adults (5 men and 4 women; average age of 27.8±1.5 years) with individual normal occlusion and without abnormality in the stomatognathic system volunteered for this study. This study was approved by the declaration of Helsinki and informed consent has been obtained from all the subjects prior to the experiment.

Device

Eight reflective markers were installed on each subject through attachments: 4 on the upper and 4 on the lower incisors (Fig. 1). These were set as indices of head and mandibular movements, respectively.

Simultaneous measurements of head and mandibular movements were recorded as time series

Table 1. Texture profile of test foods. The viscoelasticity was measured by means of a testing machine for food materials (**Tensipresser® My Boy**, TAKETOMO, JAPAN). Physical properties of food were tested by texture profile analysis 23) (**TPA**).

	Hardness [Pa]		Stickiness [10^4Pa]		Cohesiveness		Adhesiveness [uJ/m^2]	
	Mean	S.E.	Mean	S.E.	Mean	S.E.	Mean	S.E.
Kelp	5.632	(0.404)	0.360	(0.049)	0.740	(0.026)	0.000	(0.000)
Gummy	3.540	(0.044)	20.606	(5.243)	0.642	(0.013)	5.614	(3.387)
Gum	4.292	(0.041)	70.440	(22.096)	0.312	(0.007)	3.546	(0.856)

(n=5)

data by Elite Plus® (BTS Co. Milan, Italy), a motion capture system constituted of 2 CCD cameras with an infrared ray flash and a processor unit[8,9]. The setting of the coordinate axis was made to be the right-hand coordinate system. Coordinate values of the markers were shown as three-dimensional coordinates.

Task

Subjects were asked to sit in a chair with a backrest but without a headrest, located 1.5 m in front of the cameras, in a relaxed posture. The head of the subject was in a natural head position without restriction. All trials started from the intercuspal position and then recording of movements was carried out.

The measurements were carried out under the following conditions:

(1) chewing of gum, gummi candies and kelp, (2) two kinds of jaw open-close movements, indicated by operator (Hereinafter, abbreviated to *indicated*) and directed by means of metronome, of which tapping frequency was 1.2 Hz (abbreviated to *tapping*), a value near the average gum mastication rate among nine subjects in the pilot study. *Indicated* open-close was done in the same frequency as *tapping* with no advanced information to the subjects. Five mm cubes of test food were placed on the surface of tongue (Table 1).

Conversion of Coordinate Values

Upper and lower incisal points were determined as index points of head and mandibular movements respectively, which were calculated with reference to the relations between study models and markers. The values of mandibular markers were transferred relative to the head coordinates. In this experiment, only upward and downward movements of the head (set as Y coordinate value) were examined in the same way as Eriksson[4].

Analysis

The coordinate of the mandible was shown by the value of the head, and the value of the head by the value of the floor. In time series data of perpendicular movements of head and mandible, In this study, occlusal phase was defined when Y coordinate values of the mandibular movements were convergent to zero, and the boundary points of the occlusal phase were determined as the beginning of occlusal phase (BO) and the end of occlusal phase (EO) in every stroke. In addition, the inflection points of the head movements (IPH) were defined for head movements. The time at BO, EO and IPH were set as tbo, teo and tIPH ms, respectively and the Y coordinates of the head at BO, EO and IPH were set as YHbo, YHeo and YIPH mm, respectively. In this study, occlusal phase was defined as the period between BO and EO (Fig. 2). To assure steady jaw movements, the initial 5 strokes of jaw movements were excluded and the following 10 strokes were used for analysis.

Following parameters of movements were calculated so as to analyze the activity of head movements in mastication:

(1) time lag of the head movements at the beginning of occlusal phase (Tlbo ms), (2) velocity of the head movements at IPH (VIPH mm/s), and (3) average velocity of the head movements during occlusal phase (Vop mm/s).

Among all parameters, analysis of variance was used to test statistically significant differences among tasks, and when appropriate the nonparametric Friedman two-way ANOVA. Wilcoxon's matched-pairs signed-rank test patched up by Bonferroni's inequality was used for post hoc test.

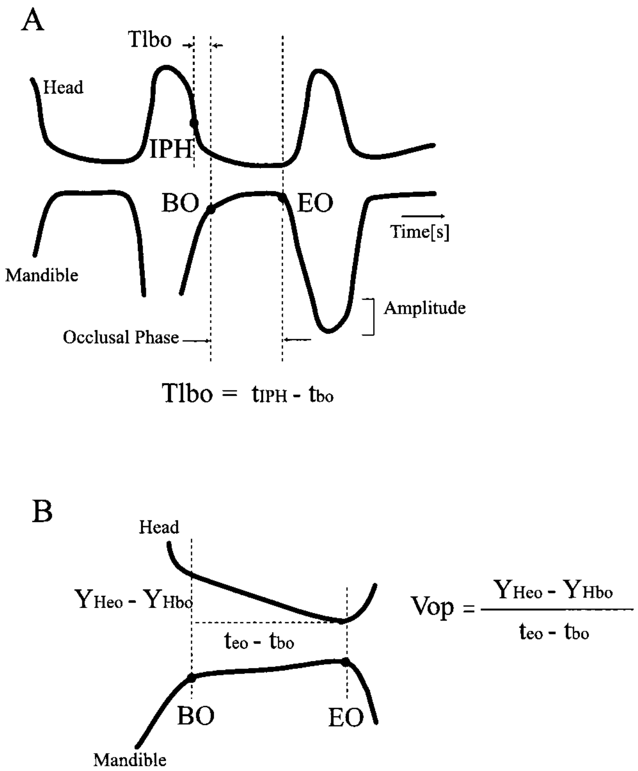


Figure 2. A: Schematic drawing of Y coordinates of movement-time series
(upper line): head movement in relation to the floor.
(lower line): mandibular movement in relation to the head.
BO: the beginning of occlusal phase, EO: the end of occlusal phase, IPH: the inflection point of head movement on Y-time curve of head movements. Tlbo ms was determined according to the above.

B: The average perpendicular velocity of the head movements in occlusal phase (Vop)
The perpendicular velocity of the head movements in occlusal phase was defined as follows.
(1) determination of the boundary points of occlusal phase; BO and EO, (2) Y-coordinate values of the head movements at BO and EO were selected and they were set as YHbo and YHeo, respectively, (3) the average velocity of the head movements in occlusal phase (Vop) was calculated according to the above.

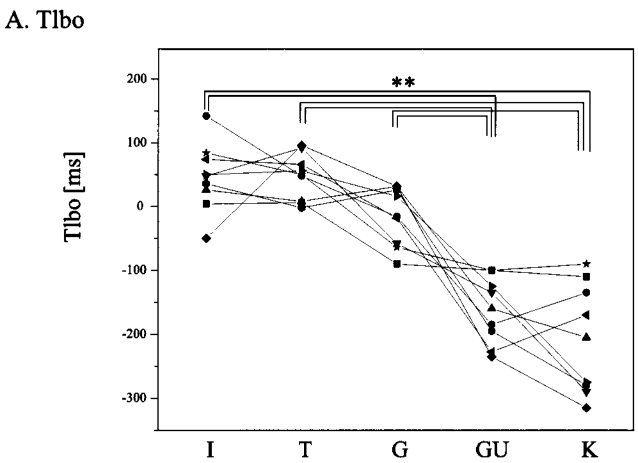
Results

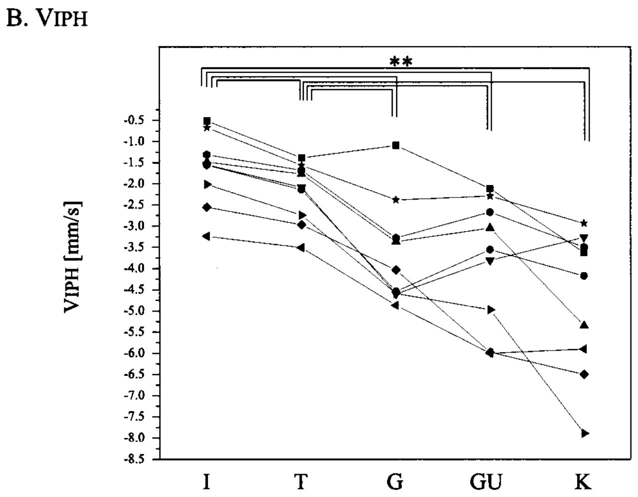
Time lag of the head movements at the beginning of occlusal phase

All data were expressed as mean ± standard errors (S.E.) in Table 2. Tlbo were compared among tasks. As a result, large values of Tlbo were obtained in chewing movements of kelp and gummi candies. On the other hand, Tlbo during *indicated* and *tapping* showed relatively small values. Wilcoxon's signed-rank test shows significance between kelp and *indicated*, kelp and *tapping*, kelp and gum, gummi candies and *indicated*, gummi candies and *tapping*, and gummi candies and gum. There was no significance between gum and *indicated*, gum and *tapping* (Fig. 3A).

Velocity of the head movements at IPH

To examine the aspect of head movements in mastication, the perpendicular velocity of head at IPH were measured (Table 2). As a result shown in Fig 3B, all VIPH's showed negative values and faster downward movements were observed during kelp, gummi candies, gum, *tapping* and *indicated* in order. VIPH were significantly higher during chewing than jaw-tapping.





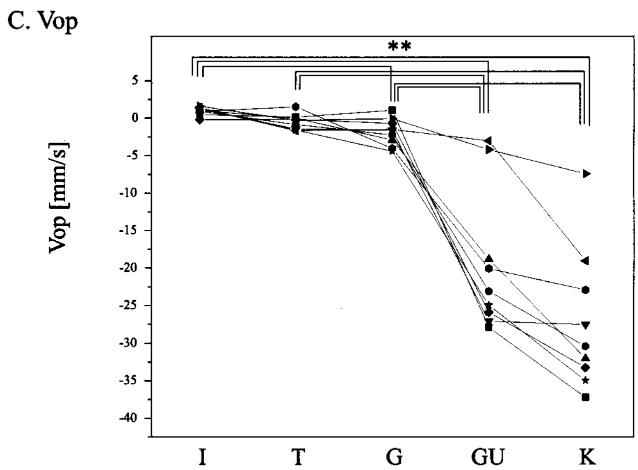


Figure 3: A Tlbo: Time lag of the head movements at BO, **B** VIPH: perpendicular velocity of the head at IPH, and **C** Vop: average velocity of the head during occlusal phase. I: jaw open-close movements indicated by the operator, T: jaw tapping movements directed by metronomes (1.2 Hz), G: gum chewing. GU: chewing of gummi candies, K: kelp chewing. Solid points represented the mean values of the subject. All the lines connecting tasks represented statistical differences (**: p<0.01).

Average velocity of the head movements during occlusal phase

Data of mean $\pm$ S.E. of average velocity of the head in occlusal phase of mastication were shown in Table 2. Our results demonstrated that the absolute values of Vop increased in the order of kelp, gummi candies, gum among eight subjects, though the values of Vop showed individual differences. In statistical test, significant difference in Vop was found in all comparisons except between kelp and gummi candies, gum and *tapping*, and *tapping* and *indicated* (Fig. 3C). These results suggest that during occlusal phase of mastication, the head moved downward as well as mandible closed upward to maxilla until upper and lower teeth were occluded.

Table 2. Data of mean±S.E. for A.Tlbo, B.VIPH, C.VOP

A (ms)

	MEAN	S.E..
I	45.60	17.60
T	48.90	12.00
G	−15.60	15.40
GU	−165.60	17.50
K	−210.00	28.70

B (mm/s)

	MEAN	S.E.
I	−1.65	0.29
T	−2.21	0.24
G	−3.64	0.42
GU	−3.82	0.50
K	−4.79	0.57

C (mm/s)

	MEAN	S.E.
I	0.95	0.18
T	−0.49	0.34
G	−1.83	0.60
GU	−19.40	3.16
K	−27.22	3.13

Discussion

Zafar[7] described that on 2 self-paced jaw tappings, the head starts to move simultaneously with, or before the mandible at the start of jaw-opening at a fast speed. At a slow speed this movement does not always occur and head always completes its movement after the mandible at the close end of occlusal phase.

The result in our experiment is not completely in agreement with Zafar's report on jaw-tapping movements. It seems quite probable that the differences come from experimental conditions. In our experiment, repeated jaw tapping movements were performed, with the use of metronomes, for both open and close movements. As a result, head movements were fully controlled and observed almost simultaneously with mandibular movements.

Contrary to the jaw open-close, IPH in kelp and gummi candies chewing was observed before the beginning of occlusal phase. In respect of gum chewing it didn't show a comparatively significant small Tlbo the same as the Eriksson's study of gum chewing[5].

It can be considered that the activities of movements were changed while food bolus was sandwiched by upper and lower teeth.

In order to efficiently achieve a repeated movement, there are some reports on stance regulation with its preparatory action of feed forward control[10]. According to some reports relevant to the activity of head-neck musculature, the activity of sternocleidomastoid muscle[11-12] with respect to functional movement of the mandible as both inhibitory and excitatory is recognized: inhibitory action to prepare for contact with a food bolus and to cushion the impact on head in mastication, yet excitatory action to reinforce mastication[3]. The reason for the appearances of IPH in mastication can be explained as follows: (1) the mechanoreceptors were stimulated by the intervention of a bolus, (2) inhibition of cervical flexor musculature such as the sternocleidomastoid muscle and activation of cervical extensor muscles such as the splenius were associated with the decreased speed of head movements and, (3) it was observed as IPH.

There are a lot of reports describing the effects of head position on the mandibular positions and movements[13-15], but there are only a few studies dealing with the pathway from trigeminal mechanoreceptors to cervical motoneurons[16,17]. There also exists some published works on the relationship between masseter activity and mechanoreceptors in occlusal phase[18-20].

We consider that the stimulation to the periodontal mechanoreceptors has been altered by some foods varying in elasticity (Table 1). In our experiment, the downward movements of head were observed especially in chewing kelp and high elastic gummi candies during the occlusal phase of mastication shown in Fig. 3B & C. These results indicate that there is a possibility that the elasticity of a food bolus affects the activities of head-neck muscle. We suggest that a food bolus, with higher elasticity and resistance, stimulates the periodontal mechanoreceptors more until the activity of musculature takes control at the end of occlusal phase. It induces a large activity of head-neck musculature and faster downward movement of the head in the occlusal phase of mastication. These are, the same as the regulatory mechanism of masticatory activity, to control head-neck musculature through the modification of trigeminal mechanoreceptors.

There seems to be two control patterns of head movements, feed back and feed forward[5,7]. Neither of them is, however, sufficient to provide an explanation of the results independently and thus it seems considerable that both feed forward and feedback controls participate in the head movements in the occlusal phase of mastication.

The mechanism of the head-mandible interrelationship needs to be further demonstrated by neurophysiological and anatomical studies.

From the viewpoint of energy level, there is certain relationship between occlusion and mandibular movement[21], and a reflex control is detected to improve the efficiency of mastication by adapting the patterns of mastication to one's own occlusion[22]. The movements of heavier head are greatly advantageous to achieve destruction of foods. In a word, the downward head movements in masticatory occlusal phase could be considered as a normal activity contributing to the destruction of a food bolus.

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