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Comparison of Temporomandibular-joint Loadings and Masticatory Muscles Activity During Mastication of Hard and Soft Foods in a Monkey

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The effects of the properties of food on the mandibular movement,electromyographic (EMG) activity, and movement of the condylar head have been separately studied. However, there have been no studies on the relationship between the load on the temporomandibular-joint (TMJ) and EMG activity in each mastication cycle. The purpose of this study was to clarify the relationship by simultaneously measuring the load on the TMJ and EMG activity in a monkey during mastication of food with different properties (hard food : sweet potato, soft food : banana). The maximum load on the TMJ of the monkey was lower during mastication of soft food than during mastication of hard food, suggesting that changes in the functional jaw movement in the mastication system caused by different properties of food affected the load on the TMJ. The maximum loading on the TMJ of the monkey in each masticatory cycle occurred in a pause of the EMG activity during mastication of the soft food as well as during mastication of the hard food. Analysis of the mastication rhythm suggested that the maximum pressure occurred at the end of occlusal phase in each mastication cycle.

Key words : TMJ-loading, EMG activity, Masticatory movement, Monkey, Properties of food

INTRODUCTION

Load on the TMJ during jaw movement has been studied by various methods[1~10]. However, since indirect methods were used in many studies, the amount of load on the TMJ during jaw movement has not been clarified. Recently, Boyd et al.[11,12] directly measured the load on the TMJ during jaw movement in monkeys for the first time using piezoelectric film. However, the load value obtained was physically unclear, because it was the load on the entire surface of the condylar head, which showed the total load determined without taking the direction of the load into consideration.

Inuzuka et al.[13,14] developed a micropressure sensor by layering a lead zirconate titanate (PZT) sintered disk as the piezoelectric material and hydroxyapatite (HAP) sintered disks with good biocompatibility, and directly measured the load on small regions (diameter, 3 mm) of the surface of the condylar head during mastication after implantation of the pressure sensor in the antero-superior surface of the condylar head of monkeys. The maximum pressure on the antero-superior surface of the condylar head of monkeys was 0.29 MPa at the maximum opening of the mouth, 0.06 MPa during chewing, and 0.05 MPa during grinding. Although these studies were performed using Japanese monkeys, measurement of changes in the load on the TMJ with mandibular movement during mastication was possible. The masticatory movement representing the functional jaw movement in the mastication system is an inte-

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grated system involving various components, such as the peripheral effector system, its possible sensory input system, central input system, and movement input system. In this mastication system, the movement mechanism may be controlled by changing the mastication rhythm and masticatory muscle activity based on sensory input in the periphery corresponding to the properties and sizes of food taken in the oral cavity[15]. The effects of the properties of foods on the mandibular movement, EMG activity, and movement of the condylar head have been separately studied. However, there have been no studies on the relationship between the load on the TMJ and the EMG activity in each mastication cycle.

The purpose of this study was to clarify the relationship by simultaneously measuring the load on the TMJ and the EMG activity in a monkey during mastication of food with different properties (hard food: sweet potato, soft food : banana).

MATERIALS AND METHODS

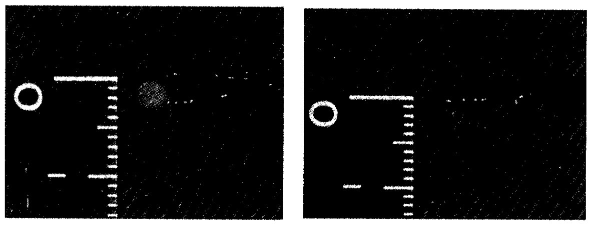
1. Experimental animal

The experimental animal was a male Japanese monkey at the estimated age of 8 years, weighing 12 kg, in which neither tooth deficiency nor systemic abnormalities were detected. Hard food (sweet potato), soft food (banana), and water in bottles were given to the monkey during the period of experiments. No significant changes in the weight were observed during the period.

2. Experimental methods

1) Structure of the micropressure sensor

The micropressure sensor used in this study was the same type as that developed by Inuzuka et al.[13] using a PZT sintered piezoelectric disk, and its preparation and calibration were performed according to their method. The micropressure sensor was prepared by placing a PZT sintered piezoelectric disk with a diameter of 3 mm and a thickness of 0.15 mm (PCM-88, Matsushita Electrical Appliance Industry Inc.) between phosphor bronze electrodes with a thickness of 0.3 mm, and covering it with HAP sintered disks with a diameter of 3 mm and a thickness of 0.5 mm. Since the PZT disk used was polarized in the direction of the thickness, the sensor responded only to the perpendicular component of the load on



A B

Fig. 1 A front view (A) and a side view (B) of the micropressure sensor used. The sensor consisted of a PZT (lead zirconate titanate) disk 3mm in diameter and 0.15mm in thickness with electrodes (phosphor bronze) cemented on its both sides, and hydroxyapatite disks covering the entire sensor. To waterproof the sensor from tissue fluid and blood, the PZT disk and output terminals of the electrodes were sealed with epoxy resin.

the HAP cover (the direction of the thickness of the sensor)[16,17]. The load value obtained by the sensor output is the total load on the HAP cover with a diameter of 3 mm (area, 7.07×10^{-6} m^2), and can be converted into pressure, assuming that the load was uniformly distributed on the sensor. To prevent the pressure sensor from getting wet with tissue fluid and blood, the PZT disk and output terminals of the electrodes were covered with epoxy resin (Barrier D, NMB, USA) (Fig. 1).

2) Implantation of the maicropressure sensor

The implantation site of the maicropressure sensor on the surface of the condylar head was determined by stress analysis of the TMJ using the finite element method[18,19]. It has been reported that the buffer region of the TMJ during strong clenching is the thick area at the back of the articular disc between the posterior slope of the articular eminence and the anterior slope of the mandibular condylar head. Therefore, in this study, the pressure sensor was implanted in the antero-superior surface of condylar head, on which the highest load was expected to be placed during mastication. Since the dominant mastication in the monkey used in this study was on the right side, the sensor was implanted in the left condylar head, in which a larger quantity of movement was speculated.

To implant the pressure sensor, preoperative shaving was performed around the left TMJ, anesthesia was induced by intramuscular injection of 10-20mg/kg ketamine chloride (Ketalar50®, Sankyo Co

Inc.), and general anesthesia was performed by intravenous injection of 25mg sodium pentobarbital (Nembutal®, Abbot Inc.). Subsequently, the surgical field was sterilized with 25% isodine, and prootic incision in the anterior tragal area without causing damage to soft tissues was performed under local anesthesia of the left TMJ with lidocaine chloride (2% Xylocaine® for dental treatment, Fujisawa Pharmaceuticals Inc.). After confirmation of the condylar head in the surgical field, the antero-superior surface of the condylar head was exposed while protecting the articular disc sufficiently, and a cavity with a diameter of 3-4 mm and a depth of 1.2-1.5 mm was made. The cavity was filled with bone cement (Surgical Simplex®, Pfizer Pharmaceutical Inc.), and the pressure sensor was applied with a cyanoacrylate adhesive (Aron Alpha A® for biological use, Sankyo Inc.)[13] (Fig. 2). To prevent infection, intramuscular injection of 150mg/day of a synthesized penicillin (Pentcillin® for intramuscular injection, Toyama Kagaku Inc. · Sankyo Inc.) was performed for over 1 week after surgery. On the next day after surgery, implantation of the pressure sensor in the antero-superior surface of the condylar head was confirmed by standardized cephalograms and three-dimensional computed tomographical images of the head of the monkey (Fig. 3).

3) Simultaneous measurement of the EMG activity and load on the TMJ in the monkey during mastication

Paired fine wires electrodes (linear Teflon-coated stainless steel, 0.42ϕ, Unique Medical Inc.) prepared using the tip of the hypodermic needles (20 gauge, 0.90×38mm, Terumo Inc.) were used for the measurement of the EMG activity[20,21]. To perform measurement of the EMG activity repeatedly in the same site under the same conditions over a long period in this study, the condition of the measurement was standardized. As shown in Fig. 4, the distance between the electrodes in the insertion sites was fixed to 10mm using chemically activated resin (Ostron II®, GC Dental Products Inc.), and the point from the tip of the hypodermic needles was marked to obtain an insertion depth of 10 mm. After confirmation of the alignment of the masseter and temporal muscles by palpation, the center of the superficial part of the masseter muscles (about 5cm above the inferior mar-

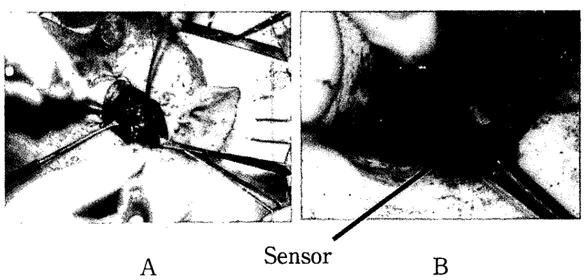


Fig. 2 Implantation of the micropressure sensor into the left temporomandibular joint of a monkey. A preauricular incision was made in the anterior area of the tragus, and dissection was performed to the condylar head with caution not to injure soft tissue. In operative field (A), the condylar head was exposed, and a minimum cavity that allow the pressure sensor implantation (3~4mm in diameter, 1.2~1.5mm in depth) was made. The cavity was filled with bone cement, and the pressure sensor was cemented using cyanoacrylate adhesive (B).

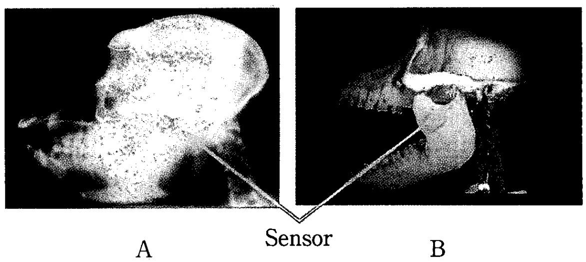


Fig. 3 A lateral cephalogram (A) and a three-dimensional computed tomographical image (B) of the head of the Japanese monkey implanted the micropressure sensor.

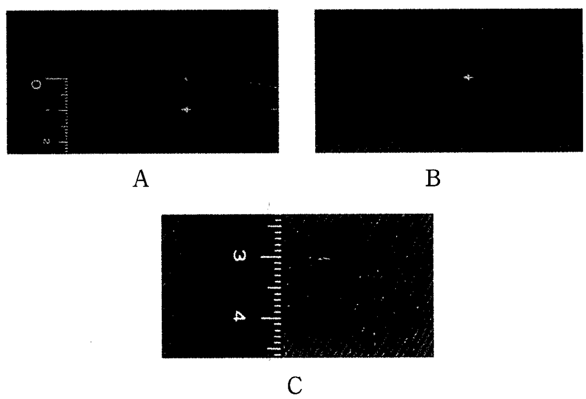


Fig. 4 A flont view (A), a side view (B), and the tip (C) of a paired Teflon-insulated fine wire electrodes used for electromyography. The inter electrode distance of 10mm was fixed with chemicaly activated resin.

A B

Fig. 5 Insertion of the wire electrodes with the aid of 20-gauge hypodermic needles into the center of superficial part of the masseter muscle (about 5cm above the inferior margin of the mandible)(A), and the anterior portion of the superficial part of the temporal muscle (about 5cm above the zygomatic arch)(B). The insertion depth of 10mm was fixed with the marks in the tip of the hypodermic needles.

gin of the mandible) and the anterior portion of the superficial part of the temporal muscles (about 5cm upward from the zygomatic arch) were marked as the insertion sites of the electrodes, and the needle electrodes were inserted (Fig. 5). The reference electrode was placed in the left femoral muscles. Simultaneous measurement of the EMG activity and load on the TMJ during mastication was started 1 week after surgery by giving hard food (sweet potato) and soft food (banana) divided into eighths (8-10g) to the monkey immobilized on a monkey chair. The food was given after the monkey was confirmed to have no food in the cheek pouch and to be relaxed by macroscopic and EMG activity observation. The measurement was repeated about once per 1 hour by changing the foods.

A general-purpose biological information program (BIMUTAS-II, Kissei Comtech Inc.) was used for the import and analysis of data. Output from the pressure sensor was transmitted by FM waves from a transmitter (ZB-581G, Nihon Koden Inc.) to a receiving apparatus via a charge amplifier (CAM-001, TSK Inc.), and imported into a computer via an A-D converter (ADJ-98, Canopus Denshi Inc.). The electric potential caused by muscular activity was recorded from the transmitter by the receiving apparatus without passing through the charge amplifier. A sampling frequency of 2kHz was used for the importation of data. The imported data of the electric potential caused by muscular activity were passed through a band-pass filter of 50～1000Hz, rectified, and analyzed. The output potential from the pressure sensor was integrated, and converted into the load using the correction curve determined by calibration. The five masticatory sequences were recorded for the mastication of hard and soft foods, respectively.

RESULTS

1. EMG activity of the masseter muscles on the working side (right) during mastication of hard or soft food

Mastication consists of chewing food, grinding, and swallowing, and during mastication, masticatory muscles show rhythmical EMG activity with pauses. This mastication rhythm was analyzed using the EMG activity measured during mastication of hard or soft food. In this study, the EMG activities of the bilateral masseter and temporal muscles were measured, and analysis was performed by focusing on the relationship between the activity of the masseter muscles and load on the TMJ on the working side (right).

1) Mastication period

In this study, the period between the start points of the EMG activity of the masseter muscle on the working side was considered a mastication cycle, and regarded as the mastication period. The mean mastication period of the masseter muscle on the working side was 348.9 msec (SD=76.5) during mastication of the hard food, while during mastication of the soft food, it was 433.2 msec (SD=97.7). The mean mastication period was significantly longer during mastication of the soft food than during mastication of the hard food ($P<0.0001$) (Table 1, Fig. 6).

2) Duration of EMG activity

The mean duration of the EMG acticity of the masseter muscle on the working side was 163.6 msec (SD=24.8) during mastication of the hard food, while during mastication of the soft food, it was 170.0 msec (SD=25.1), with the difference being not significant (Table 2, Fig. 7).

3) Peak amplitude of EMG activity in each cycle

The mean value of the peak amplitude of the masseteric EMG activity was 305.0 μV (SD=86.7) during mastication of the hard food, while during mastication of the soft food, it was 172.3 μV (SD=57.1). The mean peak amplitude was significantly lower during

Table 1 Mean values of the period in each mastication sequence. The periods were caluculated from the EMG activity of the working side masseter muscle during mastication.

Sequence No	Period (msec)	
	Hard food	Soft food
1	362.6(64.4)	433.0(86.6)
2	378.0(104.8)	458.2(99.3)
3	350.0(92.8)	438.9(111.0)
4	332.0(51.1)	406.2(114.0)
5	322.1(69.5)	429.9(77.6)
Mean	348.9(76.5)	433.2(97.7)

( ): S.D

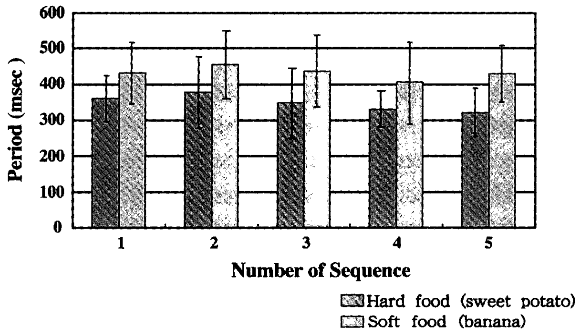


Fig. 6 Mean values of the period in each mastication sequence. The periods were caluculated from the EMG of the working side masseter muscle during mastication. The test foods were raw sweet potato with peel, represented hard food, and banana, soft food (about 8~10g each).

Table 2 Values averaged of duration of EMG activity in each mastication sequence. The duration was estimated from the EMG of the working side masseter masucle during mastication of hard and soft foods.

Sequence No	Duration of EMG activity (msec)	
	Hard food	Soft food
1	156.9(24.0)	192.9(33.9)
2	178.7(23.0)	161.9(27.1)
3	172.9(25.9)	163.9(28.8)
4	158.3(22.4)	164.4(19.3)
5	151.2(28.5)	166.7(16.2)
Mean	163.6(24.8)	170.0(25.1)

( ): S.D

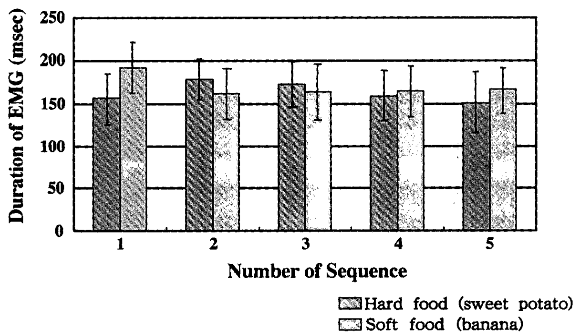


Fig. 7 Values averaged of duration of EMG activity in each mastication sequence. The duration was estimated from the EMG of the working side masseter masucle during mastication of hard and soft foods.

Table 3 The mean peak amplitude of EMG activity of the working side masseter masuce during mastication of hard and soft foods.

Sequence No	Peak amplitude of EMG activity (μV)	
	Hard food	Soft food
1	346.7(107.3)	164.8(48.3)
2	327.7(84.0)	156.6(59.2)
3	301.1(104.6)	156.6(56.2)
4	274.4(65.6)	175.2(65.2)
5	275.3(72.0)	208.1(56.4)
Mean	305.0(86.7)	172.3(57.1)

( ): S.D

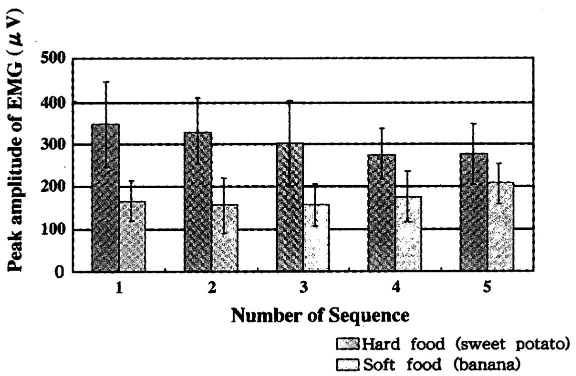


Fig. 8 The mean peak amplitude of EMG activity of the working side masseter masuce during mastication of hard and soft foods.

mastication of the soft food than during mastication of the hard food ($P<0.0001$) (Table 3, Fig. 8).

2. Maximum pressure on the TMJ in each mastication cycle during mastication of hard or soft food

The mean value of the maximum pressure on the balancing side TMJ was 0.86 MPa (SD=0.31) during mastication of the hard food (sweet potato), while

Table 4 Mean value of the maximum pressure on the antero-superior surface of the balancing side condylar head in each masticatory cycle during mastication of hard and soft foods.

Sequence No	Maximum pressure in each cycle (MPa)	
	Hard food	Soft food
1	0.81(0.43)	0.32(0.18)
2	0.85(0.22)	0.34(0.18)
3	1.01(0.38)	0.30(0.17)
4	0.87(0.32)	0.28(0.16)
5	0.77(0.22)	0.34(0.22)
Mean	0.86(0.31)	0.32(0.18)

( ): S.D

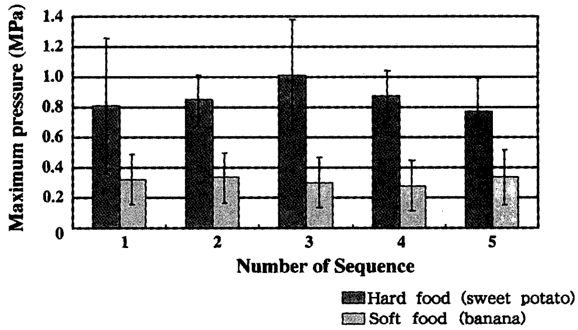
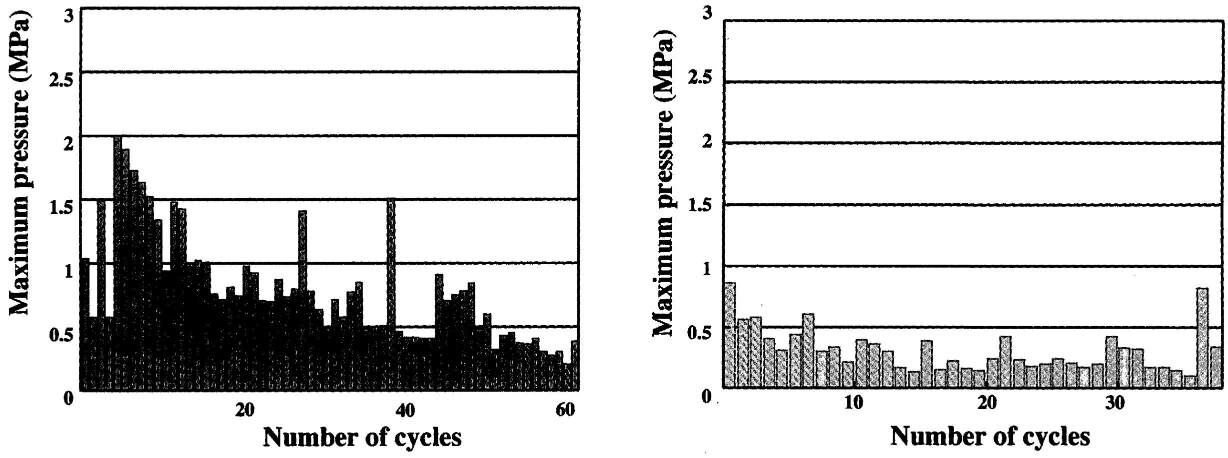


Fig. 9 Mean value of the maximum pressure on the antero-superior surface of the balancing side condylar head in each masticatory cycle during mastication of hard and soft foods..



A B

Fig. 10 Variation of the maximum pressure in each cycle during a masticatory sequence.
A : mastication of hard food, B : mastication of soft food

during mastication of the soft food (banana), it was 0.32 MPa (SD=0.18). The mean maximum pressure was significantly lower during mastication of the soft food than during mastication of the hard food ($P < 0.0001$) (Table 4, Fig. 9). In all masticatory sequences, the maximum pressure on the TMJ of the monkey gradually decreased by 2.0-0.4 MPa during mastication of the hard food and by 0.8-0.1 MPa during mastication of the soft food (Fig. 10).

3. Determination of the side of mastication in the monkey

In this study, the side of mastication in the monkey was determined by macroscopic observation, observation on video, and the EMG activity of the masseter muscles. In mastication of monkeys, it has been indicated that EMG activity of the masseter muscle on the balancing side always precedes that on the working side[22]. The start of EMG activity of the right masseter muscle was regarded as the standard, and the timelag between the starts of EMG activity of the bilateral masseter muscles was measured, and expressed with minus when EMG activity of the left masseter muscle preceded and with plus when EMG activity of the left masseter muscle delayed. The mean timelag of mastication,was -11.2 msec (SD=9.3) during mastication of the hard food and -8.5 msec (SD=10.8) during mastication of the soft food (Table 5, Fig. 11).

It was found that the EMG activity of the masster muscle precedes on the balancing side with mastication of hard or soft food, irrespective of the properties of the food. From these results, the side of mastication in the monkey was clearly determined as right.

Table 5 Mean values of the timelag between the starts of EMG activity of the bilateral masseter muscles in a masticatory sequence. The timelag was expressed with minus when EMG activity of the left masseter muscle preceded and with plus when EMG activity of the left masseter muscle delayed.

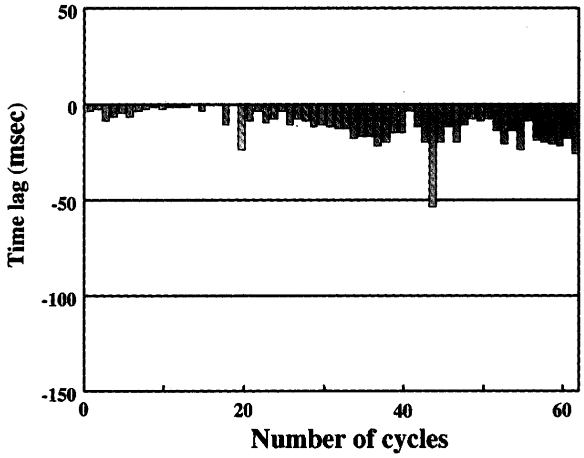
Sequence No	Timelag (msec)	
	Hard food	Soft food
1	-10.8(8.9)	-13.1(11.5)
2	-17.3(10.5)	-8.8(7.7)
3	-6.4(9.1)	-7.4(12.2)
4	-9.9(8.8)	-3.0(11.5)
5	-11.8(9.1)	-10.2(10.9)
Mean	-11.2(9.3)	-8.5(10.8)

( ) : S.D

4. Timing of the maximum pressure in each masticatory cycle

Fig. 12 shows the wave patterns of output potential from the micropressure sensor during a single masticatory sequence and wave patterns of EMG activity of the masseter and temporal muscles. Fig. 13 shows the enlarged schematic of a typical wave pattern obtained from the pressure sensor and a wave pattern of the EMG activitys of the masseter muscles on the working side during mastication of the hard (A) and soft foods (B). Based on the relationship between the load on the TMJ and EMG activity of the masseter muscle on the working side (right), the maximum load was found to occur in pauses of the EMG activity of the masseter muscles. The normal mastication pattern was characterized by the pauses of the EMG activity of the masseter muscles during the occlusal contact of teeth and the EMG activity in the central occlusal position during the end of the mastication period. Inuzuka et al.[14] examined the duration between the points of which, maximum rate of increases in load and the maximum pressure measured by the pressure sensor, and reported that the duration was almost constant irrespective of the progression of mastication.

These findings suggested that the duration was the contact period of teeth in the occlusal phase, and the maximum load was considered to occur at the end of the occlusal phase. Interestingly, it was found that the time when the load started to increase or when a rapid increase in the load started was almost the same as the timing of the peak EMG activity.



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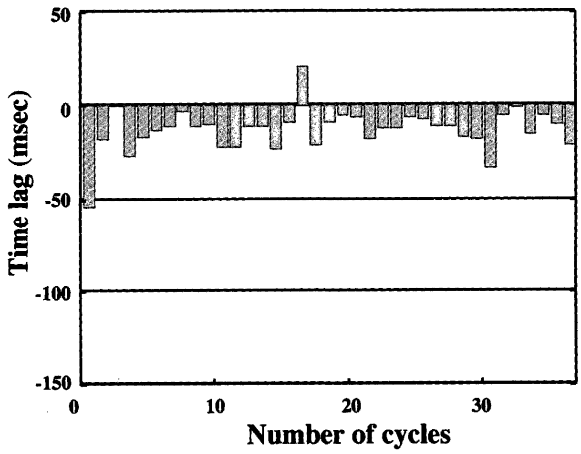


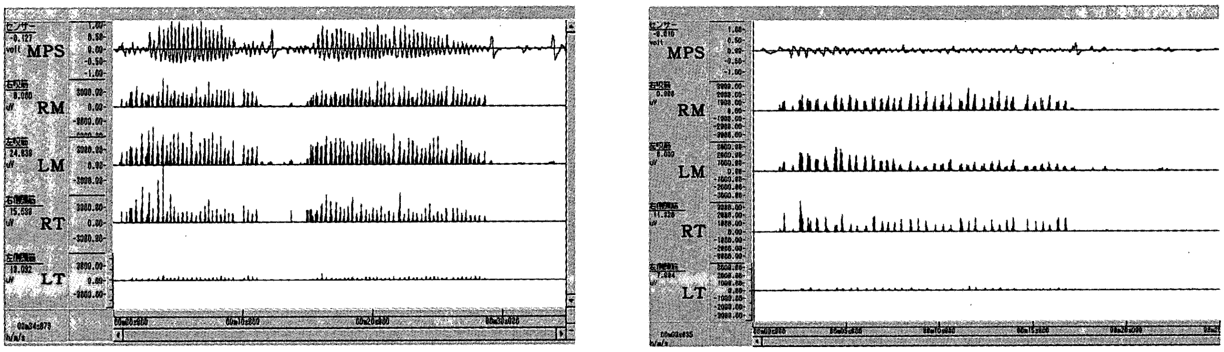
B

Fig. 11 Variation of the timelag between the starts of EMG activity of the bilateral masseter muscles in a masticatory sequence. The timelag was expressed with minus when EMG activity of the left masseter muscle preceded and with plus when EMG activity of the left masseter muscle delayed.
A : mastication of hard food, B : mastication of soft food

These findings indicated that the load on the anterosuperior surface of the condylar head of the monkey started to increase at the beginning of the occlusal phase of mastication of the hard and soft foods.

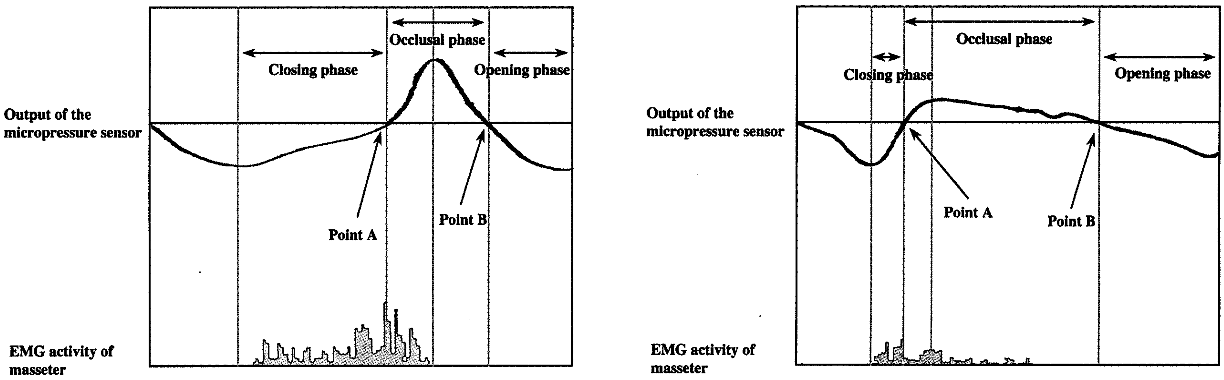
DISCUSSION

There have been a number of studies on the load in the TMJ[1~10]. In such studies, indirect methods, such as indirect determination of the load in the TMJ by directly measuring strain of the mandibular bone during mastication, and by determination of the load on the TMJ using mathematical models and the fi-



A B

Fig. 12 The output potential of the micropressure sensor and EMG activity in a masticatory sequence for the mastiction of hard food (A) and soft food (B). From upper, the output potential of the micropressure sensor (MPS), EMG activity of right masseter (RM), EMG activity of left masseter (LM), EMG activity of right temporal (RT), EMG activity of left temporal (LT).



A B

Fig. 13 The relationship between output potential of the micropressure sensor and EMG activity of the working side maseter muscle in a single masticatory cycle for the mastication of hard food (A) and soft food (B). The point A represents the initiation of an increase in the load, at point B, the maximum load occured.

nite elememt method, and direct methods, such as direct measurement of load on the TMJ or on the mandibular bone, were used. The studies performed using direct methods by Hylander et al.[23,24], Boyd et al.[11,12], and Inuzuka et al.[13,14] demonstrated loading on the TMJ during jaw movement.

Inuzuka et al.[13,14] developed a micropressure sensor that minimizes surgical invasion by reducing damage to the tissues around the TMJ, and measured the maximum pressure on the surface of condylar head of TMJ and mastication period during mastication of hard food in monkeys. Fukushima et al.[22] measured the load on the TMJ in a monkey on the working and balancing sides during mastication of hard food using a similar pressure sensor. The mean maximum pressure was 0.75 MPa (SD=0.03) on the working side TMJ and 0.76 MPa (SD=0.06) on the balancing side TMJ. In the present study, we measured the maximum pressure on the balancing side of the TMJ during mastication of food with different degrees of hardness. The mean maximum pressure obtained by 5 measurements was 0.86 MPa (SD=0.31) during mastication of hard food (sweet potato) and 0.32 MPa (SD=0.18) during mastication of soft food (banana), showing an about 3-fold difference.

Kuboki et al.[25~27] established a three-dimensional mathematical model from biological EMG activity data of the masseter muscles, and analyzed load on the TMJ during clenching. They chose beef jerky as a typical hard food and gum as an ordinary food, of which the property can be made homogeneous. Four pieces of 1 g beef jerky or 2 pieces of gum were masticated at a time. The activity patterns of the bilateral masseter muscles during mastication were almost the same with both foods. When the occlusal force during clenching of the first molar was regarded as Fb, the load on the TMJ during unilateral clenching or during unilateral mastication was 0.68 Fb on the balancing side and 0.29 Fb on the working side, which were both compressive force. The absolute load was about 2.3-fold higher on the balancing side than on the working side. Hylander[28] reported that changes in the ratio of bilateral muscular activitys markedly affected load on the TMJ, and the size and properties of food were factors affecting the ratio of bilateral muscular force. Pruzansky et al.[29] reported that the ratio of EMG activity of the bilateral masseter muscles was slightly changed with increasing hardness of food. In the present study, it was clear that changes in the properties of food affected the mastication period, duration of EMG activity, and the peak amplitude of EMG activity, which affected the load on TMJ to some extent. Tanaka[30] performed the finite element stress analysis, assuming that total muscular force during clenching was 500N, and reported that the mean stress on the surface of the cortical bone of the mandibular condylar head was a compressive stress of 1.642 MPa. These findings indicated that there was stress, although it was a low level, on the surface of the mandibular fossa, where almost no load was conventionally considered to occur. Kimura et al.[18] reported that the equivalent stress induced by loading of 0.5 kg (4.9 N) on the masseter and temporal muscles was 1.1 MPa at the center of the mandibular condylar head and 0.53 MPa at the center of the mandibular fossa, respectively. Watase et al.[19] reported that the equivalent stress induced by loading of 10 kg (98 N) as the masseteric force was 9.8-19.6 MPa in the mandibular condylar head and 1.0-4.9 MPa in the mandibular fossa, and the latter was about 1/10-1/2 higher than the former.

Although the results of these studies did not agree well, loading on the TMJ actually occurred during jaw movement, and the muscular force may affect the level of loading. However, since the model made using the finite element method was a mathematical model of the stomatognathic system, it was difficult to perform accurate analysis with various properties of food. Therefore, data obtained during mastication of hard and soft foods in experimental systems, such as the system of this study, in which biological parameters could be directly measured, and detailed data on viscoelastic characteristics of biological tissues are required. This study demonstrated that the EMG activity of the masseter muscles during mastication differed with the properties of food, which was confirmed by the data of the load on the TMJ in the monkey.

Mastication on one side is generally reflective muscular activity via the mastication center. In other words, muscular force is efficiently converted into occlusal force by reflective control of the mastication center during mastication, and consequently, the absolute load on the TMJ may be controlled to be low. Therefore, function in the stomatognathic system is efficiently controlled by the center, resulting in the effective loading function on the TMJ. This study demonstrated that the mean maximum pressure on the left TMJ (balancing side) was significantly lower during mastication of the soft food than during mastication of the hard food ($P<0.0001$). In all measurements, the maximum pressure in each masticatory cycle was slightly decreased with the progression of mastication. These findings indicated that different properties of food caused different activities of the mastication muscles, resulting in the different levels of the pressure on the TMJ. It was suggested that these results were not caused by changes in the muscular force and occlusal force with the progression of mastication but by the central control mechanism of loading on the TMJ during mastication.

Loading on the TMJ during jaw movement was elucidated, but the phase in which the maximum loading occurs and the amount of loading have not been clarified. Hylander et al.[23,24] reported that the level of loading on the TMJ during clenching was the highest among levels of loading induced by various mandibular movements. However, Boyd et al.[11,12] reported that the maximum loading on the TMJ in monkeys occurred at the nearly maximum opening of the mouth with squeal. Inuzuka et al.[13,14] speculated that the maximum loading on the TMJ in each mastication cycle occurred at the maximum opening of the mouth based on the position of markers superimposed on loading data by synchronizing at the maximum opening of the mouth. Fukushima et al.[22] indicated that the maximum pressure was induced in the opening phase based on the ratio of the occlusal phase during the mastication period and the EMG activitys of the masticatory muscles.

In this study, the maximum pressure in each masticatory cycle was detected in pauses of the EMG activitys of the masseter muscles irrespective of the properties of food. Analysis of the relationship between the output wave patterns from the pressure sensor and wave patterns of the EMG activity of the masseter muscle on the working side during mastication of the hard or soft food demonstrated that the period between the points showing the maximum rate of the increase in loading on the pressure sensor and the maximum pressure was almost constant irrespective of the progression of mastication, and the period was speculated to be the duration of teeth contact in the occlusal phase. These findings suggested that the maximum loading in each mastication cycle occurred at the end of the occlusal phase. However, since this was only speculated by the relationship between the output wave patterns from the pressure sensor and the EMG activity of the masticatory muscles, it is considered necessary to perform analysis by simultaneously measuring the mandibular movement and TMJ loadings in monkeys during mastication.

CONCLUSIONS

In this study, to evaluate the effects of properties of food on the loading of the TMJ, in particular to clarify the changes in the load on the condylar head of TMJ caused by mastication of food with different properties, the load on the condylar head of TMJ and EMG were simultaneously measured in a monkey during mastication of food with different properties (hard food : sweet potato, soft food : banana). The results were as follows:

1) The mean mastication period determined using the EMG activity of the masseter muscle on the working side was 348.9 msec (SD=76.5) during mastication of the hard food and 433.2 msec (SD=97.7) during mastication of the soft food, the latter being significantly longer than the former ($P<0.0001$).
2) The mean duration of EMG activity from the masseter muscle on the working side was 163. 6 msec (SD=24.8) during mastication of the hard food and 170.0 msec (SD=25.1) during mastication of the soft food, the difference being not significant.
3) The mean peak amplitude of EMG activity in each masticatory cycle was 305.0 μV (SD=86.7) during mastication of the hard food and 172.3 μV (SD=57.1) during mastication of the soft food, the latter being significantly lower than the former ($P<0.0001$).
4) The mean maximum pressure on the antero-superior surface of condylar head of the balancing side of TMJ occured in each masticatory cycle was 0.86 MPa (SD=0.31) during mastication of the hard food and 0.32 MPa (SD=0.18) during mastication of the soft food, the latter being significantly lower than the former ($P<0.0001$). The maximum pressure on the condylar head of the balancing side of the TMJ of the monkey tended to decrease with the progression of mastication by 0.5-1.5 MPa during mastication of the hard food and by 0.1-0.8 MPa during mastication of the soft food. The side of mastication in the monkey was unambiguously determined to be right by macroscopic observation, observation on video, and additional measurement of the timelag between the starts of EMG activity of the bilateral masseter muscles.
5) The maximum pressure on the antero-superior surface of the condylar head of the balancing side of the TMJ was detected in pauses of the EMG activity of the masseter muscles during mastication of the hard and soft foods.

These findings indicated that the maximum load on the TMJ in the monkey was lower during mastication of soft food than during mastication of hard food, suggesting that differences in the jaw movement caused by foods with different properties affected loading on the TMJ. The maximum load on the TMJ during mastication of the hard and soft foods was detected in pauses of the EMG activity of the masseter muscles. These findings suggested that the maximum loading at each mastication cycle occurred at the end of the occlusal phase.

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硬食物および軟食物咀嚼運動時におけるサル顎関節部と咀嚼筋活動との比較

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キーワード：顎関節部荷重，筋電図活動，サル，咀嚼運動，食物の性状

食物の性状の差異による下顎運動，咀嚼筋活動および下顎頭の運動過程に関する個々の報告はあるものの，各咀嚼サイクル中の顎関節部荷重と咀嚼筋活動の関係を比較，検討した報告はない．そこで本研究では，食物の性状の差異(硬食物-サツマイモ，軟食物-バナナ)による咀嚼運動時のサル顎関節部荷重および咀嚼筋活動を同時測定して，それらの関係を明確にすることを目的とした．

その結果，各咀嚼運動時のサル顎関節部最大荷重は，硬食物(サツマイモ)咀嚼時に比べ軟食物(バナナ)咀嚼時の方が低い値を示した．このことは，やはり食物の性状の相違による咀嚼系機能運動の変化が顎関節部荷重に，何かしらの影響を与えているものだと推測される．また，サル咀嚼運動時の最大荷重の発生する時期は，硬食物咀嚼運動時と同様に，軟食物咀嚼運動時においても咬筋筋活動の休止期に認められた．さらに咀嚼リズムを解析した結果，最大圧力は咬合相の終末に発生していると推測された．

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