Stomatognathic Function during Continuous Physical Activity in *Nippon Kempo*

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Key words: stomatognathic function, *Nippon Kempo*, occlusal force distribution, continuous physical activity

Abstrac :

Clarifying stomatognathic function during continuous physical activity can contribute to the advancement of dental advice for athletes, including advice on maintaining the oral environment and improving performance. We elucidated stomatognathic function during physical activity, simultaneously analyzed occlusal force distribution and electromyograms (EMGs), and investigated occlusal contact and muscle activity during attacking movements such as continuous blows. Seven *Nippon Kempo* athletes of at least first-degree ranking, with normal dentition and jaws, performed attacking movements using both fists to strike a defender wearing a trunk protector. They continued until they subjectively experienced that they were approaching their limit. A custom sensor sheet was used to measure occlusal force distribution. Measured muscles included the masseter, suprahyoid, sternocleidomastoid and biceps brachii muscles. Before performing the test activity, subjects were instructed to perform maximum voluntary clenching for obtaining maximum (100%) occlusal force distribution and to engage all the measured muscles in a maximum voluntary movement for obtaining the EMG envelope integrated value/s; this established 100% muscle activity for each subject. The test activity measurement range was set from when the subject's blow first hit the defender's trunk until the subject's final blow hit the defender's trunk. This was divided into three equal stages: initial, middle, and final. The occlusal force distribution and relative muscle activity level were compared among the stages. The occlusal force distribution and the muscle activity level of masseter muscle increased over time. The muscle activity level of the sternocleidomastoid and suprahyoid muscles exhibited the same phases as those during maximum voluntary movement in the middle and final stages. During the continuous physical activity, increased occlusal force distribution and cervical and masseter muscle activity levels may suppress the swaying of the mandible and the head related to the trunk to maintain a stable posture for exercise.

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Introduction

The correlation between stomatognathic and whole-body functions during physical activity has been the subject of several studies[1-8], which generally measured either occlusal contact[1-3] or muscle activity of the masticatory muscles[4-8]. Few studies have simultaneously recorded both occlusal contact and muscle activity.

During continuous physical activity, stomatognathic function involves a close relationship between occlusal contact and muscle activity in the cervical and masticatory muscles[9-12], which are considered to be coordinated within this context[13-15].

Previous studies measured only occlusal contact or muscle activity of the masticatory muscles. We thought that clarifying the relationship between stomatognathic function, including occlusal contact, and both of cervical and masticatory muscle activity would be able to lead to various benefits, such as contributing to stomatognathic diagnoses for athletes, improving the intraoral environment (including treatment and preventive treatment), and advancement of dental advice for performance improvement in athletes[6,14].

The competitive martial art *Nippon Kempo*[16] involves periods of continuous physical activity. Athletes wear gloves and protective gear, such as face, trunk and groin protection, which ensure safety. Matches last 3 min and winners are decided on the basis of points gained from strikes, kicks, and joint locks recognized by the referee.

In order to clarify the relationship between occlusal contact and muscle activity in the cervical and masticatory muscles more, we simultaneously measured occlusal force distribution and cervical and masticatory muscle activity levels during continuous *Nippon Kempo* attacking movements.

Materials and Methods

1. Subjects

The subjects were seven athletes with more than 4 years' experience in *Nippon Kempo*, who had attained at least first-degree ranking and were continuously engaged in training. All had normal dentition and jaws, and none had subjective or objective impaired balance or any stomatognathic system problems. Their mean height, weight, age, and years of experience are given in Table 1. Prior to participation, this study was explained to the subjects, who gave their consent. This study was approved by the medical ethical review board of Osaka Dental University (no. 110830).

2. Test activity

The test activity involved the subject in a standing position[16] with the non-dominant hand and ipsilateral shoulder and foot positioned forward (*Fig.* 1) repeatedly striking the trunk of a defender with blows using both fists[16] (*Fig.* 2). This activity continued without time limit until the subject felt that they were approaching their limit. The subject wore *Nippon Kempo* 8-ounce lace-up gloves (N-8; Meirin Co., Ltd.) but no protection; the defender wore a *Nippon Kempo* trunk protector (N-8; Meirin Co., Ltd.). The defender for all subjects was a first-degree-ranked *Nippon Kempo* athlete (height: 176 cm, weight: 92 kg, age: 28 years, experience: 6 years).

Each subject performed four trials consisting of 10s in the standing position, the test activity, and 5-min rest (*Fig.* 3). After 10s in the standing position, the subject was given a verbal warning followed, after a time delay of 1–5s (randomized in advance), by a visual signal for the test activity to begin. This activ-

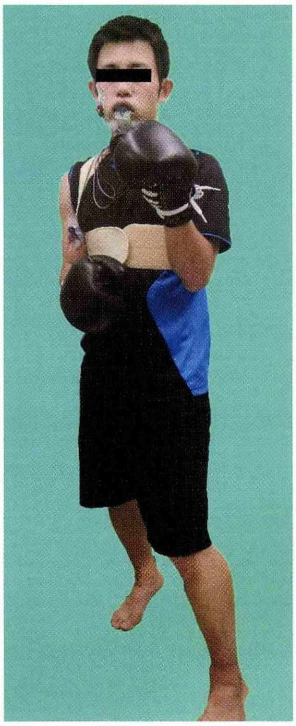

Fig. 1 Example of standing position.

Table 1 Subject characteristics.				
Subject	Height (cm)	Weight (kg)	Age (Years)	Nippon Kempo Experience (Years)
A	184	87	29	13
B	173	104	27	9
C	171	77	31	12
D	176	69	30	12
E	177	72	31	4
F	173	85	23	6
G	170	73	40	4
Mean±SD	174.86±4.74	81.00±12.15	30.14±5.18	8.57±3.91

Fig. 2 Test activity.

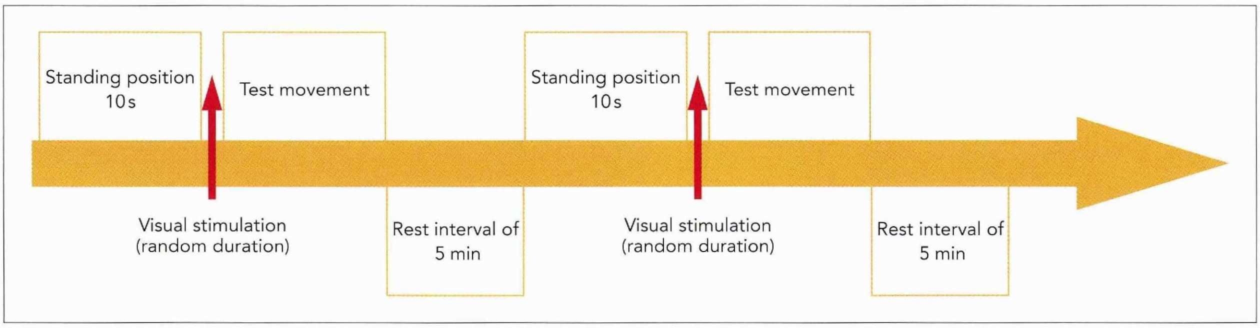

Fig. 3 Testing procedure.

ity was followed by a 5-min rest to prevent the subject from becoming fatigued, at the end of which their recovery was verbally confirmed; a further 5-min rest was allowed if a subject required it.

3. Measurement equipment

1) Occlusal force distribution

The occlusal force distribution was measured using a pressure distribution measurement system (I-SCAN ver. 5.87; Nitta Corporation,

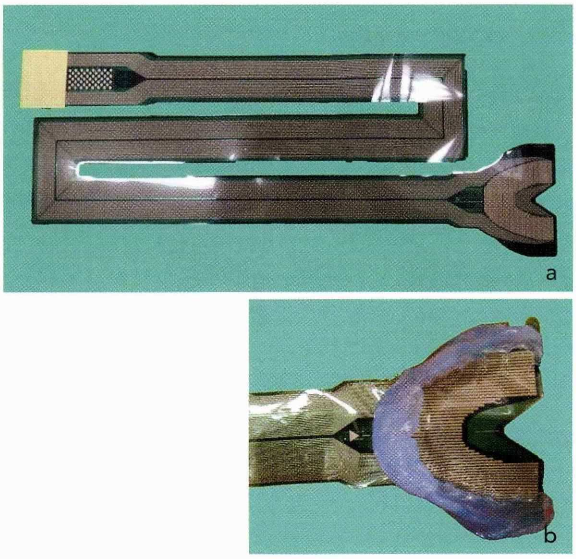

Fig. 4 Custom sensor sheet. (a) Custom sensor sheet for measuring occlusal contact. (b)Silicone impression for holding custom sensor sheet.

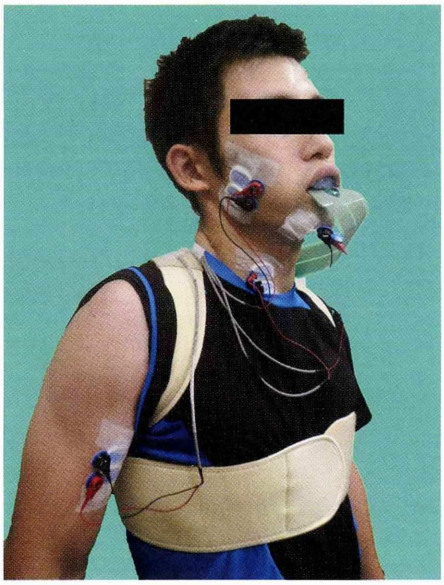

Fig. 5 Placement of surface electrodes.

Boston, MA) and a custom sensor sheet for measuring occlusal contact (FPD-T-Sports, Nitta Corporation) that had been extended in length by approximately 90 cm compared with a conventional sensor sheet so as not to impede the test activity during measurement. Vinyl silicone (Memosil®2; Heraeus Kulzer) was used on the buccal side to strongly adhere it to the lower embrasure and buccal mucosa, with the aim of creating a natural oral environment in the mandibular position during physical movement. A fixation device for the sensor sheet was fabricated for each subject in the oral cavity (*Fig.* 4), and the vinyl silicone was trimmed and adjusted. This device was held in the oral cavity during marked changes in mandibular and head position to confirm that the sensor sheet remained in place in the oral cavity. During the measurement, an assistant carefully held the sensor connector fitted to the sensor sheet with their hand so as not to impede the physical activity.

The sampling frequency was set at 100 Hz and the data obtained were stored on a computer with an installed pressure distribution measurement system.

2) Muscle activity level

Muscle activity levels were measured with a BioAmp (MP150; BIOPAC Systems, Goleta, CA), an electromyogram measurement system (AcqKnowledge ver. 3.7.3; BIOPAC Systems), and an Ag-AgC1 disposable electrode (N-00; Nihonsanteku Co., Ltd., Osaka, Japan). Muscle potential was measured in the subject's dominant-hand side masseter, sternocleidomastoid, long head of the biceps brachii[17] ('biceps brachii'), and suprahyoid muscles, using the central belly muscles on both sides of the anterior belly of the digastric muscle as an index ('suprahyoid muscle'). The distance between electrodes was set at 20 mm. They were affixed at the center of each measured muscle as parallel as possible to the direction of the central muscle fiber, and bipolar leads were attached (*Fig.* 5). The electrode lead line was affixed to each subject's body with stretchable adhesive tape (Surgical Tape -21N; NICHIBAN Co., Ltd., Tokyo, Japan), and measurements were carefully performed so as not to impede the movement of the

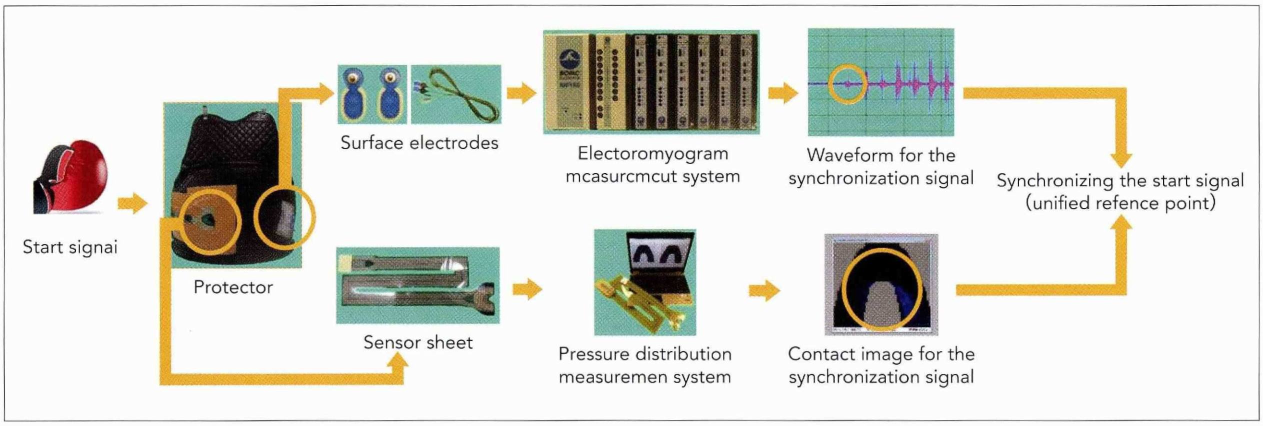

Fig. 6 System for synchronization between electromyogram measurement system and pressure distribution measurement system.

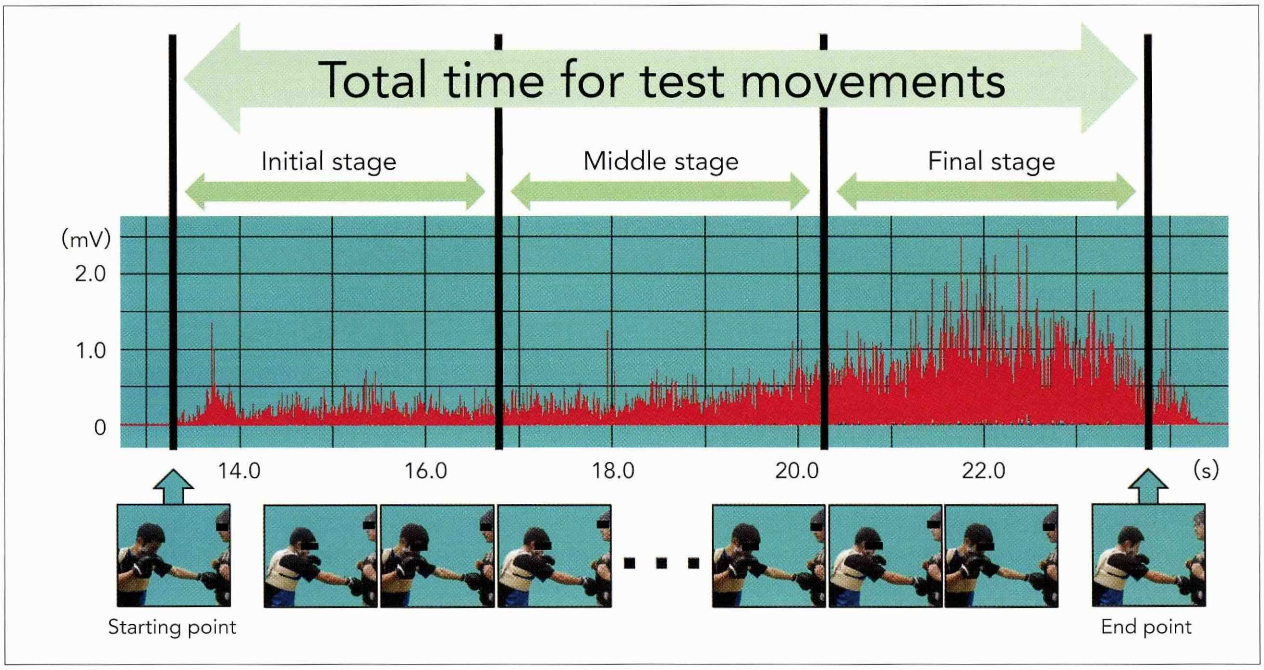

Fig. 7 Measurement methods based on test activity time.

subject. The ground electrode was placed on the subject's 7th cervical vertebra and a 5-channel measurement was simultaneously performed with 16-bit analog-to-digital (AD) resolution. The upper cutoff frequency (high cut) was set to off, the time constant at 0.03 s, and the sampling frequency at 4 kHz. Signals were amplified 1000-fold and AD converted. The muscle potential values obtained underwent differential amplification before being processed into fill-wave-rectified waveforms. Data were stored in a computer with installed myoelectric analysis software.

3) Simultaneous measurement

A sensor sheet and disposable electrode were affixed to the attack target, which was the defender's trunk protector. The computer's initiation reference points for both the pressure distribution measurement and the electromyogram measurement system were synchronized with the signal for the subject to start the test activity (*Fig. 6*). To confirm physical activity, the test activities were recorded from a fixed point 1.5 m above the

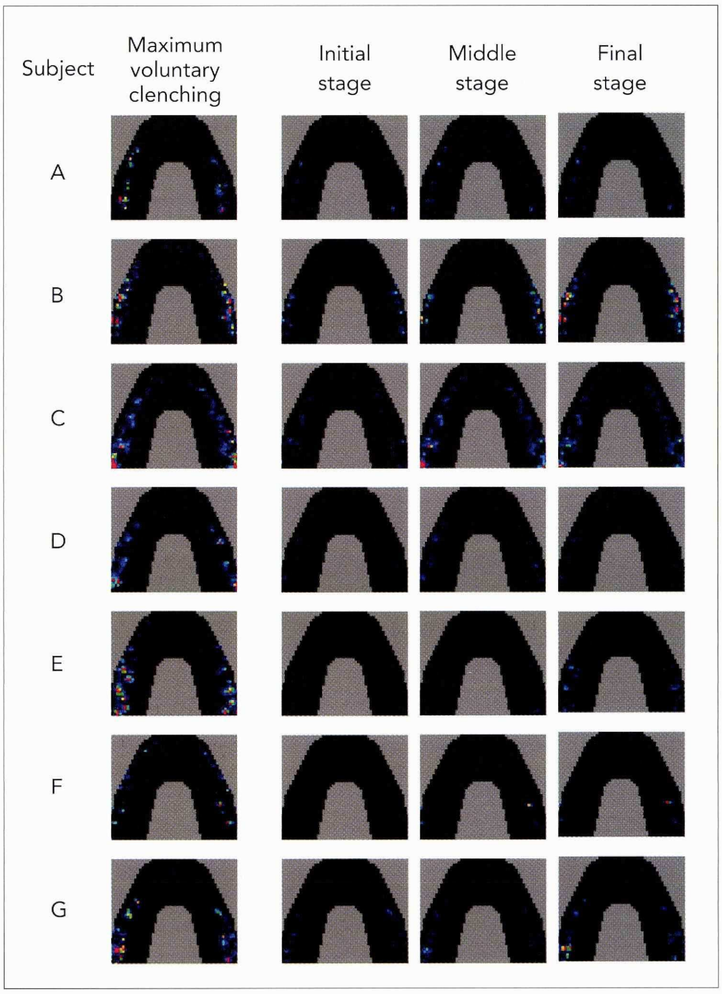

Fig. 8 Occlusal contact during test activity.

floor using a digital video camera (COOLPIX AW100; Nikon Corp., Tokyo, Japan).

4. Measurement methods

1) Time measurement

The measurement start and end points were set as the time points at which the subject's first and final blows hit the defender's trunk. Each measurement period between the start and end points of a test activity was divided equally into three stages: initial, middle, and final (*Fig.* 7).

2) Occlusal force distribution

Prior to the test activity, each subject was instructed to perform maximum voluntary clenching for 5s three times. The mean of these maximum occlusal forces was set as the 100% occlusal force for that subject, with the maximum occlusal force in the initial, middle, and final stages calculated relative to this.

3) Muscle activity levels

Similarly, the maximum voluntary muscle activity level for each muscle in each subject was measured prior to the test activity. For the masseter muscles, the subject performed maximum voluntary clenching. For the suprahyoid muscles, the subjects performed maximum voluntary mouth-opening without bending the head backward while the assistant placed both his thumbs on the subject's lower margin of the mandibular midline to resist this. For the sternocleidomastoid muscles, the subject performed maximum voluntary cranial rotation in the upward direction to the side opposite their dominant hand without bending their head backward while the assistant placed his fingers on the temporal bone to resist this. For the biceps brachii muscle, the subject performed maximum voluntary flexion of the upper arm on the dominant-hand side. Three 5-s rounds of measurement were conducted for each muscle. From the EMG envelope rectified waveforms obtained, we selected the central 2-s amplification values for each measurement round to calculate the integrated values. The mean integrated value/s for each muscle were calculated; these were considered to be the 100% muscle activity level values for the subject, against which the integrated value/s in the initial, middle, and final stages of the test activity were calculated.

5. Analysis

Mean values for three measurement rounds, excluding the first round, were used as representative values for each measured item. Paired one-way analyses of variance with the measurement period as a factor were performed using SPSS ver. 19 (IBM Corp., Armonk, NY). The level of statistical significance was set at 5%. When a statistically significant difference was observed, multiple post-hoc comparisons were performed by applying the Bonferroni correction.

Results

1. Test activity time

The average test activity time of all subjects was 14.70 ± 11.24 s. The longest test activity time was subject E at 25.94 s. The shortest test activity time was subject D at 7.94 s.

2. Occlusal force distribution

Fig. 8 shows the maximum occlusal force distribution for each subject during each stage of the test activity. No subject exhibited contact images identical to their maximum occlusal contact image. For subject F, no occlusal contact was observed in the initial stage in any measurement round. Table 2 shows the maximum occlusal force in each of the stages for each subject. For all subjects, the smallest values were in the initial stage. In the final stage for subject B and the middle stage for subject C, the occlusal force exceeded 50% of the maximum voluntary clenching figure. In subjects A, C, and D, the greatest values were observed in the middle stage, whereas in the other subjects the occlusal force ratio increased in the final stage. Fig. 9 shows the

Table 2 *Maximum occlusal force distribution as a percentage of maximum voluntary clenching.*

Subject	Initial stage (%)	Middle stage (%)	Final stage (%)
A	14.36	23.65	21.91
B	25.03	30.01	69.41
C	5.13	60.04	49.38
D	0.38	4.08	1.44
E	0.50	0.74	12.80
F	0.00	6.03	7.33
G	25.66	25.91	40.07

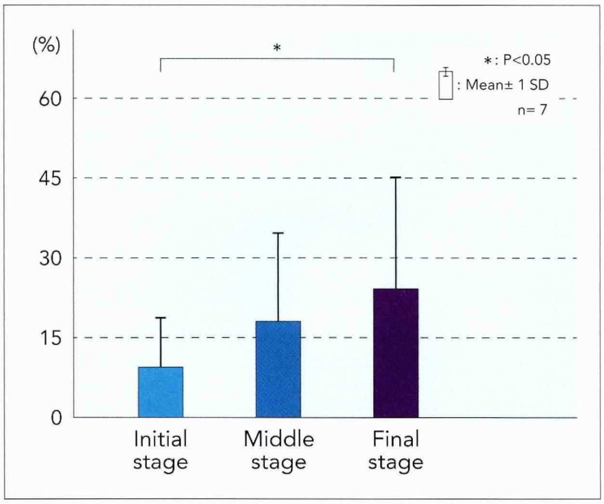

Fig. 9 Maximum occlusal force as a percentage of maximum voluntary clenching.

Table 3 Muscle activity of masseter muscle.			
Subject	Initial stage (%)	Middle stage (%)	Final stage (%)
A	53.99	61.17	61.22
B	24.01	33.66	66.63
C	46.03	53.12	58.10
D	6.83	8.80	11.27
E	42.29	60.43	74.77
F	18.07	48.52	59.31
G	40.05	40.36	52.61

Table 4 Muscle activity of suprahyoid muscles.			
Subject	Initial stage (%)	Middle stage (%)	Final stage (%)
A	73.99	107.95	140.14
B	30.51	37.39	44.60
C	73.86	76.67	78.80
D	104.79	119.76	131.79
E	74.09	132.01	160.78
F	87.58	118.15	115.00
G	85.14	93.81	90.79

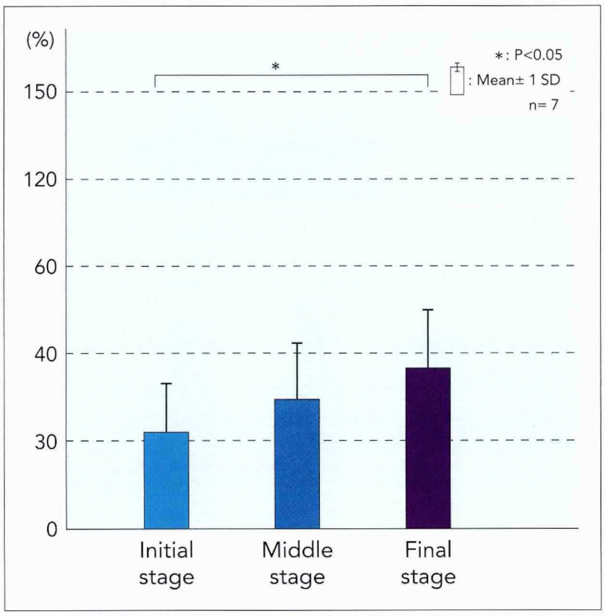

Fig. 10 Muscle activity of masseter muscle.

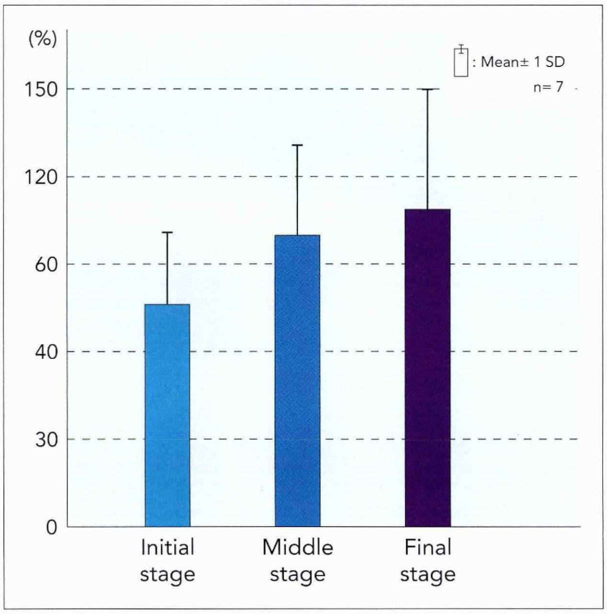

Fig. 11 Muscle activity of suprahyoid muscles.

mean and standard deviation (SD) values for each of the stages (10.15% ± 11.52%, 21.49% ± 20.64%, and 28.90% ± 24.88% for the initial, middle, and final stages, respectively). The increase in the final stage compared to the initial stage was statistically significant (P < 0.05).

3. Muscle activity level

1) Masseter muscles

Table 3 shows the maximum masseter muscle activity levels in each of the stages for each subject. In all subjects, muscle activity level increased over time. Fig. 10 shows the mean ± SD values for each stage (33.04% ± 17.00%, 43.72% ± 18.38%, and 54.84% ± 20.46% for the initial, middle, and final stages, respectively). Again, the final stage values were significantly greater than those in the initial stage (P < 0.05).

2) Suprahyoid muscles

Table 4 shows the maximum suprahyoid muscle activity levels in each of the stages for each subject. In subjects F and G, the ratio for the middle stage indicated greater muscle activity than for the final stage. Muscle activity level ratios exceeding 100% were observed in subjects A, E, and F in the middle and final stages, and in subject D for all stages. Fig. 11 shows mean ± SD values for each stage

Table 5 Muscle activity of sternocleidomastoid muscle.

Subject	Initial stage (%)	Middle stage (%)	Final stage (%)
A	68.62	84.74	110.58
B	75.62	88.95	94.03
C	78.62	82.50	81.71
D	62.92	72.35	79.41
E	90.54	130.51	148.70
F	90.70	96.25	100.44
G	95.07	92.40	99.08

Table 6 Muscle activity of biceps brachii muscle.

Subject	Initial stage (%)	Middle stage (%)	Final stage (%)
A	73.60	86.83	86.44
B	40.75	55.38	55.75
C	65.82	77.89	76.00
D	79.04	94.41	95.99
E	59.46	61.63	55.63
F	66.58	78.26	86.10
G	50.91	82.55	66.63

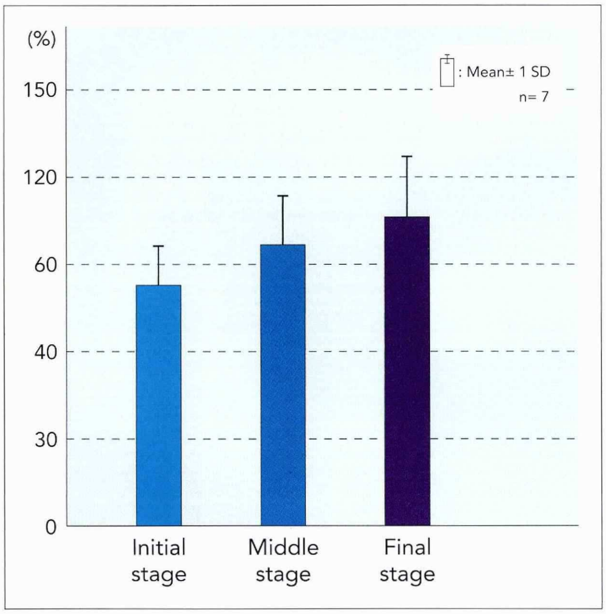

Fig. 12 Muscle activity of sternocleidomastoid.

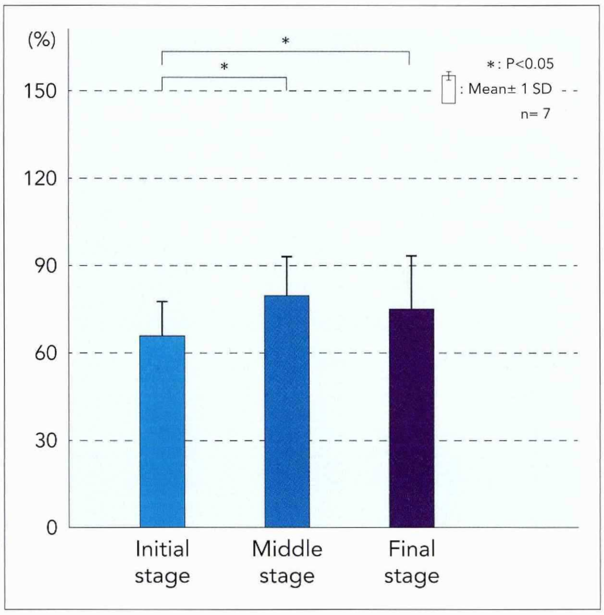

Fig. 13 Muscle activity of biceps brachii muscle.

(75.71% ± 22.83%, 97.96% ± 32.35%, and 108.84% ± 39.99% for the initial, middle, and final stages). No significant differences between the stages were observed.

3) Sternocleidomastoid muscles

Table 5 shows the maximum sternocleidomastoid muscle activity levels in each of the stages for each subject. In subject C, the muscle activity level ratio was greater in the middle stage than during the initial or final stages. Muscle activity level ratios exceeding 100% were observed in subjects A and F in the final stage and in subject E in the middle and final stages. Fig. 12 shows mean ± SD values for each stage (80.30% ± 12.21%, 92.53% ± 18.43%, and 101.99% ± 23.28% for the initial, middle, and final stages, respectively). No significant differences between the stages were observed.

4) Biceps brachii muscles

Table 6 shows the maximum biceps brachii muscle activity levels in each of the stages for each subject. Muscle activity level ratios were greater in the middle stage than during the final stage for subjects A, C, E, and G. In subject E, the muscle activity level ratio in the final stage was lower than that in the initial or middle stage. Fig. 13 shows mean ± SD values for each stage (62.31% ± 13.17%, 76.70% ± 13.76%, and 74.65% ± 15.87% for the initial, middle, and final stage, respectively). Values in the middle and final stages were significantly greater than those in the initial stage ($P < 0.05$).

Discussion

1. Study methods

1) Subjects

In order to eliminate any influence from physical or age-related changes, subjects were males with normal dentition and jaws, aged 20–40 years with a height of 170–185 cm. They had no subjective functional disorders associated with the stomatognathic system or with balance, and exhibited bilaterally even occlusal contact images during maximum voluntary clenching using I-SCAN. To standardize our subjects, they were selected by ensuring that they had at least first-degree ranking for *Nippon Kempo*, with at least 4 years' experience, and were continuously engaged in training.

2) Test activity

Nippon Kempo was selected as the test sport for this study as it requires continuous physical activity and can be safely performed wearing protective gear. However, in this study, to simplify the test activity task, the subjects wore no match-style protective gear, although they wore gloves and the defender wore a trunk protector.

Blows were selected as the test activity. Continuous blows are widely used in *Nippon Kempo* practice to foster physical flexibility and agility. As blows can be performed on the spot without much stepping to change positions, measurement is not impaired, making them appropriate for continuous physical activity measurement.

3) Measurement equipment

In order to measure occlusal contact state, we used a custom sensor sheet that had been extended in length by approximately 90 cm so as not to impede the test activity, with vinyl silicone used to strongly adhere it to the lower embrasure and buccal mucosa. Shirao et al.[13] and Himejima et al.[15] reported that the custom sensor sheet for measuring occlusal contact used in their studies did not impede the test activity. Video images during the present study confirmed that, during the test activity, the sensor fixation device was maintained within the oral cavity. The custom sensor sheet for measuring occlusal contact used in this study enabled us to observe occlusal contacts in the natural mandibular position during continuous physical activity, which would be impossible to observe with other occlusal test devices.

4) Measurement methods

(1) Occlusal force distribution

The sensor sheet used in this study has previously been used in an occlusal contact testing device that applied conductive, pressure-sensitive ink and was reported to enable the measurement with high reliability of occlusal contact area during maximum voluntary clenching[18]. However, during physical activity, even contact between teeth and the sheet caused by tongue pressure is recognized as occlusal contact. Occlusal contact area values alone cannot simply be considered as an accurate representation of occlusal contact[13]. Therefore, in the present study, we evaluated the state of occlusal contact as the occlusal force distribution and used the pressure values included in the occlusal contact sites to minimize the effects of contact between the sheet and teeth caused by tongue pressure. However, because the pressure distribution measurement system used for the analysis outputs pressure values that are based on a proprietary formula called 'raw sum,' it is impossible to calculate the integrated values for continuous data. Therefore, in the present study, we standardized values by calculating relative ratios (%) for the maximum occlusal force in each stage of the test activity, with maximum voluntary clenching considered to be 100% occlusal force.

(2) Muscle activity level

An EMG measurement system was used to analyze muscle activity level. Currently, no method is available for accurately calculating muscle strength directly from EMGs, and several studies use an envelope display to determine relative changes in muscle activity[19]. To standardize EMG analysis criteria between subjects in this study, we used EMG envelope rectified waveforms. It has been reported that various muscles function as contralateral synergist muscles during physical activity and that these contraction patterns are not uniform[6]. The sternocleidomastoid muscles (cervical muscles), masseter muscles (mouth-closing muscles), and suprahyoid muscles (mouth-opening muscles) were therefore selected as stomatognathic indices in this study. The central region of the anterior belly muscles on both sides of the digastric muscle was utilized as an index for the suprahyoid muscle surface myoelectric potential used in this study. This region has been reported to reflect the activity of the mylohyoid muscle, the anterior belly of the digastric muscle, and the geniohyoid muscle[20]. Of these, contraction of the anterior belly of the digastric muscle, which is found in the outermost layer of the lower part of the jaw, appears to have particularly contributed to suprahyoid muscle activity in the present study.

Blows, the test activity, involve smooth trunk long-axis rotation and successive elbow flexion and extension movements of the arms. To simplify investigation of muscle activity levels during the test activity, we measured activity in the elbow flexor muscles, selecting the biceps brachii muscle for this.

We calculated the mean muscle activity level integrated value/s for each stage in the test activity as a ratio of the maximum voluntary muscle activity integrated value/s for each muscle, over time. We used these ratios as indices for muscle activity level for a comparative investigation of detailed temporal changes during the test activity.

2. Results

It has been reported that the muscle activity level reflects the frequency of motor unit excitement and degree of mobilization, with increased muscle activity resulting in amplification of the exerted muscle strength[21]. In the present study, the results indicated that biceps brachii muscle activity level was significantly greater in the middle and final stages of the test activity than in the initial stage, suggesting that the number of mobilized motor units to execute the same physical activity increased over time.

Ratios of cervical and masticatory muscle activity levels in some stages exceeded the maximum voluntary muscle activity levels of the sternocleidomastoid and suprahyoid muscles in some subjects. In the middle and final stages, the same modality as the maximum voluntary muscle activity was observed for each muscle. The video footage showed that swaying of the subjects' heads and trunks increased over time. The sternocleidomastoid muscles, activated when the head rotates left and right or bends forward and backward, control the head during stomatognathic functions[22,23]. Muscle activity levels may have increased over time to maintain continuous movement in a stable posture in response to the swaying of the head and trunk.

The video confirmed that the subjects did not open their mouths widely. However, because the suprahyoid muscle activity level when the mouth was not opened widely exhibited the same or greater muscle activity level than maximum voluntary mouth-opening resistance, this appears to substantiate the suprahyoid muscle being posteriorly displaced to the mandible, as reported by Suzuki et al[24].

Masseter muscle activity level was significantly greater in the final stage of the test activity than in the initial stage, and muscle activity level tended to increase over time, exhibiting values different from those of maximum voluntary clenching. From these results we inferred that, during the test activity, the masseter muscle places the head in the optimal position for the posture at that specific moment[6]. In the present study, to fix the mandible, which was displaced in the posterior direction by the activity of the mouth-opening muscles, the increase over time in mouth-closing muscle activity appeared to help maintain a balance with the mouth-opening muscle activity[25]. Large differences observed in the masticatory muscle activity levels could be due to muscle size differences. Briefly, because the masseter muscles are large muscles in the head region, whereas the suprahyoid muscles are groups of small muscles including the mylohyoid muscle and anterior belly of the digastric muscle, the suprahyoid muscle activity level may have exhibited ratios that exceeded the maximum voluntary mouth-opening to maintain the balance.

The results for occlusal force indicated that, although occlusal contact was observed in the middle and final stages in all subjects, this did not approach the level of maximum voluntary clenching. Since occlusal contact images during the test activity, which is not the "clenching" motion, occurred in coordination with the masticatory muscles, occlusal contact images that had not reached the level of maximum voluntary clenching were observed.

Ratios of occlusal force and the extent of muscle activity levels may have differed between subjects due to differences in the modalities for coordinating occlusal contact and in each subject's cervical and masticatory muscles. This study only included seven subjects, and it was impossible to discern uniform trends for occlusal force distribution ratios and the extent of muscle activity levels. In the future, we hope to conduct further investigations with an increased sample size to discern fixed trends with standard modes.

The results of this study suggest that increased occlusal contact and cervical and masticatory muscle activity levels might contribute to stabilizing the head in response to swaying of the trunk to allow the execution of continuous physical activity in a stable posture, although the degree of activity levels differed between the subjects.

The lack of unity of morphological and structural intercuspal position with functional intercuspal position results in mandibular displacement that accompanies clenching, leading to impairment of the temporomandibular joint and the masticatory muscles[26,27]. The intercuspal position has the greatest functional importance because it is the endpoint of habitual opening and closing paths and masticatory movement[28]. Thus, maintaining uniform bilateral molar occlusal contact and correct functional movement of the cervical and masticatory muscles appears to contribute to smoothly inducing and fixating the mandible and head into the optimal position relative to the swaying trunk during continuous physical activity in response to this situation.

Conclusions

Our results suggest that during continuous physical movement in *Nippon Kempo*, increased occlusal force distribution and increased cervical muscle and masticatory muscle activity levels may help to control swaying of the mandible and the head related to the trunk to maintain a stable posture during movement.

Acknowledgments

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