EFFECTS OF MASTICATORY MOVEMENTS ON THE HEAD, TRUNK AND BODY SWAY DURING THE STANDING POSITION

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1. INTRODUCTION

One of the purposes in dental prosthetic treatment includes the recovery of the masticatory function. Mastication involves not only simple sequential jaw-opening and jaw-closing movements but also complex tongue movements, coordination of lip, and cheek movements and is associated with head movement to facilitate the intraoral transport of food from ingesting to swallowing; it affects many functions of the whole body. However, studies to evaluate the relationship between masticatory movements and the body posture are still lacking to our knowledge. The purpose of this study was to characterize the effects of masticatory movements on the head, trunk, and body sway during the standing position.

Methodology

A total of 30 healthy subjects were evaluated. The MatScanTM system was used to analyze changes in body posture (center of foot pressure: COP) and the 3-dimensional motion analysis system was used to analyze changes in the head and trunk postures while subjects remained in the standing position with the rest position, centric occlusion, and masticating chewing gum.

Results

The total trajectory length of COP and head and trunk sways during masticating chewing gum were significantly shorter and smaller respectively than it was in the rest position and centric occlusion (p<0.016). COP area during masticating chewing gum was significantly smaller than it was in the 2 mandibular positions (p<0.016).

Conclusion

Masticatory movements positively affect the stability of the head, trunk, and body sways and enhance the postural stability during the standing position.

KEYWORDS

Masticatory Movements; Head, Trunk, and Body Sways; Changing Body Posture; Standing Position; Postural Stability

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2. METHODOLOGY

2.1 Study population and ethics

30 healthy students (15 males and 15 females) with an average age of 28.6 years (range 22-32 years) were recruited among the students and staff members of the Graduate School of Dental Medicine Hokkaido University. The sample size was calculated using the software program G*Power 3.1.9.2 (Heinrich-Heine-Universität Düsseldorf). When the sample size was calculated by setting α = 0.05, β = 0.8, and effect size = 0.8, 26 participants were needed. All subjects met the following inclusionary criteria: (1) no history of head and neck or back problems, (2) no history of signs and symptoms of temporomandibular disorders or orofacial pain, (3) no history of orthopedic or otolaryngologic problems affecting body balance, (4) absence of prosthesis (i.e., crowns, bridges, implants or removable prosthetics) and class I dental occlusion, and (5) the pattern during mastication assessed by a linear or concave opening path from centric occlusion toward the working side and a subsequent convex closing path in the vicinity of centric occlusion [19].

The movement of the mandibular incisal point during chewing gum on habitual chewing side was recorded by the optical jaw motion tracking device (FUJITA Medical Instruments Co, Japan) and was analyzed using the overlapping of each cycle and average path [19] (Fig. 1).

2.2 Analysis of simultaneous measurements of head, trunk, and body sways (Fig. 2)

The COP is the center of vertical force acting on the support surface. It indicates gravity shifts in the anteroposterior and lateral directions.

The three-dimensional motion analysis system (Library Co., Ltd, Tokyo, Japan) was used to analyze head sway and trunk sways. This instrument enabled the measurement of the three-dimensional movements of target points on the surface of the facial skin and body surface simultaneously. The movements of the target points were recorded by three charge coupled device (CCD) cameras, and the three-dimensional coordinates were calculated by using an analyzing software (Library Co., Ltd, Tokyo, Japan). The target points on the face and trunk skin were marked by attaching 4 points respectively (Fig. 3).
The center of the 4 target points was calculated in each sampling frame. Then the mean coordinate of all the centers of the 4 target points on the face was defined as the virtual central coordinate of the head (MCB-h). In the same way, the mean coordinate of all the centers of the 4 target points on the trunk was defined as the virtual central coordinate of the trunk (MCB-t). The head sway was analyzed based on the coordinate system located on the trunk (A trunk coordinate system). The trunk sway was analyzed based on the coordinate system on the ground.

For all tests, the subjects were asked to remove their shoes and socks, to stand with their feet apart to the width of their shoulders in a natural stance on the force platform of the MatScanTM system. To assist in obtaining the natural standing posture, the subjects were asked to look directly into a reflected image of their eyes, two meters away with arms hanging free at their sides and to remain in this position during the measurements. Simultaneous measurement of the head, trunk, and body sways was conducted under the following three conditions: (1) The subjects maintained the rest position (teeth slightly apart and masticatory muscles in a relaxed non-contractile condition). (2) The subjects maintained the centric occlusion without clenching. (3) The subjects chew softend chewing gum on their habitual chewing side and were requested not to swallow it for the time tested. These three conditions were randomly conducted in each subject, based on the table of random numbers. Testing under each condition was recorded for 20 seconds. The recording was started after the subject stood on the MatScanTM sensor and the investigator confirmed that their head and body positions were stable. Each trial was recorded three times with a one-minute rest period.

2.3 Parameters
The total trajectory length of the COP and COP areas (Rectangular area, Outer peripheral area, Root mean square area) were used to evaluate the stability of the body posture [11,12]. Each trial of the MatScanTM system was recorded in 1200 frames for 20 seconds. The 2-dimensional coordinates of the COP were acquired for every frame. First, the effective distance of the COP between one frame and the next frame was calculated based on the pitch of the sensor sheet in each trial. The total trajectory length of the COP for each trial was then calculated by summing up all the effective distances of the COP between 1200 consecutive frames. The COP areas were the rectangular area, the outer peripheral area, and the root mean square area of the total trajectory of 1200 COPs respectively.

The lateral and anteroposterior weight distribution were used to evaluate the balance of body posture [11,12]. A four-quadrant weight distribution value was measured in percentages (%) for every frame in each trial (Fig. 4). First, the lateral weight distribution and the anteroposterior weight distribution values for each frame were calculated. Next, the mean value of the sum of all lateral weight distribution values in each trial was calculated (LWD). The same calculation was carried out for the anteroposterior weight distribution value (AWD). The calculation for the LWD and AWD was as follow: LWD (%) = 50 - (the right-anterior value + the right-posterior value), and AWD (%) = 50 - (the right-posterior value + the left-posterior value).

The head and trunk sway values were used to evaluate the stability of the head and trunk position respectively. Each trial of the three-dimensional motion analysis system was recorded in 1200 frames for 20 seconds. The 3-dimensional coordinate of the center of the 4 target points of the head was acquired for every frame. The head sway value was defined as the mean distance between MCB-h and each center of the 4 target points. The trunk sway value was obtained in the same manner as the head sway value. Each trial was repeated three times and the average value of the three trials was used as the representative value for each subject.

2.4 Statistical analysis
The total trajectory length of the COP, the COP areas (Rectangle area, Outer peripheral area, Root mean square area), the lateral and anteroposterior weight distribution and the head and trunk sway values were compared to evaluate whether the masticatory movements affected the head, trunk, and body sways. All comparisons were performed using Friedman’s two-way analysis of variance (p<0.05) and the Wilcoxon t-test with Bonferroni correction (0.05/3 = 0.016) were used. SPSS version 21 (SPSS Japan Inc., Tokyo, Japan) was used for statistical analysis.

3. RESULTS
The results of the comparisons (median values) in total trajectory length of COP among the rest position, centric occlusion, and masticating chewing gum are shown in Fig. 5. The total trajectory length of COP in the centric occlusion was significantly shorter than it was in the rest position. The total trajectory length of COP during masticating chewing gum was significantly shorter than it was in the rest position and in centric occlusion.
The results of the comparisons (median values) in the head and trunk sway values among the rest position, centric occlusion, and masticating chewing gum are shown in Fig. 8. The head and trunk sway values in the centric occlusion were significantly smaller than they were in the rest position. The head and trunk sway values during masticating chewing gum were significantly smaller than they were in the rest position and centric occlusion.

4. DISCUSSION

The results for the total trajectory length of COP (Fig. 5), COP areas (Rectangle area, Outer peripheral area, and Root mean square area) (Fig. 6), head and trunk sway values (Fig. 8) suggested that the body posture was significantly more stable when the subjects bit down in centric occlusion than when they maintained their mandibles in the rest position. Stability in the head position is indispensable to the control of the body posture. The anterior and posterior cervical muscles are concerned with the stability and movement of the head [21-24]. The loss of posterior occlusal support deprives the stomatognathic system of valuable proprioceptive information, and likely alters muscle contraction patterns. These changes are reported to effect the cervical muscles through the trigeminal nerve [16].

The cervical nerves C1 to C4 are primarily involved in controlling head posture [25] and the proprioceptive inputs from the muscles and articulations of the neck are important in the maintenance of postural balance [26]. Stimulation of the vestibular system by changing the head position has a descending influence on the triceps surae muscle and the soleus muscle, both antigravity muscles [27].

Based on these previous reports, the stability of the head is maintained through the action of the cervical area. The present result found that the body posture was significantly more stable in the centric occlusion than in the rest position, and suggests that bilateral occlusal contacts in the centric occlusion caused a change bilaterally in the peripheral inputs from each organ in the stomatognathic system and resulted in improving both the stability of the neck, the head, and the trunk positions. Consequently, body posture was more stable when the subjects bit down in the centric occlusion compared to when they maintained in a muscular rest position.

The median COP areas (Rectangle area, Outer peripheral area, and Root mean square area) are shown in Fig. 6. The median COP areas in the centric occlusion were significantly smaller than it was in the rest position. The median COP areas during masticating chewing gum were significantly smaller than they were in the rest position. The median COP areas during masticating chewing gum are shown in Fig. 7. There were no significant differences in the distribution of foot pressure among the rest position, centric occlusion, and masticating chewing gum.

The results for the comparisons (median values) in the lateral and anteroposterior weight distributions among the rest position, centric occlusion, and masticating chewing gum are shown in Fig. 7. There were no significant differences in the distribution of foot pressure among the rest position, centric occlusion, and masticating chewing gum.

The results of the comparisons among RP, CO, and MA were tested with the Friedman’s two-way analysis of variance (P < 0.05), and multiple comparisons was assessed by the Bonferroni adjustment (0.05/3 = 0.016) after Wilcoxon t-test. *: P < 0.016, and n = 30. Medians (IQR) of RP, CO, and MA were as follows: RP 40.2(34.4 - 45.9), CO 37.7(33.3 - 44.3), MA 36.2(29.6 - 42.4).

The results of the comparisons (median values) in the lateral and anteroposterior weight distributions among RP, CO, and MA were as follows: RP 1.9(0.8-3.4), CO 0.3(1.1-2.4), MA 1.5(0.5-2.6). Medians (IQR) of RP, CO, and MA for anteroposterior weight distribution were as follows: RP 0.7(5.5 - 5.7), CO 2.6(5.4 - 5.4), MA 1.1(4.0 - 5.9).

The body posture was more stable when the subjects bit down in the centric occlusion compared to when they maintained in a muscular rest position.
The results for the total trajectory length of COP (Fig. 5), COP areas (Rectangle area, Outer peripheral area, and Root mean square area) (Fig. 6), head and trunk sway values (Fig. 8) suggested that the body posture was significantly more stable when the subjects masticated chewing gum than when they bit down in centric occlusion or they maintained their mandibles in a muscular rest position.

Yagi et al. [26] reported that the leg muscles, which directly regulate the movement of the ankle joint, and the dorsal neck muscles, which change the static equilibrium through the central nervous system, are important for maintaining the standing posture. Takada et al. [28] found the increase in amplitude of the pretibial and soleus muscles undergo a nonreciprocal facilitation during mastication. Takada et al. [28] found the increase in amplitude of the pretibial and soleus H reflex showed a positive correlation with the strength of teeth clenching. Lundgren and Laurell [29] confirmed on average 37% of the total maximal bite force in habitual occlusion was utilized during chewing. Moreover, Watanabe et al. [30] suggested that the pattern of masticatory movement path with a linear or concave opening path and a convex closing path (Pattern I) had the stability of the path and rhythm and a superior masticatory function compared to the pattern of the masticatory movement path with a similar open path to that in Pattern I and a concave closing path. The present results found that the body posture was significantly more stable when the subjects masticated chewing gum than when they bit down in centric occlusion or maintained their mandibles in the rest position (Figs. 5, 6 and 8). Based on previous reports [15,26,28-30], one can infer that when the subjects masticated chewing gum, the occlusal force might have been larger compared to it in centric occlusion, and the pattern of the masticatory movement path had the stability of the path and rhythm and a superior masticatory function. Moreover, the present results showed the possibility that the peripheral inputs from each organ in the stomatognathic system during mastication may have strongly affected the muscles, pretilbial and soleus muscle, and the upper central nervous system, which regulate the craniocervical muscles, as the positive feedback control to maintain and stabilize the standing posture. Namely, a positive impact to the posture control system during mastication may have extended to both the upper and lower extremities. Consequently, the mastication movement may have affected the postural control by enhancing the postural stability standing position.

Stable human standing is usually considered to depend on an integrated reflex response to vestibular, visual, and somatosensory input [31]. When the center of gravity changes its position in space, the neuromuscular system must compensate so that the center of gravity remains in a balanced position [21]. The present results found that there were no significant differences in the distribution of the foot pressure among the rest position, centric occlusion, and masticating chewing gum anteroposteriorly and laterally (Fig. 7). These results suggest that changes in mandibular position and masticating chewing gum did not affect the postural balance anteroposteriorly and laterally.

4.1 Limitations
This study has some limitations. The simultaneous measurements of head, trunk, and body sways were carried out to evaluate a relationship between the stomatognathic function and body posture in the present study. However, analyses were not done on the motion analysis of the lower legs and muscle activities in the head, neck, trunk, and lower legs. The future direction of study should be to include the motion analysis of the lower legs and the analysis of electrical activities of craniocervical and whole body muscles to elucidate the relationship between mastication and body posture in detail. Moreover, it also needs further analysis on the subjects with the other patterns of masticatory movement path other than Pattern I (the pattern of masticatory movement path with a linear or concave opening path and a convex closing path) [30]. Kushiro et al. [13] investigated the effect of masticating chewing gum on the postural stability during upright standing, using only the force plate for postural assessment, and they suggested that mastication of chewing gum affects the postural control by enhancing the postural stability during upright standing. Goto et al. [14] also conducted a similar study and reported that the chewing gum indirectly affected postural control by influencing the vestibular function to stabilize posture during upright standing. Our results in the present study, which were obtained by adding the motion analysis to the force plate analysis, corroborate these previous studies, and suggest that the jaw sensory motor system can modulate postural control mechanisms. Gum chewing activity can enhance postural stability during upright standing in healthy young adults. Detailed investigations on the mechanism underlying these effects should be performed in future studies. Our findings could be taken into consideration in treatment and rehabilitation planning for some patients with postural instability due to balance disorders.

5. CONCLUSION
Masticatory movements affect the head, trunk, and body sways and enhance the postural stability during standing position.

CONFLICT OF INTEREST
No potential conflict of interest was reported by the authors.

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AUTHOR CONTRIBUTIONS
KS: data gathering and analysis, literature collection and writing some parts of manuscript. KS: concept and design, protocol, data gathering and analysis, their interpretation and drafting the manuscript, manuscript revision and submission. NRM: concept and design, data interpretation, critical revision of the manuscript for important intellectual content. TM: technical support of the measurement system. LPC: concept and design, critically revised the manuscript. AY: administrative, technical, and material support; study supervision. All authors read and approved the final manuscript.
REFERENCES


Questions

1. What other movements are involved in mastication besides the simple sequential jaw-opening and jaw-closing movements?
   - a. Complex tongue movements;
   - b. Coordination of lip, and cheek movements;
   - c. Head movement to facilitate the intraoral transport of food from ingesting to swallowing;
   - d. All.

2. Which of the following is not an inclusionary criteria for this study?
   - a. No history of head and neck or back problems;
   - b. No history of signs and symptoms of temporomandibular disorders or orofacial pain;
   - c. No history of orthopedic or otolaryngologic problems affecting body balance;
   - d. Malocclusion.

3. Which statistical tests were used to assess comparisons of the data in this study?
   - a. Friedman's two-way analysis of variance;
   - b. Wilcoxon t-test with Bonferroni correction;
   - c. Both;
   - d. None.

4. Which of the following is a conclusion of this study?
   - a. Masticatory movements affect head, trunk, and body sways and enhance the postural stability during standing position;
   - b. Masticatory movements affect head, trunk, and body sways and deteriorate the postural stability during standing position;
   - c. Jaw clenching affect head, trunk, and body sways and enhance the postural stability during standing position;
   - d. Bruxism affect head, trunk, and body sways and enhance the postural stability during standing position.

CV

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