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Effect of bolus hardness on the chewing pattern and activation of masticatory muscles in subjects with normal dental occlusion

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Abstract

The aim of the study was to evaluate the effect of bolus hardness on the kinematic of mastication and jaw-elevator muscle activity in subjects with normal dental occlusion and function. The mandibular motion and the surface EMG envelope of the masseter and temporalis anterior muscles were assessed in twelve subjects during mastication of a soft and hard bolus of the same size. When chewing the hard bolus, the chewing pattern in the frontal plane was significantly higher and wider, with smaller closure angle and higher peak velocity than when chewing the soft bolus. EMG peak amplitude of both the masseter and anterior temporalis muscles was higher for the side of the bolus but the contralateral side increased its activity significantly more than the ipsilateral side when the hardness of the bolus increased (for the masseter, mean ± SD: 130.4 ± 108.1% increase for the contralateral side and 29.6 ± 26.9% for the ipsilateral side). Moreover, the peak EMG activity for both muscles occurred more distant from the closure point with hard bolus. The increased activity of the contralateral side may help maintaining the mandibular equilibrium, with indirect participation to the power stroke generated by the chewing-side masseter. The results provide kinematic and EMG adaptations to bolus hardness in healthy subjects and can be used as normative data in the development of methods for early diagnosis of impaired chewing function.

Keywords: Surface EMG; Mastication; Jaw muscles; Chewing pattern

1. Introduction

Mastication is a dynamic process characterized by rhythmicity which involves synchronous movements of the jaws, tongue and cheeks to position the bolus between the largest surfaces of the teeth (Bhatka et al., 2004). Masticatory jaw movement is adjusted by mechanoreceptors located in the tongue and oral mucosa, muscle spindles and periodontal pressoreceptors. The activation of each masticatory muscle depends on the size and texture of the food bolus to facilitate efficient crushing and sharing of the bolus between the upper and lower posterior teeth on the chewing side (Plesh et al., 1986).

Concomitant assessment of the chewing pattern (kinematic) and EMG activity of the masticatory muscles provides important information on the chewing function. Knowledge on the effect of bolus hardness on mastication is important to diagnose the “ability to apply load” by patients (Lewin, 1985). However, diagnostic procedures require first the assessment of the physiological reaction of the stomatognatic system in healthy subjects as control (Bishop et al., 1990; Ferrario and Sforza, 1996; Piancino et al., 2005a,b).

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Chewing harder food results in an expanded excursive pathway outside the occlusal phase and in an increased velocity of the mandible in all phases, except during the "occlusal phase of closing" when harder food slows the mandible, thus the total duration of the chewing cycle is not altered (Anderson et al., 2002). Moreover the bite force depends on the hardness of the bolus. At the muscle level, the muscular activity of the ipsilateral muscles is higher when chewing tough meat than tender meat (Mioche et al., 2003) and the major change in muscle activity seems to be related to increased duration rather than increased intensity (Shiau et al., 1999).

Most studies on the effect of bolus hardness on mastication evaluated muscle activity and kinematic of the movement separately and sometimes in non-natural conditions (Owall, 1977; Ottenhoff et al., 1993; Peyron et al., 1997). Moreover, in many studies differences in hardness were obtained by boli of different shape and size (Horio and Kawamura, 1989; Compagnon et al., 1999; Mioche and Peyron, 1995; Lassauzay et al., 2000; Shiga et al., 2001). This contributes to the lack of consensus on the effect of bolus hardness per se since bolus size also affects the chewing cycle (Bhatka et al., 2004).

The aim of the study was therefore to evaluate the effect of bolus hardness on the chewing pattern and masticatory muscle activity of both sides in subjects with normal dental occlusion and function.

2. Materials and methods

2.1. Subjects

Twelve subjects (nine males, three females; age, mean ± SD, 24 ± 5 years) with normal occlusion and function were selected for the study. Written informed consent was obtained from all subjects. Subjects were recruited with the following inclusion criteria: (1) age range 18–30 years, (2) fully functional erupted teeth, (3) normal dental occlusion according to Angle classification (bilateral first molar and canine class), (4) centred midline, (5) 2-mm overbite and overjet. The exclusion criteria were the presence of (1) symptoms of temporomandibular joint disfunction, (2) any prosthesis, (3) any malocclusion, (4) any contact on the balancing side. A clinical examination and the analysis of dental casts of each subject were performed to assess these inclusion criteria.

2.2. Procedures

The subjects were comfortably seated on a chair. They were asked to fix a target on the wall, 90-cm far, and to avoid movements of the head. The measures were performed in a silent and comfortable environment. Each recording began with the largest number of teeth in contact. The subjects were asked to find this starting position by lightly tapping their opposing teeth together and then clenching. They were asked to hold this position with the test bolus on the tongue, prior to start the recording. Each recording consisted in a 10-s long chewing and was repeated, for each experimental session, three times for mastication on the right side and three times for the left side with a soft and a hard bolus. Two experimental sessions were performed in separate days, for a total of 24 chewing recordings of 10 s (12 with soft bolus on the right and left side and 12 with hard bolus on the right and left side).

The soft bolus was a chewing gum and the hard bolus was a winegum with the same sizes (20-mm large, 1.2-mm height, 0.5-mm width) and different weights (2 g the soft, 3 g the hard). The winegum was chosen to oppose a rubber-like resistance without sticking the teeth.

2.3. Kinematic analysis

The mandibular motion was tracked with a Kinesiograph (K6 -I, Myotonics Inc. Tukwila, WA, USA) that measures jaw movements with an accuracy of 0.1 mm. Multiple sensors (Hall effect) in a light weight (four ounce) array track the motion of a tiny magnet attached at the lower interincisor point. Before removing the magnet at the end of the experimental session, an impression, with silicone material, of the mandibular denture frontal area was taken. Thus, the magnet position could be reproduced in subsequent experimental sessions. The kinesiograph was interfaced with a computer for data storage and subsequent analysis.

2.4. Surface EMG recordings

Surface EMG signals were recorded from the masseter and temporalis anterior muscles with a multichannel electromyograph (Myotronics Research Inc., Tukwila, WA, USA; bandwidth 45–430 Hz per channel). This EMG amplifier is part of the K6-I WIN Diagnostic System (Jankelson, 1980). The relatively large high-pass frequency in EMG recordings was selected to reduce low-frequency movement artifacts during the movement. Two electrodes (Duotrode silver/silver chloride EMG electrodes, Myotronics) were located on the masseter and temporalis anterior muscles of both sides with an interelectrode distance of 20 mm. Before electrode placement, the skin was lightly abraded with abrasive paste and cleaned with ethanol. The location of the electrodes followed the indications of Castroflorio et al. (2005) and was based on anatomical landmarks. Kinetic and EMG data were collected simultaneously.

2.5. Signal analysis

The kinematic signals were analyzed with a custom made software (University of Torino, Torino, Italy). The first cycle, during which the bolus was transferred from the tongue to the dental arches, was excluded from the analyses. Other cycles were excluded if they presented at least one of the following characteristics: (1) minimum opening smaller than 4 mm; (2) duration shorter than 300 ms; or (3) vertical opening smaller than 3 mm.

From each cycle, the following variables were extracted (Fig. 1): (1) opening amplitude (Peyron et al., 1997); (2) closure angle (Wilding and Lewin, 1994); (3) cycle duration (Anderson et al., 2002); (4) cycle width (Piancino et al., 2005a,b); (5) maximum lateral excursion; and (6) maximum velocity (in the 3D space). The variable values computed for each included cycles were averaged for cycles recorded in the same day and the same side of mastication.

The surface EMG was rectified and low-pass filtered with 10 Hz cut-off frequency (signal envelope). The maximum value and position (with respect to the chewing cycle) of the maximum of the envelope were extracted to quantify muscle activity (Fig. 1).

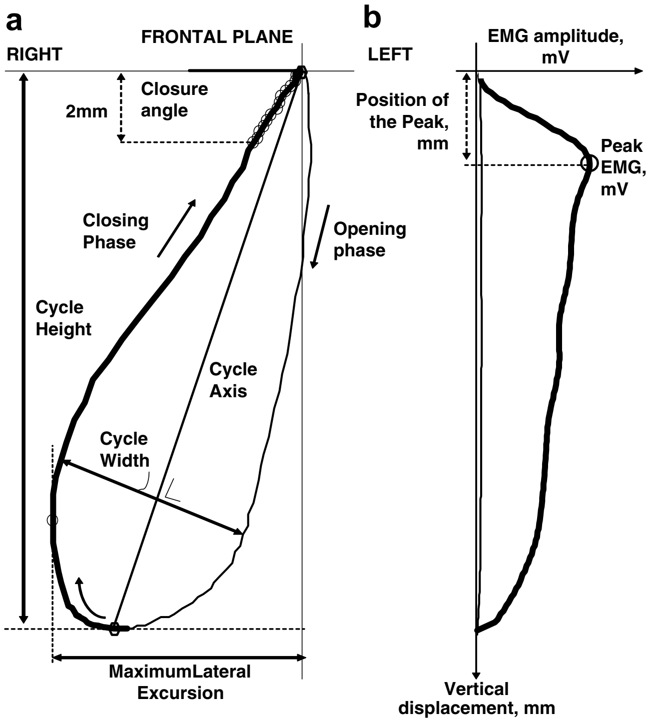

Fig. 1. Definition of the kinematic (a) and EMG (b) variables. Thin lines indicate the opening phase of the mastication, thick lines the closing phase. The closure angle is defined with respect to the horizontal line on the basis of the last 2 mm before complete closure. The velocity (not shown) is computed on the basis of the 3D motion of the mandible. The EMG is represented as a function of the vertical displacement, thus its peak value has a position which is expressed in millimeters.

In addition, the relative increase in EMG peak value between soft and hard bolus was computed as the difference in peak value when chewing the hard and soft bolus, divided by the peak value with the soft bolus and expressed in percentage.

2.6. Statistical analysis

Kinematic data were analyzed with three-way repeated measures analysis of variance (ANOVA) with factors the day of measure, side of mastication, and bolus hardness. EMG data were analyzed for the masseter and temporalis anterior with four-way repeated measures ANOVA with factors the day of measure, side of mastication, bolus hardness, and muscle side. Significant interactions were followed by post hoc Student–Newman–Keuls (SNK) pair-wise comparisons. The level for statistical significance was set to $P < 0.05$. Data are presented as mean and standard deviation (SD) in the text and table and mean and standard error (SE) in the figures.

3. Results

3.1. Kinematic variables

Fig. 2 reports a representative example of chewing cycles and EMG for the two boli in one subject. None of the kinematic variables depended on the day of measure.

The opening amplitude depended on the side of mastication ($F = 10.6$, $P < 0.01$) and the hardness of the bolus ($F = 52.1$, $P < 0.001$), being smaller for the mastication on the left side than on the right side (SNK, $P < 0.01$) and for the soft with respect to the hard bolus (SNK, $P < 0.001$) (Table 1). The closure angle depended only on the hardness of the bolus ($F = 4.5$, $P < 0.05$) and was larger for the soft than for the hard bolus (SNK, $P < 0.05$; Table 1). The cycle duration did not depend on any of the factors while pattern width, maximum lateral excursion, and maximum velocity were larger for the hard with respect to the soft bolus ($F > 12.2$, $P < 0.01$; SNK, $P < 0.01$; Table 1).

3.2. Masticatory muscle EMG

The peak of the masseter EMG envelope depended on bolus hardness ($F = 32.7$, $P < 0.001$), on the interaction between muscle side and side of mastication ($F = 53.2$, $P < 0.001$), and on the interaction among muscle side, side of mastication, and bolus hardness ($F = 9.5$, $P < 0.05$). The envelope peak was higher for the hard than the soft bolus (SNK, $P < 0.001$) and the masseter on the side of mastication had larger EMG peak than the muscle on the other side (SNK, $P < 0.01$; Fig. 3). The percent increase in masseter EMG peak when passing from the soft to the hard bolus depended on the muscle side ($F = 6.8$, $P < 0.05$), side of mastication ($F = 5.2$, $P < 0.05$), and on the interaction between muscle side and side of mastication ($F = 12.8$, $P < 0.01$). The relative increase of peak EMG with bolus hardness was larger for the masseter contralateral (130.4 ± 108.1%) than for the masseter ipsilateral (29.6 ± 26.9%) to the side of mastication (SNK, $P < 0.05$). The position of the peak of the masseter EMG depended on the bolus hardness ($F = 16.8$, $P < 0.01$) with the peak delayed (i.e. less close to the closure point) in case of hard with respect to soft bolus ($P < 0.01$; Fig. 3).

The maximum temporalis EMG envelope depended on bolus hardness ($F = 15.7$, $P < 0.01$), on the interaction between muscle side and side of mastication ($F = 16.5$, $P < 0.01$), and on the interaction among muscle side, side of mastication, and bolus hardness ($F = 17.4$, $P < 0.01$). Temporalis EMG peak was larger for the hard than the soft bolus (SNK, $P < 0.01$) and the muscle on the side of mastication had larger peak EMG than the muscle on the other side (SNK, $P < 0.05$). The percent increase in temporalis anterior EMG peak when passing from the soft to the hard bolus depended on the interaction between muscle side and side of mastication ($F = 27.0$, $P < 0.001$) and was larger for the contralateral muscle (22.1 ± 15.2%) than for the muscle ipsilateral (10.3 ± 13.4%) to the side of mastication (SNK, $P < 0.05$). The position of the peak of the temporalis EMG depended on bolus hardness ($F = 24.9$, $P < 0.001$) and on the interaction between mastication side and muscle side ($F = 11.0$, $P < 0.01$). As for the masseter, the peak EMG occurred later in space (i.e., less close to the closure point) for the hard in comparison to the soft bolus (SNK, $P < 0.001$). Moreover, it was closer to the

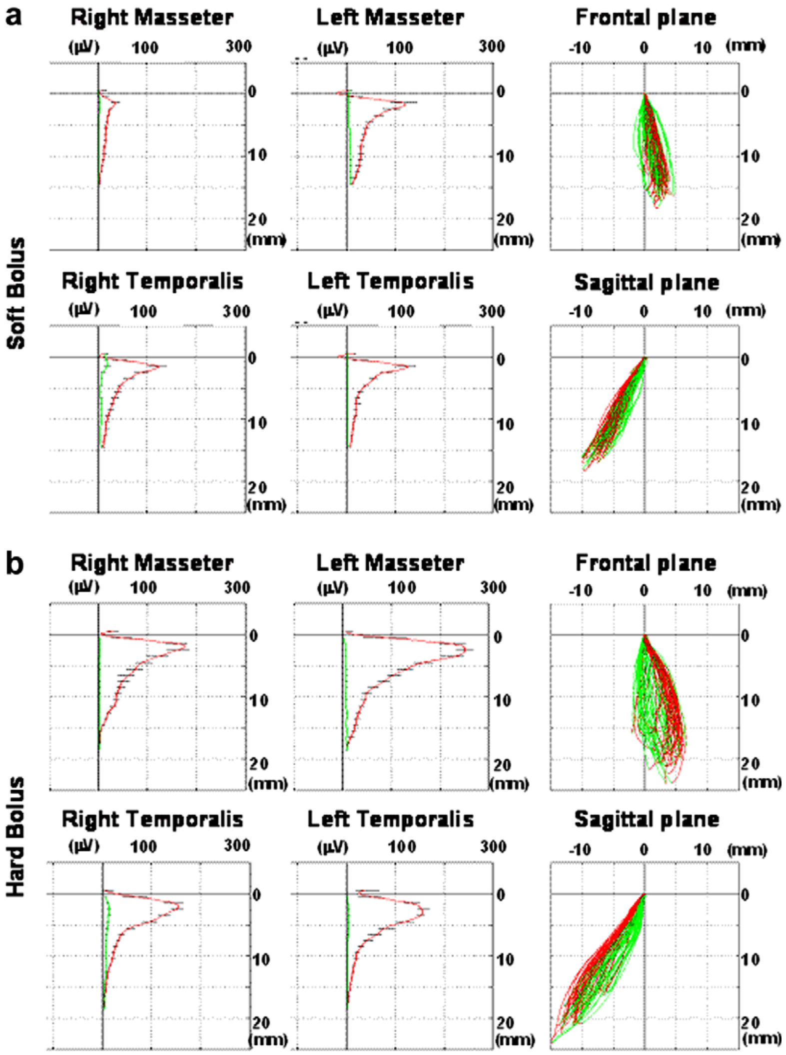

Fig. 2. Representative examples of EMG (mean and SD over all cycles in one experimental session) and chewing cycles (frontal and sagittal plane) for one subject in case of mastication (on the left side) of a soft (a) and hard (b) bolus.

Table 1
Kinematic variables (mean ± SD) for the two boli and sides of mastication

	Right mastication/ soft bolus	Right mastication/ hard bolus	Left mastication/ soft bolus	Left mastication/ hard bolus
Opening amplitude (mm)	14.4 ± 2.7	18.8 ± 3.6	13.7 ± 2.6	17.6 ± 3.3
Closure angle (°)	68.2 ± 11.3	65.1 ± 10.5	70.7 ± 7.8	67.2 ± 7.3
Duration (ms)	597.0 ± 142.9	617.4 ± 110.5	600.3 ± 149.4	603.0 ± 100.8
Cycle width (mm)	2.3 ± 1.3	3.4 ± 1.8	1.9 ± 0.9	3.2 ± 1.4
Max lateral excursion (mm)	3.2 ± 1.8	4.4 ± 1.9	2.6 ± 0.8	3.7 ± 1.5
Maximum velocity (cm/s)	13.1 ± 3.4	15.2 ± 4.3	12.8 ± 3.5	15.2 ± 3.9

Values from the two days of measurement have been averaged.

closure point for the contralateral side with respect to the ipsilateral side (SNK, $P < 0.05$).

4. Discussion

Kinematic parameters (chewing pattern) and surface EMG of the masseter and anterior temporalis muscles were assessed in adult young subjects with normal dental occlusion during chewing a soft and a hard bolus. When chewing a hard bolus, the chewing pattern was higher and wider, with smaller closure angle and larger peak velocity than when chewing the soft bolus. The peak EMG envelope of both the masseter and anterior temporalis muscles was larger for the side of the bolus but the contralateral side increased its activity significantly more than the ipsilateral side when the hardness of the bolus increased.

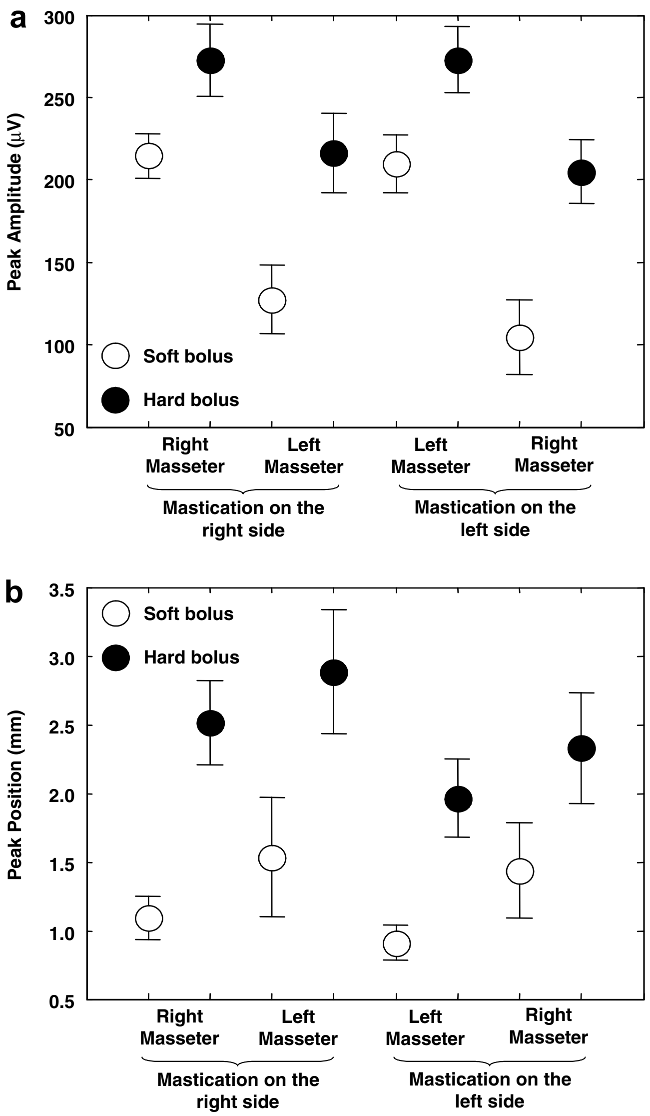

Fig. 3. Masseter surface EMG peak value (a) and position of the peak (b) (mean ± SE) in the conditions analyzed. Values from the two days of measurement have been averaged.

4.1. Kinematic parameters

The observed larger overall size of the chewing pattern with a hard bolus is in agreement with previous studies (Lewin, 1985; Wilding and Lewin, 1994; Anderson et al., 2002). This results in a greater run-up of the mandible that allows the development of greater accelerations prior to contact with the food. The larger the chewing pattern, the higher the velocity and force to break the food. These characteristics of mastication reflect an increased efficiency with hard bolus (Wilding and Lewin, 1994). The increased acceleration of the mandible is provided by increased muscle force, as confirmed by higher EMG amplitude of both the masseter and anterior temporalis muscles with the hard bolus.

The maximum velocity was larger for the hard compared to the soft bolus. Previous studies (Proschel and Hofmann, 1988; Takada et al., 1992) have reported decreased average velocity with bolus hardness. However, Anderson et al. (2002) recently showed that maximum velocity increases with hardness in all phases except during the occlusal phase of closing while average velocity may be unchanged since the opening phase is longer with hard boli (Møller, 1974). This is in agreement with the present result of unchanged pattern duration and larger maximum velocity with increasing hardness.

4.2. EMG

The chewing pattern characteristics are determined by the muscular output whose timing and intensity is controlled by the cortical and spinal networks. The joint recording of kinematic variables and surface EMG allows the identification of the changes in muscular activity that determine the adaptation of the kinematic characteristics of the chewing cycle.

EMG activity of the masseter and anterior temporalis muscles of the side of the bolus was higher than that of the other side, as previously reported (Miyawaki et al., 2000, 2001; Møller, 1974; Kimoto et al., 2000; Piancino et al., 2005a,b). Furthermore, we observed that when the bolus hardness increased, the contralateral masseter increased its activity significantly more than the ipsilateral side, thus reducing the difference in activity between the two sides. Moreover, the EMG peak of both muscles was more distant from the maximum intercuspation. These characteristics of muscular activation may help maintaining the mandibular equilibrium, with indirect participation to the power stroke generated by the chewing-side masseter (Mioche et al., 1999).

The larger increase in activity of the contralateral masseter and temporalis may also be a mechanism of protection of the temporomandibular joint from load. The contralateral joint is more heavily loaded during chewing than the ipsilateral one (Naeije and Hofman, 2003). Thus, when the required force increases, the relatively large increase of the contralateral masseter activity and the relatively earlier peak of the contralateral anterior temporalis may both protect the temporomandibular joint of the opposite side of the bolus. In this study, however, there are no biomechanical data to directly support this hypothesis.

The evaluation of kinematic and muscular activity when increasing bolus hardness may be used to assess if the stomatognathic system of patients with temporomandibular disorders is able to compensate the load. The reported kinematic and EMG variables with soft and hard bolus may be considered as indexes of the normal capability of the stomatognathic system to apply load by increasing the chewing efficiency and protecting the temporomandibular joint. When these characteristics are missing, the load on the temporomandibular joint during chewing a hard bolus might be higher than in normal conditions, increasing the intra-articular pressure and affecting the lubrication system of the joint (Nitzan, 2003).

5. Conclusion

The study reports the adaptation of the stomatognathic system to bolus hardness with a joint kinematic and EMG analysis. With increasing hardness, the chewing cycle increases in size and this is reflected in increased activity of the jaw-elevator muscles, mainly on the contralateral side. The results provide normal kinematic and EMG adaptations to bolus hardness that can be used for early diagnosis of impaired chewing function (Piancino et al., 2006).

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