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Effects of masticatory muscle training on maximum bite force and muscular endurance

TAILUN HE[1], DIMITRIOS STAVROPOULOS[1,2], CATHARINA HAGBERG[1,3], MAGNUS HAKEBERG[4] & BENGT MOHLIN[1]

[1]*Department of Orthodontics, Institute of Odontology, Sahlgrenska Academy, University of Gothenburg, Gothenburg, Sweden,* [2]*Department of Orthodontics, Athens Naval Hospital, Athens, Greece,* [3]*Division of Orthodontics and Paediatric Dentistry, Department of Dental Medicine, Karolinska Institute, Huddinge, Sweden, and* [4]*Unit of Dental Behavioural Sciences, School of Health Sciences, Jönköping University, Jönköping, Sweden*

Abstract

Objective. This study evaluates the effects of chewing training on strength and endurance of the masticatory muscles. ***Materials and methods.*** Of the 49 healthy young adults included in the study, nine served as controls for a baseline measurement of bite force. The 40 participants who actively trained their masticatory muscles were randomly divided into a 'continuous training group' (CTG) and an 'intermittent training group' (ITG). The participants performed oral motor training by clenching silicon tubes (Chewy Tubes™) according to a designed protocol. The muscular strength was studied in terms of maximum bite force. Muscular endurance was evaluated by measuring the duration for which the participants held 50% of their maximum bite force value. ***Results.*** Both the maximum bite force and the muscular endurance capacity increased after intensive training for both groups. After 2 months, the ITG stopped training for 1 month. At this point, a significant difference was identified both in the mean bite force values and the mean muscular endurance duration: the ITG exhibited lower values. For both groups, the highest values were attained after 3 months of training. The maximum bite force values and the muscular endurance duration were observed to follow similar patterns. The effects attained decreased rapidly in both groups when the training stopped. ***Conclusions.*** For both the continuous and intermittent training groups, 4 months of chewing exercises strengthened masticatory muscles, but such effects diminished gradually for both groups when the exercises stopped.

Key Words: *bite force, chewy tubes, chewing training, masticatory muscle training, oral motor training*

Introduction

Some anthropologists have suggested there is an association between masticatory muscle function and dentofacial growth and morphology [1–4]. For example, the craniofacial morphology and occlusal status of medieval populations are characterized by smaller gonial and intermaxillary angles, broader jaws and lower frequency and severity of malocclusions compared to contemporary populations [1,5–10]. Similar associations between masticatory muscle function and dentofacial growth and morphology have been reported in clinical studies in humans [4,11–13] as well as in experimental studies in animals [14–19].

An association between attrition and dentofacial morphology has been found in humans [20–22]. Individuals with increased muscle activity due to parafunction showed a low prevalence of malocclusion [19]. A prevailing explanation for these observations may be that the masticatory apparatus in contemporary populations is relatively under-developed compared to earlier populations due to reduced masticatory function caused by the industrialized and refined diets common in the modern era. Under-developed jaws may have caused tooth size/dental arch size discrepancies in contemporary populations [10,23].

In growing individuals with functional disturbances affecting the head and neck regions, abnormal jaw development and occlusion have been reported [24]. Pronounced mouth breathing has often been related to enlarged tonsils and/or adenoids and may have

Correspondence: Tailun He, Department of Orthodontics, Institute of Odontology, Sahlgrenska Academy, University of Gothenburg, Box 450, SE 405 30 Gothenburg, Sweden. Tel: +46 31 741 2261. Fax: +46 31 741 2260. E-mail: tailun.he@odontologi.gu.se

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resulted in increased vertical growth of the jaws and disturbed occlusion [25]. An association between vertical growth pattern and weak elevator muscles has also been reported [26,27].

From these observations, three questions arise with respect to intensive masticatory muscle training: Does such training help avoid unfavourable vertical facial growth? Does such training improve chewing capacity? Does such training reduce the risk of TMD (temporomandibular disorders)? Efforts have been made to improve dentofacial growth by stimulating mastication.

Gum chewing is a common method for training the masticatory muscles. Ingervall and Bitsanis [28] studied longitudinally the effects of daily chewing of a tough chewing material in 13 long-face children. In these individuals, significant increase in bite force and muscle activity was recorded after training. The anterior facial height decreased and the posterior facial height increased significantly due to training. The training also caused anterior rotation of the mandible. The effects were observed sagittally and vertically, but not transversally.

Masticatory muscle exercises have also been used to help treat open bite malocclusions [29] and TMD [30]. In traditional orthodontics, however, daily short-term clenching exercises seem to be an insufficient adjunct treatment for correcting or controlling vertical dentofacial dimensions [31].

Kiliaridis et al. [32] studied the effects of gum-chewing training on maximum bite force and masticatory muscle endurance in healthy adults. The authors concluded that training for 4 weeks with a hard chewing gum (isotonic training) seemed to influence the functional capacity of the masticatory muscles and to increase their strength. However, no increase in fatigue resistance was detected after the training [33]. Another study reported that maximum bite force (isometric training) could be easily increased with training, although actual strengthening of the masticatory muscles is more difficult to achieve [34]. A training method that involves both isotonic and isometric exercise might more effectively increase the strength of masticatory muscles.

This study compares continuous and intermittent training of masticatory muscle strength in terms of maximum bite force and muscular endurance by measuring the amount of time participants could hold 50% of their maximum bite force value. In addition, this study evaluates a new training method for masticatory muscles that combines both isotonic and isometric exercises.

Materials and methods

Subjects

This masticatory muscle training study recruited 49 students and staff members (20–35 years old) from the Institute of Odontology at the University of Gothenburg. Nine controls (three males and six females) were used for baseline measurements only; that is, they did not participate in the training programmes. The remaining 40 participants were randomly divided into two groups: a ‘continuous training group’ (CTG) and an ‘intermittent training group’ (ITG). Of these 40 participants, 13 were excluded due to non-compliance with the training protocol. Data for the remaining 27 participants (11 males and 16 females) were included in the analyses. Fifteen participants (five males and 10 females) belonged to the CTG and 12 (six males and six females) belonged to the ITG.

The participants were healthy, had no large dental restorations and/or prosthetic replacements and had no periodontal problems. They were also checked for possible TMD in order to ensure that they did not have any objective signs of a disorder. Anamnestic information followed by a clinical examination of masticatory muscles, joint function and mandibular opening capacity was carried out. This procedure was important for preventing exercise-induced aggravation of any TMD related condition. None of the participants were under orthodontic treatment.

The study was approved by the ethics committee at the University of Gothenburg. Special care was taken to ensure that all participants understood the objectives and methodology of the study and oral informed consent was obtained.

Study design

All the participants except the controls used Chewy Tubes™—resilient non-food silicon tubes—for their chewing and clenching training (Figure 1). A series of structured exercises (jaw excursion and closure) were used to build repetitive oral motor function, strength and endurance of the masticatory muscles bilaterally. The training subjects were asked to chew and clench on the Chewy Tubes™ for 100 repetitive cycles on each side twice daily. The participants were also asked to complete a training journal where they noted how much they trained and described the sensations they felt in their masticatory muscles and temporo-mandibular joints (TMJs) after training. This journal was later used to evaluate possible symptomatic effects of the training on masticatory muscles and TMJs.

The experiment was conducted over 4 months, with five measurement occasions. For the individuals who trained, maximum bite force and muscular endurance were recorded before the training started and four more times at 1-month intervals. For the controls, maximum bite force and endurance were recorded on two occasions with intervals up to 3 months.

During the first month, the training subjects chewed and clenched on Chewy Tubes™. During the 2nd and 3rd months, the CTG kept the same

Figure 1. Chewy Tube™.

training protocol, while the ITG stopped training during the 2nd month and started again in the 3rd month. Both groups stopped training at the end of the 3rd month. Final recordings were made at the end of the 4th month.

Recording procedure

All recordings were made with the subjects seated upright and looking forward in an unsupported natural position. Bite force was measured in Newtons (N) using a portable occlusal gauge (GM10, Nagano Keiki Co., Ltd., Japan) (Figure 2). This instrument consisted of a hydraulic pressure gauge and a biting element made of a vinyl material that was encased in a disposable polyethylene tube. The transducer arm with the disposable occlusal tube in place was 10-mm thick. The occlusal tube protected the participants' teeth and ensured hygienic conditions. When measuring, the transducer was placed between the upper and lower first molars. The maximum bite force was recorded 3-times on each side, starting on whatever side the subject chose. Between each bite, the subjects rested for 15 seconds. The maximum bite force was the mean value pooled from the highest recordings from the left and the right sides. The measuring range of the gauge was from 0–1200 N.

Figure 2. The portable occlusal gauge (GM10, Nagano Keiki Co., Ltd., Japan) used for measuring bite force.

The force values were displayed digitally on the gauge screen. The accuracy of this instrument has been confirmed in previous studies [35,36].

The muscular endurance was always the last measurement to be taken. Each subject clenched with the portable occlusal gauge in place and maintained a bite force value at 50% of their maximum force value as long as possible. The duration (seconds) was then recorded using a digital stopwatch. One measurement was taken on each side, starting on whatever side the subject chose, with 5 min between measurements. The mean of the two values was used as the muscular endurance value for each recording occasion.

Statistical analysis

Statistical calculations were performed using the SPSS (Statistical Package for Social Sciences for Macintosh, version 17.0, SPSS Inc. Headquarters, Chicago, IL). The Student's t-test and the Mann-Whitney test were used to examine the possible differences in mean maximum bite force and endurance measured on different measuring occasions within each group as well as the possible inter-group differences between the two variables measured on each measuring occasion. A difference was considered to be statistically significant if the p-value was less than 0.05.

Results

Control group

Neither the maximum bite force nor the muscular endurance duration changed significantly in the control group. The variables were measured on two occasions with time intervals up to 3 months. On the first measurement, the mean value for the bite force was 647 ± 120 N and the muscular endurance duration was 39 ± 8 s. On the second occasion, the maximum bite force was 685 ± 126 N and the muscular endurance duration was 39 ± 5 s.

Training groups

Baseline values in the CTG and the ITG. The CTG mean baseline values were 745 ± 184 N for the maximum bite force and 43 ± 17 s for the muscular endurance duration. The corresponding ITG baseline values were 709 ± 141 N for the maximum bite force and 37 ± 11 s for the muscular endurance duration, respectively. No statistically significant differences were found for mean baseline values of the maximum bite force or the muscular endurance duration for either the controls or the training groups or between the training groups.

Differences within the CTG and the ITG. In the CTG, both the maximum bite force and the muscular endurance duration increased significantly during

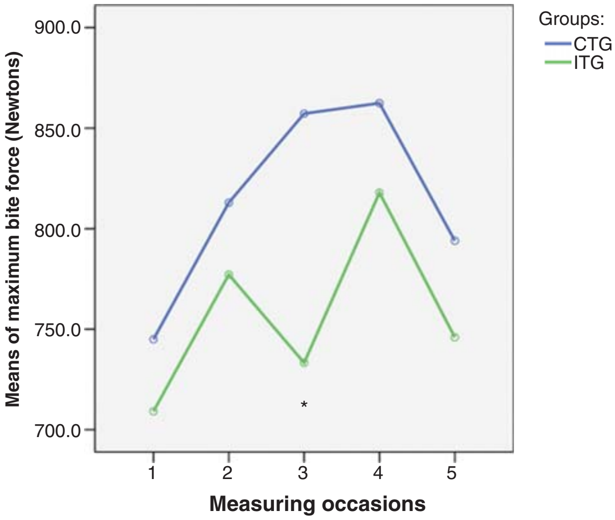

Figure 3. Changes of means of maximum bite force (Newtons) measured at different occasions for the CTG and the ITG (* $p < 0.05$, Mann-Whitney test in comparisons between the training groups). CTG, Continuous training group; ITG, Intermittent training group; Measuring occasions: 1, start; 2, end of 1st month (training for both the CTG and the ITG during the 1st month); 3, end of 2nd month (training for the CTG, no training for the ITG during the 2nd month); 4, end of 3rd month (training for both the CTG and the ITG during the 3rd month); 5, end of 4th month (no training for both the CTG and the ITG during the 4th month).

the first month of training (Figures 3 and 4). During the 2nd month of training, the maximum bite force continued to increase significantly compared to the mean value after 1 month of training, although the degree of the increase was lower than that achieved in the 1st month. The increase of the muscular endurance duration was not altered significantly during the 2nd month. The increase faded during the 3rd month of training with non-significant changes both for the bite force and the muscular endurance duration compared to values at the end of the 2nd month. During the last-month's experimental period—i.e. when all participants stopped training—the maximum bite force as well as the muscular endurance duration dropped significantly. The values for both variables measured at the end of the experiment were higher than the onset values, but they did not differ significantly (Table I and Figures 3 and 4).

In the ITG, both the maximum bite force and the muscular endurance duration increased significantly during the 1st month of training (Figures 3 and 4). During the 2nd month, when the participants in this group stopped training, both the maximum bite force and the muscular endurance values dropped, but only the drop of the maximum bite force differed significantly. A significant increase resumed for both variables when the participants in the ITG started training again during the 3rd month of the experiment. During the last-month's experimental period (i.e. when all the subjects stopped training), both the maximum bite force and the muscular endurance duration dropped significantly. This drop was also observed for the same time interval for the CTG. In addition, the ITG values for both variables measured at the end of the experiment were higher than the initial values, although the differences were not statistically significant (Table I and Figures 3 and 4).

Differences between the CTG and the ITG. During the 1st month, when both groups trained their masticatory muscles as instructed, both the mean maximum bite force and the muscular endurance duration increased the same (Table II). The corresponding values between the groups were not found to differ significantly. At the end of the 2nd month, when the CTG continued training and the ITG had already stopped training (end of 1st month), the values diverged significantly: the values in the CTG were higher than the values in the ITG. During the 3rd month, when the CTG continued training and the ITG resumed training, the values for the ITG were similar to the values for the CTG and the differences became statistically non-significant. Both the maximum bite force and the muscular endurance duration for both groups dropped similar amounts during the last month of the experiment, i.e. the 4th month, when both groups stopped training. The values measured at the end of the experimental period did not differ significantly between the two groups (Figures 3 and 4). In general, the values for maximum bite force

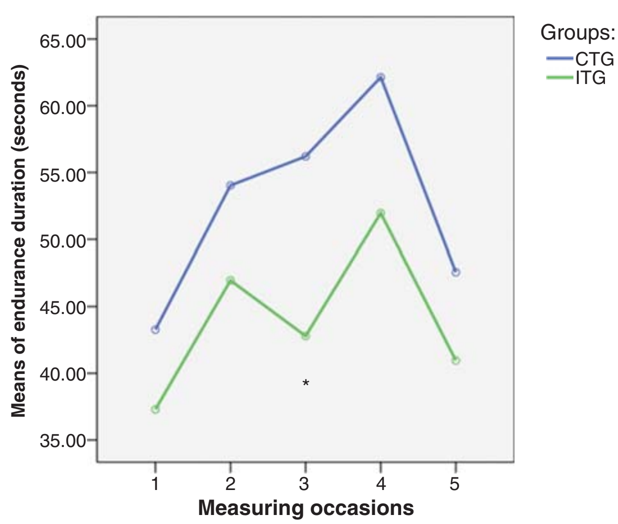

Figure 4. Changes of means of muscular endurance duration (seconds) measured at different occasions between the groups (* $p < 0.05$, Mann-Whitney test in comparisons between the training groups). CTG, Continuous training group; ITG, Intermittent training group; Measuring occasions: 1, start; 2, end of 1st month (training for both the CTG and the ITG during the 1st month); 3, end of 2nd month (training for the CTG, no training for the ITG during the 2nd month); 4, end of 3rd month (training for both the CTG and the ITG during the 3rd month); 5, end of 4th month (no training for both the CTG and the ITG during the 4th month).

Table I. Comparison of maximum bite force (Newtons) and muscular endurance duration (seconds) between different measuring occasions within the CTG and the ITG.

Variable	Difference between measuring occasions	CTG	ITG
Maximum bite force (Newtons)	1→2	⇑ S	⇑ S
	2→3	⇑ S	⇓ S
	3→4	⇑ NS	⇑ S
	4→5	⇓ S	⇓ S
	1→5	⇑ NS	⇑ NS
Muscular endurance duration (seconds)	1→2	⇑ S	⇑ S
	2→3	⇑ NS	⇓ NS
	3→4	⇑ NS	⇑ S
	4→5	⇓ S	⇓ S
	1→5	⇑ NS	⇑ NS

CTG, Continuous training group; ITG, Intermittent training group; Measuring occasions: 1, start; 2, end of 1st month (training for both the CTG and the ITG during the 1st month); 3, end of 2nd month (training for the CTG, no training for the ITG during the 2nd month); 4, end of 3rd month (training for both the CTG and the ITG during the 3rd month); 5, end of 4th month (no training for both the CTG and the ITG during the 4th month); ⇑, value increased; ⇓, value decreased; NS, non-significant; S, significant.

and muscular endurance duration exhibited a similar pattern in both groups (Figures 3 and 4).

Discussion

Both the training groups were as homogenous as possible to ensure the comparisons were valid. Therefore, a control group was also used to establish whether the values for bite force and muscular endurance duration, which were measured on two occasions (1–3 month time intervals), were similar to the participants in the experimental groups before training. No statistically significant changes were found among the groups before the CTG and the ITG started to train. Otherwise, this matter would have been a confounder.

The finding that the maximum bite force in the control group did not change significantly over time agrees with some previous studies [33,37]. However, other authors have reported that the bite force may increase. In growing young children, an increase in bite force can be ascribed to a natural increase in somatic growth [28]. In growing individuals, this may favour a normal dentofacial growth [23]. The maximum bite force depends on factors such as the strength of the masticatory muscles, the tolerance of the teeth, the condition of the periodontal tissues and the TMJs and subjective perception [33,34]. In the present study, the individuals investigated were adults with no or minor growth left, which may have contributed to the relatively stable bite force values measured in the control group.

For both the ITG and the CTG, the maximum bite force and the endurance duration increased after the chewing exercises, a finding that agrees with previous investigations [34,38]. Both the maximum bite force and the endurance duration for both the ITG and the CTG reached the highest values by the 3rd month from the start of the experiment, despite 1 month of rest after the 1st month of training in the ITG. Both groups showed a higher maximum bite force value and a slightly longer endurance duration at the end of the experiment, although the values were non-significant compared to the baseline values. The maximum bite force has been reported to remain at a high level 2 weeks after masticatory muscle training [33]. In the present study, the recordings were made with a time interval of 1 month, which may explain why this phenomenon was not observed. Another possible reason may be that more participants would be necessary to detect a statistical difference since the variance values were found to be high. In general, females show lower maximum bite force values compared to men [39]. Both test groups included males and females that were fairly evenly distributed between the groups. The wide variation in individual values for both the maximum bite force and the length of the muscular endurance duration may partly depend on gender.

Both the maximum bite force and the muscular endurance duration dropped at a higher rate during the last month of 'resting' compared to the 'resting' period during the 2nd month. At least one question remains to be answered: Is there a correlation between a higher increase in bite force and muscular endurance duration following training and a faster rate of

Table II. Values of maximum bite force (Newtons) and muscular endurance duration (seconds) measured at different occasions.

Variable	Measuring occasions	CTG (mean ± SD)	ITG (mean ± SD)
Maximum bite force (Newtons)	1	745 ± 184	709 ± 141
	2	813 ± 139	777 ± 135
	3	857 ± 130	733 ± 142
	4	862 ± 146	817 ± 188
	5	794 ± 148	746 ± 193
Muscular endurance duration (seconds)	1	43 ± 17	37 ± 11
	2	54 ± 13	47 ± 12
	3	56 ± 13	43 ± 10
	4	62 ± 16	52 ± 10
	5	48 ± 12	41 ± 8

CTG, Continuous training group; ITG, Intermittent training group; Measuring occasions: 1, start; 2, end of 1st month (training for both the CTG and the ITG during the 1st month); 3, end of 2nd month (training for the CTG, no training for the ITG during the 2nd month); 4, end of 3rd month (training for both the CTG and the ITG during the 3rd month); 5,end of 4th month (no training for both the CTG and the ITG during the 4th month).

dropping of the variables when training stops? Future studies with larger sample sizes should investigate the long-term training effects.

This study found no signs or symptoms of TMD as a result of training. At the start of the study, all subjects were objectively confirmed as healthy with regard to masticatory muscles and TMJ function. Therefore, no improvement of functional status was expected.

There are various methods available for masticatory muscle training. The use of hard chewing gums has been shown to influence both sagittal and vertical occlusal development [28]. However, for children, especially handicapped children, training alternatives to chewing gums are necessary as there is a risk of uncontrolled swallowing and subsequent obstruction of airways. The Chewy Tubes™ used in the present study were accepted without complaints from any of the participants. The devices were replaced when they started to show signs of wear at check ups or noticed by the participants. The tubes were inexpensive and easy to carry and are believed to be safe to use with young children, in that they cannot be swallowed.

For older children and adults, a mouth-driven computer game may be an alternative. Such a device has already been constructed and tested in a pilot study at the Swedish National Orofacial Centre for Rare Disorders (Mun-H-Centre) in Gothenburg. For the time being, there are no published results of these training effects. Nevertheless, the method seems promising.

How to maintain the achieved masticatory strength after completion of intensive training needs further investigation. The best choice may be a combination of methods. These methods may include a diet that includes hard-to-chew food and regularly chewing sugar-free chewing gums in conjunction with repeated periods of muscle training with oral motor devices. Furthermore, masticatory muscle exercises may be achieved by integrating biting movements into people's modern habits developed in the contemporary computer era. For example, different mouth-driven computer games could be used where a unilateral or bilateral biting plate replaces an ordinary computer mouse.

Conclusions

The present study indicated that the masticatory muscles were strengthened after subjects participated in a continuous or interrupted exercise protocol that lasted 4-months. Irrespective of whether a continuous or intermittent training protocol was used, the effects diminished gradually when the exercises stopped. 'Untrained' masticatory muscles can regain their initial strength with a short training period. Future research is needed to elucidate how to maintain the increased muscular strength as well as how to evaluate treatment modalities or likely combinations of different training methods.

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