Original Article

Comparison of Masticatory Muscle Effort when Chewing on an Anterior Bite Plane Fabricated from Hard and Soft Materials

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Abstract

Background: Different anterior bite plane materials may affect masticatory muscle effort (ME) differently. ME is defined in this study as the electrical activity used per unit of bite force. **Objective:** We aimed to compare the effects of a hard acrylic resin anterior bite plane (HARD) and a semi-soft thermoplastic anterior bite plane (SOFT) on ME over a 3-month period in children with deep bites. **Materials and methods:** Thirty-eight children with deep bites were randomly assigned to either the HARD or SOFT group (n = 19 each). Masseter and anterior temporalis activity along with maximum bite force (MBF) were measured during appliance placement. Anterior and posterior ME were calculated by dividing muscle activity by the anterior and posterior MBF, respectively. Data were collected at baseline (T0), at one month (T1), and at three months (T2). Within- and between-group comparisons were performed ($\alpha = 0.05$). **Results:** Neither significant intra-group nor between-group of ME was found throughout the study period ($P > 0.05$). **Conclusion:** Neither a hard nor soft anterior bite plane had a disadvantageous effect on ME as none of the ME values exceeded the baseline values during treatment.

Keywords: Bite force, Deep bite, Hardness, Masticatory muscles, Orthodontic appliances

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Introduction

Several parameters have been used to assess the changes in masticatory functions after orthodontic interventions. The changes can include maximum bite force, masticatory muscle activities, masticatory performance, muscle activity balance, and occlusal contact area,[1-5] all of which measure its own specific aspect of masticatory function. Another parameter namely masticatory muscle effort (ME) stands as a crucial parameter that has been extensively investigated.[6-8] It encompasses the effective completion of masticatory tasks by an oral apparatus without unnecessary time or energy consumption.[9] Various methodologies have been employed to explore this concept with the common goal of assessing the effort exerted by the masticatory system in achieving a unit of masticatory outcome.

ME has been characterized in various ways that range from assessing the effort needed for standardised comminution to measuring individual abilities to fragment foods within a specific time frame.[7] Studies have employed diverse metrics such as the ratio of electrical signals of masticatory muscles to maximum bite force (MBF),[10] work output by MBF divided by energy input via surface electromyography (sEMG),[11] or the slope of bite force/sEMG under assigned bite forces.[12] In this study, ME is defined as the electrical activity used per unit of bite force (EMG/BF ratio),[13,14] which implies that higher ME indicates increased activity of masticatory muscles in generating a unit of bite force.

Research suggests that occlusal rehabilitation and correction of malocclusion can positively impact masticatory efficiency, or, in other words, improve ME. Vertical rehabilitation with complete dentures[6] and correction of retrognathic mandibles using functional jaw orthopedics[15] have demonstrated ME improvement. Conflicting results exist with certain studies that reported no significant change in ME among patients treated with fixed orthodontic appliances.[8]

A shift from posterior to anterior occlusion can impact function, as evidenced in a study involving adults with Class I malocclusion exhibiting normal overjet and overbite. This study demonstrated increased muscular effort during anterior biting, which indicated that alterations in occlusal patterns may influence masticatory muscle function.[16] The observed differences in vertical dimensional changes may be attributed to variations in muscle activity and bite force.[4] Notably, biting an object with the incisors requires a smaller mouth opening compared to biting on the molars.

According to a mechanical advantage study,[16] a reduced mouth opening correlates with higher masticatory muscle effort needed to generate a unit of bite force. We hypothesized that individuals with a deep bite may exhibit the opposite pattern. The excessive vertical overlap of the incisors in deep bite patients may necessitate a greater mouth opening when biting on the incisors than when biting on the molars. Consequently, muscle effort may differ from that observed in subjects with a normal overbite.

It is important to consider that the use of an anterior bite plane, commonly employed to address deep bites, further increases the required mouth opening beyond the normal range. However, the impact of a removable anterior bite plane on masticatory efficiency remains unexplored. Material hardness on the biting surface is another factor that may influence muscle effort by altering the proprioceptive feedback pathway. Studies indicated that softer thermoplastic materials for orthodontic appliances might have advantages in terms of aesthetics, comfort, and flexibility. However, a direct comparison of ME between hard acrylic resin and semi-soft thermoplastic materials, particularly in the context of anterior bite planes, is lacking.

This randomised clinical study aimed to address this gap by comparing the effects of a hard acrylic resin anterior bite plane (HARD) and a semi-soft thermoplastic anterior bite plane (SOFT) on ME over a three-month period in children with a deep bite. The hypothesis posited no significant difference in ME between subjects wearing either the HARD or the SOFT.

Materials and methods

Study design

This study was a blind secondary data analysis from a previous randomized controlled trial[1] conducted at the Dental Hospital, Faculty of Dentistry, Prince of Songkla University with an equal allocation ratio. The intention-to-treat protocol was applied under the authorization of the human experimental ethics committee of the Faculty of Dentistry, Prince of Songkla University (Ethical Approval Number: EC6305-019) and submitted to the Thai Clinical Trial Registry (TCTR20210330002).

Sample size calculation

The sample size was calculated based on a study that investigated jaw-muscle mechanical advantage and activities during isometric bites in normal adults[16] using the G*power program version 3.1.[17] Using an effect size of 0.84, α = 0.05, and β = 0.80, at least 19 samples were needed per group.

Participants, eligibility, and setting

Healthy subjects aged 9-13 years with late mixed dentition who attended the Dental Hospital of the Faculty of Dentistry, Prince of Songkhla University in previous study were randomly recruited into this study. All individuals and their parents provided written informed consent prior to participation in the study.

Before enrollment in the study, all volunteers underwent a dental examination by one examiner to determine the degrees of overjet and overbite with reference to the occlusal plane. The most vertical and horizontal overlapping of the maxilla and mandibular central incisors (overbite and overjet) were evaluated using a periodontal probe. Lateral cephalometric radiographs were taken following the same protocol and using the same machine to determine the vertical and horizontal skeletal relationships. An investigator analysed the cephalometric data using Dolphin Imaging software version 11.9 (Dolphin Imaging and Management Solutions, Chatsworth, CA, USA).

The inclusion criteria included participants with (1) maxillary incisal edges that vertically covered more than 40 % of the clinical crown height of the mandibular incisors, (2) an overjet range of 1 to 5 mm, (3) skeletal Class I or mild Class II (ANB = 1-9°), (4) normodivergent or hypodivergent pattern (SN-MP < 35°), (5) angle Class I or II molar relationship, (6) no history of trauma to the lower or upper anterior teeth, (7) no signs and symptoms of a temporomandibular disorder or parafunctional habits, and (8) no prior history of orthodontic treatment.

Subjects were not enrolled if they had (1) incomplete root formation of the mandibular incisors on panoramic radiographic imaging, (2) clinical absence of the mandibular incisors or first molars, (3) insufficient tooth number or insufficient clinical crown height to provide retention of an appliance, (4) craniofacial anomalies, systemic diseases, or neuromuscular disorders, (5) long-term use of anti-inflammatory drugs, immunosuppressive medications, or neuromuscular-targeting medications, or (6) an inability to co-operate with the trial.

Randomization and blinding

The recruited subjects were consecutively randomly assigned by computer-generated numbers into the two types of anterior bite planes (n = 19 each) (www.random.org). The participants were treated by two orthodontists and the data collection and measurements were performed by one investigator. Blinding of both subjects and operators to the appliance materials was not feasible. Therefore, a single-blind approach was implemented at the level of the statistician.

Interventions

The HARD appliance was anchored with Adam's clasps around the upper first molars accompanied by a labial bow and a baseplate featuring a front bite surface made of polymethyl methacrylate (PMMA). The labial bow was extended to preserve space for the permanent canine in case of uneruption or

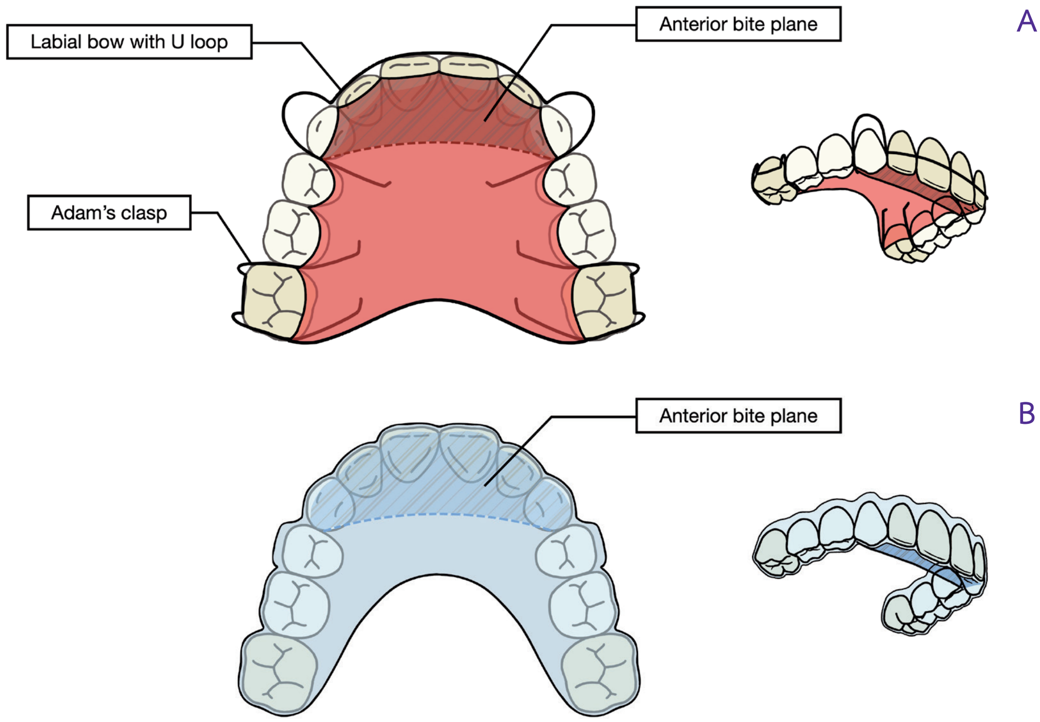


Figure 1 Occlusal view and the components of the HARD (A) and SOFT (B)

partial eruption. This configuration was positioned in the articulated dental model at the centric relation while maintaining a 2-mm separation between the first permanent molars. (Figure 1A). Four mandibular incisors were consistently occluded on the bite plane. The SOFT appliance was made from 1.80-mm-thick thermoplastic bi-laminate composed of polyethylene terephthalate glycol copolyester and polyurethane (Durasoft® pd; Scheu-Dental, Iserlohn, Germany). An anterior bite plane was prepared on the palatal surface of the maxillary incisors with plaster on the working model. The models were articulated the same as the HARD appliance, except that the first permanent molars were 2.50 mm vertically separated to compensate for the 0.30-0.50 mm shrinkage of the material thickness during the heated vacuum forming process. This ensured that both groups had an equal amount of bite opening. The margin of the SOFT appliance was then trimmed apically 2-3 mm beyond the gingival margin (Figure 1B).

The participants were instructed to wear the appliance at all times. Daily reminders were sent to the participants via a smartphone text application to enhance compliance. The participants were scheduled for follow-up every month after receiving the appliance. If an appliance broke or was lost, it was repaired or refabricated as quickly as possible.

Electromyographic examination

Surface electromyography (sEMG) was performed using an 8-channel BioEMG III and BioPAK Measurement System (BioResearch, Inc., Milwaukee, WI, USA) to evaluate the muscle activity of the masseter and anterior temporalis muscles. The data were recorded in microvolts (μV) following the Surface Electromyography for the Non-Invasive Assessment of Muscles guidelines.[18]

The participants sat relaxed in a chair with unsupported head for 5 minutes prior to the examination in a quiet environment without interruptions. The superficial skin of the target muscles was scrubbed with 70 % alcohol and dried before electrode placement. Bipolar surface electrodes (BioFLEX, BioResearch Associates, Inc., Brown Deer, WI, USA) with fixed distances of 20 mm were positioned on the target muscles and confirmed by the modified template by Castroflorio et al.[19] According to Ferrario et al.,[20] electrodes for the anterior temporalis muscles were placed vertically along the anterior muscular margin over the coronal suture. The electrodes for the masseter muscles were aligned parallel to the muscle fibres. The upper pole of the electrode was located at the intersection between the tragus-labial commissure and the exocanthion-gonion lines. Ground electrodes were attached on the most prominent part of the cervical spine on the posterior neck.[21]

Participants were instructed on the measurement procedures and allowed to practice to attain reproducibility. With the appliance in place, the subjects were instructed to clench their teeth as hard as possible for 3 seconds on 10-mm-thick cotton rolls placed on both sides of the posterior teeth. The highest value was set as 100 % as a reference point to standardise the subsequent data across the subject and timing. Following this, with the appliance still in the mouth, the participants followed the instruction to produced five series of 3 seconds of maximal clenching and 3 seconds relaxing. The average values were calculated as the percentage of maximum voluntary clenching compared to the reference value (% MVC). Data were collected at four time points: pretreatment (T0), which served as the baseline data without the appliance in place; at 1 month (T1); and at 3 months (T2) after appliance delivery measured with the appliance intraorally.

Maximum bite force (MBF) recording

A 6-mm-thick custom-made bite force meter with a force-sensing resistor was used to assess the anterior and the right and left posterior MBF. The sensor was calibrated with a Universal Testing Machine (Lloyd instruments, Model LRX-Plus, AMETEK Lloyd Instrument Ltd., Hamphshire, United Kingdom), in increments of 50 Newtons (N) from 0 to 800 N. The validity and reliability were confirmed with a Pearson's correlation of 0.99 and an intraclass correlation of 0.99. The components of the bite force recording device and measurement procedure were previously published[1,2] (Figure 2).

The MBF was recorded subsequent to the sEMG recording with 15 minutes of rest. Subjects were asked to sit upright without head support and rest for 5 minutes before the measurement. The bite force recording device was sterilized and covered with a piece of disposable latex sheet.

The centre of the device's sensor was placed on the maxillary central incisors area for the anterior MBF measurement, and on each permanent maxillary first molar to record the right and left MBF. With the appliance in place, subjects were requested to bite as hard as possible without pain for 3 seconds with 30 second intervals to avoid muscle fatigue. The MBF

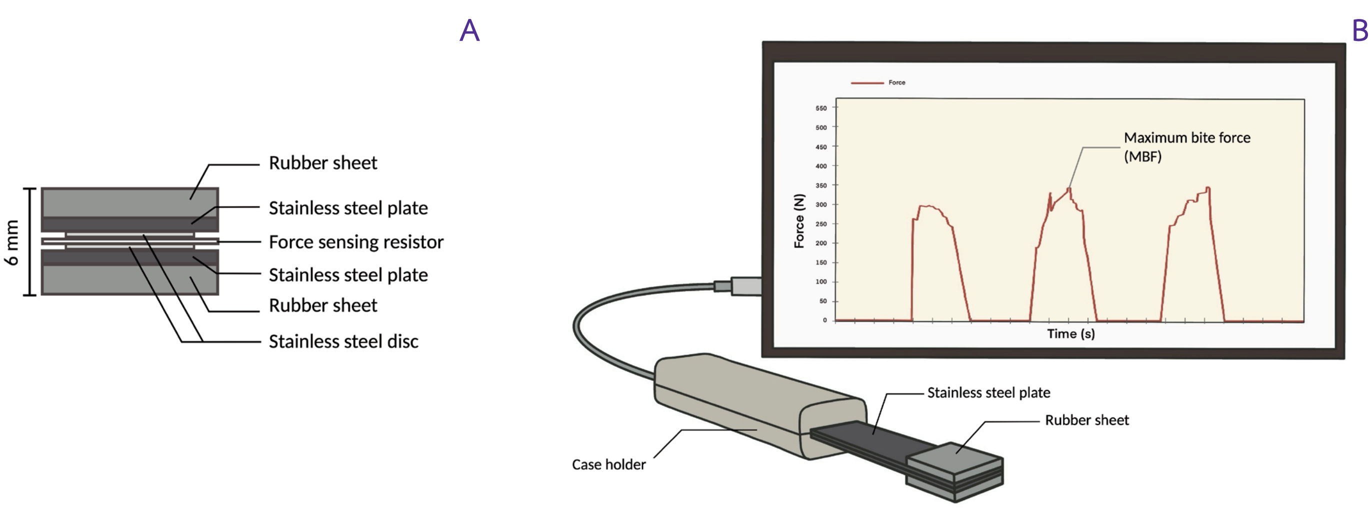


Figure 2 Composition of the custom-made bite force meter (A) and measuring program (B)

was automatically calculated and displayed in N. Three replicates were performed, and the maximum values were averaged. The posterior MBF was calculated as the average of the right and left MBF. Data were gathered at four time points following the same schedule as the sEMG measurements.

Masticatory muscle effort (ME)

The ME, which was defined as the ratio of energy input to work output, was derived from the division of the % MVC by the anterior or posterior MBF while wearing the appliance regarding each muscle (% MVC/MBF). The anterior and posterior ME of the masseter and temporalis muscles were calculated.

Statistical analysis

The results were analysed by SPSS program version 17 (SPSS Inc., Chicago, IL, USA). The Kolmogorov-Smirnov test signified the normal distribution of age and cephalometric values, while non-normal distribution was presented in other parameters. Thus, the student *t*-test was used to analyse the differences of age and cephalometric values between groups. Non-parametric statistical tests were applied due to large variations among subjects as follows: Chi-square test for gender ratio evaluation, Mann-Whitney *U* test to compare % MVC, MBF, and ME between the two treatment groups and assess similarity across the sides of MBF and % MVC, and Friedman's tests with pairwise comparisons and the Bonferroni correction for within-group comparison across the session of % MVC, MBF, and ME. The level of significance was set at $P < 0.05$.

The repeatability of the dentoskeletal evaluation and muscle activity was re-examined after 15 minutes in 10 random subjects by the same protocol and examiner. The intraclass correlation coefficient (ICC) presented acceptable reproducibility (ICC = 0.93-0.97 for lateral cephalometric variables, 0.65-0.79 for sEMG variables, and 0.55-0.85 for MBF). Dahlberg's formula indicated acceptable random error (0.50° for angular variables, 0.50 mm for linear variables, 19.83 μV for muscle activity, 15.99 N for anterior MBF, and 75.18 N for posterior MBF).

Results

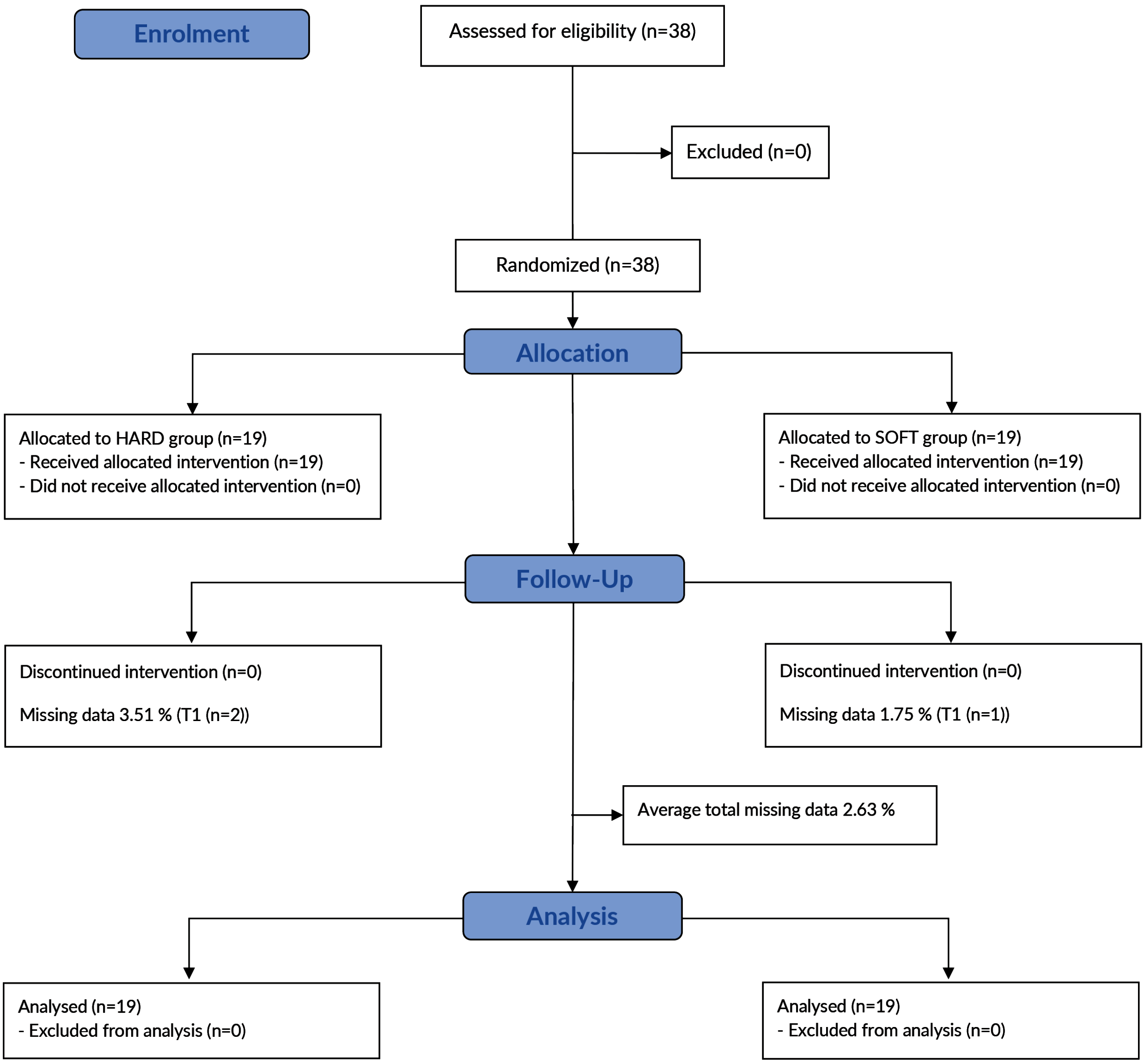
The CONSORT diagram of the patient assessment and enrolment process shows the recruitment of 38 children. 21 boys and 17 girls were consecutively randomised into two treatment groups. During the trial, no volunteers were harmed or dropped out. Since the study was conducted during the outbreak of the COVID-19 pandemic, some individuals were absent at some time points, which accounted for 2.63 % of missing data. The missing values were replaced via a simple imputation procedure based on the mean of the individual variables[22] (Figure 3).

At pretreatment, no statistically significant differences ($P > 0.05$) between the two groups in gender, age, or vertical and horizontal dental and skeletal relationships were found (Table 1). Since there were no significant differences ($P > 0.05$) between the right and left posterior MBF, % MVC of the masseter muscle, and % MVC of the temporalis muscle, the values for each parameter from the right and left sides were combined and averaged to represent the subject's posterior MBF, % MVC of the masseter muscle, and % MVC of the temporalis muscle. At T0, all parameters of the two groups were not statistically significantly different ($P > 0.05$) (Table 2).

In terms of intra-group comparisons at different time points, both the HARD and SOFT groups exhibited similar patterns of masticatory function changes. At one month (T1), % MVC of the temporalis muscles significantly decreased ($P < 0.05$), while the % MVC of the masseter muscles, anterior MBF, and posterior MBF were insignificantly changed ($P > 0.05$). All masticatory function parameters were not significantly different from the baseline (T0) at the third month (T2) ($P > 0.05$).

Inter-group comparison, it was observed that only the % MVC of the temporalis muscle in the HARD group was significantly higher than the SOFT group at one month (T1) ($P < 0.05$).

The anterior and posterior ME of the masseter and temporalis muscles did not show significant differences ($P > 0.05$) in both intra- and inter-groups comparisons (Table 3).



Abbreviations:
HARD, anterior bite plane fabricated from acrylic resin; SOFT, anterior bite plane fabricated form bi-laminate thermoplastic;
T0, pre-treatment; T1, 1 month after appliance placement, T2; 3 months after appliance placement

Figure 3 CONSORT flow diagram of the study

Table 1 Pretreatment gender ratio and median (interquartile range) of pretreatment characteristics

Variables (Median (IQR))	HARD (n = 19)	SOFT (n = 19)	*P* value
Boy:girl ratio	10:9	11:8	0.744†
Age (year)	12.03 (1.38)	11.04 (2.21)	0.124‡
SN-MP (°)	29.70 (8.40)	31.00 (7.20)	0.876‡
ANB (°)	3.20 (2.40)	5.00 (1.60)	0.179‡
Overbite (mm)	4.00 (1.50)	4.50 (3.00)	0.603§

Abbreviations: HARD, anterior bite plane fabricated from acrylic resin; SOFT, anterior bite plane fabricated from bi-laminate thermoplastic.

† *P* values for Chi-square test. ‡ *P* values for Student *t*-test. § *P* values for Mann-Whitney *U* test. * $P < 0.05$

Table 2 Comparisons of muscle activity between HARD and SOFT in different time points.

Index	Group	Examination time point (Median (IQR))			*P* value ‡ (Within-group comparison)
		T0	T1	T2	
% MVC temporalis	HARD	126.59 (54.27)[a]	95.98 (45.46)[b]	111.40 (36.48)[a]	0.017*
	SOFT	107.97 (18.27)[a]	62.11 (40.93)[b]	95.65 (18.05)[a]	0.002*
	P value† (Between-group comparison)	0.339	0.012*	0.085	
% MVC masseter	HARD	102.50 (64.07)[a]	73.65 (53.43)[a]	107.29 (62.88)[a]	0.058
	SOFT	97.03 (59.66)[a]	73.02 (66.65)[a]	107.23 (43.83)[a]	0.060
	P value† (Between-group comparison)	0.884	0.865	0.772	
Anterior MBF (N)	HARD	129.86 (40.34)[a]	109.59 (24.10)[a]	117.39 (13.38)[a]	0.422
	SOFT	128.57 (36.89)[a]	109.56 (23.85)[a]	115.18 (21.04)[a]	0.244
	P value† (Between-group comparison)	0.398	0.981	0.888	
Posterior MBF (N)	HARD	334.85 (78.88)[a]	307.43 (123.48)[a]	313.12 (73.36)[a]	0.186
	SOFT	360.88 (84.59)[a]	315.26 (113.06)[a]	312.16 (100)[a]	0.554
	P value† (Between-group comparison)	0.453	0.869	0.851	

Abbreviations: HARD, anterior bite plane fabricated from acrylic resin; SOFT, anterior bite plane fabricated from bi-laminate thermoplastic; % MVC, percentage of maximum voluntary clenching; MBF, maximum bite force; T0, pre-treatment; T1, 1 month after appliance placement; T2, 3 months after appliance placement; IQR = Interquartile range.

† *P* values for between-group comparisons at the same time-point (Mann-Whitney *U* test).

‡ *P* values for within-group comparisons between time-points (related sample Friedman's test), significance value was adjusted by the Bonferroni correction for Dunn's pairwise comparisons between time points within group.

* *P* < 0.05, ** *P* < 0.01, *** *P* < 0.005

Values with the same lower-case letters were not significantly different in post-hoc and pairwise comparisons between time points.

Discussion

The % MVC of temporalis muscles was temporally decrease after appliance insertion. It was returned to baseline at 3 months of treatment. In contrast, the % MVC of masseter muscles and MBF did not show the different from the baseline. The results were conformed with the previous study presenting the adaptation ability of muscles after appliance insertion.[1]

The within-group comparison of muscle effort in both the HARD and SOFT groups did not follow the

Table 3 Comparisons of anterior and posterior masticatory muscle effort (ME) between HARD and SOFT in different time points.

Index	Group	Examination time point (Median (IQR))			*P* value ‡ (Within-group comparison)
		T0	T1	T2	
Anterior ME Temporalis	HARD	0.94 (0.68)[a]	0.72 (0.42)[a]	0.87 (0.32)[a]	0.113
	SOFT	0.93 (0.28)[a]	0.62 (0.31)[a]	0.78 (0.28)[a]	0.095
	P value † (Between-group comparison)	0.690	0.222	0.231	
Anterior ME Masseter	HARD	0.76 (0.66)[a]	0.70 (0.57)[a]	0.97 (0.56)[a]	0.098
	SOFT	0.80 (0.41)[a]	0.64 (0.43)[a]	0.90 (0.78)[a]	0.186
	P value † (Between-group comparison)	0.589	0.778	0.778	
Posterior ME Temporalis	HARD	0.33 (0.18)[a]	0.31 (0.15)[a]	0.33 (0.16)[a]	0.170
	SOFT	0.30 (0.07)[a]	0.28 (0.13)[a]	0.30 (0.14)[a]	0.195
	P value † (Between-group comparison)	0.385	0.415	0.260	
Posterior ME Masseter	HARD	0.29 (0.16)[a]	0.23 (0.15)[a]	0.34 (0.15)[a]	0.082
	SOFT	0.28 (0.12)[a]	0.24 (0.17)[a]	0.30 (0.21)[a]	0.195
	P value † (Between-group comparison)	0.291	0.425	0.253	

Abbreviations: HARD, anterior bite plane fabricated from acrylic resin; SOFT, anterior bite plane fabricated form bi-laminate thermoplastic; ME, masticatory muscle effort; T0, pretreatment; T1, 1 month after appliance placement; T2, 3 months after appliance placement; IQR = Interquartile range.

† *P* values for between-group comparisons at the same time-point (Mann-Whitney *U* test).

‡ *P* values for within-group comparisons between time-points (related sample Friedman's test), significance value was adjusted by the Bonferroni correction for Dunn's pairwise comparisons between time points within group.

* $P < 0.05$, ** $P < 0.01$, *** $P < 0.005$

Values with the same lower-case letters were not significantly different in post-hoc and pairwise comparisons between time points.

trend of the change in % MVC of temporalis muscles. The decreasing of temporalis muscles activity, while the insignificantly changed of the posterior ME and the posterior MBF at T1, suggests that it had no impact on the production of posterior bite force. It could be inferred from the result that the masticatory muscle effort depends on the masseter. Many studies agree that the masseter is the crucial affected muscle from the changes of intraoral environment by an interocclusal appliances.[23,24]

The insignificantly differences of muscle effort to baseline levels after one month of treatment suggests that the subjects quickly adapted to the anterior bite plane regardless of the type of materials used. A study was confirmed by using functional magnetic resonance imaging (fMRI) after prosthodontic treatment and found that there was a neuroplastic adaptation after 3 months.[25]

In terms of practical application, both the HARD and SOFT can be equally chosen in terms of the MBF and muscle effort, as they both exhibited no difference after one month of appliance insertion. However, a SOFT may be more preferable due to its association with less mandibular root volume loss.[26]

This study has some limitations. First, the results can only be generalised to growing patients whose muscle activities and bite force may be different from adults. Second, masticatory function parameters were recorded with the appliance in place at T1 and T2 that follows the recommendation that the appliance should be worn during meals. Consequently, the interpretation of the results may not be generalised to the alternate recommendation that the appliance may be removed during meals. Comparing masticatory function under both conditions could provide valuable insights for establishing suitable appliance-wearing protocols to preserve normal masticatory function. Third, muscle activity and bite force were not simultaneously recorded, although both parameters were measured immediately and subsequently under the same conditions. Designing a real-time synchronizing integrated system for bite force and the recording of muscle activity would yield more accurate data on masticatory muscle effort. Fourth, non-parametric statistical analysis was chosen because of large variations among subjects and the non-normal distribution of data. Efforts were made to normalise and standardise the data, as mentioned earlier, to facilitate comparisons across subjects and over time. Increasing the sample size in future studies may improve the chances of achieving normal data distribution. Lastly, the study applied an intention-to-treat protocol, reflecting practical outcomes in clinical situations. However, this approach may obscure the true effect of the intervention if subjects strictly adhere to the study protocol.

Conclusion

Within the study's limitations, both the hard and soft anterior bite planes demonstrated no disadvantageous effects on masticatory muscle effort, as none of the values exceed the baseline during treatment.

Author contributions

PW: Conceptualization, Methodology, Software, Validation, Investigation, Data curation, Writing-Original draft preparation, Writing-Reviewing and Editing, Visualization, and Project administration; UT: Conceptualization, Methodology, Data curation, Writing-Original draft preparation, Writing-Reviewing and Editing, Visualization, Supervision, and Project administration; MP: Conceptualization, Software, Writing-Original draft preparation, Writing-Reviewing and Editing, Visualization, Supervision, and Project administration.

Ethical statement

This study was applied under the approval of the human experimental ethics committee of the Faculty of Dentistry, Prince of Songkla University (Ethical Approval Number: EC6305-019) and submitted to the Thai Clinical Trial Registry (TCTR20210330002).

Disclosure statement

Authors have no the conflicts of interest.

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