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Original article

Predictive value of masseter muscle thickness and bite force on Class II functional appliance treatment: a prospective controlled study

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Summary

Aim: To prospectively evaluate the functional capacity of the masticatory musculature as a predictive variable in determining functional appliance treatment outcomes in Class II/1 malocclusion children.

Methods: Twenty Class II/1 malocclusion children (11.4 ± 1.7 years) were treated with functional appliances during 1 year. Masseter muscle thickness and maximal molar bite force measurements, lateral cephalograms, and study casts were taken before and after treatment. Twenty age- and gender-matched untreated children were included as a control group. Regression analyses were used to identify correlations between pre-treatment muscle characteristics and treatment outcomes.

Results: All treated patients showed dentoalveolar sagittal improvement. Maximal molar bite force and masseter muscle thickness decreased during the treatment period in the experimental group but increased in the control group. Children with lower pre-treatment maximal molar bite force showed more mesial movement of mandibular first molars, distal movement of maxillary first molars, and larger change in molar class during treatment. Children with thinner pre-treatment masseter muscles demonstrated more mandibular first molar mesialisation, mandibular incisor proclination, and opening of the gonial angle during treatment.

Conclusions: The initial condition of the masticatory muscles may partly determine treatment outcomes. Children with thinner pre-treatment masseter muscles or weaker bite force show greater dentoalveolar changes.

Introduction

In the treatment of Class II malocclusion in growing children reports demonstrate that improvement in jaw relationships can be achieved during early treatment with functional appliances (1–8). Although the treatment results obtained with functional appliances are often satisfactory, large inter-individual variation is observed both in skeletal and in dental treatment changes (9–11). Not all individuals respond the same way to functional appliance treatment. The large variation seen amongst patients is often attributed to compliance issues, but evidence of this variation is also found in studies where fixed functional appliances are used and thus the influence of patient compliance is excluded (12–14).

One factor that could in part explain inter-individual differences in response to functional appliance treatment may be the masticatory musculature and its functional capacity. It is known that masticatory muscle capacity varies significantly between growing individuals, as measured both by bite force (15–17) and masseter muscle thickness (18). In view of this fact, it has been speculated that the considerable variability seen in individual response to functional appliance treatment is possibly directly related to the individuals' muscle characteristics (19). Moreover, these muscle characteristics seem to be under genetic control (20). Based on recent evidence, it has been proposed that variation in masticatory muscle characteristics in Class II malocclusion growing children, such as masseter muscle thickness and maximal molar bite force, can be one of the possible causes of the reported variation of treatment results with functional appliances (21, 22).

The primary aim of the present investigation was to evaluate, using prospective study design, whether the functional capacity of the masticatory musculature can be used as a predictive variable in determining functional appliance treatment outcomes in Class II division 1 malocclusion children. The null hypothesis was that there is no effect of the functional capacity of the masticatory musculature on Class II functional appliance treatment outcomes. The secondary aim was to evaluate the effect of functional appliances on masticatory muscles in Class II division 1 functional appliance treatment. The null hypothesis here was that functional appliances have no effect on the masticatory muscles in comparison to untreated growing children.

Materials and methods

The present study was approved by the research ethics board of the University of Geneva (identification number: 07-020).

Subjects

The patient sample for the present prospective study consisted of an experimental group and a control group. The sample size of each group was calculated by performing a power analysis, based on a retrospective study looking at the predictive value of molar bite force on Class II functional appliance treatment outcomes (22). Mean values (53.2 and –34.2 N) and standard deviations (99.4 and 78.4 N) for changes in bite force in the experimental and control groups respectively were used with a 5 per cent alpha value and an 80 per cent power, and a minimum sample size of 18 patients in each group was calculated. Based on this information it was decided to use sample sizes of 20 patients in each group.

The experimental group consisted of 20 healthy Caucasian children with a Class II division 1 malocclusion which were asked to participate in the study. These children had attended an initial consultation at our University clinic, which was subsequently followed by the collection of standard initial (pre-treatment) diagnostic records and the establishment of a treatment plan which consisted of an activator. Informed consent was obtained from all subjects and their parents before commencing treatment. Inclusion criteria were the following: late mixed dentition; an ANB angle >4 degrees; an SNB angle ≤78 degrees; a non-extreme skeletal divergence with a maxillomandibular angle from 20 to 30 degrees; a full-cusp Class II molar relationship on one side and at least a half-cusp Class II molar relationship on the contralateral side; an overjet ≥6 mm. Exclusion criteria were the following: deciduous teeth extracted prematurely or permanent teeth extracted; transverse discrepancies; signs of condylar lesions or temporomandibular dysfunction or disorders; non-nutritive sucking habits; patients with Pierre Robin sequence or any form of clefting; patients with a craniofacial anomaly or syndrome; patients with muscular disorders.

The control group consisted of 20 healthy growing children, matched for gender and age to the experimental group, and without immediate need for orthodontic treatment. These children were selected from siblings of patients under treatment at our University clinic or children of staff at the University. Inclusion criteria were the following: Class I or Class II malocclusion. Exclusion criteria were the following: Class III malocclusion; traumatic occlusion; deciduous teeth extracted prematurely or permanent teeth extracted; transverse discrepancies; signs of temporomandibular dysfunction or disorders; non-nutritive sucking habits; striking dolichocephalic or brachycephalic facial patterns; patients with any form of clefting; patients with a craniofacial anomaly or syndrome; patients with muscular disorders.

Treatment protocol

The duration of the study period was 12 months. In the experimental group an activator, as described by Pfeiffer and Grobéty (23, 24), was used as the sole treatment appliance throughout this period. Patients were instructed to wear the appliance for 12 hours daily. The patients were regularly seen for follow-up appointments where selective adaptation of the activator was carried out as needed. The control subjects did not receive any form of orthodontic treatment throughout this 12-month period.

Experimental design

The present study design was prospective and longitudinal. The experimental group had standard diagnostic records taken pre-treatment (T1) as well as after the 12-month study period (T2). Diagnostic records consisted of height measurements, photographs, study casts, a panoramic radiograph, and a lateral cephalometric radiograph. These patients also had maximal molar bite force and ultrasonographic masseter muscle thickness measurements before (T1) and after (T2) the study period. The control group only had height, maximal molar bite force, and ultrasonographic masseter muscle thickness measurements before (T1) and after (T2) the study period.

Cephalometry

Lateral cephalometric radiographs were taken of all patients in centric occlusion with the head fixed in a cephalostat. The same machine was used for all children and the magnification adjusted to zero. The radiographs obtained were analysed by one operator, following calibration to the senior author, using cephalometric software (Viewbox 4 version 4.0.1.7, dHAL Software, Kifissia, Greece). The cephalometric reference points, lines and angles used in the analysis are shown in Figure 1. The superimposition of the lateral cephalometric radiographs was performed according to the structural method described by Björk and Skieller (25), ensuring that the pre-treatment SN plane was transferred to the subsequent post-treatment cephalometric tracing.

Study casts

Study casts were taken to measure overjet, overbite, and molar relationships. The molar relationship was recorded as a percentage of the Angle Class II relationship, an Angle Class I relationship denoted by zero, and a full cusp Angle Class II relationship denoted by 100 (26).

Maximum molar bite force

Maximum voluntary molar bite force was assessed using a digital force gauge with an 8.6mm thick bite element (Occlusal Force-Meter GM 10®; Nagano Keiki Co. Ltd, Tokyo, Japan) (27). The subject was seated upright in a dental chair, and the sensor placed between the first permanent molars of each side separately and the patient was asked to exert a maximum clenching effort but to stop when painful or uncomfortable. In order to obtain as high bite force levels as possible, the subjects were encouraged to 'do their best'. The recording (measured in Newtons) was taken twice on each side, each recording taking approximately 2–3 seconds, and the highest value used as the maximum molar bite force for analysis. All

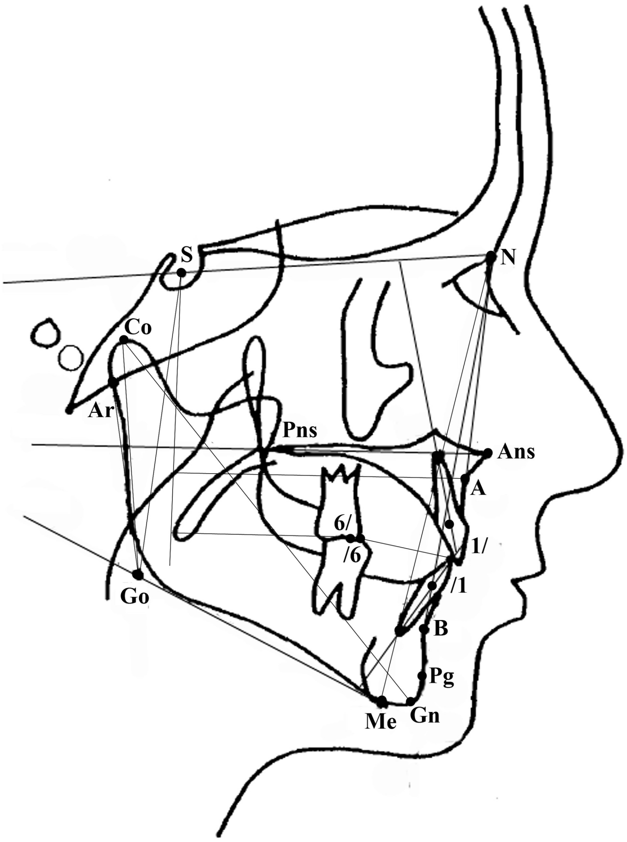

Figure 1. Cephalometric points, lines, and angles used in analysis: SNA; SNB; ANB; A-reference plane (line through S perpendicular to the maxillary plane (Ans-Pns)); gonial angle (Ar–Go–Me); maxillary incisor (1/) to SN plane; mandibular incisor (/1) to mandibular plane (Me-Go); maxillary first molar (6/) to reference plane through S perpendicular to SN; mandibular first molar (/6) to reference plane through S perpendicular to SN.

measurements were taken by one operator, who had been calibrated to the more experienced senior author.

Masseter muscle thickness

Masseter muscle thickness was measured by ultrasonography, using a real time ultrasound scanner [FALCO 100, linear array transducer (6–8 MHz), PieMedical, Imaging BV, Maastricht, The Netherlands]. The details of this technique were developed by Kiliaridis and Kalebo (28) and modified by Raadsheer *et al*. (29). All of the measurements were done by one examiner, who had been calibrated to the experienced operator who had developed the method. The participants were seated in an upright position with no head support. The masseter was scanned bilaterally on a level halfway between the zygomatic arch and the gonial angle. The scan plane was orientated perpendicular to the anterior border of the muscle and perpendicular to the surface of the underlying ramus, so that the reflection of the bone was depicted as a sharp white line. The registrations were made under two conditions, relaxed and contracted. The first was obtained by asking the participants to maintain slight interocclusal contacts, the second by asking them to clench maximally in the intercuspal position. Under all registration conditions, a generous amount of ultrasound contact gel was applied to the probe (Kendall Meditec, Mirandola (MO), Italy) and light pressure was applied so as to avoid compression of the soft tissues and muscle. All registrations were repeated twice, and the final thickness was obtained from the mean of the repeated measurements. Muscle thickness was registered to the nearest 0.1 mm.

Statistics

All statistical analyses were performed using the Statistical Package for Social Sciences version 15.0 (SPSS Inc., Chicago, Illinois, USA). Data were initially tested for normality using the Shapiro–Wilk test. All data were found to be distributed normally and thus parametric statistics were used throughout.

Maximal molar bite force or masseter muscle thickness changes during treatment or observation (T1–T2) were evaluated, and paired *t*-tests were used to assess statistical significance within each group. A comparison of changes between the treatment and control groups was also carried out using unpaired *t*-tests.

For the treatment group, cephalometric and dental changes during T1–T2 were evaluated, and paired *t*-tests performed to assess the statistical significance of the changes occurring during the treatment period. Univariate and multivariate linear regression analyses using stepwise regression were carried out to investigate possible correlations between initial maximal molar bite force or masseter muscle thickness and treatment outcomes (dental or cephalometric changes during treatment), including other possible predictor variables in the analysis (pre-treatment age, gender, change in height). Based on the results of a previous study (21), regression analysis was also used to investigate possible correlations between the gonial angle and treatment outcomes. All correlations were considered significant at $P < 0.05$.

Error of the method

To account for any random error, including possible biologic variation, the error of the method for the maximal molar bite force measurements and ultrasound technique was calculated by repeated measurements of 15 patients, on two separate occasions, 2 weeks apart, using Dahlberg's formula (SE = $\sqrt{\Sigma d^2/2n}$), where n = the number of patients undergoing repeated measurements and d = the difference in measurements (30). For maximal molar bite force measurements, the error was calculated as 61 N, whereas for masseter muscle thickness measurements it was found to be 0.4 mm.

The error of the method for the cephalometric variables was calculated by performing duplicate determinations on 15 randomly selected cephalometric radiographs, with a 2-week interval between the measurements, using Dahlberg's formula. For linear measurements, the error of the method did not exceed 0.9 mm, and for angular measurements this did not exceed 1.0 degree.

Results

Sample demographics

The present experimental subjects consisted of 14 boys and 6 girls, between the ages of 9 and 13 (x = 11.4 years; SD = 1.3 years). The control subjects, matched for gender and age to the experimental subjects, also consisted of 14 boys and 6 girls, between the ages of 9 and 13 (x = 11.2 years; SD = 1.9 years). The mean height of the children at T1 was 149.6 cm (SD = 12.0 cm) for the treatment and 146.9 mm (SD = 13.0 cm) for the control group. No significant differences between the treatment and control groups were found concerning T1 age or height.

Pre-treatment cephalometric and dental characteristics and treatment outcomes

The T1 cephalometric and dental characteristics of the 20 children in the treatment group are shown in Table I. The sample had a mean 90

Table 1. Dental and cephalometirc characteristics

	T1		T2		T2–T1			
	Mean	SD	Mean	SD	Mean	SD	95% CI	*P* value
Dental characteristics								
Molar Class (% Class II)	90.0	22.1	20.6	22.7	−69.4	23.8	−80.5 to −58.2	<0.001***
Overjet (mm)	7.1	1.9	3.7	2.1	−3.4	1.8	−4.2 to −2.5	<0.001***
Cephalometric characteristics								
Skeletal								
SNA (°)	80.8	2.8	79.7	3.1	−1.1	1.5	−1.8 to −0.3	0.006**
SNB (°)	74.2	2.8	75.4	2.8	1.2	1.4	0.6 to 1.9	0.001**
ANB (°)	6.6	1.6	4.3	1.8	−2.3	1.3	−2.9 to −1.7	<0.001***
A-reference plane (mm)	62.3	7.1	63.4	7.7	1.1	1.7	0.3 to 1.9	0.008**
Gonial angle (°)	129.7	5.1	129.0	4.2	−0.7	2.5	−1.9 to 0.5	0.221
Dental								
1/-SN plane (°)	102.1	9.5	98.6	8.3	−3.5	6.0	−6.3 to −0.7	0.016*
/1-Mandibular plane (°)	98.0	7.5	100.2	7.1	2.2	1.8	1.3 to 3.0	<0.001***
6/-reference plane (mm)	33.2	5.8	34.7	6.2	1.5	2.8	0.1 to 2.8	0.035*
/6-reference plane (mm)	32.3	6.0	36.6	7.1	4.3	2.8	3.0 to 5.6	<0.001***

*$P < 0.05$; **$P < 0.01$; ***$P < 0.001$.

per cent Class II molar relationship with a 7.1 mm overjet. The ANB angle was an average of 6.6 degrees. Controls did not have lateral cephalometric radiographs taken.

Following 1 year of active treatment, the dental Class II division 1 relationships improved in all of the experimental children. Molar class shifted towards a Class I relationship by 69.4 per cent and overjet was reduced by 3.4 mm. There was also a mean of 2.2 degrees of mandibular incisor proclination. The ANB angle decreased by an average of 2.3 degrees. The treatment outcomes (dental and cephalometric characteristics) are shown in Table I.

Masticatory muscle characteristics

Maximal molar bite force as well as ultrasonographic masseter muscle thickness measurements for both experimental and control groups are shown in Table II and Figure 2. There was a direct linear correlation between maximal molar bite force and ultrasonographic masseter muscle thickness in the whole sample ($R = 0.390$; $P = 0.013$). There were no statistically significant differences in initial (T1) masticatory muscle characteristics between the experimental and control groups. Concerning changes however (T2–T1), maximal molar bite force increased significantly in the control group ($x = 62.8$ N; SD = 85.5 N; $P = 0.004$) but not the experimental group ($x = 3.0$N; SD = 100.1 N; $P = 0.897$). A similar result was seen for masseter muscle thickness whereby masseter muscle thickness increased significantly from T1 to T2 in the control ($x = 0.5$ mm; SD = 0.5 mm; $P < 0.001$) but not in the treatment group ($x = -0.1$ mm; SD = 1.1 mm; $P = 0.761$).

In the present sample, no associations were found between changes in height and changes in masticatory muscle characteristics (either maximal molar bite force or masseter muscle thickness).

Associations

When looking at associations between pre-treatment masticatory muscle characteristics, several associations were observed. Children with a lower T1 maximal molar bite force were prone to more mesial movement of mandibular first permanent molars, distal movement of maxillary first permanent molars, and larger change in molar class during treatment (Table III; Figure 3). Children with thinner T1 masseter muscles were more likely to show more mandibular first molar mesialisation, mandibular incisor proclination, and opening of the gonial angle during treatment (Table III). For all of the stepwise multivariate linear regression analyses carried out, the other predictive variables (pre-treatment age, gender, change in height) did not show any significant association and were thus excluded.

Children with a larger T1 gonial angle showed more maxillary incisor retroclination ($R = 0.467$; $P = 0.038$) and mandibular incisor proclination ($R = 0.558$; $P = 0.011$; Figure 4) during treatment. In the present sample, no linear correlation was observed between the pre-treatment gonial angle and either maximal molar bite force or masseter muscle thickness.

Discussion

The findings of the present prospective longitudinal study suggest that the functional capacity of the masticatory muscles plays a role in determining treatment outcomes during functional appliance treatment in Class II division 1 growing children. The primary null hypothesis could thus be rejected. Despite an improvement in the sagittal malocclusion in all children, those with thinner pre-treatment masseter muscles or weaker maximal molar bite force tend to show greater dentoalveolar changes than those with thicker masseter muscles or stronger bite forces, contributing to correction of the Class II malocclusion and shifting the occlusion with a resulting Class I molar relationship and reduced overjet. These findings corroborate the results of two previous studies (21, 22), providing support from three samples derived from three different populations, strengthening the evidence linking the functional capacity of masticatory muscles to Class II functional appliance treatment outcomes. One must keep in mind however that associations were not very strong and thus the predictive power of the model is not to be considered in isolation. The functional capacity of the masticatory muscles is perhaps one of multiple predictors of Class II functional appliance treatment outcomes.

Masticatory muscle changes during treatment

Compared to the children who received no treatment, another finding of the present study was that treatment of Class II division 1 growing children with functional appliances was found to reduce

Table 2. Masticatory muscle characteristics

	Experimental group			Control group			Difference			
	Mean	SD	*P* value	Mean	SD	*P* value	Mean	SD	95% CI	*P* value
Bite force (*N*)										
T1	415.9	126.9	0.897	422.8	107.1	0.004*	6.9	37.1	−68.3 to 82.0	0.855
T2	418.9	120.8		485.6	120.8		66.7	38.2	−10.6 to 144.1	0.089
T2–T1	3.0	100.1		62.8	85.5		59.9	29.4	0.3 to 119.5	0.049*
Masseter muscle thickness (mm)										
T1	12.9	1.7	0.761	12.1	1.0	<0.001*	0.8	0.4	0.0 to 1.7	0.060
T2	12.8	1.1		12.6	2.0		0.2	0.5	−0.8 to 1.3	0.681
T2–T1	-0.1	1.1		0.5	0.5		0.7	0.3	0.7 to 1.2	0.028*

*$P < 0.05$.

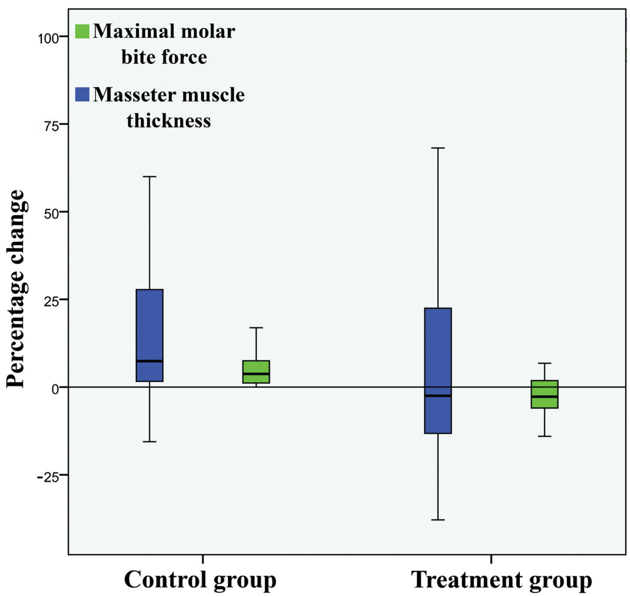

Figure 2. Box plots showing changes in maximal molar bite force and masseter muscle thickness measurements (expressed as percentage change) for the control and treatment groups. The lower border of the box represents the lower quartile, the upper border the upper quartile, and the line within the box represents the median. Whiskers represent upper and lower limits. The horizontal line at zero percent represents a line below which the measurement showed a decrease, and above which the measurement showed an increase.

both masseter muscle thickness and maximal molar bite force. This is in contrast to the findings seen in growing patients followed up without treatment, where an increase in masseter muscle thickness and maximal molar bite force was observed. The null hypothesis concerning the second aim could thus also be rejected. These findings in untreated individuals are in line with the cross-sectional findings of Raadsheer *et al.* (18) who showed an increase in masseter muscle thickness in children with increasing age, and with longitudinal studies looking at masseter muscle thickness (21) and bite force (22, 31) changes during functional appliance treatment.

Ideally for the control group, it would have been preferable to include only Class II malocclusion growing individuals. However, there were no statistically significant differences in initial masticatory muscle characteristics between the experimental and control groups. Thus, there is no reason to believe that the masticatory muscle characteristics of the experimental group would have behaved differently from the control group, had they not received treatment.

The increase in masseter muscle thickness with age seen in untreated growing individuals may be associated with a general increase in muscle force during growth (32), which can also explain the increase in bite force during this period (15, 33). The decrease in masseter muscle thickness and maximal molar bite force observed during Class II functional appliance treatment, when one would expect an increase in growing children of similar ages, could be due to mild atrophy of the masticatory muscles. Our findings suggest that the prolonged use of functional appliances can lead to prolonged reduction in masticatory muscle activity which may lead to mild atrophy, resulting in a reduction in masseter muscle thickness and consequently maximum molar bite force. This has also been observed in previous electromyographic studies (34–36) but often with a catch up of activity after some time.

A decrease in masticatory muscle activity, at least during the initial period of functional appliance wear, may be due to occlusal instability. A stable occlusion has been shown to be a prerequisite for maximal muscle activity (37, 38). Moreover, functional appliances may induce muscle relaxation similarly to occlusal splints. Previous studies have found a decrease in masseter muscle activity with the use of splints or bite plates (39, 40). The reason for this decrease in muscle activity has been proposed to be that there are less occlusal contacts, leading to an altered tactile sensation by the periodontal receptors and less proprioceptive input, hence decreased muscle activity (40).

Masticatory muscles characteristics and dentoalveolar effects during treatment

Children with a lower pre-treatment maximal molar bite force were more likely to attain an improvement in molar relationship from Class II to Class I during functional appliance treatment, even when factors such as gender and age were taken into consideration. Likewise, the headgear-like effect of functional appliances (41, 42) on the maxillary molars and the maxillary skeleton was more visible in individuals with weaker bite force. Functional appliance treatment in children that can generate weaker vertical intermaxillary forces when shifting the occlusion from Class II to Class I will show less resistance to dentoalveolar effects. Despite their short duration, vertical occlusal forces seem to be important as regards tooth movement and shifting of the occlusion. It has been observed that if an interarch obstacle is present, tooth movement is partially impeded (43). During functional appliance therapy, this comes into play notably when the child is not wearing their appliance. If one can relate maximal molar bite force to masticatory muscle thickness, thick muscles may increase the

Table 3. Correlations (statistically significant) between pre-treatment masticatory muscle characteristics and treatment changes

Independent variable (at T1)	Dependent variable (T2–T1)	*R*-value	*t*-Statistic	Beta	*P* value
Bite force	Molar class	0.447	2.123	0.447	0.048
Bite force	Maxillary first molar-reference plane	0.487	2.365	0.487	0.029
Bite force	Mandibular first molar-reference plane	0.455	−2.168	−0.455	0.044
Masseter muscle thickness	Gonial angle	0.503	−2.472	−0.503	0.024
Masseter muscle thickness	Mandibular first molar-reference plane	0.452	−2.151	−0.452	0.045
Masseter muscle thickness	Mandibular incisor-Mandibular plane	0.485	−2.353	−0.485	0.030

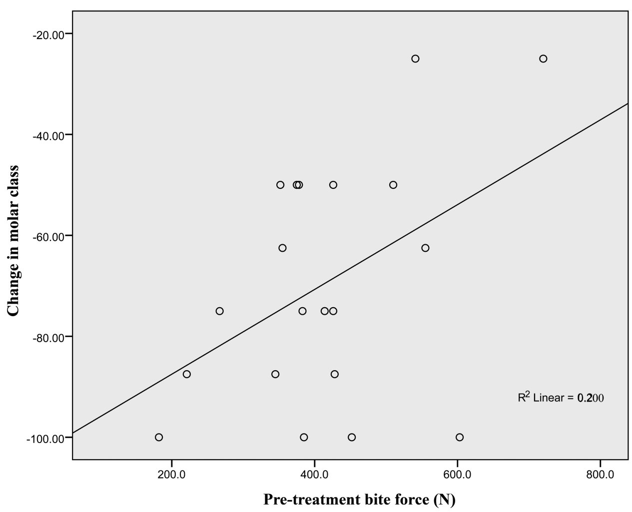

Figure 3. Scatter plot showing correlation between T1 maximal molar bite force and changes in molar class during treatment.

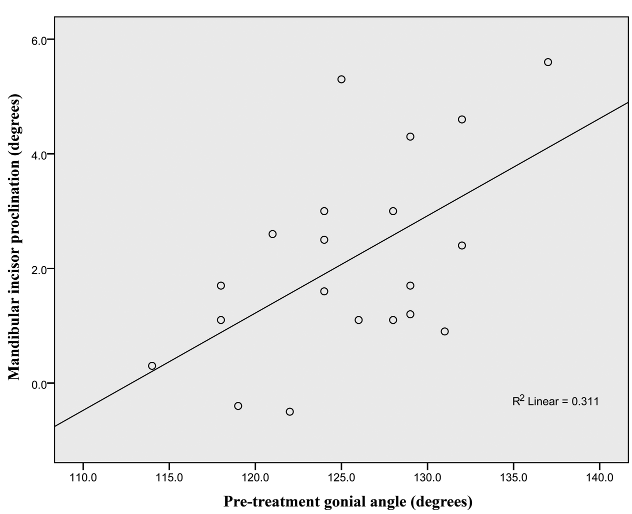

Figure 4. Scatter plot showing correlation between T1 gonial angle and mandibular incisor proclination during treatment.

anchorage of the maxillary and mandibular dentitions due to the exertion of larger masticatory forces making shifting of the occlusion more difficult. It is implied here that individuals with a higher maximal molar bite force and thicker masseter muscles exert larger masticatory forces.

It cannot be excluded that dentoalveolar changes leading to a change in molar relationship observed in the present study are not partly due to beneficial skeletal effects. The associations seen with changes in the maxillary and mandibular molars, due to the nature of the cephalometric measurements, may have also had a skeletal component. Even so, it is known that functional appliances improve Class II malocclusions mainly through dentoalveolar effects with minor skeletal influences (44).

Functional appliances have been criticized for their tendency to procline mandibular incisors and retrocline maxillary incisors (41, 45). An increase in mandibular incisor proclination translates to the mesialisation of the whole mandibular dental arch, while maxillary incisor retroclination translates to the distalisation of the entire maxillary arch. A larger dentoalveolar movement may imply a smaller skeletal effect in achieving Class I dental relationships. O'Brien *et al.* (46), in a multicenter randomized controlled trial, found the average percentage of skeletal change contributing to the reduction in overjet to be 27 per cent, with variation between individuals, the remaining amount being dentoalveolar. They further go on to reason that this variation in apparent skeletal change may be because of other factors, probably reflecting individual growth variation as opposed to growth modification because of appliance wear. A large variation in mandibular incisor proclination is apparent among children treated with functional appliances (47, 48). The results of the present investigation suggest that part of the variation may be explained by the functional capacity of the masticatory muscles. Thin pre-treatment masseter muscles were observed to correlate with greater proclination of mandibular incisors.

Another factor related to masticatory muscle characteristics and perhaps to treatment effects may be the quality of the mandibular alveolar bone. The mandibular trabecular bone is subject to physiological remodeling throughout life, and can be influenced by masticatory demands (49). Jonasson and Kiliaridis (50) have found that masseter muscle thickness is a significant determinant of mandibular alveolar bone mass. In rats, lower bone density has been associated with faster orthodontic tooth movement than in those with significantly higher bone density (51, 52). If one assumes that children with lower bite forces or thinner masseter muscles exhibit lower bone density, then that is perhaps another reason as to why more dentoalveolar changes are present during functional appliance treatment in those with weaker or thinner muscles.

Our findings show that individuals with a more obtuse gonial angle tend to show greater retroclination of maxillary incisors and proclination of mandibular incisors during functional appliance treatment, thus a greater compensation of incisor inclination. This association with the gonial angle and incisor compensation actually demonstrates the relationship between the masticatory muscle capacity and the dentoalveolar response. Individuals with a larger gonial angle suggest that the gonial process has not been subject to large mechanical muscular stimulation because of a weaker masseter muscle and lower contraction forces. The volume of the masseter muscle has been inversely correlated with the gonial angle (53), meaning that those with a more obtuse gonial angle have a smaller masseter muscle volume. Likewise, individuals with a lower bite force have been found to have on average a more obtuse gonial angle than individuals with a higher bite force (17, 54). It has been put forward that the size and shape of the gonial process being a site of muscle attachment, is dictated by the relative development and organization of the muscles, as they provide a major mechanical stimulus for bone formation (55, 56).

In a study looking into the predictors of mandibular change induced by functional appliances in Class II patients, it was found that the gonial angle could be used as an indicator which dictates whether a treatment will be favorable (increase in total mandibular length), concluding that patients with an obtuse gonial angle are expected to respond less favorably (57). Perhaps in extrapolating their data, one can assume that those with an obtuse gonial angle display weaker maximal molar bite force and masseter muscle thickness, and hence less mandibular change would be expected to occur, meaning that in order to achieve a Class I molar occlusion post-treatment, more dentoalveolar change would have to take place. This could thus explain part of the variation seen in the response to functional appliance treatment.

Clinical implications of the present results pertain to raising the clinician's awareness with regard to expected outcomes following removable functional appliance treatment in any given growing individual with Class II malocclusion. It would be premature to extrapolate these results and discuss about the possibility of changing an individual's masticatory muscle characteristics, with training of the muscles, prior to beginning functional appliance treatment, but this warrants exploration in future studies.

Conclusions

The initial condition of the masticatory muscles, represented by masseter muscle thickness and by maximal molar bite force, may be one of the factors that influence treatment outcomes. Children with thinner pre-treatment masseter muscles or weaker bite force in the present study sample seem to show greater dentoalveolar change. Children with an obtuse gonial angle are also more likely to show greater incisor compensation during treatment. The gonial angle, serving as a site of attachment of the masseter muscle, and hence the mandibular morphology, provides a good indication as to the cross-sectional thickness and the force of the masseter muscle. In practice, this angle can be measured cephalometrically and used as an indication of expected incisor compensation.

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