ORIGINAL ARTICLE

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The effect of maximum bite force on alveolar bone morphology

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Structured Abstract

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Objectives – To investigate to what extent maximum bite force contributes to alveolar bone morphology parameters, i.e. alveolar thickness, shape and arch width.

Design – An observational cross-sectional survey.

Setting and Sample Population – One hundred and fifty one 12- to 14-year-old students from a secondary school in Hatyai City, Songkhla Province, Thailand.

Material and Methods – Height, weight and maximum bite force of each subject were recorded. Alveolar bone morphology parameters were measured from study models.

Results – Maximum bite force moderately correlated with alveolar thickness and shape (r = 0.31–0.44, $p < 0.001$), but weakly correlated with arch width (r = 0.03–0.05, $p > 0.05$). After adjusting for gender and body mass index (BMI), the maximum bite force significantly determined alveolar thickness and shape ($p < 0.001$), accounting for 10–20% of the variations. Boys were associated with larger posterior arch width ($p < 0.01$), where BMI was not associated with alveolar bone morphology parameters ($p > 0.01$) after Bonferroni correction for multiple testing.

Conclusion – Maximum bite force had a selective influence on alveolar thickness and shape, but not on arch width.

Key words: alveolar bone; arch width; body mass index; maximum bite force

Introduction

The role of alveolar bone on orthodontic treatment has been widely stated. In terms of morphology, inadequacy of alveolar bone dimensions limits the amount of tooth movement and may lead to treatment complications (1), such as, bone dehiscence (2) and root resorption (3). Also, alveolar bone thickness is a key factor for safe insertion of orthodontic mini-implants (4). Studies in animals measuring alveolar bone mass, dimensions, and bone formation/apposition rates have lead to the suggestion that alveolar bone is influenced by masticatory function (5–8). In humans, positive relationship between masticatory functions, determined by masseter thickness and number of occluding posterior teeth, and alveolar bone mass and thickness were also reported (9).

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Maximum bite force (MBF) has been recognized as an indicator of masticatory function (10, 11). It results from the combination of jaw elevator muscle action and sensory feedback mechanisms (12). Clinically, MBF recordings can be simply performed (13). MBF has been related to craniofacial morphology in several studies (14, 15). However, its influence on alveolar bone has been reported mostly from the microscopic aspect. Bite forces have been demonstrated to produce strains in and around the alveolar process (16). Normal levels of strain regulate physiological bone turnover, whereas excessive strains lead to bone hypertrophy (17). Understanding of MBF's effects on alveolar bone morphology may lead to better insight into the control of alveolar bone modeling, which would in turn be useful for preventive orthodontics and appropriate treatment planning.

Gender and body mass index (BMI) have been reported to be associated with the craniofacial morphology. Generally, males have larger craniofacial structures than females (18, 19). Adolescents with a high BMI present craniofacial characteristics which are different from their lower BMI counterparts (20, 21). Among a group of 18- to 84-year-old subjects, males had thicker and denser mandibular alveolar bone than females, and BMI was a significant predictor of skeletal bone mineral density (22). The influences of gender, BMI and MBF on alveolar bone morphology have never been assessed together at a population level. We hypothesized that MBF independently affects alveolar bone morphology in a positive direction. This study was conducted to test whether MBF could independently predict alveolar bone morphology parameters (ABMP's), i.e., thickness, shape, and arch width, after adjustment for gender and BMI.

Material and methods

This observational cross-sectional study was approved by the ethics committee of the Faculty of Medicine, Prince of Songkla University. Informed consent was obtained from parents of all study subjects.

Subjects

A secondary school in Hatyai city with diversified sources of students was chosen to be the study site. Subjects were part of a research project studying various factors influencing young adolescents' alveolar bone morphology. All 12- to 14-year-old students given informed consent by the parents were screened. Adolescent subjects were chosen because their periodontal structures, including alveolar bone, were less likely to be affected by periodontal pathology. Also, their tooth shapes were unlikely to be altered from age-related attrition or erosion, which could bias our measurement. All subjects should have a permanent dentition from right 1st molar to left 1st molar with Angle's Class I occlusion. Exclusion criteria were oral or systemic conditions that could influence the variables of interest, such as dentofacial deformity or obvious skeletal discrepancy, dental anomalies in size, shape or number, major tooth destruction or reconstruction, torus mandibularis, extreme gingival recession, major malposition of the teeth, temporomandibular disorders including minor symptoms such as clicking or crepitation, and history of orthodontic treatment.

Sample size was calculated with Cohen's formula for hypothesis testing of correlation coefficient (r) (23). Based on the pre-requisite that $H_0: r = 0$ would be rejected with a power of 80% when $|r| \geq 0.25$ at a level of significance of 0.05, the sample required 124 subjects.

A sub-sample of twenty consecutive subjects from a randomly selected classroom was also chosen for the assessment of intra-subject variation in MBF measurement at a 2-week interval.

Methods

Each subject was measured for height (m) to the nearest of 0.01 m in erect position.

To determine MBF, two $20 \times 30 \times 11$ mm force sensing resistor based bite force measuring devices were used. The design of the device was modified from Fernandes et al. (24). It comprised a force sensor (Force Sensing Resistor®, Part No 402, Interlink Electronics, Camarillo, CA, USA) sandwiched between a pair of stainless steel plates whose outer surface was covered with rubber sheets to serve as the dental protection component. Tested against a universal testing machine, the sensor had an average error of 3.9% and coefficient of variation of 2.2% at the load range of 200–1400 N. Tested in human subjects, the interincisal distance measured during MBF recording was approximately 12–14 mm. To prevent cross-contamination, each device was covered with a thumb tip part of a latex glove, which was disposed of after each use, and the biting surfaces then sterilized with disinfecting solution. One sensor was routinely used for all unilateral MBF measurements. The other was used only when bilateral MBF measurement was to be registered.

Each subject was given a full description of the procedure and was allowed to familiarize him/herself with the device before actual data collection. He/she was seated upright with relaxed head posture on a stool without a backrest. The sensor was placed between the upper and lower right posterior teeth from upper 1st premolar onwards posteriorly. Strongest possible bite was applied for a period of 2 s, three times in succession, with at least 20 s resting interval. The greatest value was taken as the MBF. The procedure was repeated on the left hand side after 1 min rest. Finally, bilateral MBF was measured using two sensors, one on each side. The measurement was performed in the same fashion as unilateral MBF. The sum of forces recorded from both sides was taken as bilateral MBF (10). The highest value was used for further analysis.

Alveolar bone morphology parameters

Impressions of the mandibular arch were taken using alginate (Alginoplast®, Heraeus Kulzer GmbH&Co. KG, Hanau, Germany). The models were poured with dental stone within the same day by the same dental technician.

As illustrated in Fig. 1, assessment of alveolar thickness and shape methods were adapted from Jonasson et al. (25). In brief, mandibular right 1st and 2nd premolar and 1st molar were selected for measurement. All measurements were taken at the middle of the mesio-distal tooth dimension from each tooth. Three bucco-lingual parameters (*t, c* and *m*) were measured by means of a dial caliper (Kori®, Kori Seiki MFG Ltd., Tokyo, Japan) with a precision of 0.05 mm. *Tooth width* (*t*) was measured at the estimated level of the cemento-enamel junction (CEJ). *Cervical crestal width* (*c*) was measured at 2.5 mm bucco-apically and 2 mm linguo-apically from the CEJ. *Mid-crestal alveolar width* (*m*) was measured at 6 mm bucco-apically and 5 mm linguo-apically from the CEJ. From these, *cervical crestal alveolar thickness* (*c-t*), *mid-crestal alveolar thickness* (*m-t*), and *cervical alveolar shape* (*m-c*) were computed.

Alveolar arch width was measured as follows. At mid-crestal level of each mandibular canine and 1st molar, a point at the mid-buccal surface was marked, so was the mid-lingual surface. A digital caliper (Digimatic®, Mitutoyo Corp, Kanagawa, Japan) with a precision of 0.01 mm was used for the measurements. *Anterior arch width* (*aaw*) was defined as the mean of inter-buccal and inter-lingual widths of the canines, whereas *posterior arch width* (*paw*) was the mean of the inter-buccal and inter-lingual widths of the 1st molars (Fig. 2).

Altogether, *c-t, m-t, m-c, aaw*, and *paw* were used as ABMP's for the hypothesis testing.

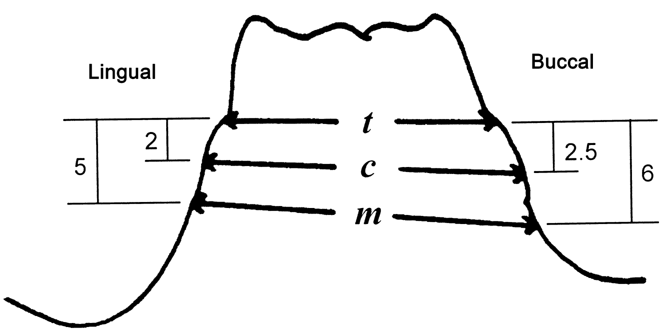

Fig. 1. Diagram of a study model sectioned at the middle of the mesio- distal root distance of tooth 46 demonstrating the measurement of tooth and alveolar crest widths according to Jonasson et al. (25). *t,* tooth width; *c,* cervical crestal width; *m,* mid-crestal width. Unit of measurement = mm. (For details, see text).

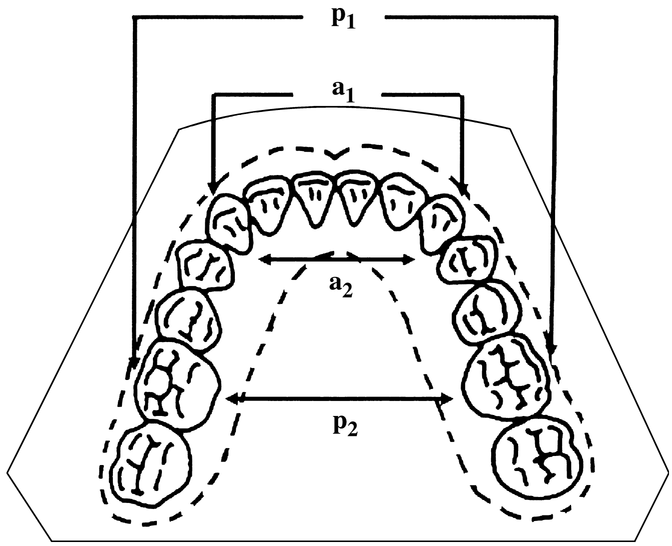

Fig. 2. Top view diagram of a mandibular study model. At mid-crestal level, points at the mid-buccal and mid-lingual surfaces of canines and 1st molars were marked (the arrow heads). Anterior alveolar arch width (*aaw*) = $(a_1 + a_2)/2$, and posterior alveolar arch width (*paw*) = $(p_1 + p_2)/2$. (See text for details).

To determine the intra-observer reliability ABMP's were re-measured on twenty randomly selected study models after a two-week interval.

Data analysis

The error of measurement (S_e) was calculated using Dahlberg's formula (26):

$$S_e = \sqrt{\frac{\sum d^2}{2n}}$$

where d is the difference between the two measurements and n is the number of pairs of repeated measurements. Measurement reliability was determined by Houston's method (27): $(1 - S_e^2/S_i^2) \times 100$ where S_i^2 is the total variance of the measurement.

Body mass index was calculated using the formula weight/height^2. The subject's *c-t* was computed from the mean of *c-t* from three teeth. So were *m-t*, and *m-c*. Means ± SD were used to describe the characteristics of each variable. Independent t-tests were employed to examine the difference of the variables between sexes. Since chewing forces produced by ipsilateral masseter muscle were higher than those produced by contralateral masseter muscle in a unilateral gum chewing experiment (28), we believed that localized chewing force should exert a dominant effect on ipsilateral alveolar thickness and shape parameters. Hence, these latter variables were correlated against ipsilateral MBF using Pearson's correlation coefficients (r). On the other hand, alveolar arch widths were tested against bilateral MBF.

The effects of corresponding MBF on ABMP's with adjustment for gender and BMI were determined from percent sum of squares from multiple linear regression. Since five outcome variables were tested simultaneously, under Bonferroni correction for five simulated hypothesis testing, a critical significance level of $p < 0.05$ was reset to $p < 0.01$ (29). In the other comparisons, a significance level of 0.05 was chosen.

Results

Error of the method

The errors for the determination of ABMP's ranged from 0.06 mm to 0.16 mm and the reliability ranged from 97.7% to 99.7%.

The intra-subject MBF measurement error was 20.61 and 26.20 N for unilateral and bilateral measurement respectively. The errors could be considered as small since our measurement of MBF lay above 200 N. The intra-subject reliability of unilateral and bilateral MBF measurement was 97.8 and 95.9%, respectively.

Results

Of 249 male and 292 female students approached, 122 males and 163 females had parents' consent to participate in the study, an overall response rate of 52.7%. Of these, 151 (27.9%) passed the selection criteria (61 males, 90 females, age 13.8 ± 0.4 years). The main reason for exclusion was tooth destruction due to dental caries. Age was not significantly different between sexes. Compared to females, males were significantly taller, heavier, and had stronger MBF and larger ABMF's ($p < 0.05$), except for *m-c* and *aaw* (Table 1).

Excluding the high correlations due to linkage in mathematical formulae, i.e., *c-t* vs. *m-t*, and *m-t* vs. *m-c*, and due to anatomical conformation between *aaw* and *paw*, Pearson's correlation coefficients among ABMP's were low and mostly non-significant (r = 0.01–0.21) (Table 2). BMI was weakly correlated with ABMP's (r = 0.08–0.21). The only high levels of correlation were between MBF and alveolar thickness and shape (r = 0.31–0.44, $p < 0.001$). These relationships were confirmed with multiple regressions elaborating the effect of MBF with adjustment for sex and BMI ($p < 0.001$) (Table 3). MBF alone could explain approximately 10–20% of alveolar thickness and shape variations, whereas it contributed less than 3% to the variations of arch width. After Bonferroni correction, gender independently determined *paw*, whereas BMI failed to demonstrate any effects on ABMP's.

Discussion

There were clear differences of most parameters between sexes. MBF was associated with alveolar thickness and shape, but not with arch width. After adjustment for sex and BMI, MBF explained one-tenth to one-fifth of the variations of alveolar thickness and shape, but barely explained the variations of arch width.

Table 1. **Mean (SD) of physiological characteristics, maximum bite force, and alveolar bone morphology parameters of 151 subjects**

Variables	Pooled (n = 151)	Male (n = 61)	Female (n = 90)	$p^{\dagger}$
Physiological characteristics				
Age (years)	13.8 (0.4)	13.8 (0.4)	13.9 (0.5)	NS
Height (m)	1.6 (0.1)	1.6 (0.1)	1.5 (0.1)	***
Weight (kg)	51.7 (12.3)	56.0 (14.6)	48.7 (9.5)	***
BMI (kg/m^2)	20.4 (3.9)	21.1 (4.6)	19.9 (3.5)	NS
Maximum bite force (N)				
Right maximum bite force	654.8 (205.6)	721.8 (200.6)	609.4 (197.3)	***
Left maximum bite force	652.7 (192.1)	707.7 (189.2)	615.5 (185.9)	**
Bilateral maximum bite force	916.2 (276.2)	1001.6 (268.9)	858.4 (267.3)	**
Alveolar thickness and shape (mm)				
Cervical crestal alveolar thickness (*c-t*)	2.1 (0.6)	2.3 (0.5)	2.0 (0.6)	**
Mid-crestal alveolar thickness (*m-t*)	2.4 (0.9)	2.6 (0.9)	2.2 (0.9)	*
Cervical alveolar shape (*m-c*)	0.2 (0.6)	0.3 (0.6)	0.2 (0.5)	NS
Alveolar arch width (mm)				
Anterior alveolar arch width (*aaw*)	20.3 (1.7)	20.6 (1.9)	20.2 (1.6)	NS
Posterior alveolar arch width (*paw*)	43.0 (2.3)	43.7 (2.1)	42.4 (2.3)	**

†Independent t-test between males and females.
BMI, body mass index; NS, non-significant.
$*p < 0.05$, $**p < 0.01$, $***p < 0.001$.

Table 2. **Pearson's correlation coefficients for the relationship between maximum bite force, sex, BMI, and alveolar bone morphology parameters**

	Maximum bite force			Alveolar bone morphology parameters			
	U-MBF	B-MBF	BMI	*c-t*	*m-t*	*m-c*	*aaw*
B-MBF	0.93***						
BMI	0.07^{NS}	0.09^{NS}					
c-t	0.38***	–	0.16^{NS}				
m-t	0.44***	–	0.14^{NS}	0.78***			
m-c	0.31***	–	0.08^{NS}	0.21**	0.73***		
aaw	–	0.05^{NS}	0.15^{NS}	0.06^{NS}	-0.02^{NS}	-0.08^{NS}	
paw	–	0.03^{NS}	0.21*	-0.04^{NS}	-0.01^{NS}	0.02^{NS}	0.41***

U-MBF, unilateral maximum bite force; B-MBF, bilateral maximum bite force; BMI, body mass index; *c-t*, cervical crestal alveolar thickness; *m-t*, mid-crestal alveolar thickness; *m-c*, cercival alveolar shape; *aaw*, anterior alveolar arch width; *paw*, posterior alveolar arch width; –, correlation not tested; NS, non-significant.
$*p < 0.05$, $**p < 0.01$, $***p < 0.001$.

Significant correlations between MBF and alveolar thickness and shape imply the role of masticatory function on alveolar bone modeling. The influence of strains produced from masticatory forces on alveolar bone has been previously reported (30, 31). When masticatory function is increased, alveolar bone is strengthened by means of increased apposition, allowing the bone to withstand high bending forces (30). Strain produced by bite force developed along the supporting bone with diminishing values from the cervical level towards the apical level of the root (31).

Although the association was significant, 10–20% contribution of the MBF on the variation of alveolar thickness and shape suggests that the effect was minor. Previous studies have shown a strong influence of heredity on craniofacial structures (32–34). It is likely that alveolar thickness and shape may be largely determined by genetic influences as well.

The present area of investigation was confined to alveolar crestal bone. Greater contribution of MBF on *m-t* than *c-t,* in conjunction with a positive effect on *m-c* may indicate a greater effect of loading stimuli in the mid-crestal area than in the cervical crestal area. Further investigation on microscopic response of different areas of alveolar crest to bite force should provide more insight into the role of masticatory loading on alveolar bone modeling.

Table 3. **Multipleregression analysis to test the significance of maximum bite force, sex, and BMI in 151 subjects on alveolar bone morphology parameters**

Dependent variables: Alveolar bone morphology parameters (mm)	Predictors	Constant	Maximum bite force[†] (N)	Sex[‡] (Female)	BMI (kg/m^2)
Cervical crestal alveolar thickness (*c-t*)	β	1.24	9.6×10^{-4}	−0.14	0.02
	SE	0.27	2.1×10^{-4}	0.09	0.01
	t	4.56***	4.47***	−1.65	1.64
	%SS		14.47	1.97	1.50
	adjusted R^2 = 0.163				
Mid-crestal alveolar thickness (*m-t*)	β	0.65	1.8×10^{-3}	−0.14	0.03
	SE	0.41	3.2×10^{-4}	0.13	0.02
	t	1.59	5.59***	−1.03	1.92
	%SS		19.57	0.88	1.94
	adjusted R^2 = 0.208				
Cervical alveolar shape (*m-c*)	β	−0.58	8.4×10^{-4}	7.7×10^{-3}	0.01
	SE	0.28	2.2×10^{-4}	0.09	0.01
	t	−2.06	3.78***	0.09	1.21
	%SS		9.52	< 0.01	0.89
	adjusted R^2 = 0.086				
Anterior alveolar arch width (*aaw*)	β	19.00	-3.5×10^{-4}	−0.50	0.07
	SE	1.09	6.4×10^{-4}	−0.35	0.04
	t	17.36***	−0.06	−1.42	1.74
	%SS		0.27	2.63	3.30
	adjusted R^2 = 0.029				
Posterior alveolar arch width (*paw*)	β	41.81	-5.0×10^{-4}	−1.32	0.11
	SE	1.47	8.5×10^{-4}	0.47	0.06
	t	28.39***	−0.59	−2.79**	2.03*
	%SS		0.13	8.59	3.90
	adjusted R^2 = 0.098				

[†]Unilateral MBF was used to predict *c-t, m-t* and *m-c*, while bilateral MBF was used to predict *aaw* and *paw*.
[‡]Reference: male.
β, regression coefficient; %SS, % sum of square.
*$p < 0.05$, **$p < 0.01$, ***$p < 0.001$, Significance was accepted at $p < 0.01$ according to Bonferroni correction.

The current absence of MBF effect on arch width opposed the corresponding significant relationship reported by previous studies where arch widths were measured at the dental level (35, 36). Bucco-lingual dental inclination may enhance the relationship in those studies since buccally upright mandibular first molars were reported in subjects with wide arch width and strong bite force (36). The different results may also be due to varied MBF measuring methods.

The relationship between masticatory function and arch width may be interfered with by other factors, such as heredity and adjacent soft tissues. Cassidy et al. (33) demonstrated that as much as 60% of arch width variations were influenced by heredity. On the other hand, a negative relationship between MBF and arch width was also reported in a group of Duchenne-type myodystrophy patients (37). Compared with normal subjects, these patients had lower MBF but larger dental arch width. Tongue position was suggested to be the cause of widening dental arch.

Although the sex difference in physical characteristics is evident since childhood (38), bone mineral content is consistent in both sexes up until 16-years-old (39). This may explain the lack of association between gender and alveolar thickness and shape among adolescent subjects in our study.

Findings related to the influence of gender on arch width in adolescence have been inconsistent in various studies. The lack of sexual dimorphism in *aaw* in our study is consistent with work by Ferrario et al. (40), but is different from that of Cassidy et al. (33), where males had larger anterior arch width than females. On the other hand, significantly larger *paw* in our male subjects is in agreement with the latter (33), but is in contrast to the others (36, 40). Again, the comparison must be made with caution due to different measuring methods.

Studies on the effect of obesity on bone dimensions have also provided controversial results. For whole body bone, obesity (BMI ≥ 95th percentile) among children and adolescents was positively associated with bone dimensions and mass (41). In contrast, overweight (85th ≤ BMI ≤ 94th percentile) and obese (BMI ≥ 95th percentile) children in another study had low bone area for weight and low bone mass (42). In craniofacial region, adolescents diagnosed as obese exhibited larger mandibular and maxillary dimensions than controls, both vertically and sagittally (43), while the BMI effect on ABMP's could not be confirmed in our study. BMI's of the majority of our subjects were within normal limit with low variation, thus might decrease the chance to detect the effect from extreme BMI cases.

Some limitations about the use of MBF as an indicator for masticatory function in our study must be considered. First, the minor effect of MBF on ABMP's among our child subjects could not be inferred to adult populations, as the children's masticatory system is in an adaptive state. MBF has been shown to increase with growth (44) and has been assumed to reach the mature stage early in the third decade when the eruption of teeth and growth of the mandible have terminated (45). Second, although a standardized bite force measurement protocol was developed to prevent as many measurement errors as possible, MBF is not independent from motivation and cooperation of the subject, which is difficult to control (13). Last, although powerful mechanical stimuli have been believed to be responsible for bone regulation (46), sub-maximal loadings, if applied at an adequate frequency, may also enhance bone morphology. It has been reported that low-magnitude, high-frequency mechanical stimuli increased weight-bearing skeleton bone mass in young women (47). Increased bone area at the femoral neck from the effect of regular jumping exercise among prepubescent children has also been found (48). The results of these bone studies may suggest that low-level, dynamic loadings, such as chewing forces, may be more likely to determine the ABMP's than MBF which is the measurement of force in a static situation.

Due to the ethical restrictions on conducting a study among normal populations, the application of radiographs was inappropriate, hence, limiting the possibilities to measure bone density, bone microstructure, and the subject's skeletal growth stage. However, high turnover rate of alveolar bone in response to mechanical stimuli throughout life makes it appropriate for cross-sectional studies of the role of bite force on bone modeling (49). While subjects were selected under a set of strict criteria making a homogeneous sample resulting in good internal validity, natural variation of parameters might have restricted the power to detect significant correlations, if exist.

Conclusions

Within the limitations of this study, MBF is shown here to have a selective effect on ABMP's. However, it could explain only less than 20% of the variation of ABMP's. More powerful explanatory variables should be looked for.

Clinical relevance

Reinforcing alveolar bone modeling by masticatory loadings, if effective, would facilitate orthodontic treatment and reduce substantial clinical workloads. Microscopic effects on alveolar bone from masticatory muscle forces are well known. This observational study demonstrates a limited effect of maximum bite force on alveolar bone morphology. The possible use of masticatory forces to aid orthodontic treatment is therefore questionable.

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