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Abstract

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ORIGINAL ARTICLE

Masseter muscle thickness and mechanical advantage in relation to vertical craniofacial morphology in children

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Abstract

Objective. To investigate the relationship between vertical craniofacial morphology and masseter muscle thickness and mechanical advantage in children. ***Material and methods.*** The sample comprised 72 children (36 F, 36 M), 8.5–9.5 years of age, with various malocclusions and no previous orthodontic treatment. The thickness of the masseter was measured bilaterally by means of ultrasonography, and the recordings were performed both in relaxation and under contraction. Mechanical advantage was measured on the lateral cephalograms as the ratio between the masseter moment and the bite force moment arms. Two linear ratios and three angular measurements were used to describe vertical craniofacial morphology. ***Results.*** The mean masseter thickness was greater in the male group ($p < 0.05$) in both relaxed and contracted conditions. There were no significant sex differences for the mechanical advantage or for the measurements of vertical craniofacial morphology. In females, there is a positive association between masseter muscle thickness and its mechanical advantage. Multiple regression analysis showed a positive association between posterior to anterior facial height ratio in both genders and a negative association between masseter thickness and the intermaxillary angle in females. ***Conclusions.*** There is a significant association between posterior to anterior facial height and the masseter muscle in children. The importance of the masseter muscle is more evident in the vertical facial morphology of females.

Key Words: *Biomechanics, masseter muscle, ultrasonography, vertical dimensions*

Introduction

The significance of masticatory muscle function on the basic mechanisms of craniofacial growth has been illustrated in various animal experimental studies. Clinical studies, mostly performed in adults, have shown the relationship between craniofacial morphology and masticatory muscle function, estimated by recording the maximal bite force [1–3], the electromyographic (EMG) activity of these muscles [4,5], or by measuring the cross-sectional thickness by means of computed tomography (CT) [6–8], magnetic resonance imaging (MRI) [9,10] and ultrasonography [11–13]. Despite the different techniques of measuring the functional characteristics of these muscles, the aforementioned studies clearly indicate a significant association between the masticatory muscles and the vertical as well as the transverse craniofacial dimensions. In particular, long-face subjects seem to have thinner, i.e. weaker, masticatory muscles, while subjects with broader faces have thicker and stronger muscles.

Among the group of masticatory muscles, the masseter muscle seems to represent the functional capacity of the masticatory apparatus [10–15]. Moreover, the superficial position of the masseter allows easy access for application of quantitative measurements, such as by means of ultrasonography.

For clinical evaluations, ultrasonography has several advantages over CT and MRI. It is a rapid, inexpensive technique, the equipment can be handled readily and transported, and it has no known cumulative biological effect. The accuracy of this method in measuring masseter muscle thickness has been confirmed in several studies in humans [11,16–19].

In parallel, biomechanical models have been developed using lateral cephalograms to provide estimates of muscular force and bite resistance

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[20]. The mechanical advantage of the masseter muscle is as a biomechanical variable and it indicates the proportion of muscle tension applied to the generation of occlusal force. In other words, it is one factor in the performance of a muscle indicating how efficient the muscle can generate force in a given bite position. It is estimated by the ratio between the muscular moment arm and the bite-force moment arm [21,22]. Results from biomechanical investigations show that the mechanical advantage of the masseter muscle is greater in short-faced subjects than in long-faced subjects, suggesting that there is a relation between the mechanical advantage of the masseter muscle and craniofacial morphology [21].

Thus, different studies show that the functional capacity of the masseter muscle, or its mechanical advantage, is associated with the craniofacial morphology. However, the possible complementary effect and the relation of these two factors to the craniofacial morphology have not been studied previously. Therefore, the aim of the study is to investigate in a group of children the relation between masseter muscle thickness and its mechanical advantage, and the association of these two factors with vertical craniofacial dimensions.

Subjects and methods

Subjects

The subjects of the study were recruited from a private orthodontic practice in Thessaloniki, Greece, the sample comprising 72 children (36 F, 36 M), 8.5–9.5 years of age, and based on the following inclusion criteria:

- No history of previous orthodontic treatment
- Any kind of dental or skeletal malocclusion
- Available lateral cephalometric radiograph for each subject
- Presence of the 1st permanent molars and at least the 2nd primary molars
- No marked jaw asymmetries or craniofacial and TMJ disorders
- No congenital or developmental anomalies of the lips, mouth or face

Methods

Measurement of masseter muscle thickness. The thickness of the masseter muscle was measured based on the method proposed by Kiliaridis & Kälebo [11]; this procedure was part of the routine examination that all subjects undergo in the above-mentioned private clinic prior to any orthodontic treatment.

All children were examined by the same operator (I.G.) using a real time scanner (Pie Medical Scanner 480) with a 7.5 MHz linear array transducer. Imaging and measurements were performed bilaterally with the subject seated in an upright position and without lining on a head rest, under two different conditions: muscle in relaxation, while the teeth were occluding gently, and muscle during contraction (maximal clenching in the intercuspal position). The site of measurement was the thickest part of the masseter close to the level of the occlusal plane. Care was taken to ensure that the transducer was in perpendicular orientation to the mandibular ramus, since oblique scanning would increase the muscle thickness values. A generous amount of gel was used under the probe to avoid tissue compression.

Imaging and measurements were performed twice, with at least a 5-min interval between the two recordings. The thickness per side was calculated as the mean of the two measurements. The measurements were taken directly from the image at the time of scanning with a read-out distance to the nearest 0.1 mm; the scans were then printed on film paper using a videocopy printer (model P66E; Mitsubishi, Japan).

Measurement of masseter muscle mechanical advantage. The mechanical advantage of the masseter muscle (MMA) was measured from the lateral profile radiographs (Figure 1), *which* were traced by a single operator (MC) on mat acetate paper with a sharp pencil (Tikky II, 0.35 mm*; Rotring,* Hamburg, Germany).

The mechanical advantage (in percentage) was estimated by taking the ratio between the masseter muscle moment and the bite force moment arms [21,22]. The following planes were used:

- Masseter muscle line of action: *go-or* (*gonion-orbitale*) [22].
- Masseter muscle moment arm (A): the line from *condylion* (cd) perpendicular to the masseter line of action.
- Bite force line of action: the line perpendicular to the *functional occlusal plane* (FOP) (defined as the tangent to the buccal tips of the lower premolars passing through the mesiobuccal cusp of the lower 1st molar) in the mesiobuccal cusp of the lower 1st permanent molar [20].
- Bite force moment arm (B): the line from *condylion* (cd) perpendicular to the bite force line of action.

Measurements of vertical craniofacial morphology. Two linear ratios (in percentage) and three angular measurements were obtained from the lateral cephalometric radiographs, which, according to many studies, describe the vertical craniofacial morphology [10,14,23,25,29,34] (Figure 2).

Using a sharp pencil (Tikky II, 0.35 mm; Rotring, Hamburg, Germany), the radiographs were traced

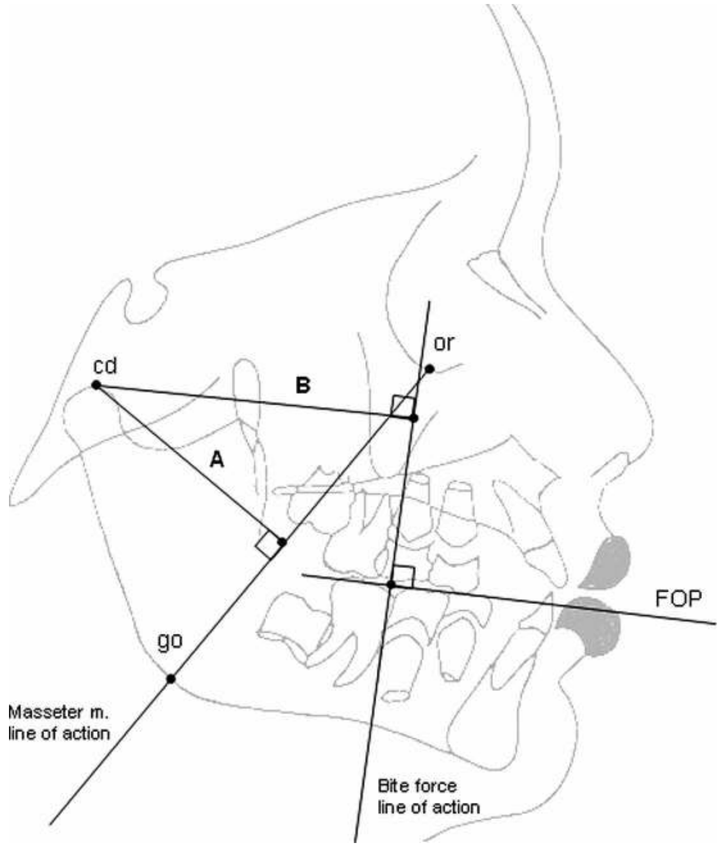

Figure 1. Measurement of the masseter muscle mechanical advantage (MMA) from lateral cephalometric radiographs: A. Masseter muscle moment arm. B. Bite force moment arm MMA: A/B.

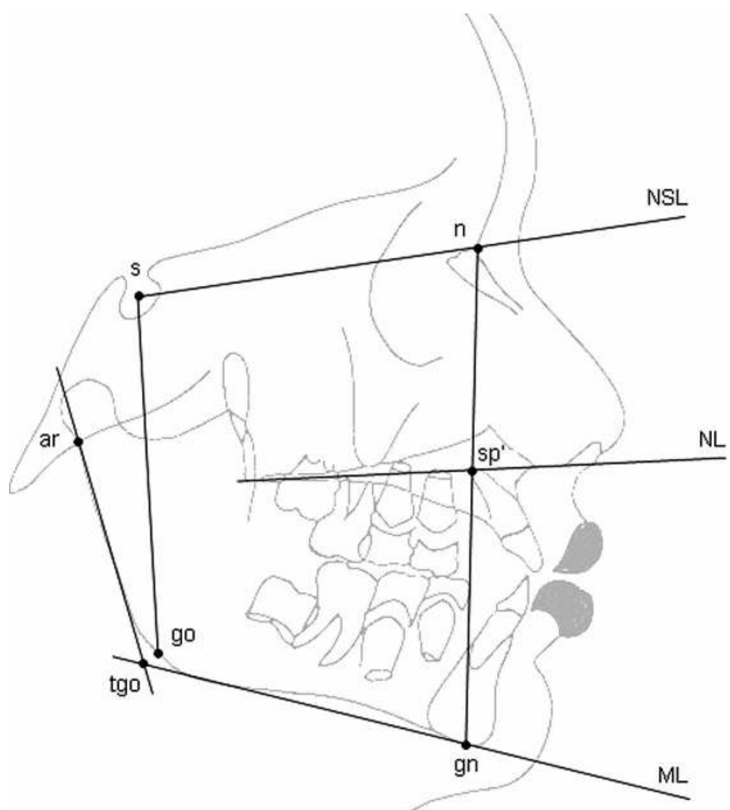

Figure 2. Angular and linear measurements from the lateral cephalometric radiographs posterior-to-anterior total facial height ratio *(s-go/n-gn)*, upper-to-lower anterior facial height ratio *(n-sp'/sp'-gn)*, intermaxillary angle *(ML-NL)*, mandibular plane angle *(ML-NSL)*, gonial angle *(ar-tgo-gn)*.

by a single operator (M.C.) on mat acetate paper. No correction was made for radiographic magnification (approximately 5% in the median plane), as only angles and ratios were measured.

Statistical analysis

All variables were checked for normal distribution and, since this was the case, parametric methods were used for further analysis of the results. An independent sample *t*-test was used to check for differences in the craniofacial morphology, muscle thickness and mechanical advantage between males and females. Correlation analysis was used to investigate the relation between masseter thickness and its mechanical advantage.

Multiple regression analysis was used to study the relation between vertical craniofacial morphology and masseter thickness and mechanical advantage in males and females. The statistical analysis was performed using the software SPSS 12.0.1 for Windows (SPSS, Chicago, Ill., USA).

Error method study

Ultrasonography. Recordings on 20 subjects were performed by one operator (I.G.) on two different occasions with an interval of approximately 2 weeks. Error variance (Se) was calculated using the formula $Se = \sqrt{\Sigma d^2/2n}$, where d is the difference between the two recordings of the individual and n the number of double recordings. The error for masseter thickness was 0.3 mm in relaxation and 0.2 mm during contraction. A paired *t*-test was performed and no systematic error was found at the 5% level between the two recording occasions.

Radiographs. After calibration of the examiner (M.C.) with co-authors (S.K., H.K.), double tracings of 25 radiographs were performed with 2 weeks interval. Using the aforementioned formula, the intra-individual random error did not exceed 0.5 mm for any of the landmarks except *condylion*, where it was 1.2 mm. For detection of the systematic error, a paired *t*-test was used and there was no significant difference, at the 5% level, between the first and second measurements.

Results

No statistically significant differences were found between males and females for measurements of the vertical craniofacial morphology and mechanical advantage.

Nor was there any statistical difference in masseter thickness between the right and left sides; therefore, the thickness was expressed as the mean from both sides. The mean masseter thickness was significantly greater in the male than in the female group in both conditions (relaxation-contraction) (Table I).

Correlation coefficient showed a significant positive association between the masseter thickness and its mechanical advantage in females ($r = 0.39$), while in males no such association was found ($r = 0.15$).

The results from the multiple linear regression analysis were similar whether the masseter was considered relaxed or contracted. Therefore, for presentation of the results we chose to show the case with the masseter during contraction, due to the lower methodological error.

In the female group, masseter muscle thickness and intermaxillary angle (ML-NL) showed a significant negative association. The mechanical advantage showed a significant negative association with the mandibular plane angle (ML-NSL) and a positive association with the posterior-to-anterior total facial height ratio (s-go/n-gn). The multiple regression model could explain 31% of the total variance in the s-go/n-gn ratio. There was no significant association between gonial angle (ar-tgo-gn), upper-to-lower anterior facial height ratio (n-sp'/sp'-gn) and masseter thickness or mechanical advantage (Table II).

Table I. Measurements of vertical craniofacial morphology, masseter muscle mechanical advantage and masseter muscle thickness (in relaxation MT-Re – during contraction MT-Co), in males and females.

	Males		Females		
	Mean	SD	Mean	SD	*p*-value
Vertical craniofacial morphology					
ML-NL (^{0})	27.0	5.6	26.6	4.2	0.78
ML-NSL (^{0})	35.1	5.4	35.4	4.1	0.76
ar-tgo-gn (^{0})	127.6	6.7	126.2	4.9	0.32
s-go/ n-gn (%)	62.6	4.5	61.5	3.4	0.24
n-sp'/sp'-gn (%)	82.6	6.2	85.0	6.0	0.11
Masseter m. mechanical advantage (%)	74.3	4.0	73.5	5.0	0.45
Masseter m. thickness (mm)					
MT-Re	11.7	1.4	10.8	1.3	*0.007*
MT-Co	11.9	1.4	11.1	1.4	*0.015*

Table II. Multiple regression analysis to test the significance of masseter muscle thickness during contraction (MT-Co) and masseter muscle mechanical advantage (MMA) on vertical craniofacial morphology in females.
Multiple regression analysis model: $Y = b_0 + b_1$ MT-Co $+ b_2$ MMA.
Independent variables: Masseter thickness (mm) during contraction (MT- Co), masseter mechanical advantage (MMA). b_0 = constant, b_1, b_2 = regression coefficients, R = correlation coefficient, R^2 = percentage of explained variance.

(a) Dependent variable (Y): ML-NL (^{0})
$Y = 54.997 + b_1$ MT-Co $+ b_2$ MMA

Variables	Coefficient b	Standard error	Significance (p)
MT-Co	−1.075	5.155	0.045
MMA	−22.350	14.910	0.143

Significance of the model: $R = 0.499$, $R^2 = 24.9\%$, $p = 0.01$.

(b) Dependent variable (Y): ML-NSL (^{0})
$Y = 61.757 + b_1$ MT-Co $+ b_2$ MMA

Variables	Coefficient b	Standard error	Significance (p)
MT-Co	−1.611	5.233	0.760
MMA	−33.265	15.137	0.035

Significance of the model: $R = 0.409$, $R^2 = 16.7\%$, $P = 0.053$.

(c) Dependent variable (Y): s-go/n-gn
$Y = 0.312 + b_1$ MT-Co $+ b_2$ MMA

Variables	Coefficient b	Standard Error	Significance (p)
MT-Co	0.028	0.041	0.487
MMA	0.370	0.117	0.003

Significance of the model: $R = 0.555$, $R^2 = 30.8\%$, $p = 0.003$.

In the male group, the only association that was close to the level of significance was that between the mechanical advantage and the s-go/n-gn ratio. The multiple regression model could explain 16% of the total variance concerning this variable. The ML-NL angle, the ML-NSL angle, the ar-tgo-gn angle and the n-sp'/sp'-gn ratio were not associated with either the masseter thickness or the masseter mechanical advantage (Table III).

Discussion

The results of the present study indicate that there is a positive association between the mechanical advantage and the posterior to anterior total facial height ratio in both males and females. This means that for a given anterior facial height subjects with larger mechanical advantage, indicative of more efficient muscle in generating bite force, have an increased posterior facial height. The relationship of masseter thickness and vertical morphology was significant in females for the ML-NL variable, indicating that the stronger the masseter muscle the smaller the ML-NL angle. In the male group, no such association could be found between muscle thickness and any of the variables describing the vertical craniofacial morphology. These findings are supported by experimental studies; rats fed a soft diet showed reduced masticatory function and, furthermore, a lower bone apposition in the angle of the mandible, and an increased anterior facial height was observed [24].

Since a positive association has been shown between the number of occluding teeth, bite force and masseter muscle (EMG activity, thickness) [25,26], our intention was to measure masseter thickness under stable occlusal conditions in all individuals, thus reducing variation in the recordings of muscle thickness due to missing teeth. We therefore selected children in the early mixed dentition, i.e. before shedding of the primary molars and before any orthodontic treatment had been performed that could have influenced the study results.

The comparison between males and females showed no statistical difference for the variables that describe vertical craniofacial morphology. Moreover, the means of the variables are within the normal range [27], indicating that the sample is composed of individuals that could represent a bigger population for this age group.

The biomechanical part of the investigation included measurement of the mechanical advantage of the masseter muscle. Some methodological considerations arise when calculating the mechanical advantage using the profile radiographs: the masseter muscle line of action should be placed close to the central axis of the muscle; however, muscles are three-dimensional structures and the two-dimensional representation in the lateral radiographs is only an approximation [28]. In the present study, we used the masseter line of action as proposed by Throckmorton & Dean [22], connecting the landmarks *gonion* (go) and *orbitale* (or), which was applied later by Ferrario *et al.* [29] in a radiographic

Table III. Multiple regression analysis to test the significance of masseter muscle thickness during contraction (MT-Co) and masseter muscle mechanical advantage (MMA) on vertical craniofacial morphology in males.
Multiple regression analysis model: $Y = b_0 + b_1$ MT-Co $+ b_2$ MMA.
Independent variables: Masseter thickness (mm) during contraction (MT- Co), masseter mechanical advantage (MMA). b_0 = constant, b_1, b_2 = regression coefficients, R = correlation coefficient, R^2 = percentage of explained variance.

(a) Dependent variable (Y): ML-NL (^{0})
$Y = 53.999 + b_1$ MT-Co $+ b_2$ MMA

Variables	Coefficient b	Standard error	Significance (p)
MT-Co	−1.148	6.496	0.860
MMA	−34.508	24.064	0.161

Significance of the model: $R = 0.242$, $R^2 = 5.9\%$, $p > 0.1$.

(b) Dependent variable (Y): ML-NSL (^{0})
$Y = 69.125 + b_1$ MT-Co $+ b_2$ MMA

Variables	Coefficient b	Standard error	Significance (p)
MT-Co	−2.139	6.187	0.731
MMA	−42.399	22.918	0.073

Significance of the model: $R = 0.308$, $R^2 = 9.5\%$, $p > 0.1$.

(c) Dependent variable (Y): s-go/n-gn
$Y = 0.279 + b_1$ MT-Co $+ b_2$ MMA

Variables	Coefficient b	Standard error	Significance (p)
MT-Co	0.006	0.050	0.900
MMA	0.458	0.184	0.018

Significance of the model: $R = 0.398$, $R^2 = 16\%$, $p = 0.057$.

investigation of a large heterogeneous orthodontic population. This proposal appeared to be the most readily reproducible, in its use of cephalometric landmarks that are reliable to identify in lateral cephalometric radiographs that are commonly available in orthodontic patients. On the other hand, there was bigger methodological error (>1 mm) in identifying the landmark *condylion* (cd), which is generally difficult to identify because the radiographic shadow of the cranial base is partially superimposed on the mandibular condyle [30–32].

The mean values for the mechanical advantage found in our study were not significantly different between genders and were similar to the values reported in previous investigations, where no sex differences were found either [22,33]. On the contrary, males had thicker masseter muscles than females in both the relaxed and contracted condition. This is in agreement with findings in the literature of masseter muscle thickness that refer to adults [11] and to growing individuals [12]. Gender differences in young and older adults regarding masseter muscle thickness could be explained by the fact that there are differences in the fiber-type and fiber-size composition of the masseter muscle between males and females [34]. Whether this applies to children is not known for the masseter muscle. A possible explanation for the gender differences in children could be the influence of sex hormones, as this is strongly suggested for other skeletal muscles found to be larger in young boys than in girls [35].

The association between masseter muscle thickness and its mechanical advantage was significant only in girls, indicating that the thicker the masseter muscle the larger its mechanical advantage. The association between vertical craniofacial morphology and the two factors together, i.e. masseter thickness and mechanical advantage, was generally moderate. In girls, the variable that showed the strongest association with the masseter was the posterior-to-anterior facial height ratio, and the regression model explained 30.8% of the total variance. In this case, the mechanical advantage had the biggest impact on the model. In boys, the association that almost reached a statistically significant level ($p = 0.057$) was that between the mechanical advantage and the posterior-to-anterior facial height ratio (s-go/n-gn) and the regression model could explain only 16% of the total variance.

In agreement with our findings, Ferrario et al. [33] found a significant association between the masseter muscle mechanical advantage and the posterior-to-anterior facial height ratio in a big heterogeneous population, but no other vertical variables were investigated. Masseter thickness has been investigated in adults, and Satiroglu et al. [14] showed a strong association between masseter thickness and vertical facial morphology in a sample composed of males and females, where gender differences were not discussed. Our results are in line with those of Kiliaridis & Kälebo [11], who demonstrated in adults a significant association between masseter thickness and facial morphology in women, i.e. women with thinner muscles have proportionally longer faces, but no association was found in men. It is interesting to note that this was the case not only for the vertical dimension but for the transverse plane as well, as shown by Kiliaridis et al. [36], who found a significant positive association between maxillary dental arch width and masseter thickness in females but not in males.

A possible explanation to our findings regarding the different influence of the masseter muscle in the craniofacial morphology for each gender can be that genetic factors have a different impact on the genders. A genetic study of cephalometric variables performed in twins showed that the genetic determination for vertical variables was 77.3% for boys and 72.8% for girls [37]. This could explain the gender differences found in our study, in the sense that females have a weaker genetic determination than males for the vertical craniofacial morphology, so the epigenetic influence of the masseter muscle on the morphology may be more evident. Moreover, the fact that we found a significant correlation between masseter thickness and its mechanical advantage only in girls implies that these two factors complement each other, i.e. in order to enhance the functional capacity of the masseter muscle in girls. According to Frost's theory [38], the masticatory muscles could influence the craniofacial complex, provided that the tension that they apply to the facial bone structures is above a certain strain level. However, the level above which the impact of the masseter muscle becomes evident, is not clear.

In conclusion, there seems to be a significant association between the posterior-to-anterior facial height ratio and the masseter muscle in children, indicating that subjects with stronger masseter muscles have an increased posterior facial height for a given anterior facial height. Girls show greater associations than boys between the masseter muscle and vertical craniofacial morphology.

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