Correlation between maximum bite force and facial morphology in children

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Bite force in adults who have long-face morphology is lower than in adults who have skeletal deep bite.[1-4] Electromyographic studies of the masticatory muscles have revealed low activity levels in long-faced adults.[5,6] The small bite force in these individuals is in line with the decreased thickness and volume of their mandibular elevator muscles as revealed by ultrasonography,[7,8] computer tomography,[9,10] and magnetic resonance imaging.[11]

While the correlation between masticatory muscle strength and facial form is well documented in adults, some controversy exists regarding the relationship in children. Electromyographic studies have shown low levels of activity in the mandibular elevator muscles in children with long-face morphology,[12-15] and some studies have shown reduced bite force at the molars[15,16] and incisors.[17]

On the other hand, Proffit and Fields[18] were unable to find any correlation between bite force and facial morphology in children; they hypothesized that the correlation between masticatory muscle force and facial form develops during adolescence. Bite force increases during childhood and continues to increase until adulthood.[17,19] Proffit and Fields[18] were also unable to find the same bite force difference between long-

Abstract

The correlation between maximum bite force and facial morphology was studied in 54 boys, 8 to 16 years old, and 66 girls, 7 to 17 years old. Bite force was measured at the first molars with a miniature bite force recorder. Facial morphology was evaluated on profile cephalograms. In addition, the number of teeth in contact in the intercuspal position was recorded with occlusal foils. In the girls, maximum bite force was correlated with the inclination of the mandible, the size of the gonial angle, and the ratio between posterior and anterior face heights. The correlations implied a large bite force with a small mandibular inclination and gonial angle, a large posterior face height in relation to the anterior face height, and a small bite force with the opposite facial characteristics. These correlations were nonexistent or weaker in boys. In both sexes, bite force was correlated with the number of occlusal contacts. Elimination of the influence of age and occlusal contact in the group of girls by the use of partial correlations reduced the correlation between bite force and facial morphology. A significant correlation with the size of the gonial angle remained, however, and the correlation with mandibular inclination was close to significance. In addition to the correlations found with facial morphology, the study clearly demonstrated the need to take gender and occlusal contacts into consideration in future studies of masticatory muscle function and strength in relation to facial morphology.

Key Words

Bite force • Facial morphology

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Figure 1
Reference points and lines used in the cephalometric analysis

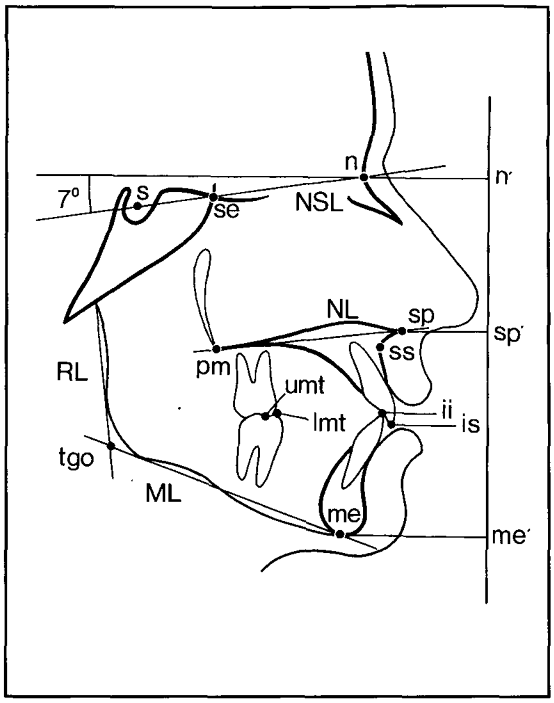

Figure 1

faced children and controls that is present in adults. They suggested that individuals with long-face morphology have normal bite force during childhood but do not develop strength in the mandibular elevators in the later phase of the growth period. Therefore, long-faced adults have less bite force than other adults.

Van Spronsen[20] proposed that the lack of development of masticatory muscle strength in long-faced children (often with anterior openbite) may be the result of poor working conditions for the muscles due to occlusal instability. This hypothesis is supported by the results of Bakke,[21] who found a positive relationship between masticatory muscle strength during static and dynamic functions and the number of occlusal contacts. According to van Spronsen,[20] the masticatory muscles of long-faced adults are characterized by disuse atrophy because the low muscle strength cannot be explained solely by the small cross-sectional area of the muscles. This muscle atrophy takes place during the development of the long-face morphology.

Before the validity of the theories of Proffit and Fields[18] and van Spronsen[20] can be confirmed, the question of bite force in children with varying facial morphologies must be further evaluated. The present study was done in order to elucidate the relationship between the strength of masticatory muscles and facial morphology in children.

Material and methods

One hundred twenty individuals (54 boys and 66 girls) were included in the study. The boys ranged in age from 8 years 3 months to 15 years 9 months (median 11 years 10 months) and the girls ranged from 7 years 2 months to 16 years 8 months (median 10 years 8 months). The study comprised all children who were to start orthodontic treatment at the Department of Orthodontics, University of Bern, during the period covered by the investigation. The subjects, therefore, had varying facial morphologies, varying types of malocclusion, and were in varying stages of dental development. None had symptoms or signs of functional disorders of the stomatognathic system.

The facial morphology of the subjects was evaluated on profile cephalograms taken with the mandible in the intercuspal position and including a linear enlargement of 3.3%. The reference points and lines used for the analysis are shown in Figure 1, and the variables measured are given in Table 1. Two ratios were calculated from the cephalometric measurements, one being the ratio of the lower anterior face height to the total anterior face height (lower face height %). This ratio was calculated from the distances sp'-me' and n'-me' where n', sp', and me' are the projections of the points n, sp, and me on a vertical line drawn perpendicular to a horizontal line making an angle of 7 degrees to NSL, i.e., approximating the vertical line of natural head position. The other ratio (PFH:AFH x 100) was that of posterior face height (distance s-tgo) to anterior face height (n-me).

Bite force in Newtons (N) was measured with a miniature bite force recorder (as described by Flöystrand et al.[22]) that was calibrated in a bench for a linear relationship between load and recorded value. The strain-gauge transducer of the recorder was contained in steel housing (11 x 15 x 4 mm) mounted on a handle. To avoid contamination, the transducer was placed in a thin latex finger cot during measurement. For the bite force measurements, maxillary and mandibular acrylic splints were made for each subject from dental casts. The splints had a flat occlusal surface and covered the buccal and lingual surfaces of the teeth. The splints allowed stable positioning of the bite force recorder during the measurements, loading the sensor at right angles. The upper and lower splints together increased the vertical dimension at the first molars by 2 to 5 mm (median 3 mm) in addition to the thickness of the bite force recorder (4 mm). Three measurements of maximum bite force at the both the right and

Table 1
Median, mean, standard deviation and range for maximum bite force, cephalometric variables, and tooth contacts in boys and girls.

	Boys (n = 54)				Girls (n = 66)				Significance of
	Median	Mean	SD	Range	Median	Mean	SD	Range	difference
Bite force (N)	607.0	632.2	157.4	330 - 1019	534.5	539.8	141.2	286 - 895	**
s-n-ssϒ	80.2	80.7	3.8	74 - 90	80.3	80.7	3.5	71 - 88	
s-n-smϒ	77.1	76.9	4.0	68 - 89	77.0	76.9	3.3	70 - 84	
ss-n-smϒ	4.3	3.9	2.2	-2 - 7	3.8	3.7	2.2	-1 - 8	
NSL/NLϒ	7.1	7.4	2.7	2 - 13	7.0	7.5	3.0	2 - 15	
NSL/MLϒ	32.8	32.5	5.5	17 - 43	34.3	33.5	5.4	19 - 48	
NL/MLϒ	25.4	25.1	5.2	11 - 37	25.2	25.9	5.4	13 - 38	
RL/MLϒ	124.0	124.5	5.5	113 - 137	125.8	124.8	6.3	109 - 138	
n-sp mm	49.4	49.6	4.0	43 - 59	47.1	47.3	3.5	41 - 56	***
sp-me mm	62.2	62.5	4.6	51 - 74	61.7	61.4	4.4	52 - 73	
Lower face height (%)	56.1	55.8	1.7	53 - 59	56.6	56.5	2.3	51 - 61	*
se-pm mm	43.7	44.0	3.3	37 - 53	42.8	43.4	3.8	36 - 55	
s-tgo mm	71.3	71.6	6.1	60 - 88	68.3	69.0	6.3	56 - 85	**
n-me mm	109.6	110.3	7.0	94 - 129	106.9	107.1	6.1	94 - 123	*
PFH : AFH x 100	62.5	63.3	4.4	55 - 77	62.7	62.8	4.0	56 - 75	
NL-is mm	27.0	26.7	2.3	22 - 32	26.2	25.8	2.7	19 - 32	*
NL-umt mm	20.0	20.1	2.4	14 - 26	19.4	19.6	2.1	14 - 24	
ML-ii mm	37.7	38.3	2.6	33 - 46	37.1	37.0	2.4	32 - 43	*
ML-lmt mm	29.1	29.4	2.0	25 - 34	28.4	28.5	2.6	23 - 36	*
MTC number	6.0	6.9	2.3	3 - 13	7.0	6.9	2.6	3 - 14	
MPTC number	5.0	5.4	1.4	2 - 8	5.0	5.2	1.7	2 - 8	
NC number	7.0	7.9	3.2	3 - 16	7.5	8.0	3.4	3 - 17	

* = $0.01 < p < 0.05$, ** = $0.001 < p < 0.01$, *** = $p < 0.001$

left first permanent molars were made in random order. Care was taken to avoid lateral or protrusive deviations of the mandible during the measurements. Children were allowed to rest between each measurement. Measurements were made with the child sitting slightly reclined in a dental chair with a headrest. To obtain the highest bite force values possible, the children were urged to do their very best.

Before the bite force measurements were made, the total number of maxillary teeth (permanent or deciduous) in contact in the intercuspal mandibular position (MTC), the number of maxillary posterior teeth (molars and premolars or deciduous molars) in contact (MPTC), and the total number of interocclusal contacts (NC) were recorded. The recording was made with the aid of strips of occlusal foil with a thickness of 8 μ (Shimstock Metal Foil, Hanel-GHM-Dental, Nürtingen, Germany). A tooth contact was recorded if the strip could be maintained between the teeth against a strong pull during biting with moderate occlusal force.

The largest of the six bite force measurements was taken to represent the maximum bite force of the individual. Maximum and the median bite forces on the right and left sides were also used and the median value of all six measurements was calculated.

Errors of the method

In order to evaluate the errors of the method of the bite force measurements, the recordings of tooth contact, and the cephalometric variables, duplicate determinations were made in 28 randomly selected individuals. The new bite force measurements and recordings of tooth contact were made 3 to 59 days (median 24 days) after the first recordings using the same acrylic splints. Duplicate measurements were made of the profile cephalograms of the 28 individuals, preceded by new localization of the reference points and new tracings.

Table 2
Significant rank (*R*) and product moment (*r*) correlation coefficients between the maximum bite force, age, cephalometric variables, and tooth contact variables in boys and girls.

Variable	Boys (n=54) *R*	Boys (n=54) *r*	Girls (n=66) *R*	Girls (n=66) *r*
Age			0.42***	0.44***
NSL/ML		-0.28*	-0.50***	-0.49***
NL/ML			-0.42***	-0.44***
RL/ML		-0.28*	-0.48***	-0.53***
n - sp			0.26*	0.27*
se - pm				0.27*
s - tgo	0.32*	0.36**	0.44***	0.54***
PFH : AFH x 100		0.30*	0.46***	0.51***
NL - umt			0.32*	0.37**
ML - ii	0.34*			
ML - lmt	0.34*	0.36**		0.30*
MTC	0.31*	0.42**	0.51***	0.47***
MPTC	0.38**	0.44***	0.54***	0.58***
NC	0.33*	0.34*	0.49***	0.45***

* = $0.01 < p < 0.05$, ** = $0.001 < p < 0.01$, *** = $p < 0.001$

The systematic errors of the method were evaluated with the paired *t*-test, and the accidental errors (si) were calculated with the formula

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

where *d* is the difference between the two determinations.

All parameters of bite force (maximum force, maximum forces on the right and left sides, median forces on the right and left sides, and median bite force) showed significant systematic differences between the two determinations. A larger value was generally recorded at the second determination. The smallest accidental error (39.6 N) was found for maximum bite force (based on all six measurements). This is equivalent to a coefficient of variation of 7%. The error for the median value was 49.2 N. Also, the maximum values on the right and left sides had smaller accidental errors than the median values.

No significant systematic errors were found between the duplicate determinations of tooth contact. The accidental error was 0.99 for the total number of maxillary teeth in contact, 0.35 for the number of maxillary posterior teeth in contact, and 1.37 for the number of intermaxillary tooth contacts.

Of the 18 cephalometric variables, five showed small, significant, systematic differences between the two determinations. The largest mean differences were 0.22 mm and 0.40 degrees, respectively. The accidental errors varied between 0.24 and 0.79 mm or degrees.

Statistical methods

Differences between sides were tested with Wilcoxon's matched-pairs signed-ranks test; differences between sexes were tested with Mann Whitney's U-test. Correlations between variables were studied with Spearman rank correlation and product moment correlation. Partial product moment correlation was calculated with the CANCORR procedure of SAS[23] (no equivalent nonparametric method was available). Normality of the distribution of the variables used in partial correlation analysis was checked graphically using normal quantile plots. In addition, multivariate normality of the variables used in each partial correlation analysis was assessed using Mahalanobis' distance-chi square quantile plot.[24]

Results

There were no significant differences between maximum bite force values at the right and left sides either in the whole group or in boys or girls. Because the maximum bite force (based on all six measurements) had the smallest accidental error, this parameter was used in the further analysis.

The values for bite force, cephalometric variables, and tooth contact for boys and girls are given in Table 1. Bite force was significantly larger in boys than in girls. There was no difference between the sexes in the number of tooth contacts or in the form of the face (angular cephalometric variables). The majority of the means of linear cephalometric variables (facial dimensions) were somewhat larger in boys than in girls. All variables recorded had large ranges, which were similar in boys and girls.

The significant coefficients of correlation between maximum bite force, age, cephalometric variables, and tooth contact variables are given in Table 2. Bite force was correlated with age in girls but not in boys. A clear correlation between bite force and facial form was found in girls but not in boys (see rank-correlation coefficients). Thus, in girls, bite force was negatively correlated with the inclination of the mandible (variables NSL/ML, NL/ML) and with the size of the gonial angle (RL/ML), that is, with variables markedly different in short- and long-face morphologies. In analogy with this relationship, a positive correlation was found to the quotient between the posterior and anterior face heights (variable PFH: AFH x 100). In both sexes, bite force was positively correlated with the number of teeth in contact and with the number of interocclusal contacts (NC). This correlation was stronger in girls than in boys and strongest for the number of maxillary posterior teeth in contact (MPTC).

Because more significant correlations between bite force and the other variables were found in girls, further analysis was restricted to the group of girls. In girls, the variables NSL/ML, NL/ML, RL/ML and PFH:AFH were significantly correlated with age, with coefficients of correlation (*R*) of -0.43, -0.48, -0.50, and 0.48, respectively ($p>0.001$). Tooth contact variables were significantly correlated with age ($R=0.37$ - 0.38, $0.001 < p < 0.01$). It was further found, in girls only, that tooth contact was significantly correlated with the form of the face. Thus, MPTC was correlated with NSL/ML ($R=-0.38$), NL/ML ($R=-0.38$), RL/ML ($R=-0.35$), $0.001 < p < 0.01$, and PFH:AFH ($R=0.43$, $p < 0.001$). It was therefore unclear if the correlation between bite force and facial form (Table 2) was due to the correlation with age and tooth contact. Product moment partial correlation coefficients (*r*) were therefore calculated eliminating the influences of age and tooth contact (MPTC). The partial correlation coefficients are given in Table 3. The *p*-values can be relied on, as graphical checks of the assumptions underlying partial correlation analysis did not show any relevant deviations.

The partial correlations with respect to age and MPTC, respectively, reduced the correlation between bite force and facial form (compare Tables 2 and 3). However, when either age or tooth contact was eliminated in the partial correlation analysis, the coefficients of correlation between bite force and the morphological variables remained significant. The partial correlation eliminating the influence of both age and tooth contact further reduced the strength of the correlation between bite force and facial form. In this case, only the correlation between bite force and gonial angle (RL/ML) remained significant. The correlation with the inclination of the mandible (NSL/ML) was, however, close to significance ($p = 0.06$). From the partial correlation analyses, it is clear that the correlation between bite force and facial form found by calculation of the simple correlations (Table 2) is, to some extent, due to the influence of age and tooth contact, but a correlation still exists after the elimination of the influence of these factors.

As a supplementary check of the dependence of the correlation between bite force and facial morphology on age and occlusal contact, a further analysis was made among young girls (girls 12 years of age or older were excluded). The sample then consisted of 47 girls. The reduction in sample size reduced the standard deviation of practically all variables. When coefficients of correlation between the maximal bite force and the other variables were calculated (n=47), few significant correlations were found. A negative correlation was found between bite force and the size of the gonial angle (RL/ML, $R=-0.44$, $r=-0.38$, $0.001 < p < 0.01$) and positive correlations with the three variables for tooth contact (MTC, $R=0.37$, $0.001 < p < 0.01$, MPTC, $R=0.46$, $p < 0.001$, NC, $R=0.34$, $0.01 < p < 0.05$). In this sample, bite force was not significantly correlated with age and no significant correlations were found between tooth contact and facial morphology. Therefore, the calculation of partial correlations, eliminating the influence of tooth contact (MPTC), did not change the correlation between bite force and the size of the gonial angle (RL/ML), which remained the same ($r=-0.38$, $0.001 < p < 0.01$).

Table 3
Partial product moment correlation coefficients in girls between maximal bite force and NSL/ML, NL/ML, RL/ML, and PFH: AFH x 100 after eliminating influence of age and tooth contact (MPTC)

Variable	Partial with respect to age	Partial with respect to MPTC	Partial with respect to age and MPTC
NSL/ML	-0.34**	-0.31*	-0.24
NL/ML	-0.27*	-0.25*	-0.15
RL/ML	-0.38**	-0.38**	-0.29*
PFH:AFH x 100	0.35**	0.30*	0.21

* = $0.01 < p < 0.05$, ** = $0.001 < p < 0.01$

Discussion

The use of splints covering the occlusal surfaces of the teeth during the bite force measurements offered distinct advantages. The splint distributed the force over a larger part of the occlusal surface, thus avoiding damage to the enamel or filling material. The flat splints also increased the possibilities for reasonable axial loading of the teeth. Axial loading has been shown to result in greater maximal force than eccentric loading.[25] The combined thickness of the splints and the force-measuring device (median 7 mm), however, prevented strict axial loading. An increased vertical dimension is also known to influence maximal bite force.[26,27] The increase of the vertical dimension may, however, be assumed to influence bite force in the same way in all subjects[28] and should not, therefore, influence the correlation between bite force and facial morphology.

Measurement of maximum bite force is dependent on the effort of the subject, which is influenced by motivation, pain, and fear, among other factors. These factors add to the normal biological intra-individual variation and to technical imperfections. A relatively large error of the method is therefore to be expected in the measurement of maximal bite force. The accidental error in this study, however, compared favorably with the error in a previous study of maximal bite force in children[17] and was of similar magnitude to that found by Linderholm et al.[29] An explanation for the relatively low error in this study may be the use of the splints during the measurements. The consistently larger bite forces recorded at the second measurement of the duplicate determinations illustrate the influence of motivation and fear on measurements of this kind.

The error of the method for the determination of tooth contact was smallest for the variable MPTC and of the same relative size as for maximal bite force, i.e., 7% in terms of coefficient of variation. The recording of tooth contact, like the measurement of bite force, is dependent on the cooperation of the child, who can exert varying biting forces on the strip. Riise[30] demonstrated the importance of the biting force at the recording of tooth contact in adults. In addition, the number and distribution of occlusal contacts change throughout the day depending on the physical state of the masticatory muscles and the mental state of the patient.[31] A further factor in this study that may contribute to the error of the method in the recording of tooth contact is the development of the dentition; the interval between duplicate determinations was, in the extreme case, up to 2 months (median 24 days) during a period of extensive occlusal changes in many of the children.

No difference in maximum bite force was found between the right and left sides, in agreement with the results of previous bite force measurements in children[32-34] and in a combined sample of children and adults.[19] The increase in bite force with age is in accordance with previous bite force measurements in children.[17,19,33-35] The median age of the boys in the present study was more than 1 year greater than that of the girls. This might explain the larger median bite force in boys; in previous bite force studies in children of comparable age, no sex difference was found,[17,32,33,35] with the exception of the study by Shiau and Wang.[34]

In this study, median maximal bite forces were greater than those for children of comparable ages in studies by Lindqvist and Ringqvist,[32] Helle et al.,[33] Fields et al.,[27] Bakke et al.,[19] and Shiau and Wang,[34] but similar to those of Kiliaridis et al.[17] The differences may be related to methodological circumstances (the use of splints and the amount of increase of the vertical dimension). Splints increase the likelihood of axial loading of the teeth and also increase the force distribution on the teeth. With increased force distribution, a higher threshold for the alarm function of the periodontal pain receptors during biting is achieved. In the studies referred to, no splints were used.

The calculation of simple correlations revealed a clear correlation between maximum bite force and facial form in girls, with the same tendency, but less evident, in boys. The reason for the differences in correlations with gender are unknown. When the error for the determination of bite force was calculated separately for boys and girls, no difference was found. Thus, a larger error of the method, diluting the strength of correlations in the boys, is an unlikely explanation. In fact, a gender difference in the correlation between masseter muscle thickness and facial form was found in an earlier study. Kiliaridis and Kälebo,[7] studying young adults, found masseter thickness to be related to the form of the face in women but not in men. From the results of this study and that of Kiliaridis and Kälebo,[7] it is clear that gender has to be taken into consideration in future studies of the correlation between masticatory muscle strength and facial morphology.

Correlations between bite force and facial morphology were found primarily by cephalometric variables expressing the inclination of the mandible, which is in line with the results of earlier studies in children.[13,16] A clear correlation was also found with the size of the gonial angle. These variables have also been found to correlate with masticatory muscle thickness and volume in adults[8-10] and to deviate in so-called long-faced children.[36] A further cephalometric variable clearly correlated with bite force was the quotient between the posterior and anterior face heights. Unexpectedly, however, no correlation was found with the ratio of lower anterior face height to total face height (lower face height %), which may possibly be due to the small variance of this variable. From the correlation analyses, it seems that posterior face height is of greater importance for bite force than anterior face height. Proffit and Fields[18] selected their long-faced children on the basis of the ratio of lower anterior face height to total face height, which may be one reason why they found no difference in bite force between these children and controls.

In a recent study by Braun et al.[37] of the correlation between maximum bite force and facial morphology in young adults, the authors found correlations that are very similar to those of the present study, i.e., a negative correlation with the mandibular plane angle and the mandibular plane/palatal plane angle and a positive correlation with the ratio of posterior to anterior face height but not with the ratio of lower anterior face height to total face height. As in this study, the authors found positive correlations between bite force and upper and lower posterior dentoalveolar heights, which they found surprising. All their results are, however, verified by the present study with almost identical findings.

In agreement with the results of Bakke et al.,[19] who studied a combined sample of children and adults, the number of antagonistic tooth contacts was found to greatly influence bite force. Two explanations for this relationship are possible: (1) many tooth contacts in the intercuspal position implies that during the bite force measurements, force is distributed across many teeth, resulting in a higher pain threshold or positive feedback from periodontal receptors;[38] or (2) good occlusal stability has resulted in strong masticatory muscles, able to develop great force. It is not clear which of these explanations is correct. Explanation 1 (force distribution) is appealing, but Shiau and Wang[34] also found the bite force in children to vary with the number of teeth when they used a bite fork that covered only 1 or 2 teeth, i.e., without force distribution on the teeth. The rapid change of occlusal conditions in many of the children in the present investigation (being in a stage with exfoliation of the deciduous and eruption of permanent teeth) makes the second explanation less likely. On the other hand, the unexpected correlations (in subjects of this age) between tooth contact and relevant morphologic variables support explanation 2. A third explanation for the relationship between the number of tooth contacts and bite force is also possible. It is thus conceivable that strong muscles with resultant hard biting and increased function cause better occlusal stability and an increased number of antagonistic contacts. In any case, it is clear that the number of antagonistic contacts must be taken into consideration in future studies of masticatory muscle strength. One possible way to arrive at a plausible explanation for the correlation between tooth contact and muscle force in children would be to relate the number of tooth contacts to the cross-sectional area of the masticatory muscles. Such studies in adults have revealed a positive correlation with masseter muscle thickness.[8,39]

The influences of age, gender, and tooth contacts make evaluation of the correlation between bite force and facial morphology in children difficult. However, even when these factors are accounted for, a weak correlation still exists, even in children below pubertal age (sample of girls younger than 12 years). The weakness of the correlation does not exclude the possibility that a stronger correlation exists because the variance due to methodological problems reduces the possibility of demonstrating strong correlations.

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References

1. Ringqvist M. Isometric bite force and its relation to dimensions of the facial skeleton. Acta Odont Scand 1973, 31: 35-42.
2. Proffit WR, Fields HW, Nixon WL. Occlusal forces in normal- and long-face adults. J Dent Res 1983, 62: 566-571.
3. Sassouni V. A classification of skeletal facial types. Am J Orthod 1969, 55: 109-123.
4. Ingervall B, Helkimo E. Masticatory muscle force and facial morphology in man. Arch Oral Biol 1978, 23: 203-206.
5. Möller E. The chewing apparatus. Acta Physiol 1966, 69: suppl 280.
6. Bakke M, Micheler L. Temporalis and masseter muscle activity in patients with anterior open bite and craniomandibular disorders. Scand J Dent Res 1991, 99: 219-228.
7. Kiliaridis S, Kälebo P. Masseter muscle thickness measured by ultrasonography and its relation to facial morphology. J Dent Res 1991, 70: 1262-1265.
8. Bakke M, Tuxen A, Vilmann P, Jensen BR, Vilmann A, Toft M. Ultrasond image of human masseter muscle related to bite force, electromyography, facial morphology, and occlusal factors. Scand J Dent Res 1992, 100: 164-171.
9. Weijs WA, Hillen B. Relationships between masticatory muscle cross-sections and skull shape. J Dent Res 1984, 63: 1154-1157.
10. Gionhaku N, Lowe AA. Relationship between jaw muscle volume and craniofacial form. J Dent Res 1989, 68: 805-804.
11. van Spronsen PH, Weijs WA, Valk J, Prahl-Andersen B, van Ginkel FC. A comparison of jaw muscle cross-sections of long-face and normal adults. J Dent Res 1992, 71: 1279-1285.
12. Ahlgren J. Mechanism of mastication. Acta Odont Scand 1966, 24: suppl 44.
13. Ingervall B, Thilander B. Relation between facial morphology and activity of the masticatory muscles. J Oral Rehabil 1974, 1: 131-147.
14. Ingervall B. Facial morphology and activity of temporal and lip muscles during swallowing and chewing. Eur J Orthod 1976, 46: 372-380.
15. Ingervall B, Bitsanis E. A pilot study of the effect of masticatory muscle training on facial growth in long-face children. Eur J Orthod 1987, 9: 15-23.
16. Ingervall B, Thüer U, Kuster R. Lack of correlation between mouth-breathing and bite force. Eur J Orthod 1989, 11: 43-46.
17. Kiliaridis S, Kjellberg H, Wenneberg B, Engström C. The relationship between maximal bite force, bite force endurance, and facial morphology during growth. Acta Odont Scand 1993, 51: 323-331.
18. Proffit WR, Fields HW. Occlusal forces in normal and long-face children. J Dent Res 1983, 62: 571-574.
19. Bakke M, Holm B, Leth Jensen B, Michler L, Möller E. Unilateral, isometric bite force in 8-68-year-old women and men related to occlusal factors. Scand J Dent Res 1990, 98: 149-158.
20. van Spronsen PH. Masticatory muscles in normal and long-face humans (thesis). Amsterdam: University of Amsterdam, 1993.
21. Bakke M. Mandibular elevator muscles: physiology, action, and effect of dental occlusion. Scand J Dent Res 1993, 101: 314-331.
22. Flöystrand F, Kleven E, Oilo G. A novel miniature bite force recorder and it clinical application. Acta Odont Scand 1982, 40: 209-214.
23. SAS/STAT User's guide, Vol. 1, Version 6: The Cancorr Procedure. Cary, NC: SAS Institute Inc, 1990:367-385.
24. Hartung I, Elpelt B. Multivariate Statistik: Lehr- und Handbuch der angewandten Statistik, Oldenbourg Verlag, München 1992, pp 602-605.
25. Widmalm S-E, Ericsson SG. Maximal bite force with centric and eccentric load. J Oral Rehabil 1982, 9: 445-450.
26. Manns A, Miralles R, Palazzi C. EMG, bite force, and elongation of the masseter muscle under isometric voluntary contractions and variations of vertical dimension. J Prosthet Dent 1979, 42: 674-682.
27. Fields HW, Proffit WR, Case JC, Vig KWL. Variables affecting measurements of vertical occlusal force. J Dent Res 1986, 65: 135-138.
28. Lindauer SJ, Gay T, Rendell J. Effect of jaw opening on masticatory muscle EMG-force characteristics. J Dent Res 1993, 72: 51-55.
29. Linderholm H, Lindqvist B, Ringqvist M, Wennström A. Isometric bite force in children and its relation to body build and general muscle force. Acta Odont Scand 1971, 29: 563-568.
30. Riise C. A clinical study of the number of occlusal tooth contacts in the intercuspal position at light and hard pressure in adults. J Oral Rehabil 1982, 9: 469-477.
31. Berry DC, Singh BP. Daily variations in occlusal contacts. J Prosthet Dent 1983, 50: 386-391.
32. Lindqvist B, Ringqvist M. Bite force in children with bruxism. Acta Odont Scand 1973, 31: 255-259.
33. Helle A, Tulensalo T, Ranta R. Maximum bite force values of children in different age groups. Proc Finn Dent Soc 1983, 79: 151-154.
34. Shiau Y-Y, Wang J-S. The effects of dental condition on hand strength and maximum bite force. J Craniomandibular Pract 1993, 11: 48-54.
35. Brawley RE, Sedwick HJ. Studies concerning the oral cavity and saliva. II Biting pressure. (2) Measurements of biting pressure in children. Am J Orthod Oral Surg 1940, 26: 41-46.
36. Fields HW, Proffit WR, Nixon WL, Phillips C, Stanek E. Facial pattern differences in long-faced children and adults. Am J Orthod 1984, 85: 217-223.
37. Braun S, Bantleon H-P, Hnat WP, Freudenthaler JW, Marcotte MP, Johnson BE. A study of bite force, part 2: Relationship to various cephalometric measurements. Angle Orthod 1995, 65: 373-377.
38. Lund JP, Lamarre Y. The importance of positive feedback from periodontal pressoreceptors during volontary isometric contraction of jaw closing muscles in man. J Biol Buccale 1973, 1: 345-351.
39. Bakke M, Stoltze K, Tuxen A. Variables related to masseter muscle function: a maximum R2 improvement analysis. Scand J Dent Res 1993, 101: 159-165.

Commentary: Correlation between maximum bite force and facial morphology in children

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This article explores a question that has interested orthodontists for decades: What is the relationship between masticatory muscle function and the morphological development of the facial skeleton? Several investigators have attempted to answer this question, yet the results from previous studies have been inconclusive and often contradictory.

The premise of this study is that while previous work has demonstrated relatively clear relationships between bite force and facial morphology in adults, the relationship in children has been more difficult to discern. This study offers the advantage of being able to statistically factor out the influence of age changes and occlusal contact differences in calculating correlations between bite force and facial morphology. However, after reading this article, one finds the relationship still not very clear, thereby confirming the evidence already presented. The article does raise some worthwhile questions about current concepts concerning the relationship between masticatory muscle function and the development of facial morphology.

It is generally well accepted that individuals with long mandibles, flat mandibular planes, acute gonial angles, and short lower facial heights exhibit the greatest absolute masticatory muscle activity during function. However, closer review of these previous studies reveals that although statistically significant differences in bite force have been demonstrated in adults with skeletal deep bite morphologies as compared with those with long-face morphologies, substantial variation in bite force and muscle function remain largely unexplained by differences in morphology. In other words, even in adults, a large amount of functional variation exists that cannot be attributed to differences in facial morphology. Apparently this unexplained variation is even greater in children.

In this study, correlations between facial morphologic characteristics and bite force were statistically significant but mathematically weak; the largest being r=0.54. This means that less than 30% (0.54^2) of the observed differences in bite force can be explained by any individual morphological variation alone. However, these results were in qualitative agreement with previous studies in adults. Correlations between bite force and occlusal contact measures found in this study were somewhat stronger. The authors propose two possible explanations for these associations: (1) tooth contacts allow greater force distribution among teeth, thus reducing localized pain perception and permitting harder biting; and (2) good occlusal stability results in strong muscles permitting harder biting. I favor a third hypothesis: strong muscles, harder biting, and increased muscle function cause better occlusal stability and increased tooth contacts to develop. The question is whether form dictates function or vice versa. In all probability, both mechanisms interact dynamically to influence each other during facial development. Though this has been a popular area for study in the past, continued research is warranted to further elucidate these mechanisms.

One of the more perplexing findings in this study was the difference in the degree of correlation between bite force and morphology in girls and boys. The reasons for this variation are unknown, but are not, as the authors correctly point out, inconsistent with previous findings. In girls, facial morphology, bite force, age, and occlusal contacts were all found to be interrelated. Statistical elimination of the effects of age and occlusal contacts somewhat diminished the correlations between facial morphologic features and bite force.

Overall, this is a well conceived, soundly performed, and well documented study. The relatively inconclusive results reflect a rather weak relationship between muscle function and facial morphology despite our desire, as orthodontists, to believe that form exclusively follows function. If form does follow function, perhaps we are not measuring all the functional characteristics that dictate form. Otherwise, there may be other factors, such as inherited determinants or other environmental influences, that affect morphological development. Someday we may be able to account for all the component influences on the development of facial morphology. Until then, it is useful to remain informed about the extent to which we can explain why functional morphologic characteristics develop in the way they do.