The relationship between maximal bite force, bite force endurance, and facial morphology during growth

A cross-sectional study

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The aims of this investigation were to study the relation between facial morphology and bite force at different ages during growth and to investigate possible relations between bite force and the variables age, finger force, stature, and sex in growing healthy individuals. One hundred and thirty-six individuals were included, consisting of six groups of males and females, 7–9, 10–12, and 20–24 years old. Standardized photographs were taken to determine the facial type. The occlusal relationship, body height, finger force, maximal bite force, and bite force endurance amplitude were recorded. All bite force variables and finger force increased with age in both sexes. A positive correlation was found between the maximal bite force in the incisor region and the ratio of upper to lower facial height; that is, subjects with a high bite force had a relatively short lower anterior height. The maximal bite force for molars and endurance amplitude were positively correlated to stature and finger force but not to facial characteristics. A longitudinal study to follow each individual child during growth would be of interest to evaluate the importance of muscular influence on facial growth. □ *Bite force; face; growth; masticatory muscles; stature*

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Clinical and animal experimental studies have shown the significant role played by the masticatory muscle function in craniofacial growth. Various methods have been used to evaluate clinically the physiologic characteristics of the masticatory muscles. One of these methods is the measurement of the voluntary maximal bite force.

Previous studies, in adult patients, have shown that the occlusal forces of individuals with normal facial proportions are intermediate between those of long-faced and short-faced types, who exert low and high forces, respectively (1–3). The facial morphology of short-faced individuals is characterized by a small anterior face height, anterior inclination of the mandible, and 'parallelism' between the jaw bases, whereas long-faced individuals are characterized by a large anterior facial height, an obtuse gonial angle, and a steep mandibular plane. Compared with adult long-faced individuals, adult normal-faced individuals exerted two to three times higher bite force values during swallowing, chewing, and maximal biting (2). However, no such differences were found between long-faced and normal-faced children (4), which raises the question of the age at which these differences develop.

With regard to general muscle strength, girls are as strong and as large as boys until puberty. The increase in muscle mass during puberty, influenced by androgenic steroids, creates the differences between male and female muscle strength (5). This pattern was also found when measuring masticatory muscle strength. Several investigators have shown that the bite force increases with age up to adolescence (6) and that the difference between the sexes is first seen at puberty (7).

However, few data have been reported about how bite force is related to facial morphology during growth. Thus the aim of this investigation was to study the relation between facial morphology and bite force and between bite force and the variables age, general muscle force measured as finger force, height, and sex in normally growing healthy individuals.

Subjects and methods

Subjects

The subjects studied comprised 136 individuals: 99 randomly selected children 7–13 years of age, with no history of orthodontic treatment, and 37 dental students 20–24 years of age. Age and sex distribution are shown in Table 1.

Methods

Clinical recordings. A clinical intraoral examination was performed to record the sagittal, vertical, and transversal occlusal relation of the dental arches and to measure space discrepancies. Body height was recorded.

Photographs. The facial morphology was determined by measuring standardized photographs, taken in profile and en face, with the patients standing up in a relaxed position while looking in a mirror. The recordings were made with the teeth in the intercuspal position. The mandibular ridge was marked, to find the soft-tissue menton. The following variables were calculated: the ratio of the upper to the lower facial height, UFH/LFH (%), and the ratio of the total facial height (on en face photographs) to the

Table 1. Descriptive statistics for females and males in different age groups

	7–9 years		10–13 years		20–24 years	
	$\bar{x}$	SD	$\bar{x}$	SD	$\bar{x}$	SD
Females, n =	29		28		22	
Height (cm)	131.5	5.4	150.5	11.3	168.5	5.1
Fac. height (mm)	114.0	8.1	123.0	8.4	134.5	10.4
UFH (mm)	46.0	3.2	51.5	3.9	57.0	4.9
LFH (mm)	68.0	6.2	71.0	6.3	78.0	7.4
UFH/LFH (%)	69.0	6.0	73.0	7.0	73.5	7.6
FH/FW (%)	77.0	5.0	78.5	3.8	78.0	3.7
MBF mol (N)	472.0	82.1	569.0	131.3	650.0	196.1
MBF inc (N)	111.0	48.4	177.0	66.2	223.0	57.2
MF finger (N)	39.0	7.2	50.0	14.4	78.0	18.6
End. time (s)	33.0	17.1	23.0	11.6	39.5	15.6
End. ampl. (N)	279.0	77.5	392.0	137.0	487.0	169.1
Males, n =	25		17		15	
Height (cm)	133.0	48.4	151.0	7.4	183.0	6.1
Fac. height (mm)	117.5	6.3	128.5	6.6	146.5	13.3
UFH (mm)	45.0	3.2	52.0	3.9	62.5	7.0
LFH (mm)	72.5	4.5	76.5	4.4	84.0	7.1
UFH/LFH (%)	62.5	4.8	68.0	5.7	74.5	5.4
FH/FW (%)	76.5	3.8	79.0	4.0	82.0	4.5
MBF mol (N)	470.0	97.7	589.0	88.2	807.0	140.3
MBF inc (N)	116.0	58.2	199.0	62.9	244.0	59.8
MF finger (N)	41.0	7.8	58.0	14.1	111.0	17.1
End. time (s)	27.5	16.3	38.5	19.5	49.5	19.7
End. ampl. (N)	277.0	108.0	430.0	109.8	629.0	168.9

UFH = upper facial height; LFH = lower facial height; FH = total facial height; FW = facial width; MBF = maximal bite force.

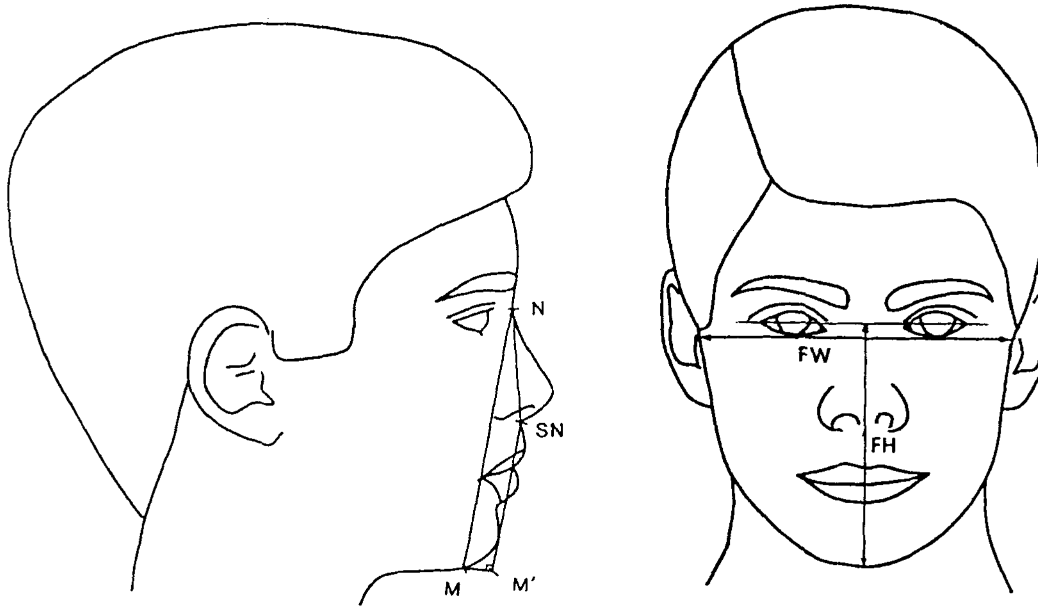

Fig. 1. Variables used to evaluate facial morphology: facial height (FH), N–M; facial width (FW); upper facial height (UFH), N–SN; lower facial height (LFH), SN–M′; facial height to facial width, FH/FW (%); and upper to lower facial height, UFH/LFH (%).

facial width, FH/FW (%). The reference points and lines used in the present study are defined in Fig. 1. The measurements were made to the nearest 0.5 mm.

Bite force and finger force measurements. Maximal bite force (MBF) was determined with a bite force recorder, as described and used previously by Helkimo et al. (8). The device consisted of a metal fork with a plastic coating to protect the enamel from chipping. The fork was connected to a strain gauge. When pressure was applied to the fork, the bite force was recorded graphically on a recorder (Speedomax, Leeds & Northrup), which had a maximal recording range of 980 N. The thickness of the fork was 6.9 mm (metal) + 4 mm (plastic coating), which was decreased slightly during biting. The device was calibrated regularly for a linear relation between load and recorded deflection.

The individual placed the shanks of the metal fork in three positions: between the first molars on each side and between both central incisors.

The bite force endurance amplitude was determined in the right or left molar region. The individual's side of preference was chosen. The person was instructed to bite as hard as possible and maintain the force as long as possible. The length of the endurance period was measured in seconds with a stopwatch. The mean amplitude of the maximal bite force level during the first 10 sec of the period was calculated by measuring the bite force every second and then taking the mean.

The maximal finger strength on both the left and the right hand was measured between the thumb and the index finger, using the same apparatus. All recordings were performed twice in each position. To obtain the highest values, the patients were urged to do their very best. They were allowed to look at the recorder after each of their efforts to see the results and compete with themselves. The highest value was used as the maximal force in the given region.

Statistics

The mean, standard deviation, and range were calculated for each of the variables measured. Differences between the means were tested between the age groups and the sexes by means of Student's t test.

To find a possible correlation between characteristics of jaw muscle forces, growth variables, and facial morphology, multiple regression analyses were used.

Error of the method

The error of the method for recording facial morphology and bite force was calculated by duplicate determinations of 20 patients in accordance with the formula:

$$S_e = \sqrt{\Sigma(a_1 - a_2)^2/2n}.$$

The error of the evaluation of the facial morphology was 1.8(%) for the ratio FH/FW and 2.6(%) for the ratio UFH/LFH.

The methodologic error for the maximal bite force recordings was 69 N, whereas the error of the method for the mean amplitude of the maximal bite force recorded during the first 10 sec in the endurance test was 46 N.

Results

Somatic characteristics

The stature of the individuals naturally increased with age ($p < 0.0001$). Differences in stature between the sexes were first seen in the adult group ($p < 0.0001$). A large variation was observed in the 10- to 12-year age group, especially in the girls (Table 1).

The facial morphology for the proportion of the upper to the lower face (UFH/LFH ratio) showed a difference between males and females in the children's groups ($p < 0.0001$) owing to a proportionally longer lower facial height in males. The proportion was altered gradually in the older groups in favor of the upper facial height, with no difference between males and females in the adult group. The proportion of the total facial height to facial width (FH/FW) showed no statistically significant difference between sexes and age groups, except in the adult group, in which the facial height in proportion to facial width was higher for males than females ($p < 0.007$) (Table 2).

Table 2. Interrelation between facial morphology, bite force, sex, and body height, by means of multiple regression analysis. $Y = a + b_1Sex + b_2Height + b_3Endr + b_4MBFinc$. Dependent variables: Y = upper to lower facial height (UFH/LFH), facial height to facial width (FH/FW), lower facial height (LFH). Independent variables: X = sex†, height, maximal bite force endurance during 10 sec (Endr), maximal bite force incisors (MBFinc) (b = coefficient of regression)

Multiple regression analysis of data from all individuals (n = 136)					
Dep. var. Y	b_1Sex	b_2Height	b_3Endr	b_4MBFinc	R^2
UFH/LFH	4.74***	0.11*	NS	0.02*	0.29***
FH/FW	NS	0.12*	NS	NS	NS
LFH	−3.97***	0.29***	NS	NS	0.46***
Multiple regression analysis of data from all children (n = 99)					
Dep. var. Y	b_1Sex	b_2Height	b_3Endr	b_4MBFinc	R^2
UFH/LFH	6.16***	NS	NS	0.04**	0.33***
FH/FW	NS	NS	NS	NS	NS
LFH	−4.39***	0.30***	NS	−0.02*	0.39***
Multiple regression analysis of data from all adults (n = 37)					
Dep. var. Y	b_1Sex	b_2Height	b_3Endr	b_4MBFinc	R^2
UFH/LFH	NS	NS	NS	NS	NS
FH/FW	−6.82**	NS	NS	NS	0.33*
LFH	NS	NS	NS	NS	0.25*

* $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$. R^2 = coefficient of determination.

† In the multiple regression analysis concerning the independent dummy variable 'sex', 1 stands for males and 2 for females.

Occlusion

In all subjects at least the first molars and the incisors had erupted. Of the children 90 had a neutral, 8 a postnormal, and 1 a prenormal molar relationship. Eighteen children were found to need orthodontic treatment (for postnormality, prenormality, crowding, spacing, forced lateral cross-bite, and open bite). In the adult group all had a complete dentition with no signs of periodontal problems. Four had a slight postnormal and one a slight prenormal occlusion; otherwise, no serious malocclusions were noted. Individuals with different types of sagittal occlusal relationships (Angle Classes) were first analyzed separately to find differences that could influence the results. No significant differences in bite force or facial dimensions were found, so it was decided to include all patients in the study.

Finger force

The maximal finger force increased with age in both sexes ($p < 0.0001$). Sex differences were not found in the children's group, but among the adults males were stronger ($p < 0.0001$). An increase in variation was observed with increasing age (Table 1). The correlation test showed that finger force was positively correlated to maximal bite force for molars and for the mean amplitude of the endurance when all individuals were included. When adults only were tested, no significant correlation could be found between finger and bite force (Table 3).

Bite force

All bite force variables increased with age in both sexes ($p < 0.001$) except for the maximal bite force for molars in females 10–13 and 20–24 years old and for the incisal bite force of males in the same age groups. No differences were observed between the sexes, except in the adult group, in which the maximal bite force in the molar region was highest for the males ($p < 0.011$). The mean amplitude of the maximal bite force endurance for the first 10 sec increased with

Table 3. Interrelation between bite force, sex, age, body height, and finger force by means of multiple regression analysis. $Y = a + b_1Age + b_2Sex + b_3Height + b_4Fingerf$. Dependent variables: Y = maximal bite force molars (MBFmol), maximal bite force incisors (MBFinc), maximal bite force endurance during 10 sec (Endr). Independent variables: X = age, sex†, height, finger force (b = coefficient of regression)

Multiple regression analysis of data from all individuals (n = 136)					
Dep. var. Y	b_1Age	b_2Sex	b_3Height	b_4Fingerf.	R^2
MBFmol	NS	NS	4.35**	2.25**	0.48***
MBFinc	NS	NS	NS	NS	0.40***
Endr	NS	NS	6.67***	1.61*	0.54***
Multiple regression analysis of data from all children (n = 99)					
Dep. var. Y.	b_1Age	b_2Sex	b_3Height	b_4Fingerf.	R^2
MBFmol	NS	NS	NS	2.86**	0.34***
MBFinc	2.04***	NS	NS	NS	0.41***
Endr	NS	NS	NS	3.06**	0.45***
Multiple regression analysis of data from all adults (n = 37)					
Dep. var. Y	b_1Sex	b_2Height	b_3Fingerf.	R^2	
MBFmol	NS	NS	NS	0.27*	
MBFinc	NS	NS	NS	NS	
Endr	NS	14.97**	NS	0.36**	

* $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$. R^2 = coefficient of determination.

† In the multiple regression analysis concerning the independent dummy variable 'sex', 1 stands for males and 2 for females.

age ($p < 0.0001$) except for females 10–13 and 20–24 years old. The variation between individuals with regard to the maximal bite force in the molar region and the mean amplitude of the endurance test for the first 10 sec was found to increase with age. No such increase in variation was observed for the maximal bite force in the incisor region (Table 1). A positive correlation was found between body height and mean amplitude of the maximal bite force endurance ($p < 0.0001$) and for the maximal bite force for molars ($p < 0.002$). When the adult group was studied separately, the same tendencies could be seen, but when the children were studied alone, no statistically significant correlations between bite force and height could be found. The maximal bite force for incisors increased with age in the children's groups but not in the adults (Table 3).

The ranges of maximal bite force in the different age groups for Angle Class II, males and females together, was 385–610 N for 7–9 years, 450–680 N for 10–13 years, and 420–650 N for adults, for molars, whereas the range for incisors was 60–130 N, 110–160 N, and 160–270 N, respectively. For Angle Class III, the values for the two patients concerned were 470 N for molars and 90 N for incisors for one patient in the 7- to 9-year age group and 690 N and 190 N, respectively, for one adult patient.

Relation between muscle characteristics and facial morphology

Multiple regression analyses (Table 2), when used either for all patients or for children only, revealed slight, significant, positive relationships between the UFH/LFH ratio and the maximal bite force for incisors. When testing adults only, no such correlations were found (Table 2). No other correlations between facial morphology and bite force variables were found.

Discussion

The present study has shown that in growing individuals the vertical proportions of the anterior facial morphology are interrelated to the individual's incisal maximal bite force. No relation was found between the facial characteristics and the maximal bite force in the molar region or the maximal bite force endurance.

The use of photographs instead of radiographs decreases the possibility of accurately measuring the facial morphology, the measurements being subject to greater errors, such as due to differences in the soft tissue. This rough method of determining facial morphology enables, however, the investigation of a large number of individuals without using radiography, thereby avoiding ethical considerations.

In studies on occlusal bite force the variability of the results is often considerable. Facial morphology, growth changes, general muscular force, and differences between sexes are only some of the factors that may influence the results. Others, such as state of dentition, location within the dental arch where the bite force is measured, psychologic and mental conditions during the effort, attitude of the investigator and subject, malocclusions, and the extent of the vertical separation of the teeth and the jaws due to the bite fork, may influence the values obtained (9, 11). An attempt to come closer to the real capacity of the masticatory muscles was made by calculating the mean amplitude of the maximal bite force level during the first 10 sec of the endurance period during maximal clenching. Although this method still includes similar disadvantages as when recording the maximal bite force, it seemed to reduce the variability by including the factor time (10 sec), since a smaller error of the method was found.

Fields et al. (10) found that increasing the vertical opening between the teeth resulted in a slight decrease in maximal bite forces leading to a minimum at 20 mm. They did not find any difference in maximal bite force between 2.5 and 6 mm of vertical openings, either in children or in adults. In the present study the thickness of the bite fork was about 11 mm, which means that the real maximal bite force is probably higher than what was measured.

Finger force was measured as an indicator of general muscle force. We found a clear correlation between finger force and maximal bite force in the molar region, but not in the incisor region, and only for children, not for adults, which is in accordance with the findings of Linderholm & Wennström (12) and Linderholm et al. (13). Furthermore, no correlation was found between finger force and bite force in male adults by Helkimo & Ingervall (14). A possible explanation of the correlation differences between children and adults may be the effect of physical training of certain muscle groups in adults due to a special sport, work, and so forth. Although there was a correlation between finger force and bite force for molars, this was not the case for the incisors. This may be due to a greater influence of other factors on the incisors, such as degree of proclination, overbite, and root development.

The observed increase in bite force during growth is in agreement with the report by Brawley & Sedwick (6), who found that the average rate of increase in bite force of the first permanent molars in children was approximately 2.3 kg (≈23 N) per year from 7 to 16 years. The present study showed the same tendency in groups studied up to adulthood (23 years).

In the youngest age group (7–9 years) the roots of the incisors were not fully developed. This must be taken into consideration when estimating the results of the correlation test between age and maximal bite force for the incisors. The strong correlation may be influenced by the higher load per surface unit on the roots of the youngest individuals, reaching more easily the pain threshold and thus resulting in a lower bite force. This has also been pointed out by Linke et al. (15), who found a nonlinear correlation between bite force and age with the lowest incisor bite force around the age of 7 years. Several authors have found positive correlations in children between bite force and growth variables such as age, body height, and weight (13, 16–18). In female adults, however, Ringqvist (3) found significant correlations between body height and maximal molar bite force, whereas Linderholm & Wennström (12) did not. In the present investigation, when testing adults only, a correlation between body height and the mean amplitude of the maximal bite force in the endurance test was found, but not between body height and maximal molar bite force.

Sex differences in bite force were found in the adult group only, and these referred to the maximal bite force for molars, not for incisors. This is in concordance with the report of Shiau & Wang (19), who found that boys became significantly stronger than girls after the age of 13 years. Other studies have shown divergent results depending on the age group tested and on the teeth involved in the test (7, 11, 13, 15, 20). Garner & Kotwal (7) found that males over 17 years of age bite harder than females, but that the average bite force values for females 11–16 years old were equal to or even higher than those for males.

In the present study a correlation between facial morphology and maximal incisal bite force in children was found; individuals with a proportionally smaller lower facial height had the highest maximal bite force between the incisors. This is in accordance with the findings of Garner & Kotwal (7) that a positive correlation exists between the incisal bite force and overbite, since individuals with proportionally small lower facial height usually have deeper overbite. Although a correlation was found between facial morphology and maximal incisal bite force, the present study did not demonstrate any correlations between facial morphology and maximal bite force in the molar region, as have been described in adults in several other investigations (1, 2), possibly because of the differences in the selection of the sample examined. We examined individuals of a 'normal sample', in contrast to previous studies, which were mostly based on comparisons of subjects deviating from the average either in bite force or facial morphology. This made it possible to more easily detect existing correlations disguised by, for example, the error of the method. However, it is noteworthy that despite the extreme cases selected by Proffit & Fields (4), no difference in the bite force for molars could be found between long-faced and normal-faced children (6- to 11-year-old boys and girls), possibly owing to the large variation in the bite force values in the sample of long-faced children. This may be due to the imperfection of the bite force as an evaluating method of the masticatory muscle capacity. Although the measuring device may have a good precision, the bite force can vary considerably, as can other recordings of muscular contraction forces in the body. This biologic variation is included in the 'error of the method' and may have disguised small differences between the subjects.

The studies of Throckmorton et al. (21), using a two-dimensional model, showed how the geometry of the mandible can affect the occlusal force directly by varing the mechanical advantage of the muscles. Their results suggest that in long-faced individuals the greater maxillary height, the more obtuse gonial angle, and the steep mandibular plane should produce a decreased mechanical advantage for the temporalis and masseter muscles, which in part could explain the correlation we and other researchers found between bite force and the vertical proportions of the anterior facial morphology. However, other opinions were stated by Proffit et al. (22) in a study in which the facial morphology was radically changed using orthognatic surgery. Both an increase and a decrease in bite force occurred, and the changes in bite force could not be related to jaw geometry.

No unanimity has been achieved concerning the function of the masticatory muscles and its relation to sagittal deviations of the facial morphology and occlusion of the teeth (1, 20, 23, 24). In the present study the few cases studied with malocclusions showed that no differences in bite force between the Angle Classes were noticeable, which is in agreement with the reports of Ahlgren (23) and Ahlgren et al. (24), who found only slight or no differences in muscular function between patients with different sagittal patterns of the facial morphology and/or between occlusal relations (different Angle Classes).

In conclusion, a positive correlation was found between the maximal bite force in the incisor region and the vertical proportions of the anterior facial morphology; that is, subjects with a high bite force had a relatively short lower anterior height. No relation was found between the facial characteristics and the maximal bite force in the molar region or the maximal bite force endurance. A longitudinal study to follow up each individual child during growth would be of interest to evaluate the importance of muscular influence on facial growth.

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References

1. Ingervall B, Helkimo E. Masticatory muscle force and facial morphology in man. Arch Oral Biol 1978;23:203–6.
2. Proffit WR, Fields HW, Nixon WL. Occlusal forces in normal- and long-face adults. J Dent Res 1983; 62:566–71.
3. Ringqvist M. Isometric biteforce and its relation to dimensions of the facial skeleton. Acta Odontol Scand 1973;31:35–42.
4. Proffit WR, Fields HW. Occlusal forces in normal- and long-face children. J Dent Res 1983;62:571–4.
5. Falkner F, Tanner JM. Human growth. Part 2. Postnatal growth. New York: Plenum Press, 1978:273–294, 381–412.
6. Brawley RE, Sedwick HJ. Studies concerning the oral cavity and saliva. II Biting pressure. (2) Measurements of biting pressure in children. Am J Orthol Oral Surg 1940;26:41–6.
7. Garner LD, Kotwal NS. Correlation study of incisive biting forces with age, sex and anterior occlusion. J Dent Res 1973;52:698–702.
8. Helkimo E, Carlsson GE, Carmeli Y. Bite force in patients with functional disturbances of the masticatory system. J Oral Rehabil 1975;2:397–406.
9. Carlsson GE. Bite force and chewing efficiency. Front Oral Physiol 1974;1:265–92.
10. Fields HW, Proffit WR, Case JC, Vig KWL. Variables affecting measurements of vertical occlusal force. J Dent Res 1986;65:135–8.
11. Hagberg C. Assessments of bite force: a review. J Craniomandib Disord 1987;1:162–9.
12. Linderholm H, Wennström A. Isometric bite force and its relation to general muscle force and body build. Acta Odontol Scand 1970;28:679–89.
13. Linderholm H, Lindqvist B, Ringqvist M, Wennström A. Isometric biteforce in children and its relation to body build and general muscle force. Acta Odontol Scand 1971;29:563–8.
14. Helkimo E, Ingervall B. Bite force and functional state of the masticatory system in young men. Swed Dent J 1978;2:167–75.

15. Linke PG, Dette KE, Hoppmann I. Die Entwicklung der Kaukraft bei Kindern in abhängigkeit von Geschlecht, Alter, Körpergröße und Gewicht. I. Untersuchungen an Kindern im Vorschulalter. Aerztl Jugendkde 1971;62:338–49.
16. Linke PG, Keuerleber I, Sandau D. Die Entwicklung der Kaukraft bei Kindern in abhängigkeit von Geschlecht, Alter, Körpergröße und Gewicht. II. Die Ermittlung der von Schulkindern erzielbaren Kaukräfte der Sechsjahrmolaren und die Korrelation mit verschiedenen somatischen Größen. Aerztl Jugendkde 1972;63:73–85.
17. Helle A, Tulensalo T, Ranta R. Maximum bite force values of children in different age groups. Proc Finn Dent Soc 1983;79:151–4.
18. Ranta R, Tulensalo T, Helle A. Individual changes of maximum bite force in children. IRCS Med Sci 1984;12:1020.
19. Shiau YY, Wang JS. The effects of dental condition on hand strength and maximum bite force. J Craniomandib Pract 1993;11:48–54.
20. Helkimo E, Carlsson GE, Helkimo M. Bite force and state of dentition. Acta Odontol Scand 1977; 35:297–303.
21. Throckmorton GS, Finn RA, Bell WH. Biomechanics of differences in lower facial height. Am J Orthod 1980;77:410–20.
22. Proffit WR, Turvey TA, Fields HW, Phillips C. The effect of orthognatic surgery on occlusal force. J Oral Maxillofac Surg 1989;47:457–63.
23. Ahlgren JGA. Mechanism of mastication. A quantitative cinematographic and electromyographic study of masticatory movements in children, with special reference to occlusion of the teeth. Acta Odontol Scand 1966;24 Suppl 44.
24. Ahlgren JGA, Ingervall BF, Thilander BL. Muscle activity in normal and postnormal occlusion. Am J Orthod 1973;5:445–56.

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