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Maximum voluntary molar bite force in subjects with normal occlusion

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SUMMARY The aims of this investigation were to determine whether stabilization of maximum voluntary bite force (MVBF) occurs between 15 and 18 years of age in subjects with a normal occlusion, and to assess the influence of gender, body mass index (BMI), morphological occlusion, and jaw function measured by the number of occlusal contacts, overjet, overbite, maximal mouth opening, mandibular deflection during opening, sagittal slide between the retruded contact position and the intercuspal position, and number of dental restorations.

The sample comprised 60 Caucasian subjects aged 15 (15 males and 15 females) and 18 (14 males and 16 females) years with a neutral occlusion, balanced facial profile, and absence of a previous orthodontic history. Bite force measurements were undertaken using a portable occlusal force gauge on both the left and the right sides of the jaw in the first molar region during maximal clenching. Two independent samples *t*-tests and multiple regression were used for statistical analysis.

MVBFs were age and gender related ($P < 0.05$). Males showed a significant increase in bite force between 15 and 18 years of age ($P = 0.002$), but gender differences were significant only in the 18-year-olds ($P = 0.003$). In subjects with a neutral occlusion, MVBF could best be predicted using multiple regression from age and gender. The regression model accounted for 31.3 per cent of the variance in MVBF ($P = 0.031$), with gender contributing 17.9 per cent and age 7.9 per cent. Morphological occlusion, jaw function, and BMI explained the remaining 5.5 per cent of variance. While controlling for all other parameters, the independent contribution of gender to the prediction of MVBF was 16.2 per cent, age 6 per cent, number of occlusal contacts 3.2 per cent, and BMI 1.3 per cent.

Introduction

Maximum voluntary bite force (MVBF) is related to the health of the masticatory system (Kampe *et al.*, 1987; Ow *et al.*, 1989) and has an influence on muscle efficiency and development of masticatory function in dental development (Ingervall and Minder, 1978; Braun *et al.*, 1995, 1996); thus, it could be used as a method for their assessment.

Large variations in human bite force have been recorded in the first molar area (Bates *et al.*, 1975; Proffit *et al.*, 1983; Lundgren and Laurell, 1986), some of which can be explained by the fact that the studies have been performed on different populations, or by the difference in measuring instruments and techniques (Sasaki *et al.*, 1989).

Nevertheless, several factors that influence MVBF have been proposed: the condition of the dentition, the strength of the jaw-closing muscles, and the pain threshold of the subject (Tortopidis *et al.*, 1998). Bite force varies within the regions of the oral cavity and is greatest in the first molar area (Tortopidis *et al.*, 1998). It is also likely that the degree of jaw opening, and hence muscle length, is important in influencing maximum bite force.

MVBF also varies in different age groups. It is greater in adults with a rectangular craniofacial morphology and skeletal deep bite than in those who have a long face and open bite (Abu Alhaija *et al.*, 2010). These correlations are less apparent in children (Sonnesen and Bakke, 2005). It is also possible that signs and symptoms of temporomandibular dysfunctions can interfere with correct masticatory function and muscle strength in children (Duarte Gaviao *et al.*, 2006) as well as in adults (Kogawa *et al.*, 2006).

Masticatory performance has been shown to be decreased in subjects with malocclusions when compared with those with a normal occlusion (English *et al.*, 2002; Yawaka *et al.*, 2003; Tsai, 2004). With regard to general muscle strength, this has been shown to be as strong and as large in females as in males until puberty (Kiliaridis *et al.*, 1993). It is believed that gender-related bite force differences develop during the post-pubertal period in association with greater muscle development influenced by androgenic steroids in males (Kiliaridis *et al.*, 1993; Braun *et al.*, 1996) and that a decline in occlusal force is associated with masticatory performance with ageing (Ikebe *et al.*, 2006).

Some investigations have established the influence of age and gender on MVBF (Garner and Kotwal, 1973; Braun *et al.*, 1996; Shinogaya *et al.*, 1999), while others investigated the association of MVBF with weight, height, and body mass index (BMI; Linderholm and Wennström, 1970; Shiau and Wang, 1993; Braun *et al.*, 1995; Canbarro and Shinkai, 2006; Castelo *et al.*, 2007). However, no study has investigated the possibility of prediction of MVBF by taking those parameters into account.

Although malocclusions and compromised dentitions (loss of teeth and occlusal contacts) are often associated with reduced maximum bite force (Bakke, 2006), there are a limited number of studies primarily based on subjects with a normal occlusion in order to define the range of normal maximal masticatory forces in subjects without disturbed morphological and functional occlusion. Objective information concerning the stabilization of MVBF in the human dentition would be beneficial for both investigators and practitioners. Reference values in different age groups and the stabilization of MVBF can be used as a basic model in the objective evaluation of the occlusion in orthodontic patients either pre- or post-treatment.

The aims of this investigation were to determine whether stabilization of MVBF occurs between 15 and 18 years of age, and to assess the influence of gender, BMI, morphological occlusion, and jaw function on MVBF in subjects with normal occlusion. It was hypothesized that MVBF increases during the period between 15 and 18 years of age and that it is influenced by gender, BMI, morphological occlusion, and jaw function. A further aim was to explore the possibility of predicting the amount of MVBF by taking into account these parameters, and to assess the independent contribution of each on MVBF.

Subjects and methods

The subjects and their parents signed an informed consent to participation in the study, and the research was approved by the Ethics Committee of the School of Dental Medicine University of Zagreb, Croatia (reference number: 05-PA-26-37/06).

The sample comprised 60 Caucasian subjects with a neutral occlusion (Class I molar relationship) with balanced facial profiles, a symmetric appearance in the frontal view, harmoniously shaped competent lips, and absence of previous orthodontic treatment. Thirty subjects (15 males and 15 females) were aged 15 years and 30 (14 males and 16 females) 18 years. They were selected during an epidemiological survey on the prevalence of malocclusion in Croatia (Spalj *et al.*, 2010). None of the subjects had craniofacial anomalies or systemic muscle or joint disorders. Morphological examination verified the neutral occlusal relationship (both canines and molars were Angle Class I), the presence of all permanent teeth, except third molars, and the absence of any dental malocclusion, even minor rotations. The evaluation of inclusion criteria for each subject was conducted by two trained orthodontists (SV and SS) using a mouth mirror and artificial lighting from a loop on the examiner's head.

All measurements were made with the subjects seated, looking forward, and in an unsupported natural position. Measurements of MVBF were undertaken during a single session for each subject, using a portable occlusal force gauge (GM10; Nagano Keiki, Tokyo, Japan). The instrument consisted of a hydraulic pressure gauge and a biting element (17 mm in width and 5.4 mm in height) made of a vinyl material encased in a disposable plastic tube (Figure 1). Each tube was used for one recording after which the device was cleaned with a cloth moistened with alcohol. The measuring range of the instrument was from 0 to 1000 N with an accuracy of ±1 N. Bite force was displayed digitally. It was measured unilaterally on both the left and right sides of the jaw in the first molar region during a few seconds of maximal clenching; according to a standard procedure (Bakke *et al.*, 1989). The maximum bite force was measured four times on each side and was repeated in reverse order after a 2–3 minutes interval. MVBF was determined as the average of 16 recordings. None of the subjects experienced any discomfort or pain during biting on the instrument.

Clinical examination comprised measurements of morphological occlusion and jaw function. Maximal mouth opening, mandibular deflection during opening, sagittal slide between the retruded contact position (RCP) and the intercuspal position (ICP), overjet, and overbite measurements were performed using a digital sliding calliper with an accuracy of ±0.03 mm (Levior S.R.O., Prerov, Czech Republic). Occlusal contacts were assessed in terms of the number of teeth in contact in ICP. This was done by registering the subject's ability to hold a plastic strip, 0.05 mm thick and 6 mm wide (Hawe transparent strips No 690, straight; Kerrhawe SA, Bioggio, Switzerland) between the teeth against a strong pull when their jaws were firmly closed (Bakke *et al.*, 1990). The method error has previously been reported to be 10 per cent of the mean value (Bakke and Michler, 1991). The number of occlusal contacts and their location were recorded. The number of dental restorations was determined using a mouth mirror and artificial lighting.

Body height was measured with the subject in an erect position without shoes using a height metre with a precision of 0.1 cm, and weight was recorded in kilograms with

Figure 1 Occlusal force gauge.

personal scales to the precision of 0.1 kg. The BMI of each subject was calculated. All the measurements were conducted by one examiner (SV).

Statistical analyses were performed using the Statistical Package for Social Sciences, version 10.0 (SPSS Inc., Chicago, Illinois, USA). As Shapiro–Wilk's test showed that the data were normally distributed ($P > 0.05$), two independent sample *t*-tests and multiple regression analysis were used.

Results

Reliability was evaluated by repeating the measurement in 10 randomly selected subjects after a 1 week interval (Table 1). Statistical procedures suggested by Bland and Altman (1996) were used. Biological variations of variables assessed as the standard deviation were always higher than the measurement error. Since functional measurements are subject to learning effects, systematic errors between measurements were quantified. Repeatability for MVBF was 213.84 at the first and 178.8 at the second examination and for maximal mouth opening 8.36 and 6.18, respectively. Differences between the two measurements for the same subject were lower than repeatability values in 88–95 per cent of subjects. To avoid random error, the mean of MVBF and maximal mouth opening were used for further statistical analysis.

There were no significant differences in MVBF between the left and right sides of the jaw (Table 2). MVBF was significantly related to age and gender, being, in general, higher in males and older subjects. Males showed a significant increase in bite force between the ages of 15 and 18 years ($P = 0.002$), but gender differences were significant only in 18-year-olds ($P = 0.003$; Table 2 and Figure 2). Bite force was 522.3 ± 181.7 N in males and 465.1 ± 234.6 N in females at 15 years of age. It increased to 777.7 ± 78.7 N in males and 481.6 ± 190.4 N in females at 18 years of age.

Distribution of BMI and morphological occlusion and jaw function parameters in the two age groups and genders is shown in Table 3. In subjects with a neutral occlusion, according to multiple regression analysis, MVBF could be best predicted from age and gender (Table 4). The first regression model that considered prediction of MVBF using only age and gender, accounted for 25.4 per cent of variance of MVBF ($P < 0.001$), with gender contributing 16.4 per cent and age 9 per cent. An extended model controlling for age and gender accounted for 31.3 per cent of the variance of MVBF ($P = 0.031$), with gender contributing 17.9 per cent and age 7.9 per cent. Parameters of morphological occlusion, jaw function, and BMI in the model explained the remaining 5.5 per cent of variance. The number of occlusal contacts and overjet had the highest contribution, 3.5 and 1.3 per cent, respectively. Controlling for all other parameters, the independent contribution of gender to the prediction of MVBF was 16.2 per cent and age 6 per cent. The correlation for gender increased from $r = -0.4$ to $r = -0.44$ but for age decreased from $r = 0.29$ to $r = 0.28$. For other parameters, the highest independent contribution to prediction of MVBF, while controlling for all other factors, was the number of occlusal contacts (3.2 per cent) and BMI (1.3 per cent) with correlations increasing from $r = 0.18$ to $r = 0.21$ for contacts and from $r = 0.01$ to $r = 0.13$ for BMI.

Table 1 Reproducibility, measurement error, and repeatability of measurements.

Variable	Intraclass correlation coefficient	Measurement error	Repeatability
Maximal voluntary bite force	0.89	64.55	178.8
Maximal opening	0.87	2.23	6.18
Body mass index	0.99	0.06	0.17
Number of contacts	0.89	0.24	0.67
Number of fillings	0.99	0.22	0.61
Overjet	0.9	0.3	0.83
Overbite	0.99	0.2	0.55
Retruded contact position–intercuspal position	0.88	0.22	0.61
Deflection	0.87	0.25	0.69

Table 2 Descriptive statistics for maximal voluntary molar bite force (MVBF).

	Age, years	Gender	*N*	Mean	Standard deviation	Range minimum–maximum	95% Confidence interval for mean
MVBF left (L)	15	Male	15	521.3	180.21	190–769	421.5–621.1
		Female	15	471.7	238.11	118–922	339.9–603.6
	18	Male	14	779.0	80.59	642–917	732.5–825.5
		Female	16	480.1	189.79	218–739	379.0–581.3
MVBF right (R)	15	Male	15	523.4	184.58	195–771	421.2–625.6
		Female	15	458.5	233.08	136–906	329.4–587.5
	18	Male	14	776.4	77.32	640–895	731.8–821.1
		Female	16	483.3	191.18	202–754	381.4–585.1
Mean MVBF L/R	15	Male	15	522.3	181.7	193–758	421.7–623.0
		Female	15	465.1	234.55	127–914	335.2–595.0
	18	Male	14	777.7	78.7	641–906	732.3–823.2
		Female	16	481.6	190.42	210–747	380.2–583.1

Discussion

MVBF seems to provide useful information for objective evaluation of occlusion (Shinogaya *et al.*, 1999), but few studies have primarily been based on subjects without morphological and functional occlusal disturbances. Shinogaya *et al.* (1999) reported that 80 per cent of total bite force is distributed in the molar area. Therefore, in the present investigation, MVBF was measured in the first permanent molar region, and the subjects were selected according to strict inclusion criteria.

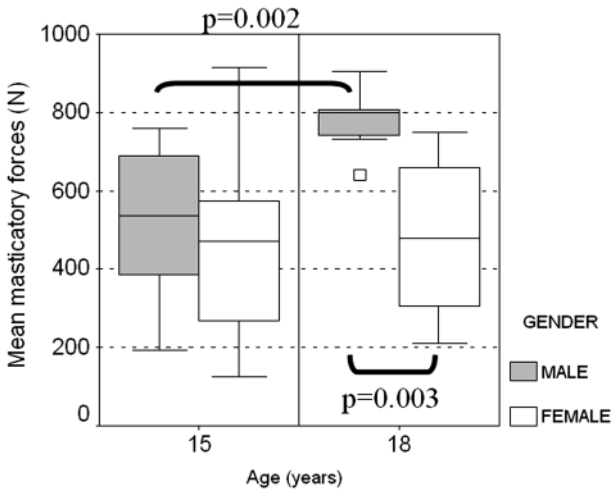

Figure 2 Mean maximal voluntary bite forces according to age and gender.

When measuring bite force, attention must be paid to the method and the measuring device since they can influence the accuracy of the final results (Kamegai *et al.*, 2005). The subject can avoid producing maximal biting performance due to concerns regarding dental fracture and/or pain if the bite element of the force gauge is made of a rigid material (Braun *et al.*, 1995). The occlusal force gauge used in this study had a soft biting element made of vinyl encased in a plastic tube that enabled safe, accurate, and comfortable MVBF recording. Furthermore, multiple recordings were used; it is known that multiple recordings are more reliable than a single recording of MVBF (Castelo *et al.*, 2007). To avoid random error, the mean of MVBF was used.

Unilateral and bilateral bite forces are significantly correlated and both measurement methods are suitable for evaluation of the functional state of the masticatory system (Van der Bilt *et al.*, 2008). One shortcoming of unilateral

Table 3 Descriptive statistics for body mass index (BMI) and variables of morphological occlusion and jaw function.

	Age, years	Gender	*N*	Mean	Standard. deviation	Range minimum–maximum	95% Confidence interval for mean
BMI	15	Male	15	21.7	2.152	18.3–26	20.5–22.9
		Female	15	22.86	3.475	18.3–29.7	20.9–24.8
	18	Male	14	21.56	1.938	19–23.7	20.4–22.7
		Female	16	20.55	1.804	16.9–22.5	19.6–21.5
Number of contacts	15	Male	15	10.0	2.27	7–12	8.7–11.3
		Female	15	10.6	1.92	7–12	9.5–11.7
	18	Male	14	11.0	1.66	8–12	10.0–12.0
		Female	16	10.6	1.71	8–12	9.7–11.5
Number of fillings	15	Male	15	3.5	3.18	0–11	1.8–5.3
		Female	15	3.9	3.06	0–9	2.2–5.6
	18	Male	14	2.9	1.96	0–6	1.7–4.0
		Female	16	5.3	1.98	2–8	4.2–6.3
Overjet	15	Male	15	1.9	0.59	1–3	1.6–2.3
		Female	15	1.6	1.06	1–3	1.0–2.2
	18	Male	14	2.4	0.94	1–4	1.9–3.0
		Female	16	2.0	0.52	1–3	1.7–2.3
Overbite	15	Male	15	3.2	1.57	2–5	2.3–4.1
		Female	15	2.7	1.67	1–5	1.8–3.7
	18	Male	14	3.3	1.20	1–5	2.6–4.0
		Female	16	3.0	1.37	2–5	2.3–3.7
Maximal opening	15	Male	15	52.3	8.29	40–72	47.7–56.9
		Female	15	51.7	6.33	41–61	48.2–55.2
	18	Male	14	50.7	4.29	45–57	48.2–53.2
		Female	16	49.1	5.94	39–58	46.0–52.3
Retruded contact position–intercuspal position	15	Male	15	0.1	0.52	0–2	0.0–0.4
		Female	15	0.0	0.00	0	0.0–0.0
	18	Male	14	0.0	0.00	0	0.0–0.0
		Female	16	0.0	0.00	0	0.0–0.0
Deflection	15	Male	15	0.1	0.26	0–1	0.0–0.2
		Female	15	0.3	0.59	0–2	0.0–0.6
	18	Male	14	0.0	0.00	0	0.0–0.0
		Female	16	0.1	0.34	0–1	0.0–0.3

Table 4 Multiple regression analysis for variables predicting maximum voluntary molar bite force in subjects with normal occlusion aged 15 and 18 years.

	Unstandardized coefficients B	Standard error	Standardized coefficients β	Significance	Correlations		
					Zero-order	Partial	Semi-partial
Model 1*							
Constant	−77.807	272.259		0.776			
Age	43.982	16.412	0.307	0.01	0.293	0.335	0.307
Gender (0 = Male and 1 = Female)	−176.379	49.263	−0.41	0.001	−0.4	−0.428	−0.41
Model 2**							
Constant	−346.049	531.966		0.518			
Age	38.703	18.777	0.27	0.045	0.293	0.282	0.244
Gender (0 = Male and 1 = Female)	−192.851	56.731	−0.448	0.001	−0.4	−0.437	−0.403
Body mass index	10.452	11.004	0.121	0.347	0.010	0.134	0.112
Overjet	16.821	37.998	0.065	0.660	0.193	0.063	0.052
Overbite	−12.528	20.399	−0.083	0.542	−0.005	−0.087	−0.073
Maximal opening	−2.293	4.296	−0.067	0.596	−0.078	−0.076	−0.063
Retruded contact position–intercuspal position	−64.065	103.949	−0.076	0.541	−0.012	−0.088	−0.073
Deflection	−12.406	75.821	−0.021	0.871	−0.139	−0.023	−0.019
Number of contacts	22.233	14.601	0.194	0.134	0.179	0.213	0.18
Number of fillings	7.173	11.32	0.089	0.529	−0.036	0.09	0.075

*$R = 0.504$; $R2 = 0.254$; $F = 9.691$; $P < 0.001$. **$R = 0.559$; $R2 = 0.313$; $F = 2.231$; $P = 0.031$.

recordings could be in the case of denture wearers because of possible tilting of the mandibular prosthesis if only one side of the jaw was loaded. The subjects in the present study were fully dentate so the reliability of the unilateral method that was used could not be influenced in this way.

It is known that MVBF are age and gender related. They tend to increase through various stages of a development but stabilize after puberty. There is some evidence that they reach their peak at 12 years of age, stabilize after the age of 14 years, and decline slightly by the age of 17 years (Braun *et al.*, 1996; Shinogaya *et al.*, 1999). The average increase in the rate of bite force on the permanent molars in children has been reported to be 23 N per year from 7 to 16 years (Brawley and Sedwick, 1940) or even up to the early twenties (Kiliaridis *et al.*, 1993; Braun *et al.*, 1996). All correlations between MVBF and age diminish between 26 and 41 years (Braun *et al.*, 1995) and then forces decrease after the age of 45 years (Bakke *et al.*, 1990). According to the present results, there is less increase in bite force when the pubertal growth spurt ceases: pubertal spurt starts and ends earlier in females than in males [15 years of age in females and 17 years of age in males (Hägg and Taranger, 1982)]. This statement is reasonable because it was found that gender differences in MVBF were not significant in 15-year-olds but were in 18-year-olds. This finding can be explained by the difference in the appearance and pattern of the pubertal spurt between genders.

The fact that the gender differences were evident at 15 years of age was in concordance with the report of Shiau and Wang (1993), who found that bite force in males became significantly stronger than in females after 13 years of age. This is also in agreement with the finding that there are no significant differences between bite force of males and females between 7 and 13 years (Kiliaridis *et al.*, 1993; Garcia-Morales *et al.*, 2003) but that males over 17 years of age, on average, bite harder than females (Garner and Kotwal, 1973). On the other hand, some other data suggest that the average bite force values of females aged 11–16 years are equal to, or even higher, than those of males (Garner and Kotwal, 1973) and that there could be some gender differences even in the primary dentition (Tsai, 2004).

The mean MVBF found in this investigation in subjects aged 18 years (males 777.7 ± 78.7 N and females 481.6 ± 190.42 N) exceeded the values given by Braun *et al.* (1996) of 176 N in the same age range (18–20 years) and was similar to the values (738 N) found by the same authors in an older age group (26–41 years; Braun *et al.*, 1995). Gibbs *et al.* (1981) observed similar results (720 N), while Sasaki *et al.* (1989), in a study of adult clenching strength, reported lower values (189 ± 78 N) than the present finding. The difference in MVBF between the latter investigation and the present findings could be due to the fact that subjects in the study of Sasaki *et al.* (1989) comprised randomly selected fully dentate adults. A normal occlusion was not a required parameter.

The variability of MVBF in 18-year-old males (777.7 ± 78.7 N) was lower than in females (481.6 ± 190.42 N) or 15-year-olds (males 522.3 ± 181.7 N and females 465.1 ± 243.55 N). While less variability in the older than in the younger age group could be explained by the difference between each subject when entering and finishing the puberty, the difference between 18-year-old males and females could not be explained in this way. It is possible that the difference in variability of MVBF in 18-year-old males and females is related to self-presentation: the males could be more confident in the strength of their masticatory muscles and thus present MVBF with less caution then females. Although they all received the same instructions regarding the protocol, this could be a reason for the observed results.

The present research did not show a correlation between BMI and MVBF. This finding is in agreement with several other studies (Linderholm and Wennström, 1970; Braun *et al.*, 1995; Castelo *et al.*, 2007). A possible explanation for the differences between children and adults, and the lack of a relationship with body weight and BMI, could be the effect of physical training of certain muscle groups in adults due to a sport or work (Kiliaridis *et al.*, 1993).

The relationship between parameters of morphological occlusion or jaw function and MVBF has not been reported in previous studies. Based on the present findings, their influence on biting force, or *vice versa*, in adolescents with a normal occlusion was found not to be statistically significant.

Determination of factors that have an influence on MVBF, and exclusion of those with a low impact, and provision of normal values of bite force in adolescents enables assessment of elevator muscle strength and the function of the masticatory system in patients using this simple screening method.

Conclusions

1. MVBF in subjects with normal complete dentitions is significantly related to age and gender, being in general higher in males and older subjects.
2. Gender differences were significant only in the 18 year-old age group.
3. Males showed significant increase in bite force between 15 and 18 years of age.
4. In subjects with a neutral occlusion, MVBF could be best predicted using multiple regression analysis by age and gender.
5. BMI, morphological occlusion, and jaw function in subjects with a normal occlusion had a low contribution to prediction of MVBF values.

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