Maximum occlusal bite force for children in different dentition stages

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SUMMARY This study was carried out to record maximum occlusal bite force (MOBF) among different dentition stages in children and to study the relation of occlusal bite force to weight, height, and gender. A total of 1011 children (500 females and 511 males) aged from 3 to 18 years were examined. The subjects were divided into 5 groups according to their dentition stage as the following:- early primary dentition stage (100 males and 100 females, average age was 3.37 ± 0.23 years), late primary dentition stage (104 males and 100 females, average age was 5.86 ± 1.15 years), early mixed dentition stage (100 males and 100 females, average age was 8.15 ± 0.67 years), late mixed dentition stage (100 males and 100 females, average age was 9.97 ± 0.86 years), and permanent dentition stage (107 males and 100 females, average age was 14.03 ± 2.14 years). Occlusal bite force was measured using a hydraulic occlusal force gauge.

The means of MOBF for the different dentition stages were:- 176 N in early primary stage, 240 N in late primary stage, 289 N in early mixed stage, 433 N in late mixed stage, and 527 N in the permanent dentition stage, respectively. Gender differences were detected in groups 2, 3 and 4. Height and age significantly correlated with the MOBF in all dentition stage groups except group 1.

In conclusion, the MOBF increased with age. Age, gender, and height were significant predictors of the MOBF.

Introduction

Mastication can be measured by several means, including masticatory ability, efficiency, and performance (Magalhaes et al., 2010). Occlusal bite force (OBF) is one indicator of the functional state of the masticatory system that results from the action of jaw elevator muscles modified by the craniofacial biomechanics (Bakke, 2006). Many studies have been performed to determine the relationship between OBF and masticatory efficiency (Hatch et al., 2001; Gaviao et al., 2007). Hatch et al. (2001) reported that OBF is one of the key determinants of masticatory performance.

Several factors have been suggested to affect OBF measurements, such as age, gender, craniofacial morphology, periodontal support of teeth, signs and symptoms of temporomandibular disorders, and dental status (Kiliaridis et al., 1993; Kovero et al., 2002; Ferrario et al., 2004; Olthoff et al., 2007; Bonakdarchian et al., 2009; Abu Alhaija et al., 2010; Palinkas et al., 2010). Palinkas et al. (2010) reported that among all the age groups (7–80 years), gender was found to be a significant factor associated with MOBF showing 30 per cent higher mean in males than in females. On the other hand, some studies reported no gender differences in OBF measurements (Serra et al., 2007; Su et al., 2009; Abu Alhaija et al., 2010).

The relationship between OBF and craniofacial morphology has been investigated (Proffit et al., 1983; Abu Alhaija et al., 2010). Proffit et al. (1983) found that the mean OBF in the molar region was twice as great in normal as in long-face subjects; short-face subjects generating even higher forces than normal-face subjects. This result has also been confirmed by Abu Alhaija et al. (2010) who reported that subjects with a short face had the highest, while the long-face types had the lowest MOBF.

Malocclusion can negatively affect the masticatory system to process and break down food (English et al., 2002). Fontijn-Tekamp et al. (2000) reported that the number of occlusal units was the most important factor that affected the median particle size of masticatory performance and the swallowing threshold. In one study, only Class III cases showed a low area with corresponding low performance. Henriksen et al. (1998) found better masticatory performance in girls aged 11–15 years with normal occlusion than those with Class II malocclusion. Magalhaes et al. (2010)
reported that malocclusion results in decreased masticatory performance, especially as it relates to a reduced occlusal contact area.

Up to our knowledge, the literature is deficient in studies on the magnitude of OBF in the different dentition stages (early primary dentition, late primary dentition, early mixed dentition, late mixed dentition, and permanent dentition stages). The aims of this study were to

1. report on the MOBF among different dentition stages in children and
2. study the relation of OBF to weight, height, and gender.

Materials and methods

This study was cross-sectional in design and was carried out between March and June 2011. Ethical approval for the study was obtained from the Institutional Review Board (IRB) at the Jordan University of Science and Technology (JUST). A total of 1011 children, who fulfilled the inclusion criteria, aged from 3 to 18 years of age were examined. An examination form was filled for each subject by the same researcher (MS). Using power analysis, it was calculated that at least 200 subjects in each group were required to detect a medium effect size (0.25 SD) between the five groups at a significance level of 0.05 with a power of 0.99.

The study population included 500 females and 511 males from 3 to 18 years of age. They were randomly selected from kindergartens, private and public schools, and private dental clinics (JUST Dental Teaching Center). The list that contained the names of schools enrolling the required age groups was obtained from the Directorate of Education in Irbid Governorate. These schools were categorized into sections according to age. Schools in each section were numbered and those with even number were visited.

The inclusion criteria included the following:

1. Age above 3 years (completely into language).
2. Angle Class I molar relationship without an anterior or posterior crossbite or open bite.
3. No missing teeth in the regions of recording (molar area).
4. No local pain experienced at the deciduous molars.
5. No heavily restored teeth on the area of recording.
6. No gingival inflammation, no periodontal diseases, and no mobility of the teeth.
7. No reported systemic disease (chronic arthritis) or apparent facial asymmetry that could affect the recordings.
8. No parafunctional habits, no pathological wearing facits, or any other soft tissue abnormalities.
9. No temporomandibular joint dysfunction.

The subjects were divided into five groups according to their dentition stage as the following:

1. Group 1: early primary dentition stage (children who have just completed the eruption of all primary teeth; n = 200, 100 males and 100 females, average age was 3.37 ± 0.23 years).
2. Group 2: late primary dentition stage (children just before the eruption of the first permanent molar; n = 204, 104 males and 100 females, average age was 5.86 ± 1.15 years).
3. Group 3: early mixed dentition stage (children after the eruption of the permanent first molars and lower incisors and before the eruption of the permanent lower canines and premolars; n = 200, 100 males and 100 females, average age was 8.15 ± 0.67 years).
4. Group 4: late mixed dentition stage (children after the eruption of permanent teeth except for the second premolars and/or upper permanent canines; n = 200, 100 males and 100 females, average age was 9.97 ± 0.86 years).
5. Group 5: permanent dentition stage (children after the complete eruption of permanent teeth excluding third molars; n = 207, 107 males and 100 females, average age was 14.03 ± 2.14 years).

Each child who fulfilled the inclusion criteria received a consent form and an abstract of the study and its goals and method of examination. Those children who returned the consent form signed by their parents were examined. The examination form consisted of two major parts: the demographic data part including the name of the child and the date of birth, height, and weight and the measurement part including the measurement of OBF. The OBF was measured bilaterally in the second primary (subjects in groups 1, 2, and 3) or the first permanent (subjects in groups 4 and 5) molars region (according to the dentition stage) using a portable occlusal force gauge (GM10; Nagano Keiki, Tokyo, Japan; Figure 1). Subjects were seated upright without head support with the Frankfort plane nearly parallel to the floor. The OBF gauge consists of a hydraulic pressure gauge and a biting element made of a vinyl material encased in a polyethylene tube (Sakaguchi et al., 1996). Before the recording, subjects were trained to perform their highest possible OBF. Some behavioural difficulties were faced especially when taking the OBF measurements for children in groups 1 and 2. Children who did not manage to bite as instructed were excluded. OBF was measured alternately on the right and left sides with a 15 second resting time between each bite. Subjects were instructed to bite three times as hard as possible on the gauge without moving the head. The highest value of the three OBF measurements per side was recorded as the MOBF for that side. The mean value for the right and left sides was considered as the subject’s MOBF and used in the analysis.

The null hypothesis
MOBF measurements are not affected by the dentition stage.

Method error
All examinations were performed by the same examiner. To quantify the method error, 25 subjects (five from each group) received the examination two times in two different occasions. Dahlberg’s formula (Dahlberg, 1940) and Houston coefficient of reliability (Houston et al., 1983) were calculated for the MOBF measurement. Dahlberg error was 5 N and Houston coefficient of reliability was 88 per cent.

Statistical analysis
Data were coded and entered using Microsoft Excel 2007 program and then exported to the Statistical Package for Social Sciences (SPSS, version 16.0) software and then the statistical analysis was done. Descriptive statistics were performed for height, weight, age, and MOBF. Independent t-test was used to detect gender differences. Analysis of variance test using Bonferroni tests were used to detect any differences in MOBF between the different dentition stages. Regression analysis was used to detect the effect of gender, weight, and height on MOBF. Level of significance was set at $P < 0.05$.

Results
Means and standard deviations (SDs) for the height, weight, and age for children in each group are shown in Table 1. The means and SD for the MOBF measurements in each group in respect to gender are shown in Table 2. Gender differences were detected in the late primary and the mixed dentition stages’ subjects. Results of the regression analysis are shown in Table 3.

Group 1: early primary dentition stage
MOBF was positively correlated with height ($r^2 = 0.123; P = 0.041$) and with weight ($r^2 = 0.144; P = 0.021$). This implies that children with increased height and weight had higher MOBF. However, regression analysis revealed insignificant correlations ($r^2 = 0.025$) between MOBF and the dependent variables.

Group 2: late primary dentition stage
In this stage, significant correlation was detected between MOBF and gender ($r^2 = 0.163; P = 0.01$), height ($r^2 = 0.174$; $P = 0.01$), and weight ($r^2 = 0.144; P = 0.021$). Regression analysis revealed insignificant correlations ($r^2 = 0.025$) between MOBF and the dependent variables.

Table 1 Means and standard deviations (SDs) for the height and weight and age for children in each dentition group.

<table>
<thead>
<tr>
<th>Group</th>
<th>Males</th>
<th>Females</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Height (cm), mean (SD)</td>
<td>Weight (kg), mean (SD)</td>
<td>Age (years), mean (SD)</td>
</tr>
<tr>
<td>Early primary dentition stage</td>
<td>107.75 (6.27)</td>
<td>19.54 (3.85)</td>
<td>3.40 (0.20)</td>
</tr>
<tr>
<td>Late primary dentition stage</td>
<td>117.87 (5.87)</td>
<td>22.27 (3.22)</td>
<td>5.96 (1.19)</td>
</tr>
<tr>
<td>Early mixed dentition stage</td>
<td>127.69 (7.82)</td>
<td>26.95 (10.59)</td>
<td>8.13 (0.72)</td>
</tr>
<tr>
<td>Late mixed dentition stage</td>
<td>138.82 (6.87)</td>
<td>36.07 (10.24)</td>
<td>10.38 (0.61)</td>
</tr>
<tr>
<td>Permanent Dentition Stage</td>
<td>165.09 (11.71)</td>
<td>60.45 (11.60)</td>
<td>14.01 (2.08)</td>
</tr>
</tbody>
</table>

Table 2 Means and standard deviations (SDs) for OBF measurements, difference between means, and standard error of the difference (SE) in each group in respect to gender. OBF, Occlusal bite force; MOBF, maximum occlusal bite force.

<table>
<thead>
<tr>
<th>Group</th>
<th>Males</th>
<th>Females</th>
<th>Gender differences</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>MOBF (N), mean (SD)</td>
<td>MOBF (N), mean (SD)</td>
<td>Mean (SE)</td>
<td>MOBF (N), mean (SD)</td>
</tr>
<tr>
<td>Early primary dentition stage</td>
<td>182.85 (74.84)</td>
<td>169.04 (66.53)</td>
<td>13.81 (10.01)</td>
<td>175.94 (70.97)</td>
</tr>
<tr>
<td>Late primary dentition stage</td>
<td>255.15 (89.30)</td>
<td>225.01 (93.81)</td>
<td>30.15 (12.82)*</td>
<td>240.37 (92.56)</td>
</tr>
<tr>
<td>Early mixed dentition stage</td>
<td>314.24 (105.24)</td>
<td>264.28 (93.50)</td>
<td>50.02 (14.08)**</td>
<td>289.28 (102.41)</td>
</tr>
<tr>
<td>Late mixed dentition stage</td>
<td>454.17 (90.91)</td>
<td>411.07 (80.12)</td>
<td>44.21 (12.19)**</td>
<td>432.62 (88.15)</td>
</tr>
<tr>
<td>Permanent Dentition Stage</td>
<td>522.34 (80.34)</td>
<td>531.36 (92.72)</td>
<td>9.02 (12.04)</td>
<td>526.70 (86.45)</td>
</tr>
</tbody>
</table>

* $P < 0.05$, ** $P < 0.001$. 
$P = 0.007$), and weight ($r^2 = 0.138; P = 0.025$). Regression coefficient ($r^2 = 0.056$) indicated weak correlation between MOBF and the studied variables. However, the set of beta-coefficients, after adjusting for the effects of other variables, suggested that only gender has an effect on MOBF ($P = 0.022$).

Table 3: Regression analysis output with MOBF as dependent variable. MOBF, maximum occlusal bite force.

<table>
<thead>
<tr>
<th>Stage</th>
<th>Pearson’s correlation coefficients</th>
<th>Regression analysis</th>
<th>$R^2$</th>
<th>Standardized coefficients</th>
<th>$P$ values</th>
</tr>
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<tbody>
<tr>
<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Stage 1</td>
<td></td>
<td>Gender</td>
<td>0.098</td>
<td>0.025</td>
<td>0.063</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Height</td>
<td>0.123*</td>
<td></td>
<td>0.022</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Weight</td>
<td>0.144*</td>
<td></td>
<td>0.110</td>
</tr>
<tr>
<td>Stage 2</td>
<td></td>
<td>Gender</td>
<td>0.163**</td>
<td>0.056</td>
<td>−0.159</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Height</td>
<td>0.174**</td>
<td></td>
<td>0.133</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Weight</td>
<td>0.138*</td>
<td></td>
<td>0.052</td>
</tr>
<tr>
<td>Stage 3</td>
<td></td>
<td>Gender</td>
<td>0.245***</td>
<td>0.124</td>
<td>0.214</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Height</td>
<td>0.280***</td>
<td></td>
<td>0.261</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Weight</td>
<td>0.138*</td>
<td></td>
<td>−0.011</td>
</tr>
<tr>
<td>Stage 4</td>
<td></td>
<td>Gender</td>
<td>0.250***</td>
<td>0.083</td>
<td>0.215</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Height</td>
<td>0.182**</td>
<td></td>
<td>0.031</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Weight</td>
<td>0.186**</td>
<td></td>
<td>0.126</td>
</tr>
<tr>
<td>Stage 5</td>
<td></td>
<td>Gender</td>
<td>0.052</td>
<td>0.110</td>
<td>0.203</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Height</td>
<td>0.276***</td>
<td></td>
<td>0.364</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Weight</td>
<td>0.219***</td>
<td></td>
<td>−0.004</td>
</tr>
</tbody>
</table>

* $P < 0.05$, ** $P < 0.01$, *** $P < 0.001$.

Group 3: early mixed dentition stage
MOBF was significantly correlated with gender ($r^2 = 0.245; P = 0.000$), height ($r^2 = 0.280; P = 0.000$), and weight ($r^2 = 0.138; P = 0.025$). Regression coefficient ($r^2 = 0.124$) indicated good correlation between MOBF and the studied variables. However, the set of beta-coefficients, after adjusting for the effects of other variables, suggested that gender ($P = 0.002$) and height ($P = 0.002$) have the strongest effect on MOBF.

Group 4: late mixed dentition stage
MOBF significantly correlated with gender ($r^2 = 0.250; P = 0.000$), height ($r^2 = 0.182; P = 0.005$), and weight ($r^2 = 0.186; P = 0.004$). Regression coefficient ($r^2 = 0.083$) indicated weak correlation between MOBF and the studied variables. However, the set of beta-coefficients suggested that only gender ($P = 0.003$) has an effect on MOBF.

Group 5: permanent dentition stage
In this stage, MOBF was significantly correlated with height ($r^2 = 0.276; P = 0.000$) and weight ($r^2 = 0.219; P = 0.001$). Regression coefficient ($r^2 = 0.110$) revealed weak correlation between MOBF and the studied variables. However, the set of beta-coefficients suggested that in this stage, height ($P = 0.002$) has the strongest effect on MOBF followed by gender ($P = 0.006$).

Differences between the different groups
MOBF was affected by the dentition stage. Figure 2 shows the means plot of the MOBF for the different dentition groups in males and females. MOBF increased with progression in dentition groups, with the highest difference

Figure 2: Plot graphs of maximum occlusal bite force for different dentition stages in males and females.
found during transition from early mixed to late mixed dentition stage (mean difference was 143.34 N; Table 4).

Figure 3 shows the means plot of the approximate age in years in relation to the MOBF for males and females. MOBF in males keeps increasing from age 3 to 5 years, followed by a major significant increase for age 6 years, dropping from 6 to 7 years of age, to start increasing again throughout the ages from 8 to 18 years of age. In females, MOBF increases from age 3 to 5 years, followed by a significant increase for age 6 years and stays stable from 6 to 7 years of age. An insignificant drop occurs from 7 to 8 years and then it starts increasing again.

Discussion

A number of interrelated factors such as occlusion, the architecture of the occlusal surfaces, the presence of dental diseases, and the intermaxillary space affect the measurement of the OBF. Furthermore, OBF values can be directly influenced by the accuracy of the measuring apparatus itself (Kamegai et al., 2005). In this study, a hydraulic pressure gauge was used with a biting element encased in a plastic covering. The accuracy of this OBF gauge has been previously reported (Nakano et al., 1994; Sakaguchi et al., 1996).

The means of MOBF in this study were comparable with other studies (Rentes et al., 2002; Kamegai et al., 2005). However, Kamegai et al. (2005) reported higher OBF in female subjects. These differences could be related to the different classification of the subjects and naming of the study groups, in addition to difference in sample size and racial differences.

The findings of this study indicated that there is a significant positive relationship between MOBF and the dentition stage. This relation could be related to the development of the masticatory system and masticatory muscle and improvement of masticatory efficiency throughout the different dentition stages. This relation was significantly noticed by the transition from the early mixed to the late mixed dentition stage when comparing each dentition stage with its succedaneous stage. This result is in agreement with Sonnesen et al. (2001) who reported a positive relationship between MOBF and increasing stages of dental eruption in children aged 7–13 years. This finding may be explained by the increase in the number of occlusal contact during transition through the different dentition stages. Fontijn-Tekamp et al. (2000) suggested that masticatory performance will improve as the number of occlusal contacts increases.

The results of this study confirmed that MOBF increases with age. This was in agreement with other studies that

<table>
<thead>
<tr>
<th>Mean difference</th>
<th>MOBF (N)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Groups 1 and 2</td>
<td>64.43*</td>
</tr>
<tr>
<td>Groups 1 and 3</td>
<td>113.34*</td>
</tr>
<tr>
<td>Groups 1 and 4</td>
<td>256.68*</td>
</tr>
<tr>
<td>Groups 1 and 5</td>
<td>350.75*</td>
</tr>
<tr>
<td>Groups 2 and 3</td>
<td>48.90*</td>
</tr>
<tr>
<td>Groups 2 and 4</td>
<td>192.24*</td>
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<tr>
<td>Groups 2 and 5</td>
<td>286.32*</td>
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<tr>
<td>Groups 3 and 4</td>
<td>143.34*</td>
</tr>
<tr>
<td>Groups 3 and 5</td>
<td>237.41*</td>
</tr>
<tr>
<td>Groups 4 and 5</td>
<td>94.07*</td>
</tr>
</tbody>
</table>

*P < 0.001.
reported the positive correlation between age and OBF (Kiliaridis et al., 1993; Braun et al., 1996; Kamegai et al., 2005; Pereira-Cenci et al., 2007; Usui et al., 2007). On the other hand, Braun et al. (1995) reported that MOBF did not correlate well with age, and this could be related to the sample, which consisted of adults between the ages of 26 and 41 years. The effect of age was significant through the different dentition stages from the late primary till the permanent dentition stage, which was in agreement with Kamegai et al. (2005) who concluded that the mean OBF increased through the various stages of development from 3 to 14 years of age. The decline in OBF could be explained by that the newly erupted teeth (permanent molars) require time to be functional and so, bite force starts to increase again after 8 years of age.

In agreement with other studies (Olthoff et al., 2007; Bonakdarchian et al., 2009), the results of this study showed that OBF was affected by gender. Among the different dentition groups, males registered higher MOBF, except for the last group (permanent dentition group), in which females had a higher MOBF. However, these gender differences were not significant in the early primary and permanent dentition stages. This was in agreement with Su et al. (2009) who reported insignificant relationship between gender and MOBF in children of early ages and Abu Alhaaja et al. (2010) who found no gender differences in OBF measurements in adult subjects. On the other hand, the result of this study was in disagreement with Sonnesen et al. (2001) who concluded that gender is not related to OBF in children aged 7–13 years and Serra et al. (2007) who reported no gender effect on OBF in children from 6 to 9 years of age. However, both studies were based on small sample size using a pressurized tube transducer for OBF measurement.

In this study, both weight and height showed a significant positive but weak correlation with the MOBF. These results were in agreement with Rentes et al. (2002) who concluded that the body variables (height and weight) are of low influence on bite force, indicating that only 6 and 5 per cent variability in MOBF could be explained by the weight and height, respectively, in children aged 3–5 years.

On the other hand, Su et al. (2009) reported that height and weight have no relationship with MOBF in children from 4 to 6 years of age. Although their study was based on a comparable sample size as this study, the difference could be related to the different device used for the OBF measurement. Furthermore, Koç et al. (2011) reported that body mass index (BMI; weight/height²) had no direct effect on MOBF. However, the use of BMI in their study to detect the effect of height and weight in a relatively small sample size (34 subjects) may have masked their effect.

Limitations of this study include facing some behavioural difficulties, especially when taking the OBF measurements for children in groups 1 and 2. Some got fatigued quickly; others needed to repeat the test as they opened their mouth before getting the maximum measurement. Also, the device used in this study had a plastic covering that could be considered hard to bite, making it difficult to measure the bite force accurately in younger children.

Conclusions

1. On average, MOBF for the different dentition stages were 176 N in early primary stage, 240 N in late primary stage, 289 N in early mixed stage, 433 N in late mixed stage, and 527 N in the permanent dentition stage.
2. MOBF increased with age.
3. Age, gender, and height were significant predictors of the MOBF.

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