Maximum voluntary molar bite force in subjects with malocclusion: multifactor analysis

Mohammad Khursheed Alam\textsuperscript{1} and Ahmed Ali Alfawzan\textsuperscript{2}

Abstract

Objective: This study was performed to determine the maximum voluntary molar bite force (MVMBF) in relation to age, sex, lip competency, midline shifting, dental and skeletal malocclusion, overjet, overbite, and crowding.

Methods: One hundred Saudi patients with orthodontic malocclusion aged 14 to 25 years (51 male and 49 female patients) were investigated in this cross-sectional study. The baseline MVMBF on the right and left side was evaluated in all patients before commencing any orthodontic treatment. The MVMBF was registered with a portable occlusal force gauge in the first molar region during maximal clenching.

Results: The MVMBF significantly varied with respect to all nine confounding variables. The MVMBF significantly increased with an age of $>18$ years, male sex, right-side lip competency, no midline shift, dental and skeletal Class I malocclusion, normal overjet, normal overbite, and mild crowding.

Conclusion: All nine variables examined in the present study significantly influenced the MVMBF.

Keywords

Bite force, malocclusion, fixed orthodontic treatment, confounding variables, lip competency, midline shift, cross-sectional study

Date received: 5 May 2020; accepted: 3 September 2020
Introduction
In routine dental practice, clinicians encounter a variety of patients with various types of malocclusion. Extensive research is being performed to examine the bite force in patients with different problems and elucidate the effects of different methods of oral rehabilitation on the bite force to increase the accuracy of diagnosis and treatment planning. The bite force is a valuable indicator of the efficacy of the masticatory apparatus. According to Fontijn-Tekamp et al.,\(^1\) the bite force is a measure of masticatory performance. In addition, the maximum voluntary molar bite force (MVMBF) may vary according to age and sex\(^2\), as well as height and facial morphology.\(^3\),\(^4\)

Notably, studies focusing on the actual relationship between the bite force and these variables have produced inconsistent results.\(^5\),\(^6\) The MVMBF is associated with the efficiency of the masticatory system\(^7\) and may impact the development of masticatory function during dental development.\(^8\) Hence, its measurement could serve as an important screening method. The findings to date, particularly in relation to the MVMBF, are quite variable.\(^9\) Such vast variations are attributed to differences in the test populations (ethnic groups) or to disparities in the devices and methodologies employed in these previous studies.\(^10\)

However, Tortopidis et al.\(^11\) indicated that several other patient-specific factors, such as the pain threshold, dentition status, and strength of the muscles involved in mastication, might influence the MVMBF. The degree of jaw opening may also substantially influence the MVMBF.

Studies have been performed to evaluate the MVMBF in pre-orthodontic children with a unilateral crossbite\(^12\) and in patients with different facial types to determine the effect of the type of functional occlusion and the influence of premature contacts and parafunctional habits.\(^13\) Studies have also focused on patients with Class I normal occlusion and different types of malocclusions\(^14\) to examine the effects of sex, body mass index, morphological occlusion, and jaw function evaluated using 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.\(^5\) Moreover, research has been performed to compare patients with normal occlusion and different Angle malocclusions, to analyze the frequency of occurrence of each type of occlusion, and to identify any disparities between force and body mass index-associated bite force.\(^15\) In another study, whether appliance type affects changes in MVMBF and the number of occlusal contacts during retention, controlling for sex, age, and body mass index.\(^5\)

Both investigators and clinicians would benefit from objective data regarding stabilization of the MVMBF. Reference values of such data for different age groups could be used to objectively evaluate the occlusion of patients with orthodontic problems (either evaluation of various malocclusion conditions or prospective evaluation during different treatment phases). This is the first-in-human study to evaluate the MVMBF in relation to nine different confounding variables in orthodontic patients.

Methods
In 2014, de Araújo et al.\(^15\) found that the mean MVMBF was 372.2 ± 133.8 and 265.1 ± 105.9 N in patients with normal occlusion and class III malocclusion, respectively. According to these values, the calculated Cohen’s d and effect-size r were 0.887 and 0.405, respectively.\(^15\) The software used in that study was G*Power software version 3.0.10 with power of 80%, z of 0.05, and effect size (d) of 0.4.\(^15\) The total
sample in the present cross-sectional study was determined to be 102. Only patients with a full complement of permanent teeth were included in the study. Patients with disorders of the temporomandibular joint, neurologic diseases, missing or restored permanent first molars, or chronic illnesses were not included in the study. After obtaining ethical clearance from the Institutional Ethics Committee of Jouf University, Sakaka, Saudi Arabia (LCBE 1-19-9/39), 100 patients (51 male and 49 female patients) aged 14 to 25 years from the specialist orthodontic clinic at the College of Dentistry, Jouf University, Sakaka, Saudi Arabia were included in the study. Written consent was obtained from all volunteers; in case of minor patients, consent was obtained from both the patient and his or her legal guardian after explaining the procedure and nature of the study.

All patients were divided into various groups based on data in their routine orthodontic records, such as their history and clinical examination findings, model analysis, orthopantomographs, and lateral cephalometric radiographs. The patient distribution and group splitting among all nine confounding are shown in Table 1. This study explored the MVMBF of the right and left sides in relation to sex (male and female), age (<18 and >18 years), lip competency (competent and incompetent),16 midline shifting (shift and no shift),16 dental malocclusion (Class I, II, and III Angle molar occlusion), skeletal malocclusion (Class I, II, and III ANB values), overjet (normal, increased, and decreased), overbite (normal, increased, and decreased),18 and crowding (mild, moderate, and severe).16

**Bite force measurement**

A portable occlusal force gauge (GM10; Nagano Keiki, Tokyo, Japan) was used to measure the MVMBF in the permanent first molar region in this study. This device has a hydraulic pressure gauge and a biting element enclosed in a plastic tube.17,18 The registered bite force is displayed on the digital screen of the device in Newtons. The sensitivity and reliability were investigated and approved by Sakaguchi et al.18 The patients were trained to bite as hard as they could after placing the device on the first molar on one side, and the MVMBF was evaluated. This was repeated on the other side to complete the process of recording the bite force. The procedure was repeated three times in every participant on each side with a time gap of 3 minutes to prevent any influence of muscle fatigue, and the arithmetic means of all measurements were calculated. The mean values calculated for both sides were regarded as the patient’s MVMBF.

**Table 1. Patient distribution and confounding variables.**

| Variables                        | Groups | N = 100 |
|----------------------------------|--------|---------|
| Age, years                       | <18    | 49      |
|                                  | >18    | 51      |
| Sex                              | Female | 49      |
|                                  | Male   | 51      |
| Lip competency                   | Competent | 52    |
|                                  | Incompetent | 48  |
| Midline shift                    | No shift | 37    |
|                                  | Shift  | 63      |
| Dental malocclusion              | Class I | 41    |
|                                  | Class II | 29   |
|                                  | Class III | 30  |
| Skeletal malocclusion            | Class I | 44    |
|                                  | Class II | 29   |
|                                  | Class III | 27  |
| Overjet                          | Normal | 36      |
|                                  | Increased | 33    |
|                                  | Decreased | 31   |
| Overbite                         | Normal | 42      |
|                                  | Increased | 27    |
|                                  | Decreased | 31   |
| Crowding                         | Mild   | 43      |
|                                  | Moderate | 25   |
|                                  | Severe  | 32      |
After each recording, the latex finger cots were changed and the device was sterilized with 70% isopropyl alcohol.

**Statistical analysis**

IBM SPSS Statistics for Windows, Version 22.0 (IBM Corp., Armonk, NY, USA) was used for the statistical analyses. Measurements were repeated after a 2-week interval in 20 randomly selected patients to confirm the reliability and tested using the intraclass correlation coefficient. The Shapiro–Wilk test revealed a normal data distribution; therefore, a paired-sample *t* test, independent-sample *t* test, and one-way analysis of variance with multiple comparisons by the Bonferroni post-hoc test were used. The level of statistical significance for all tests was set at *p* < 0.05.

**Results**

The intraclass correlation coefficient ranged from 0.86 to 0.98.

The results of the paired *t* test comparison are presented in Table 2. There were significant disparities in the MMVBF among all nine confounding variables. The MVMBF was significantly higher on the right than left side at >18 years of age (508.94 ± 69.97 vs. 469.12 ± 89.06 N, respectively; *p* = 0.001). It was also higher on the right than left side in male patients (486.08 ± 116.9 vs. 464.77 ± 99.41 N, respectively). The MMVBF was greater in patients with lip competence, no midline shift, Class I malocclusion, skeletal Class I malocclusion, normal overjet, normal overbite, and mild crowding (*p* < 0.05 for all).

The results of the independent *t* test comparison are presented in Table 3, and the results of the one-way analysis of variance are presented in Table 4. The maximum MMVBF was observed on the right side in patients without a midline shift (527.39 ± 97.262 N). The MVMBF was significantly related to malocclusion among all confounding variables and was generally higher on the right side, in male patients, and in patients aged >18 years. The MVMBF was lower in patients with Class III malocclusion (both dental and skeletal type) (Table 3).

**Discussion**

This study was performed to identify the significant variances of the MVMBF with respect to different malocclusions, aesthetic outcome-related factors, and junctures of multiple confounding variables. The aim was to ascertain the existence of a relationship between the MVMBF and malocclusion within a sample of the Saudi population. No such studies in which nine confounding and frequently diagnosed variables are investigated have been previously conducted in this population.

Malocclusion refers to abnormalities in the alignment of the teeth and relationship between the maxillary and mandibular teeth. It may not only result in a poor facial appearance but can also lead to debilitating functional defects. Poor oral hygiene resulting in periodontitis is one of the most common diseases associated with malocclusion. In addition, malocclusion may affect speech, digestion, temporomandibular joint function, and respiration. Different types of malocclusions have been identified, defined, and classified. In this study, the most common types of malocclusion that are encountered in daily practice were investigated to explore the disparities in the MVMBF.

In this study, we observed significant differences in the MVMBF relative to the different sexes. These findings are consistent with the outcomes of studies conducted by Palinkas et al.,

Braun et al.,

Bakke, and

Varga et al. It is generally understood that the occlusal bite force is greater in men than in women, on the right than left side, and in
Table 2. Comparison between left and right sides in each subgroup.

| Variables           | Groups | Side | Mean       | SD      | 95% CI        | p value | Lower   | Upper   |
|---------------------|--------|------|------------|---------|---------------|---------|---------|---------|
| Age, years          | <18    | Left | 265.041    | 199.318 | −67.231 − 8.565 | 0.012   |         |         |
|                     |        | Right| 302.939    | 195.930 |               |         |         |         |
|                     | >18    | Left | 469.118    | 89.063  | −63.048 − 16.599 | 0.001   |         |         |
|                     |        | Right| 508.941    | 69.986  |               |         |         |         |
| Sex                 | Female | Left | 269.571    | 198.852 | −86.312 − 28.014 | 0.000   |         |         |
|                     |        | Right| 326.735    | 195.270 |               |         |         |         |
|                     | Male   | Left | 464.765    | 99.413  | −43.644 1.016   | 0.061   |         |         |
|                     |        | Right| 486.078    | 116.900 |               |         |         |         |
| Lip competency      | Competent | Left | 387.615    | 187.903 | −81.502 − 33.229 | 0.000   |         |         |
|                     |        | Right| 444.981    | 172.343 |               |         |         |         |
|                     | Incompetent | Left | 349.083    | 179.038 | −46.344 8.636   | 0.174   |         |         |
|                     |        | Right| 367.938    | 177.757 |               |         |         |         |
| Midline shift       | No shift | Left | 495.838    | 83.630  | −48.697 − 14.385 | 0.001   |         |         |
|                     |        | Right| 527.378    | 97.262  |               |         |         |         |
|                     | Shift  | Left | 294.698    | 186.196 | −70.763 − 15.618 | 0.003   |         |         |
|                     |        | Right| 337.889    | 178.277 |               |         |         |         |
| Dental malocclusion | Class I | Left | 477.878    | 132.246 | −37.574 − 2.392 | 0.027   |         |         |
|                     |        | Right| 497.951    | 133.264 |               |         |         |         |
|                     | Class II | Left | 379.241    | 179.387 | −115.515 − 32.416 | 0.001  |         |         |
|                     |        | Right| 453.207    | 157.243 |               |         |         |         |
|                     | Class III | Left | 210.700    | 131.683 | −70.487 9.153   | 0.126   |         |         |
|                     |        | Right| 241.367    | 134.083 |               |         |         |         |
| Skeletal malocclusion | Class I | Left | 451.682    | 112.198 | −57.603 − 2.079 | 0.036   |         |         |
|                     |        | Right| 481.523    | 96.285  |               |         |         |         |
|                     | Class II | Left | 328.586    | 196.275 | −77.475 − 4.525 | 0.029   |         |         |
|                     |        | Right| 369.586    | 213.149 |               |         |         |         |
|                     | Class III | Left | 278.111    | 210.597 | −87.531 − 15.136 | 0.007  |         |         |
|                     |        | Right| 329.444    | 199.041 |               |         |         |         |
| Overjet             | Normal | Left | 458.861    | 104.326 | −70.453 − 8.214 | 0.015   |         |         |
|                     |        | Right| 498.194    | 71.300  |               |         |         |         |
|                     | Increased | Left | 326.394    | 187.771 | −71.773 − 3.864 | 0.030   |         |         |
|                     |        | Right| 364.212    | 208.367 |               |         |         |         |
|                     | Decreased | Left | 310.387    | 214.321 | −73.105 − 5.863 | 0.023   |         |         |
|                     |        | Right| 349.871    | 193.210 |               |         |         |         |
| Overbite            | Normal | Left | 440.333    | 142.403 | −59.177 − 21.156 | 0.000  |         |         |
|                     |        | Right| 480.500    | 139.958 |               |         |         |         |
|                     | Increased | Left | 211.667    | 115.028 | −105.592 − 11.297 | 0.017 |         |         |
|                     |        | Right| 270.111    | 139.523 |               |         |         |         |
|                     | Decreased | Left | 409.774    | 202.917 | −56.677 16.483 | 0.271   |         |         |
|                     |        | Right| 429.871    | 190.600 |               |         |         |         |
| Crowding            | Mild   | Left | 452.023    | 120.873 | −56.824 − 6.013 | 0.017   |         |         |
|                     |        | Right| 483.442    | 113.592 |               |         |         |         |
|                     | Moderate | Left | 237.160    | 156.252 | −112.196 − 44.764 | 0.000  |         |         |
|                     |        | Right| 315.640    | 158.021 |               |         |         |         |
|                     | Severe | Left | 360.813    | 213.393 | −55.709 19.772 | 0.339   |         |         |

SD, standard deviation; CI, confidence interval.
younger than older individuals. The present study showed significant differences in the MVMBF relative to the different sexes. The MVMBF was significantly related to malocclusion with respect to all confounding variables. Such associations may be attributed to the deviation of the occlusion from normal (malocclusion). In general, occlusion is considered to have two important components: that at rest is referred to as the static component, and that when the mandible is functioning is referred to as the dynamic component. The relationship between the adjacent teeth of the same arch, their relationship with the teeth of the opposing arch, and the relationship of the teeth with the periodontium (supporting alveolar bone) when the mandible is at rest constitute the static component of occlusion. The term “dynamic” refers to a persistent change in the position of an object, and “dynamic occlusion” refers to the interarch and intra-arch relationships between the teeth and the relationship of the teeth with the supporting bone when the mandible is functioning. In contrast to the current study, Sathyanarayana et al. found that the sagittal morphology does not significantly affect the MVMBF value; consistent with the current study, however, they found a significant correlation with the vertical morphology. In agreement with the current study, de Araújo et al. also found that the type of occlusion influenced the MVMBF. The authors reported that the number of occlusal contacts determined the chewing efficiency and that chewing was less efficient in patients with malocclusion than normal occlusion. Therefore, it can be assumed from the findings of the present study that the patients with significantly lower bite force were those with Class III malocclusion and fewer occlusal contacts.

Table 3. Comparison of MVMBF between two groupings of confounding variables.

| Variables          | Groups          | Side | Mean  | SD    | 95% CI       | 95% CI       | 95% CI       | p value |
|--------------------|-----------------|------|-------|-------|--------------|--------------|--------------|---------|
|                    |                 |      | Lower | Upper |              |              |              |         |
| Age, years         | <18 Left        | 265.041 | 199.318 | -264.939 | -143.215 | <0.001       |
|                    | >18 Left        | 469.118 | 89.063  | 508.941 | 355.215 | <0.001       |
|                    | <18 Right       | 302.593 | 195.930 | -263.941 | -148.064 | <0.001       |
|                    | >18 Right       | 508.941 | 69.986  | 508.941 | 355.215 | <0.001       |
| Sex                | Female Left     | 269.571 | 198.852 | -257.215 | -133.172 | <0.001       |
|                    | Male Left       | 464.765 | 99.413  | 464.765 | 355.215 | <0.001       |
|                    | Female Right    | 326.735 | 195.270 | -222.919 | -95.768  | <0.001       |
|                    | Male Right      | 486.078 | 116.900 | 486.078 | 355.215 | <0.001       |
| Lip competency     | Competent Left  | 387.615 | 187.903 | -34.438  | 111.502  | 0.297        |
|                    | Incompetent Left| 349.083 | 179.038 | 349.083 | 111.502 | 0.297        |
|                    | Competent Right | 444.981 | 172.343 | 444.981 | 111.502 | 0.297        |
|                    | Incompetent Right| 367.938 | 177.757 | 367.938 | 111.502 | 0.297        |
| Midline shift      | No shift Left   | 495.838 | 83.630  | 495.838 | 136.800 | 265.479 | <0.001 |
|                    | Shift Left      | 294.698 | 186.196 | 294.698 | 136.800 | 265.479 | <0.001 |
|                    | No shift Right  | 527.378 | 97.262  | 527.378 | 126.370 | 252.609 | <0.001 |
|                    | Shift Right     | 337.889 | 178.277 | 337.889 | 126.370 | 252.609 | <0.001 |

MVMBF, maximum voluntary molar bite force; SD, standard deviation; CI, confidence interval.

6 Journal of International Medical Research
of the orofacial muscles and facial skeleton as well as the possible etiological factors of abnormalities will help us understand the complicated nature of the development of normal and abnormal occlusion. A thorough understanding of the underlying physiological concepts makes it possible to predict that the occlusal bite force might be increased in a patient with Class II malocclusion with a deep bite, while the occlusal bite force might be considerably decreased in a patient with an open bite with excessive vertical growth. A similar concept can be seen in patients with normal bites and crossbites. Sonnesen et al.\textsuperscript{12} found that the differences in the muscle function associated with unilateral crossbite led to a significantly smaller bite force in the crossbite group than in controls. In another study, the average

| Table 4. Comparison of MVMBF among three groupings of confounding variables. |
|---------------------------------|-----------------|----------|----------|----------|
| Variables                      | Groups          | Side     | Lower    | Upper    | p value  |
| Dental malocclusion            | Class I vs Class II | Left  | 11.590   | 185.684  | 0.021   |
|                                | Class I vs Class III |      | 180.985  | 353.371  | <0.001  |
|                                | Class II vs Class III |     | 75.117   | 261.966  | <0.001  |
|                                | Class I vs Class II | Right | −38.508  | 127.996  | 0.581   |
|                                | Class I vs Class III |      | 174.149  | 339.020  | <0.001  |
|                                | Class II vs Class III |     | 122.489  | 301.192  | <0.001  |
| Skeletal malocclusion          | Class I vs Class II | Left  | 24.571   | 221.621  | 0.009   |
|                                | Class I vs Class III |      | 72.870   | 274.271  | <0.001  |
|                                | Class II vs Class III |     | −59.685  | 160.635  | 0.801   |
|                                | Class I vs Class II | Right | 14.704   | 209.169  | 0.018   |
|                                | Class I vs Class III |      | 52.699   | 251.457  | 0.001   |
|                                | Class II vs Class III |     | −68.573  | 148.856  | 1.000   |
| Overjet                        | Normal vs Increased | Left | 31.173   | 233.761  | 0.006   |
|                                | Normal vs Decreased |      | 45.490   | 251.459  | 0.002   |
|                                | Increased vs Decreased |     | −89.121  | 121.135  | 1.000   |
|                                | Normal vs Increased | Right | 36.260   | 231.704  | 0.004   |
|                                | Normal vs Decreased |      | 48.971   | 247.676  | 0.001   |
|                                | Increase vs Decreased |     | −87.080  | 115.762  | 1.000   |
| Overbite                       | Normal vs Increased | Left  | 133.930  | 323.403  | <0.001  |
|                                | Normal vs Decreased |      | −60.381  | 121.499  | 1.000   |
|                                | Increase vs Decreased |     | −299.208 | −97.008  | 0.000   |
|                                | Normal vs Increased | Right | 115.881  | 304.897  | <0.001  |
|                                | Normal vs Decreased |      | −40.092  | 141.350  | 0.531   |
|                                | Increase vs Decreased |     | −260.616 | −58.903  | 0.001   |
| Crowding                       | Mild vs Moderate | Left  | 114.332  | 315.394  | <0.001  |
|                                | Mild vs Severe |      | −2.109   | 184.530  | 0.058   |
|                                | Moderate vs Severe |     | −230.347 | −16.958  | 0.017   |
|                                | Mild vs Moderate | Right | 66.284   | 269.320  | <0.001  |
|                                | Mild vs Severe |      | 10.425   | 198.896  | 0.024   |
|                                | Moderate vs Severe |     | −170.883 | 44.601   | 0.470   |

MVMBF, maximum voluntary molar bite force; SD, standard deviation; CI, confidence interval.
MVMBF was higher in patients with premature contacts than those without; it did not differ in patients with different types of functional occlusion or in the presence of parafunctional habits. The current study showed alterations in the MVMBF related to midline shift. The midline can be deviated by an asymmetrical mandibular position, or midline deviation might be the reflex of intra-arch dental deviations and associated with differences in the dental occlusion between the right and left sides. More than an aesthetic problem, midline deviation can reveal mandibular functional deviation or intra-arch dental deviation with reflex on the intercuspation of teeth, leading to an asymmetrical relationship between the two sides. These problems should be taken into consideration when interpreting a patient’s midline shift, and future studies on this topic are warranted.

A thorough understanding and comprehensive knowledge of the different types of malocclusion and their associated aesthetics-related problems will aid clinicians in establishing an ideal treatment plan. Recording the MVMBF is a simple, inexpensive chair-side procedure, and assessment of the MVMBF helps orthodontists to identify disturbances in the stomatognathic system and accordingly plan the type of mechanics to be employed. The bite force is the force generated during mastication, and it is a good measure of the status of the stomatognathic system. Measurement of the bite force helps to identify the presence of any derangement in this system due to any change in the occlusion, thus aiding in more accurate planning and the mechanics to be used. This study furthers new areas of research in this field, particularly the influence of the bite force on the development of malocclusion. A limitation of this study is the single ethnic group that was investigated; further studies involving different ethnic groups are needed to validate the results of this study. Additionally, because the results of this study revealed the influence of many confounding factors on the MVMBF, it would be desirable to examine each confounding factor after matching groups based on all other confounding factors to yield a clear conclusion about the examined factor. Long-term evaluation of prospective changes would be helpful to obtain confirmatory results.

Conclusion

In this study, the MVMBF was evaluated using a simple chair-side procedure in relation to age, sex, lip competency, midline shift, dental and skeletal malocclusion, overjet, overbite, and crowding. The MVMBF was significantly related to all nine variables. The findings of these relationships between the MVMBF and the various types of malocclusions assessed in this study will enable a better understanding of the etiology, manifestations, and treatments of such occlusions.

Declaration of conflicting interest

The authors declare that there is no conflict of interest.

Funding

The authors disclosed receipt of the following financial support for the research, authorship and/or publication of this article: This work was supported by the Deanship of Research, Jouf University (Research fund: 40/002).

ORCID iDs

Mohammad Khursheed Alam https://orcid.org/0000-0001-7131-1752
Ahmed Ali Alfawzan https://orcid.org/0000-0002-3088-0120

References

1. Fontijn-Tekamp FA, van der Bilt A, Abbink JH, et al. (2004) Swallowing threshold and
masticatory performance in dentate adults. *Physiol Behav.* 83: 431–436.

2. Bakke M. (2006) Bite force and occlusion. *Semin Orthod.* 12: 120–126.

3. Bonjardim LR, Gaviao MB, Pereira LJ, et al. (2005) Bite force determination in adolescents with and without temporomandibular dysfunction. *J Oral Rehabil.* 32: 577–583.

4. Roldán S, Buschang PH, Isaza Saldarriaga JF, et al. (2009) Reliability of maximum bite force measurements in age-varying populations. *J Oral Rehabil.* 36: 801–807.

5. Varga S, Spalj S, Lapter Varga M, et al. (2011) Maximum voluntary molar bite force in subjects with normal occlusion. *Eur J Orthod.* 33: 427–433.

6. Kogawa EM, Calderon PS, Lauris JR, et al. (2006) Evaluation of maximal bite force in temporomandibular disorders patients. *J Oral Rehabil.* 36: 559–565.

7. Ow RK, Carlsson GE and Jemt T. (1989) Biting forces in patients with craniomandibular disorders. *Cranio.* 7: 119–125.

8. Braun S, Hnat WP, Freudenthaler JW, et al. (1996) A study of maximum bite force during growth and development. *Angle Orthod.* 66: 261–264.

9. Lundgren D and Laurell L. (1986) Occlusal force pattern during chewing and biting in dentitions restored with fixed bridges of cross-arch extension. *J Oral Rehabil.* 13: 57–71.

10. Sasaki K, Hannam AG, Wood WW. (1989) Relationships between the size, position, and angulation of human jaw muscles and unilateral first molar bite force. *J Dent Res.* 68: 499–503.

11. Tortopidis D, Lyons MF, Baxendale RH, et al. (1998) The variability of bite force measurement between sessions, in different positions within the dental arch. *J Oral Rehabil.* 25: 681–686.

12. Sonnesen L, Bakke M and Solow B. (2001) Bite force in pre-orthodontic children with unilateral crossbite. *Eur J Orthod.* 23: 741–749.

13. Abu Alhaija ES, Al Zo’ubi IA, Al Rousan ME, et al. (2010) Maximum occlusal bite forces in Jordanian individuals with different dentofacial vertical skeletal patterns. *Eur J Orthod.* 32(1):71–77.

14. Sathyanarayana HP, Premkumar S and Manjula WS. (2012) Assessment of maximum voluntary bite force in adults with normal occlusion and different types of malocclusions. *J Contemp Dent Pract.* 13: 534–538.

15. de Araújo SC, Vieira MM, Gasparotto CA, et al. (2014) Bite force analysis in different types of angle malocclusions. *Revista CEFAC.* 16: 1567–1578.

16. Alam MK and Iida J. (2013) Overjet, overbite and dental midline shift as predictors of tooth size discrepancy in a Bangladeshi population and a graphical overview of global tooth size ratios. *Acta Odontol Scand.* 71: 1520–1531.

17. Kamegai T, Tatsuki T, Nagano H, et al. (2005) A determination of bite force in northern Japanese children. *Eur J Orthod.* 27: 53–57.

18. Sakaguchi M, Ono N, Turuta H, et al. (1996) Development of new handy type occlusal force gauge. *Japanese J Med Elect Bio Eng.* 34: 53–55.

19. Palinkas M, Nassar MS, Cecílio FA, et al. (2010) Age and gender influence on maximal bite force and masticatory muscles thickness. *Arch Oral Biol.* 55: 797–802.

20. English J, Peltomaeki T and Pham-litschel K. (2009) *Mosby’s Orthodontic Review.* Philadelphia: Elsevier Health Science.