

Manuscript Number: AJODO-D-14-00797R3

Title: Preliminary biometric analysis of mesiodistal tooth dimensions in subjects with normal occlusion

Article Type: Original Article

Corresponding Author: Dr. Niki Arveda,

Corresponding Author's Institution: University of Ferrara

First Author: Luca Lombardo

Order of Authors: Luca Lombardo; Maurizio Marcon; Niki Arveda; Gabriella La Falce; Enrico Tonello; Giuseppe Siciliani

Abstract: Aim: To confirm the efficacy of the Bolton Index in a group of natural class I White Italian patients with complete dentition, minimum crowding, and no history of previous orthodontic treatment, and to evaluate mesiodistal tooth dimensions via multivariate cluster analysis.

Methods: Tooth measurements were obtained from a sample of 56 patients with normal occlusion, normal Bolton Index (22 males, 34 females, mean age 27.8 years), without previous orthodontic treatment or prosthetic and/or Black's class II restorations. Maxillary and mandibular measurements were analysed separately in males and females. Clustering was performed using the PAM algorithm and PCA-based transformed data. Statistical analysis was conducted using the Dahlberg Index and t-test.

Results: Multivariate analysis revealed 3 distinct clusters of both maxillary and mandibular tooth dimension measurements in males and females. Statistically significant differences were found between the two genders in terms of average tooth measurements, and there was significant proportionality between the upper and lower arch clusters.

Conclusion:

Although the Bolton index is useful for identifying dentodental discrepancy in the majority of patients, cluster analysis enabled mandibular and maxillary tooth dimensions of males and females to be divided into 3 general classes (clusters), and the precise location of such discrepancy to be pinpointed.

Comments from the Reviewers:

- 1) ...However, there is 1 major issue that must be addressed: at the bottom of page 13, the text refers to tables X and XI, whereas the tables included only go through IX. I don't know whether some had been consolidated or what, but this needs to be addressed.

Dear Reviewers we have made a mistake in table numeration (table X and XI no longer exist) so we have changed the text according to your advice.

- 1) On page 14, line 10, it should read, "It is impossible to either pinpoint the location..." rather than, "...it is unable either to pinpoint..."

Dear Reviewers we have changed the text according to your advice.

- 2) On page 15, line 9, I believe that 'buccal' rather than 'vestibular' cusps were what you were referring to.

Dear Reviewers we have changed the text according to your advice.

Preliminary biometric analysis of mesiodistal tooth dimensions in subjects with normal occlusion

Luca Lombardo, Maurizio Marcon, Niki Arveda, Gabriella La Falce, Enrico Tonello, Giuseppe Siciliani.

Department of Orthodontics, University of Ferrara, Ferrara, Italy.

Via Montebello 31, 44100 Ferrara, Italy

Luca Lombardo (study idea, study design and text revision):

Degree in Dentistry

Assistant Professor

Contrada Nicolizia,

92100 Licata, AG, Italy.

Tel: +39-3496189796.

E-mail: lulombardo@tiscali.it

Maurizio Marcon (study design, sample selection and measurement):

Degree in Dentistry

Resident

Ferrara University

Via Montebello, 31

44100 Ferrara, Italy

Tel: +39-053-2202528.

E-mail: mauri.marcon@gmail.com

Niki Arveda (study design, sample selection and measurement and text revision):

Degree in Dentistry

Resident

Ferrara University

Via Montebello, 31

44100 Ferrara, Italy

Tel: +39 339 3474600.

E-mail: nikiarveda@live.it

Gabriella La Falce (text revision):

Degree in Dentistry

Resident

Ferrara University

Via Montebello, 31

44100 Ferrara, Italy

Tel: +39-0532202528.

E-mail: gabriella.lafalce@hotmail.it

Enrico Tonello (text revision):

Degree in Dentistry

Resident

Ferrara University

Via Montebello, 31

44100 Ferrara, Italy

Tel: +39-0532202528.

E-mail: enrico.tonello1@gmail.com

Giuseppe Siciliani (study idea, study design and text revision):

Degree in Medicine

Chairman, Ferrara Postgraduate School of Orthodontics

Via Montebello 31,

44100 Ferrara, Italy.

Tel: +39-0532202528.

E-mail: sci@unife.it

*Corresponding author: Niki Arveda

Via Montebello 31

44100 Ferrara (FE), Italy.

Tel: 339 3474600

E-mail: nikiarveda@live.it

Authors' contributions section

Luca Lombardo: study idea, study design and text revision

Maurizio Marcon: study design, sample selection and measurement

Niki Arveda: study design, sample selection and measurement and text revision

Gabriella La Falce: text revision

Enrico Tonello: text revision

Giuseppe Siciliani: study idea, study design and text revision

All Authors read and approved the final manuscript and declare that they have no competing interests.

HIGHLIGHTS

- Although the Bolton index is useful for identifying dentodental discrepancy in the majority of patients, cluster analysis enabled mandibular and maxillary tooth dimensions of males and females to be divided in general classes (clusters), and the precise location of such discrepancy to be pinpointed.
- Multivariate analysis revealed 3 distinct clusters of both maxillary and mandibular tooth dimension measurements in males and females.
- Statistically significant differences were found between the two genders in terms of average tooth measurements, and there was significant proportionality between the upper and lower arch clusters.

HIGHLIGHTS

- Bolton index is useful for identifying dentodental discrepancies
- Cluster analysis enables divisions into general classes
- Multivariate analysis revealed 3 clusters of tooth dimension measurements
- Statistically significant tooth measurement differences were found between sexes
- Significant proportionality was seen between maxillary and mandibular arch clusters

Preliminary biometric analysis of mesiodistal tooth dimensions in subjects with normal occlusion

Aim: To confirm the efficacy of the Bolton Index in a group of natural class I White Italian patients with complete dentition, minimum crowding, and no history of previous orthodontic treatment, and to evaluate mesiodistal tooth dimensions via multivariate cluster analysis.

Methods: Tooth measurements were obtained from a sample of 56 patients with normal occlusion, normal Bolton Index (22 males, 34 females, mean age 27.8 years), without previous orthodontic treatment or prosthetic and/or Black's class II restorations. Maxillary and mandibular measurements were analysed separately in males and females. Clustering was performed using the PAM algorithm and PCA-based transformed data. Statistical analysis was conducted using the Dahlberg Index and t-test.

Results: Multivariate analysis revealed 3 distinct clusters of both maxillary and mandibular tooth dimension measurements in males and females. Statistically significant differences were found between the two genders in terms of average tooth measurements, and there was significant proportionality between the upper and lower arch clusters.

Conclusion:

Although the Bolton index is useful for identifying dentodental discrepancy in the majority of patients, cluster analysis enabled mandibular and maxillary tooth dimensions of males and females to be divided into 3 general classes (clusters), and the precise location of such discrepancy to be pinpointed.

INTRODUCTION

To assess the degree of crowding, the dentodental relationships between the upper and lower teeth, as well as the skeletal and dentobasal relationships, needs to be determined with precision. It is therefore vital to consider the dimensions of the individual teeth before treatment with a view to quantifying and localizing any dental discrepancies,^(1-3, 3-21) and planning the amount of stripping and/or restorative build-up required, all prerequisites for good occlusal interdigitation.⁽¹⁷⁾

The most common method of identifying and calculating the degree of dental discrepancy, and determining whether it is in the anterior or posterior sectors, is the Bolton index.^(8,9) In subjects with normal occlusion, Bolton reported an overall mean inter-maxillary dentodental relationship, from first molar to first molar, of 91.3 ± 0.26 , and an anterior relationship, from canine to canine, of 77.2 ± 0.22 .⁽⁷⁾ However, the Bolton index does present certain limitations. First and foremost, the overall and anterior ratios are very wide ranging (Anterior Ratio, AR 74.5 – 80.4 and Overall Ratio, OR 87.5 – 94.8), implying that there is an equally wide range of what is considered normal in an optimal occlusion.⁽¹¹⁾ Furthermore, the index cannot tell us the precise location of the discrepancy within a sector, or quantify its severity.⁽¹¹⁾ It is also unable to

take into account ethnic variations,⁽¹²⁻¹⁵⁾ and, due to the fact that it relies on measurements made on plaster models, it is subject to imprecision.^(18, 22-24)

Nevertheless, many Authors assert that the Bolton index can be correlated with the type of malocclusion. Nie et al. for example, measured this parameter in 300 orthodontic patients, classified according to their malocclusion type (I, II and III), finding that patients with class III tended to have higher Bolton indices than those with class I, whereas class II tended to be correlated with lower Bolton indices than class II.⁽¹⁰⁾ Hence, according to some Authors, class III malocclusion is correlated with a relative excess in the lower dentition, while class II involves a relative excess in the upper dentition. However, in their review of the literature on tooth size discrepancies, Othman et al. concluded that the standard deviations of the Bolton indices are not an ideal guide for evaluating clinically significant discrepancies in tooth dimension.⁽¹¹⁾ They also stated that researchers should focus more on the degree of the discrepancy, rather than just the Bolton index alone.

Whatever the case, the job of measuring the tooth dimensions, and the Bolton index, has been made considerably easier of late, due to the advent of digital gauges and their dedicated software, and the measurement of dental discrepancies is set to gradually become routine in clinical practice. Hence, it is timely to analyse such dimensions using the latest technological and statistical analysis tools. In particular, we set out to use these tools to:

- Verify the validity of the Bolton indices in a sample of untreated naturally class I White Italian subjects with complete dentition and minimal crowding.
- Measure the mesiodistal diameters of the tooth crowns, analyse the data via multivariate cluster analysis (males, females, upper teeth and lower teeth), and ultimately propose a method for the precise localization and quantification of the inter-arch discrepancy, thereby overcoming some of the limitations of the Bolton index.

MATERIALS & METHODS

Tooth measurements were taken in a sample of 56 White Italian patients (22 males, 34 females, mean age 27.8 years) with normal occlusion, selected according to the following criteria: molar and canine class I, complete dentition excluding the third molars, normal overjet (OJ) and overbite (OB) (between 1 and 3 mm), minimal crowding (less than 1.5 mm, considering both arches), no previous orthodontic and/or prosthetic and/or conservative treatment (no Black class II restorations).

Plaster models of these 56 patients' dentition were scanned using a 3D 3Shape R700 scanner, and the mesiodistal diameters of each crown, from second molar to second molar, were measured using 3Shape OrthoAnalyzerTM software (Fig. 1). In order to obtain precise, reliable measurements, each tooth was measured as follows:

- On a vestibular view of each tooth (Fig. 2), the “2D cross-section” tool was used to section the digital rendering; the incisors were sectioned from the distal point of contact, keeping the plane parallel to the incisal margin, and the remaining teeth were sectioned from the juncture between the most distal and most mesial points (Figs. 3 and 4).
- On an occlusal view of each tooth, the “distance” tool was used to measure the mesiodistal diameter between the ideal points of contact, taking into account any rotation or inclination, and ensuring that the points of contact in the posterior sectors were located vestibular to the central occlusal fossa (Fig. 5).

Each measurement was taken twice by two different investigators, and both sets of measurements were recorded on an Excel spreadsheet. Male patients were numbered 1 to 22, and female patients from 1 to 34. Each tooth was assigned a two-figure number, according to the FDI numbering system (Fédération Dentaire Internationale).

Statistical analysis

The Dahlberg index was used to calculate the random error (values were between 0.03 and 0.31 mm) of the two sets of measurements taken for each tooth in each patient.⁽²⁵⁾ A t-test for independent samples was used to evaluate the systematic error, which was found to have no significant influence on the measurements ($p= 0.05$). Table I shows the measurement repeatability values calculated via the Dahlberg index and the t-test (Table I).

A t-test was used to compare the scores of males and females for each of the two Bolton indices (OR and AR), to calculate the difference between the mean measurements for each of the 28 teeth considered in males and females, and to compare left and right measurements. Given the large number of comparisons, p-values were corrected for multiple comparisons using the False Discovery Rate method.^(26, 27)

Subsequently, cluster analysis was applied to the data yielded by the study sample. Essentially, cluster analysis is designed to find groups in datasets. The idea is to group items in such a way that those in the same group, or cluster, are similar to each other, but as dissimilar as possible to items in the other clusters. The most central value of each cluster, known as the medoid, can then be identified, and, being of extremely low standard deviation and possessing minimal average dissimilarity to all the other values in the cluster, can be used to distinguish it from the other clusters (32).

Separate cluster analyses were performed on data pertaining to males and females, and to the upper and lower arches of each gender by means of the PAM algorithm (Partitioning Around Medoid). (32) The interdependence of the maxillary and mandibular clusters with respect to gender was determined using the Cochran-Mantel-Haenszel test.

RESULTS

Preliminary Analysis

1- Gender-related differences

No significant differences in either Bolton's index were found between the male and female groups: AR $t_{(37.51)} = -0.82, p = 0.41, d = 0.24$, OR $t_{(46.38)} = 0.66, p = 0.51, d = 0.18$ (Table II).

However, when teeth were measured singly, statistically significant differences between the sexes were revealed, as shown in Table III (Table III.)

2- Side-related differences

At a significance threshold of $\alpha = 0.05$, no significant differences between left and right teeth were found, and we can therefore assume that the two hemispheres are comparable.

3- Multivariate cluster analysis

Cluster analysis furnished 4 distinct groups of values, and the Cochran-Mantel-Haenszel test proved the interdependence of the male and female maxillary and mandibular clusters. As in the article by Lee, ⁽²⁸⁾ the test showed an association between the two ($\chi^2_{(4)} = 32.18, p < 0.001$). Nevertheless, when Kaiser's criterion was applied, it was difficult to distinguish whether there were in fact 4 clusters, or only 3. ⁽²⁹⁾ Hence, we performed PAM cluster analysis for both 3- and 4-group scenarios.

Then, through multivariate analysis using the PAM algorithm, based on the value of the average silhouette width we discerned 3 distinct maxillary tooth clusters and 3 distinct mandibular tooth clusters ("large", "medium" and "small") in both male and female datasets (Figures 6, 7, 8 and 9). As there were no statistically significant differences revealed between the left and right tooth measurements, the means of both were considered. The x-axes of Figures 6 to 9 show the tooth numbers assigned according to the international tooth numbering system, and the y-axes show the mesial-distal tooth measurements in millimetres. Medoids are represented by coloured curves, with blue being the "large" cluster, red the "medium", and green the "small" (Figure 6, Figure 7, Figure 8, Figure 9, Table IV, Table V, Table VI, Table VII).

Multivariate analysis of clusters

The analysis showed a certain homogeneity within the "large" and "small" clusters. However, the "medium" cluster, and therefore the measurements within, tended towards the "large" in both maxillary and mandibular clusters, particularly in males, in whom the "medium" and "large" maxillary clusters in particular differed only in terms of measurements between 12/22, 16/26 and 17/27, and in the mandible between 33/43 and 37/47. In females, on the other hand, the cluster trends were fairly homogeneous, and the "medium" and "large" clusters overlap at 36/46 and 17/27.

Differences between clusters

Analysis of variance was used to determine any statistical differences between the measurements in the various clusters ("large", "medium" and "small"), in terms of either gender or location (upper jaw, lower

jaw). As shown in Figure 10, the maxillary values varied according to both cluster ($F_{(2,50)} = 95.72, p < 0.001, \eta^2 = 0.62$) and gender ($F_{(1,50)} = 44.48, p < 0.001, \eta^2 = 0.14$), and the measurements within the clusters also varied according to gender ($F_{(2,50)} = 11.07, p < 0.001, \eta^2 = 0.07$) (Fig. 10). Analogous results were also found in the mandible where, once again, values varied in function of the cluster ($F_{(2,50)} = 74.85, p < 0.001, \eta^2 = 0.56$), and gender ($F_{(1,50)} = 61.13, p < 0.001, \eta^2 = 0.23$), and the measurements within the clusters varied in function of the gender ($F_{(2,50)} = 3.28, p < 0.05, \eta^2 = 0.02$) (Fig. 11).

Intra-arch cluster combinations

The Bolton index was evaluated for each combination of maxillary and mandibular clusters able to guarantee the attainment of normal occlusion. (Table VIII, Table IX). The mean Bolton AR of each group varied between 0.733 and 0.810 (Table VIII), and the mean OR between 0.891 and 0.931 (Table IX). The corresponding standards identified by Bolton were, respectively, 0.772 and 0.913. The male and female clusters that most closely fit the standards identified by Bolton are marked in grey. The empty cells indicate the combinations not considered in our sample.

DISCUSSION

Although today's orthodontists still rely on the Bolton indices, identified more than 50 years ago, the literature is full of discrepancies regarding their application, particularly in terms of ethnicity and type of malocclusion. Indeed, some researchers have concluded that inter-arch relationships are correlated with gender, ethnicity, and the type of malocclusion,^(15-17, 28) while others refuse such findings.⁽²⁰⁾ Moreover, the Bolton indices are essentially means of very wide ranges of values (anterior 74.5–80.4, overall 87.5–94.8), indicating a great inter-individual variability in what is considered normal occlusion.

Hence, the use of mere statistical means to evaluate inter-individual variation is not sufficient, particularly in light of the availability of modern technology and statistical tools. **It impossible to either pinpoint the location** of the discrepancy or to quantify it, and, although 50% of cases of dentodental discrepancy can be attributed to the lower second premolars, upper lateral incisors, or lower central incisors,⁽¹⁴⁾ we are still unable to determine the degree of discrepancy contributed by each tooth. In order to overcome these limitations and verify the validity of the Bolton index, we therefore set out to measure the mesiodistal diameters of the teeth in our sample of 56 untreated White Italian patients with normal occlusion. We specifically chose to measure patients with no previous orthodontic treatment because they generally present with intact dentition, no extractions, and no stripping.

The 3D scanner 3Shape R700 was used to scan the plaster models of these 56 patients, as this method provides more accurate, reliable, and clinically acceptable readings than manual measurement, a process that is hampered by even slight crowding and rotations.^(18, 22-24) Indeed, it is possible to use such

digital tools to enlarge and rotate 3D renderings, without altering their effective dimensions in millimetres, ⁽²³⁾ which considerably facilitates the identification of the mesial and distal points of the teeth.

Our digital measurements enabled us to conclude that subjects with normal occlusion consistent to Andrews' principles, can have 'incorrect' Bolton indices. Although the means of the inter-arch relationships of the patients considered are comparable to Bolton's standard, the range of these ratios, both anterior (71.53–83.05) and overall (87.38–94.58), were larger than those proposed by Bolton. This confirms the great inter-individual variability in the dimensions of teeth that are, nevertheless, able to provide good occlusion.

As regards the OR, all combinations showed Bolton indices within the norm, i.e., within the range of standard deviation, but this was not true of the AR. The fact that some combinations did not display 'correct' Bolton AR values indicates, as proposed by other Authors, ⁽²⁸⁾ that the Bolton index may not be a reliable indicator of good occlusion. Indeed, though the relative proportions of the upper and lower teeth are important, it is not only the mesiodistal dimensions of the teeth that affect the quality of the occlusion. Indeed, the thickness of the incisal margins of the upper anterior teeth and the buccal cusps of the upper posterior teeth, as well as the axial inclination (torque) of the teeth, and the arch form, all play a role. ^(1, 2, 30) Rather than taking the Bolton indices as absolute values (means and standard deviations), therefore, it would be wiser to take them merely as an indicative guide.

In contrast, the multivariate cluster analysis used as an alternative means of evaluating inter-arch dentodental discrepancy in this study enabled us to largely overcome the limitations of the Bolton method. Indeed, this innovation in biomedical statistics enables us to interpret a large data set while preserving the information relative to each single measurement within it. ^(17, 28)

Our cluster analysis yielded four graphs (Figs. 6, 7, 8, 9) showing the "small", "medium" and "large" clusters identified within the dataset subdivided by gender and by arch. These graphs could be useful as reference graphs in the orthodontic practice. Indeed, a comparison of the tooth dimensions calculated for a patient with those reported in the reference graphs could enable us to identify, not so much the ideal relationship, but the tooth or teeth that are anomalous with respect to the normal models of tooth dimensions.

As we found no significant differences between left- and right-sided tooth dimensions, the graphs we have produced should be equally useful for identifying even single tooth size anomalies on each side of the arch in question. If, for example, we have a patient who presents a high Bolton index, without these graphs we can only state that there is a dentodental size discrepancy between the two arches, and are unable to determine whether it has arisen due to an excess of dental material in one arch or a lack in the other. However, using those of our cluster analysis graphs appropriate for the patient, e.g., "female maxillary teeth" and "female mandibular teeth", we are able to determine, first, whether our patient belongs to the "small", "medium", or "large" group, and, second, to accurately pinpoint the tooth (or teeth) that is anomalous with respect to the normal values within that cluster.

This approach may also be helpful in more complex cases in which, for example, a single discrepancy is to be found at a premolar, and it is necessary to quantify the extent of the excess or deficit. In this case, comparison of the tooth dimensions in the anomalous quadrant with the reference graphs would immediately highlight not only the site of the discrepancy, but also its degree. Indeed, to discover the extent of the discrepancy, on the y-axis, we merely have to calculate the difference between the size of the anomalous tooth in our patient, and that of the same “ideal” tooth on the reference graphs we provide.

These graphs show another interesting application in dental agenesis cases. Clinicians could use reference graphs to obtain a perfectly proportioned arches: as a matter of fact their use could provide an important aid to calculate the space amount needed for implant restoration.

In this study the parallel trend in the lines divided by cluster indicate that there is a proportional relationship between the tooth dimensions within each cluster. Indeed, the tooth dimensions in males tend to be larger than those in females, especially when considering the “small” and “medium” clusters, while in the “large” cluster, female patients tend to have larger upper and lower central and lateral incisors, upper first and second premolars, and lower canines with respect to the males. ⁽³¹⁾

Therefore, cluster analysis is better able to evaluate the inter-individual difference in such values than the simple statistical mean used to calculate the Bolton index. Being in a position to compare our patient’s measurements with a distinct medoid value for each cluster, gender and arch enables us not only to identify any inter-arch dentodental discrepancy (as per the Bolton index), but also to differentiate on the basis of cluster and gender. Furthermore, it allows us to identify where precisely the discrepancy is found. This kind of information would be extremely useful in clinical practice, as it could enable us to accurately target interventions designed to correct it (e.g., stripping /inter-proximal reduction (IPR) or conservative addition, according to whether there is a deficit or excess of space, respectively).

That being said, there are several limitations to this study. In particular, we only considered patients with minimal crowding (up to 1.5 mm), which, although not considered clinically significant, could represent a source of bias. Furthermore, the numerous compensatory factors known to influence the inter-arch relationship were not considered, but do merit further investigation in the future. Finally, the relatively small and homogeneous (White) sample considered may mean that the clusters generated here are not representative of a wider population. Indeed, there are several upper arch/lower arch cluster combinations missing from Tables VIII and IX, and therefore our sample, and it is feasible that these would be identified in a larger group.

Although several algorithms could be used in this type of statistical analysis, we chose a clustering algorithm due to the type of data available and the particular purpose of the analysis. For the purposes of this study, and given the size of the sample and the quality of data, we decided that the most appropriate algorithm was data partitioning around medoids (PAM). Compared to other approaches, such as k-means, PAM is more robust, because it minimizes a sum of dissimilarities instead of a sum of squared Euclidean

distances. Moreover, as reported by Lee and colleagues, it accepts a wide range of variability without removal of any data. (32) That being said, the power of cluster analysis is strongly dependent on the size of the sample, and a wider group of patients, comprising those of different ethnicities, is required to test the validity of the findings of this preliminary analysis.

CONCLUSIONS

This study enables us to draw the following conclusions regarding our White Italian sample:

- The Bolton index is a useful tool for identifying dentodental discrepancy in the majority of patients, even though some good occlusal relationships can present an 'incorrect' anterior Bolton index.
- The mandibular and maxillary values of our patients, both male and female, could each be divided into 3 general classes (clusters), namely "large", "medium" and "small".
- Subjects with a discrepancy between maxillary and mandibular clusters could, nevertheless, have Bolton indices within the normal range.
- Comparison of the mesiodistal dimensions of a patient's teeth with the "normal occlusion" tooth clusters generated enabled us to determine the precise location and degree of any dental discrepancy.

References

1. Harris EF, Burris BG. Contemporary permanent tooth dimensions, with comparisons to G.V. Black's data. *J Tenn Dent Assoc.* 2003;83:25-9.
2. Agenter MK, Harris EF, Blair RN. Influence of tooth crown size on malocclusion. *Am J Orthod Dentofacial Orthop.* 2009;136:795-804.
3. Puri N, Pradhan KL, Chandna A, Sehgal V, Gupta R. Biometric study of tooth size in normal, crowded, and spaced permanent dentitions. *Am J Orthod Dentofacial Orthop.* 2007;132:279.e7,279.14.
4. Ballard ML. Asymmetry in tooth size: a factor in the etiology, diagnosis, and treatment in malocclusion. *Angle orthod.* 1944:67-71.
5. Neff CW. Tailored occlusion with the anterior coefficient. *Am J Orthod.* 1949;35:309-13.
6. Steadman SR. Predetermining the overbite and overjet. *Angle Orthod.* 1949:101-109.

7. Bolton WA. Thesis for Master's degree [dissertation]. ; 1952.
8. Bolton WA. Disharmony in tooth size and its relation to the analysis and treatment of malocclusion. *Angle Orthod.* 1958;28:113-130.
9. Bolton WA. The clinical application of tooth-size analysis. *Am. J. Orthod.* 1962:504-529.
10. Nie Q, Lin J. Comparison of intermaxillary tooth size discrepancies among different malocclusion groups. *Am J Orthod Dentofacial Orthop.* 1999;116:539-44.
11. Othman SA, Harradine NW. Tooth-size discrepancy and Bolton's ratios: a literature review. *J Orthod.* 2006;33:45,51; discussion 29.
12. Smith SS, Buschang PH, Watanabe E. Interarch tooth size relationships of 3 populations: "does Bolton's analysis apply?". *Am J Orthod Dentofacial Orthop.* 2000;117:169-74.
13. Santoro M, Ayoub ME, Pardi VA, Cangialosi TJ. Mesiodistal crown dimensions and tooth size discrepancy of the permanent dentition of Dominican Americans. *Angle Orthod.* 2000;70:303-7.
14. Uysal T, Sari Z, Basciftci FA, Memili B. Intermaxillary tooth size discrepancy and malocclusion: is there a relation? *Angle Orthod.* 2005;75:208-13.
15. Paredes V, Gandia JL, Cibrian R. Do Bolton's ratios apply to a Spanish population? *Am J Orthod Dentofacial Orthop.* 2006;129:428-30.
16. Wedrychowska-Szulc B, Janiszewska-Olszowska J, Stepień P. Overall and anterior Bolton ratio in Class I, II, and III orthodontic patients. *Eur J Orthod.* 2010;32:313-8.
17. Lee SJ, Ahn SJ, Lim WH, Lee S, Lim J, Park HJ. Variation of the intermaxillary tooth-size relationship in normal occlusion. *Eur J Orthod.* 2011;33:9-14.
18. Garino F, Garino GB. Comparison of dental arch measurement between stone and digital casts. *W. J. Orthod.* 2002;3:1-5.
19. Moorrees CF, Reed RB. Correlations among Crown Diameters of Human Teeth. *Arch Oral Biol.* 1964;9:685-97.
20. Crosby DR, Alexander CG. The occurrence of tooth size discrepancies among different malocclusion groups. *Am J Orthod Dentofacial Orthop.* 1989;95:457-61.
21. Proffit WR. Contemporary orthodontics. Anonymous St. Louis: Mosby-Year Book; 1993.

22. Santoro M, Galkin S, Teredesai M, Nicolay OF, Cangialosi TJ. Comparison of measurements made on digital and plaster models. *Am J Orthod Dentofacial Orthop.* 2003;124:101-5.
23. Gracco A, Buranello M, Cozzani M, Siciliani G. Digital and plaster models: a comparison of measurements and times. *Prog Orthod.* 2007;8:252-9.
24. Tarazona B, Llamas JM, Cibrian R, Gandia JL, Paredes V. Evaluation of the validity of the Bolton Index using cone-beam computed tomography (CBCT). *Med Oral Patol Oral Cir Bucal.* 2012 1;17:e878-83.
25. Dahlberg G. *Statistical methods for medical and biological students.* London, George Allen and Unwin LTD; 1940.
26. Benjamini Y, and Hochberg Y. Controlling the false discovery rate: a practical and powerful approach to multiple testing. *Journal of the Royal Statistical Society Series B.* 1995;57:289-300.
27. Benjamini Y, and Yekutieli D. The control of the false discovery rate in multiple testing under dependency. *Annals of Statistics.* 2001:1165-1188.
28. Lee SJ, Lee S, Lim J, Ahn SJ, Kim TW. Cluster analysis of tooth size in subjects with normal occlusion. *Am J Orthod Dentofacial Orthop.* 2007;132:796-800.
29. Kaiser HF. The application of electronic computers to factor analysis. *Educational and Psychological Measurement.* 1960;20:141-51.
30. Garn SM, Lewis AB, Walenga A. Evidence for a secular trend in tooth size over two generations. *J Dent Res.* 1968;47:503.
31. Fattahi HR, Pakshir HR, Hedayati Z. Comparison of tooth size discrepancies among different malocclusion groups. *Eur J Orthod.* 2006;28:491-5.
32. Kaufman L, Rousseeuw PJ. *Finding groups in data: an introduction to cluster analysis.* Hoboken New Jersey, John Wiley & Sons Inc; 1990.

FIGURE LEGENDS

Figure 1. Plaster models were scanned using a 3D 3Shape R700 scanner.

Figure 2. Vestibular view of a right lower first molar.

Figure 3. Plane passing through the mesial and distal contact points of a left upper second premolar.

Figure 4. Plane passing through the distal contact point of a right upper lateral incisor, parallel to the incisal margin.

Figure 5. Occlusal view and measurement of the mesiodistal diameter of a right lower first molar

Figure 6. Maxillary tooth measurement clusters in our female sample

Figure 7. Mandibular tooth measurement clusters in our female sample

Figure 8. Maxillary tooth measurement clusters in our male sample

Figure 9. Mandibular tooth measurement clusters in our male sample

Figure 10. Graph showing how tooth dimensions vary in function of the cluster and gender in the maxilla

Figure 11. Graph showing how tooth dimensions vary in function of the cluster and gender in the mandible

TABLE LEGENDS

Table I. Validity of measurements. The mean, standard deviation, Dahlberg index, and systematic error (t-test) of each tooth measurement are reported.

Table II. Means and standard deviations (in brackets) of Bolton indices. Table III. Significant t-test results when comparing tooth measurements of males and females.

Table IV. Mean values (medoids) of female maxillary clusters in millimetres

Table V. Mean values (medoids) of female mandibular clusters in millimetres

Table VI. Mean values (medoids) of male maxillary clusters in millimetres

Table VII. Mean values (medoids) of male mandibular clusters in millimetres

Table VIII. Mean Bolton Anterior Ratio of each cluster of patients

Table IX. Mean Bolton Overall Ratio of each cluster of patients

Figure 1
[Click here to download high resolution image](#)

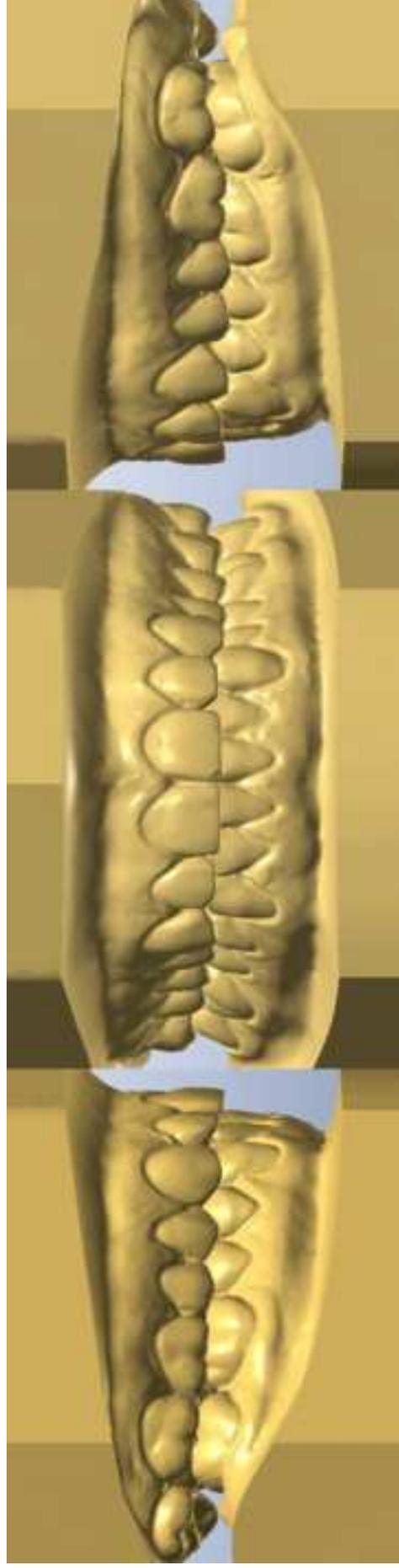


Figure 2
[Click here to download high resolution image](#)

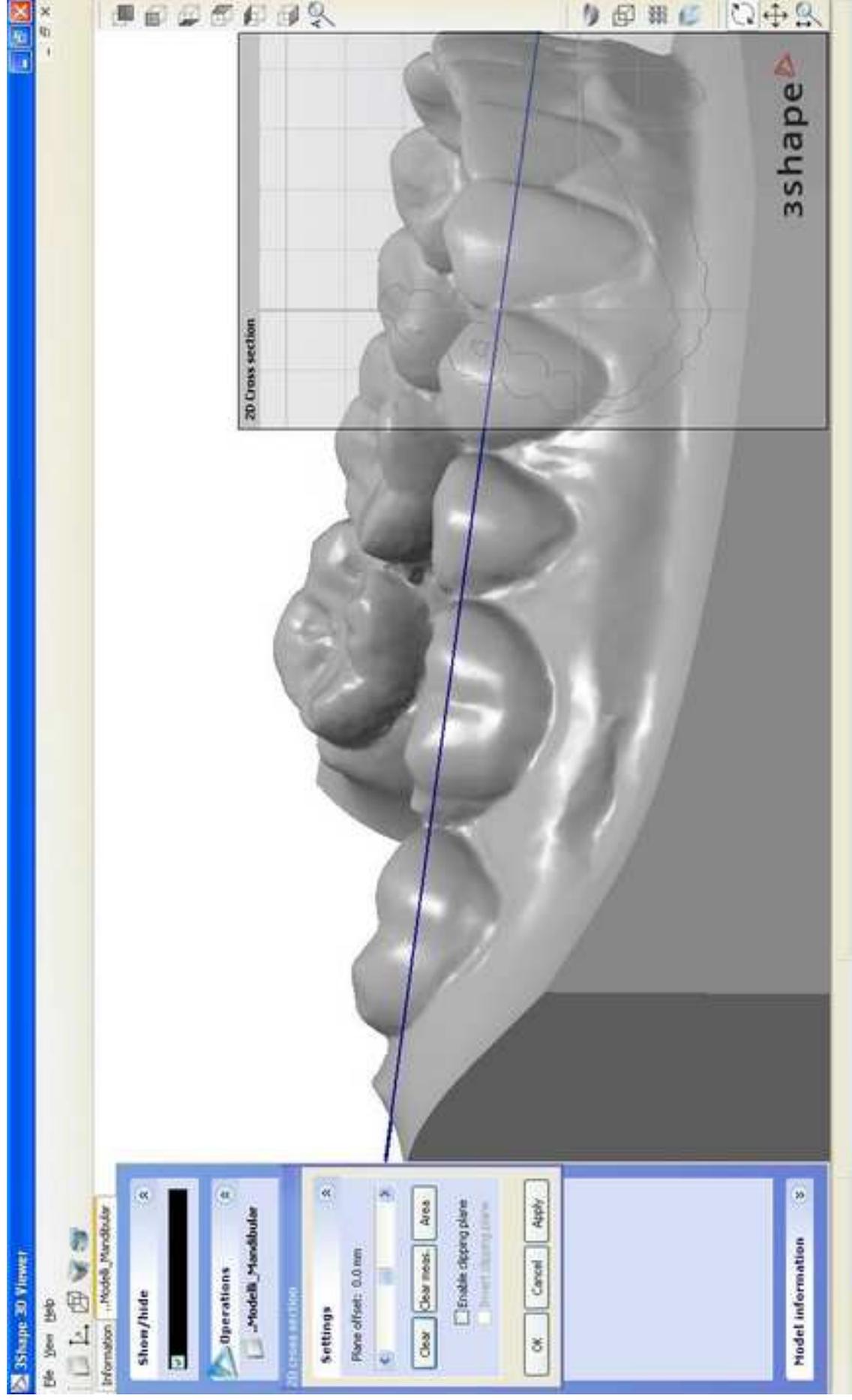


Figure 3
[Click here to download high resolution image](#)

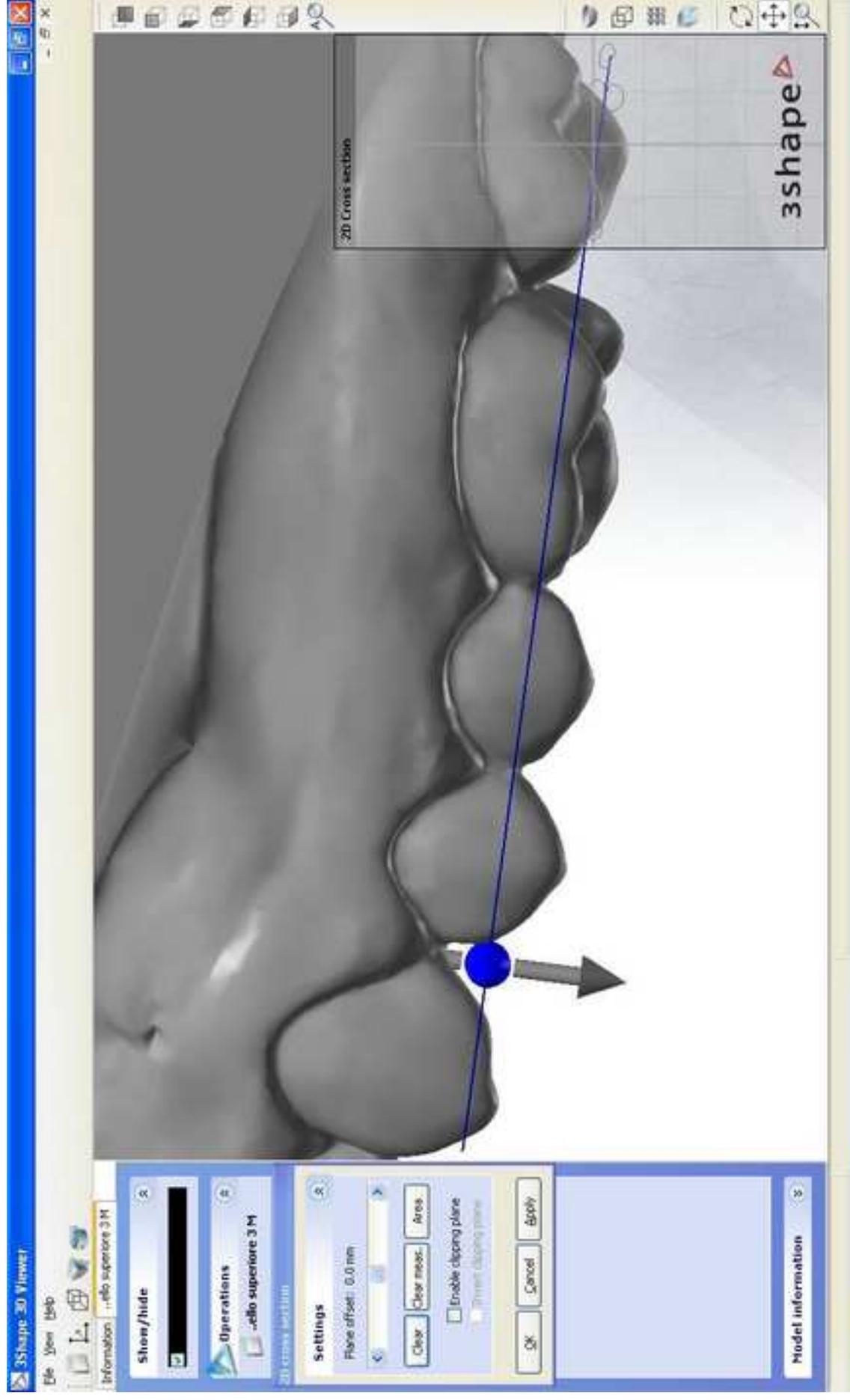


Figure 4
[Click here to download high resolution image](#)

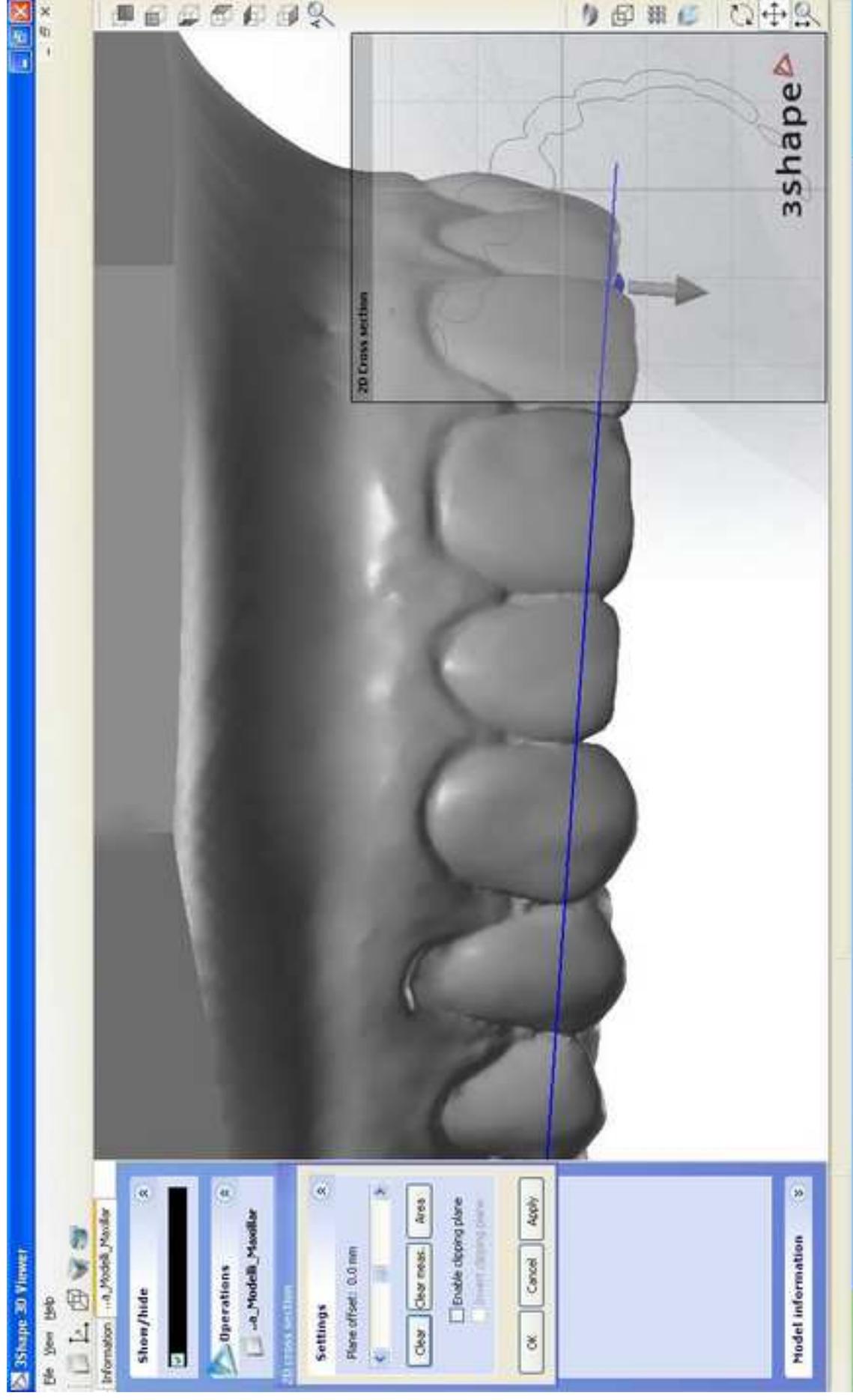
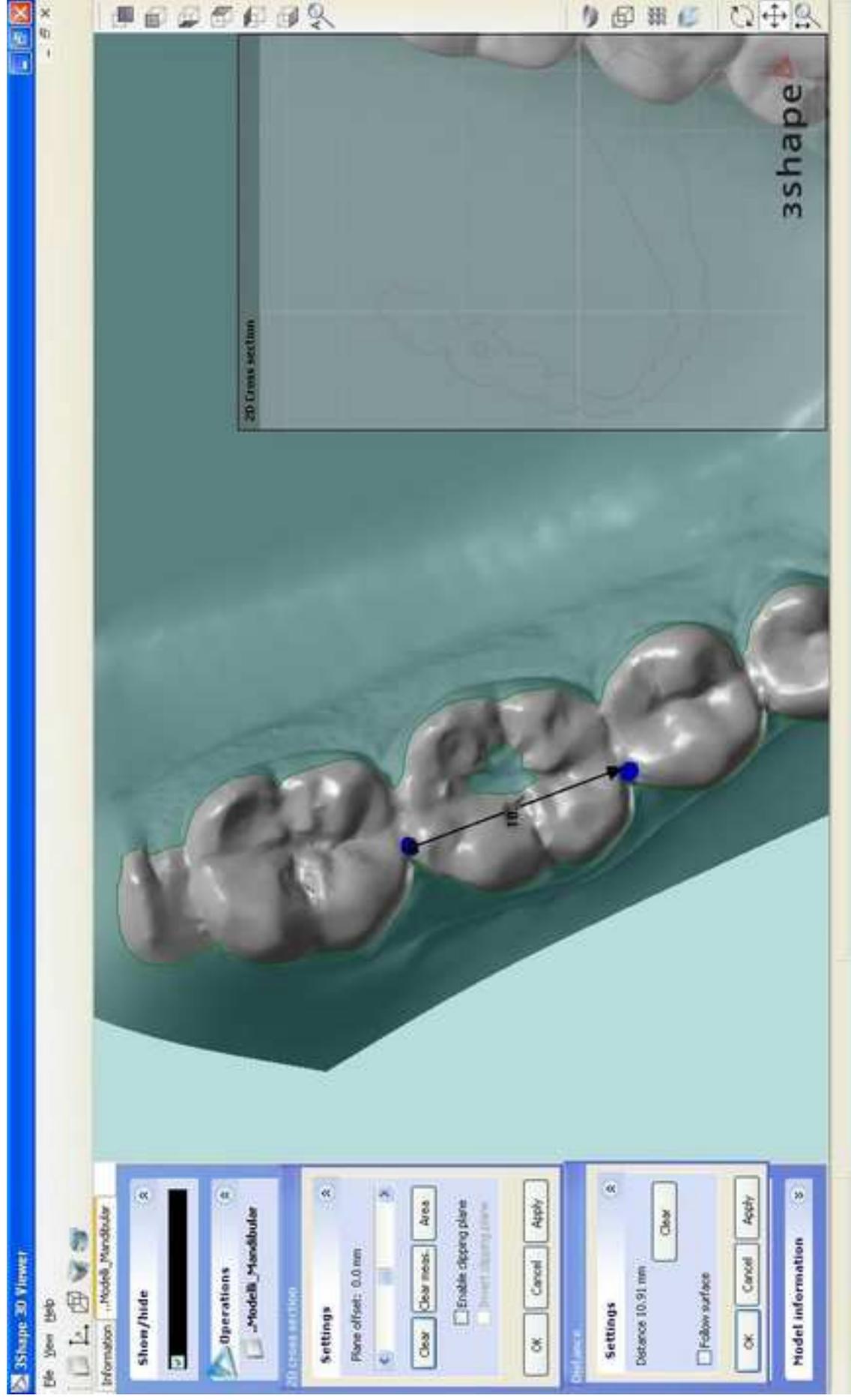


Figure 5
[Click here to download high resolution image](#)



Female maxillary teeth

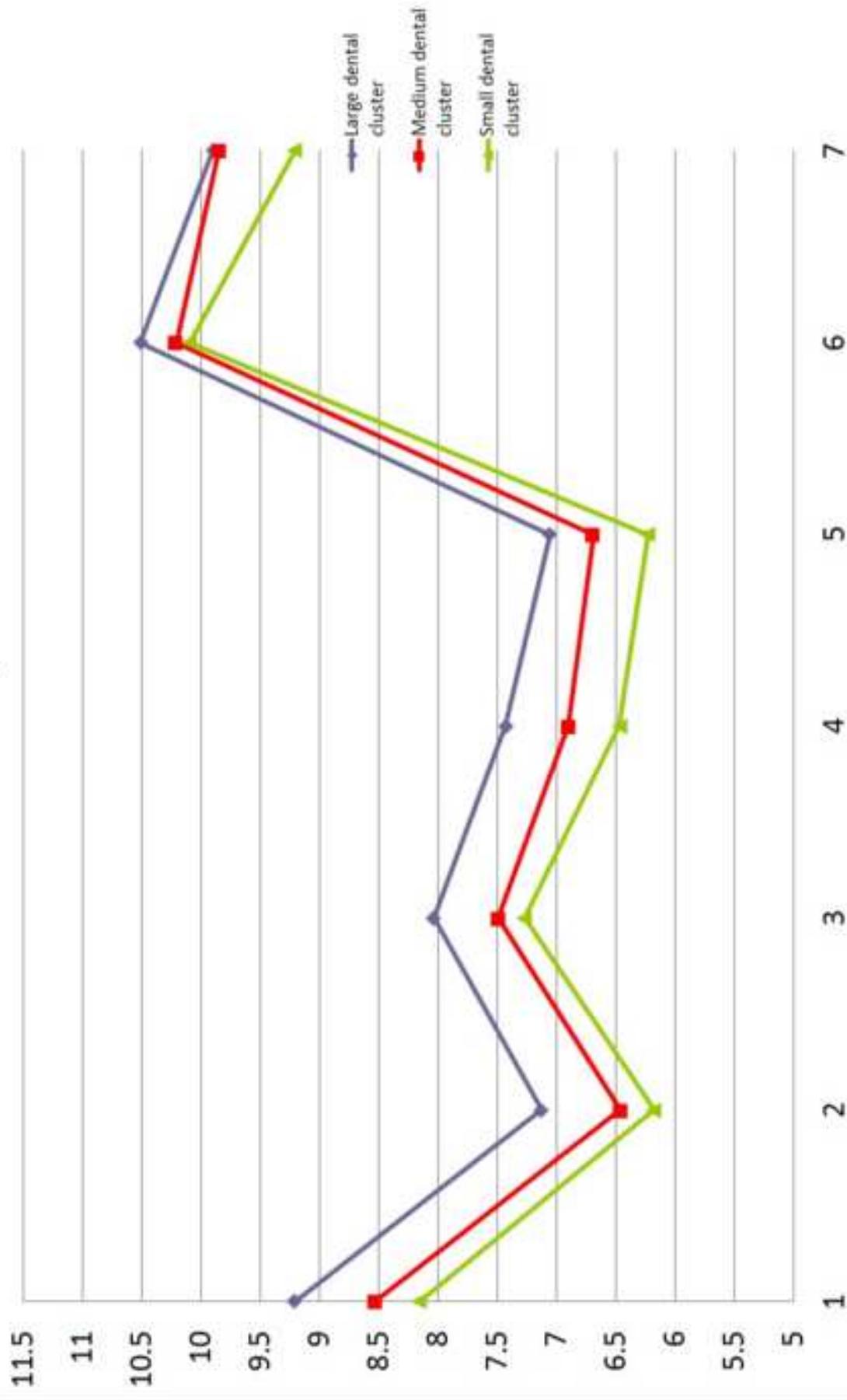


Figure 6
[Click here to download high resolution image](#)

Female mandibular teeth

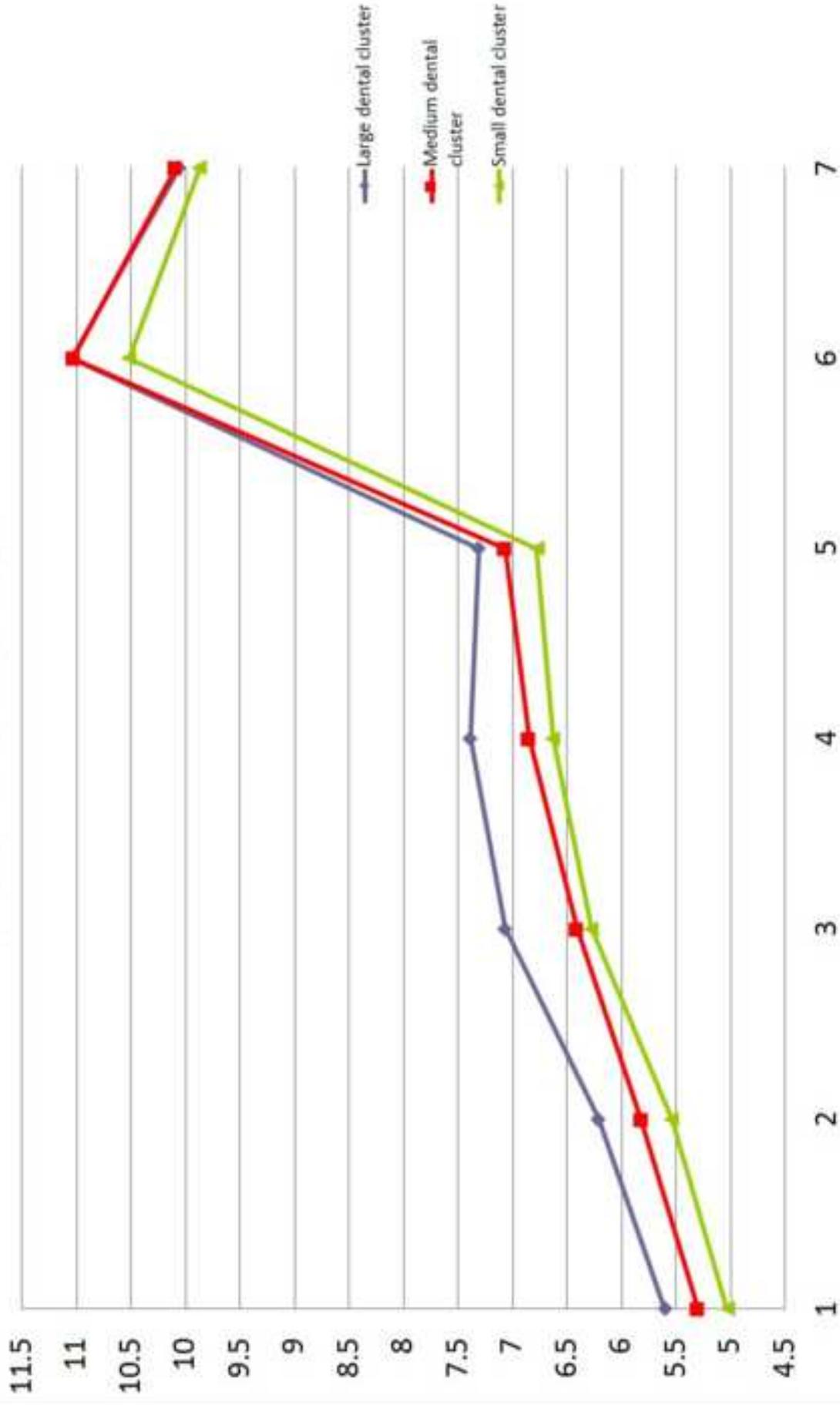


Figure 7
[Click here to download high resolution image](#)

Male maxillary teeth

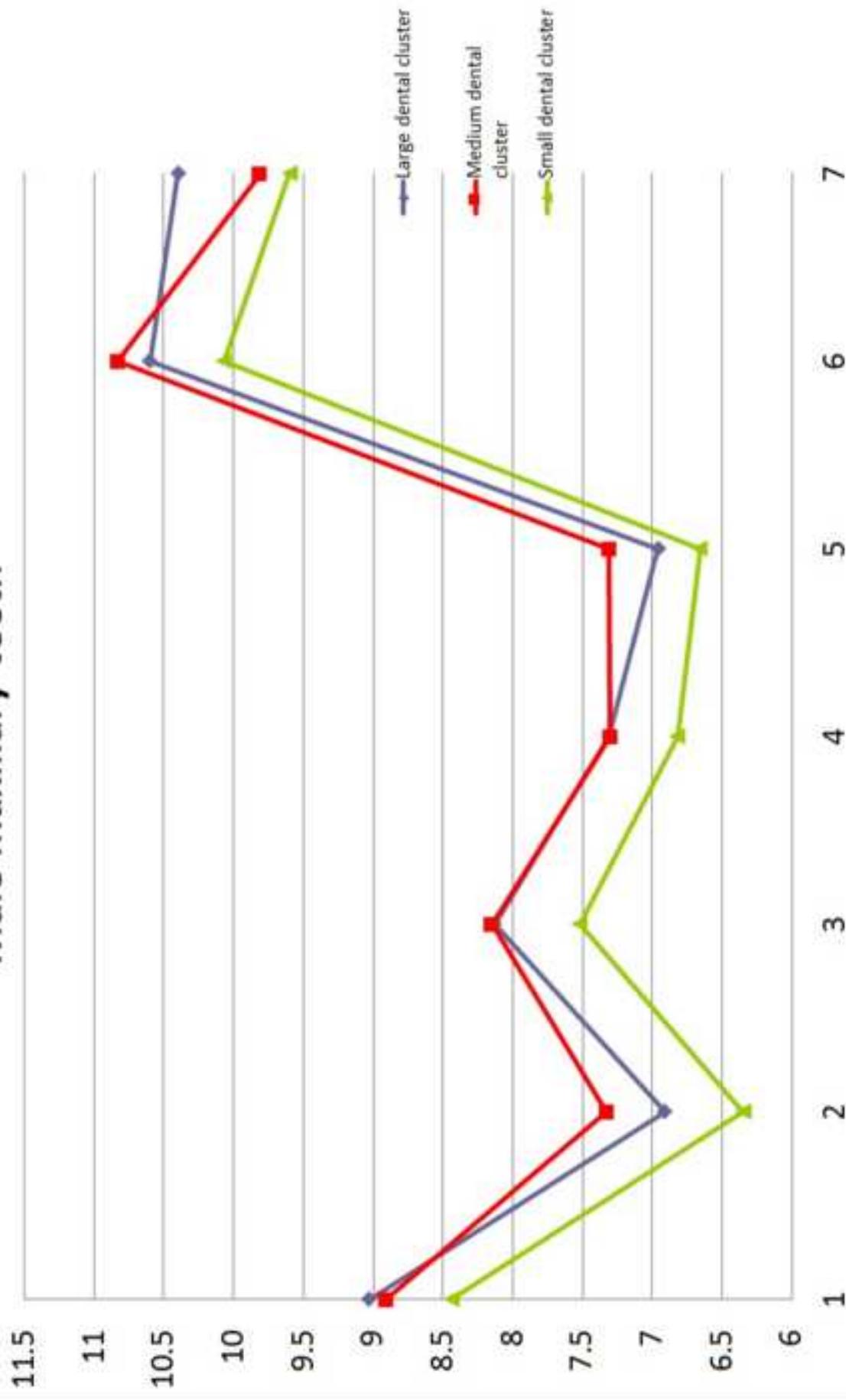


Figure 8
[Click here to download high resolution image](#)

Figure 9
[Click here to download high resolution image](#)

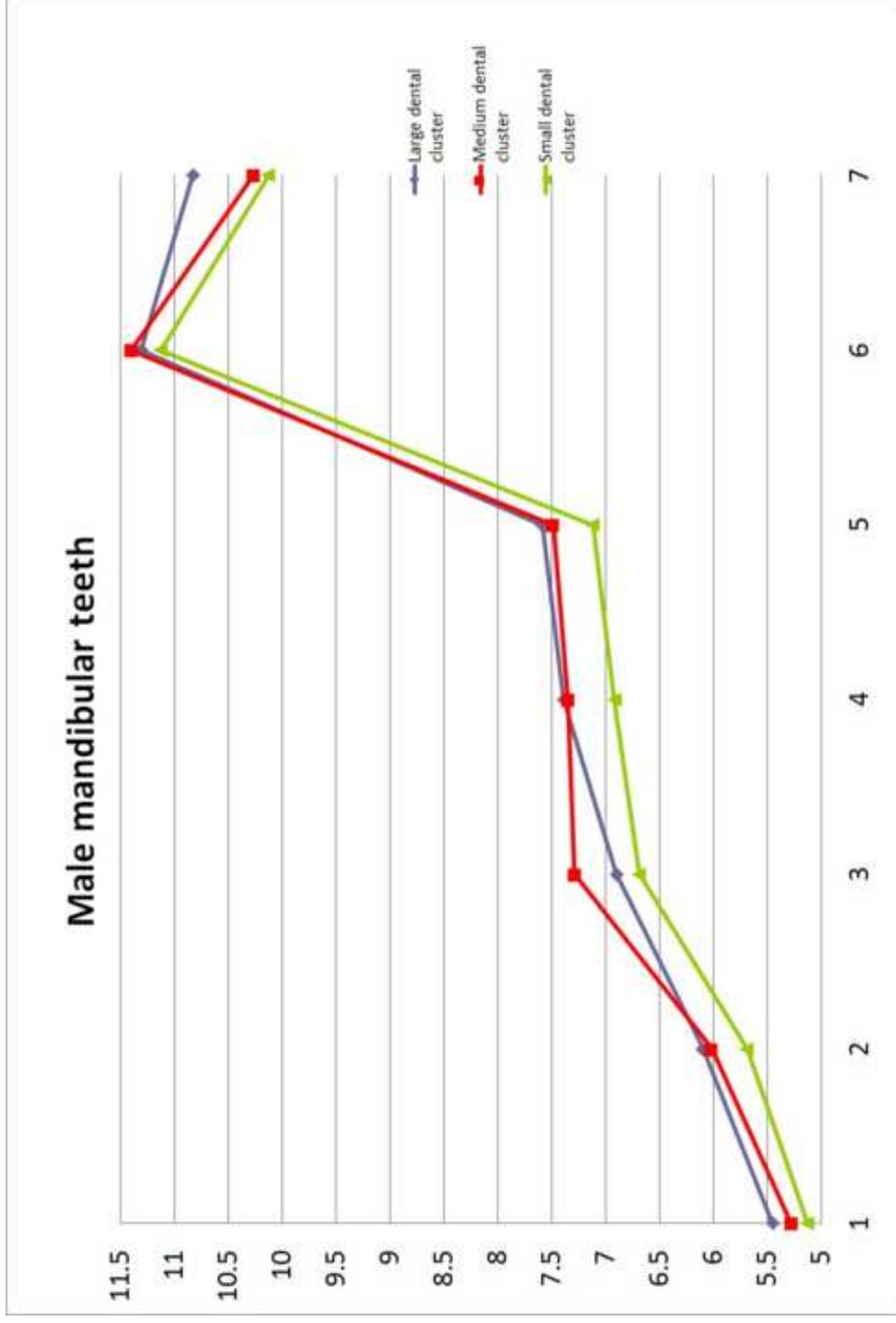


Figure 10
[Click here to download high resolution image](#)

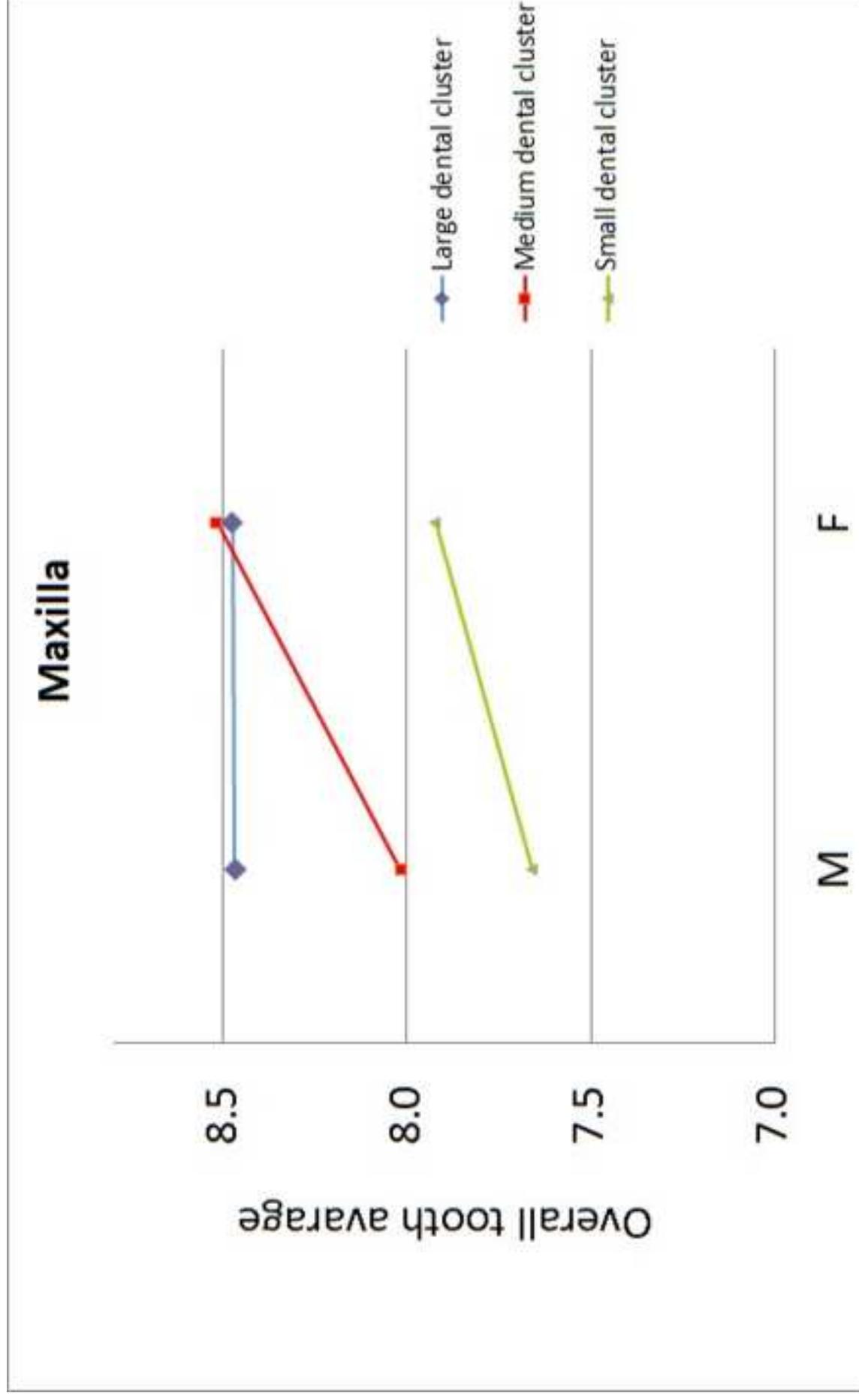


Figure 11
[Click here to download high resolution image](#)

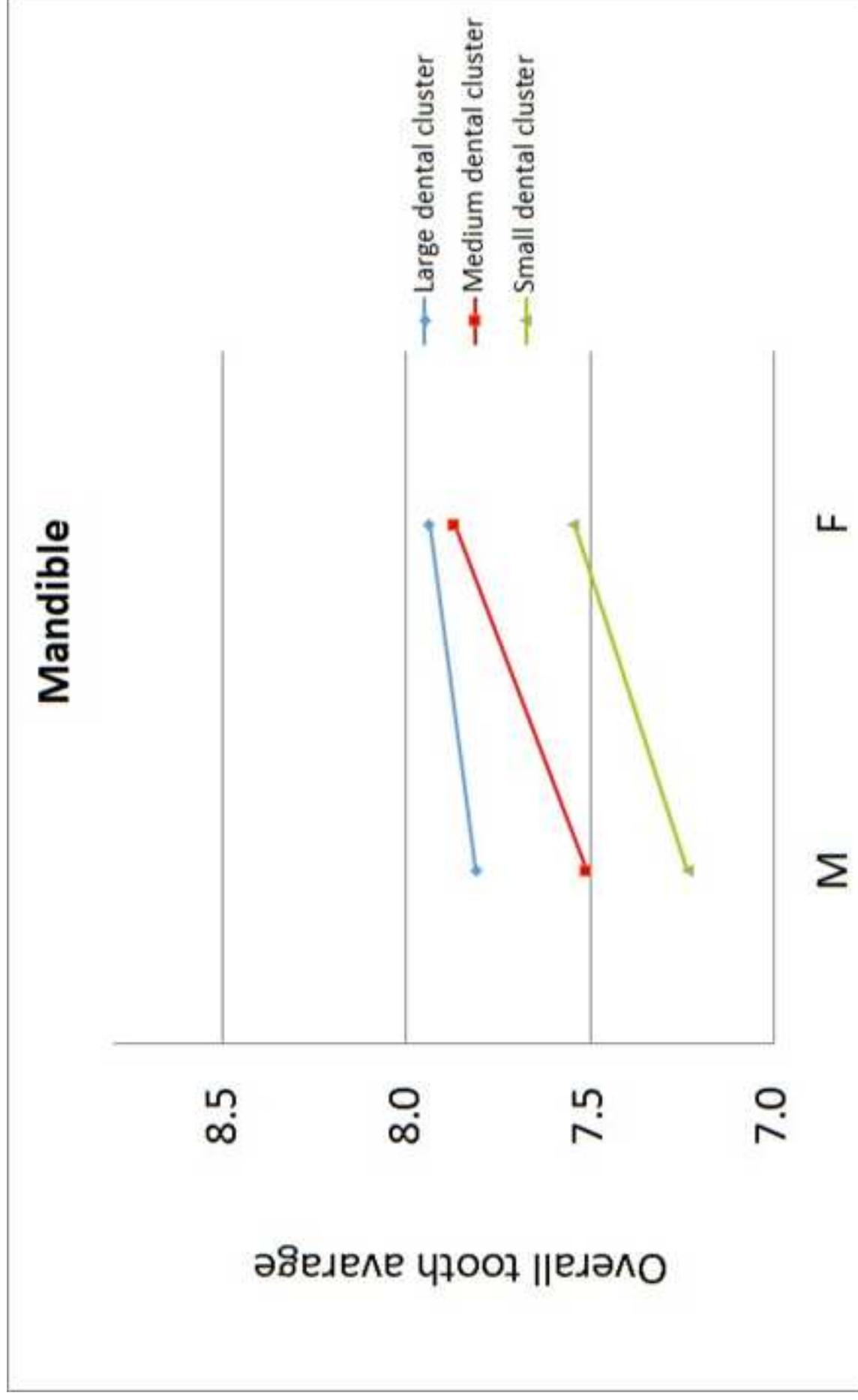


Table I

Tooth	Mean	Std. dev.	Dahlberg's test	<i>t</i> value	<i>p</i> value
17	9.79	0.54	0.04	-0.06	0.96
16	10.31	0.46	0.04	0.16	0.88
15	6.74	0.40	0.03	0.00	> 0.99
14	6.98	0.39	0.04	-0.25	0.81
13	7.70	0.43	0.03	-0.02	0.98
12	6.62	0.50	0.03	-0.07	0.94
11	8.60	0.43	0.03	0.00	> 0.99
21	8.65	0.43	0.03	0.12	0.91
22	6.62	0.51	0.03	0.00	> 0.99
23	7.67	0.44	0.19	-0.55	0.58
24	6.95	0.39	0.03	-0.04	0.97
25	6.74	0.40	0.03	0.00	> 0.99
26	10.32	0.45	0.04	0.05	0.96
27	9.72	0.52	0.05	0.05	0.96
47	10.19	0.52	0.08	-0.06	0.96
46	10.99	0.51	0.08	0.22	0.82
45	7.15	0.34	0.06	0.22	0.83
44	7.01	0.40	0.03	-0.01	0.99
43	6.65	0.40	0.13	-0.37	0.71
42	5.86	0.36	0.10	-0.17	0.87
41	5.32	0.38	0.28	-0.83	0.41
31	5.29	0.39	0.29	-0.78	0.44
32	5.85	0.37	0.09	-0.29	0.78
33	6.68	0.51	0.31	0.42	0.68
34	7.01	0.39	0.03	0.04	0.97
35	7.16	0.38	0.07	0.05	0.96
36	11.03	0.51	0.14	0.28	0.78
37	10.15	0.53	0.09	-0.22	0.82

Table II

	Bolton AR	Bolton OR
Males	0.7730 (0.03)	0.9157 (0.02)
Females	0.7788 (0.02)	0.9155 (0.02)

Table III.

Tooth	<i>t</i> value	<i>df</i>	Adjusted <i>p</i>	Cohen <i>d</i>
15	2.71	44.42	< 0.05	0.74
13	3.87	44.45	< 0.01	1.06
24	2.44	49.82	< 0.05	0.65
25	3.41	48.38	< 0.01	0.91
27	2.32	42.38	< 0.05	0.64
47	2.83	44.36	< 0.05	0.78
46	3.23	50.51	< 0.05	0.85
45	3.73	42.34	< 0.01	1.04
44	3.07	51.07	< 0.05	0.80
43	3.57	52.00	< 0.01	0.93
33	2.90	28.96	< 0.05	0.89
34	3.05	52.25	< 0.05	0.79
35	4.23	42.53	< 0.01	1.18
36	3.00	49.94	< 0.05	0.79
37	2.68	42.18	< 0.05	0.75

Table IV.

	1	2	3	4	5	6	7
Large	9.21	7.13	8.04	7.43	7.06	10.51	9.90
Medium	8.53	6.46	7.49	6.90	6.69	10.21	9.85
Small	8.16	6.18	7.27	6.47	6.23	10.10	9.21

Table V

	1	2	3	4	5	6	7
Large	5.60	6.21	7.07	7.39	7.31	11.04	10.06
Medium	5.30	5.82	6.41	6.85	7.07	11.03	10.09
Small	5.03	5.54	6.28	6.63	6.78	10.52	9.87

Table VI

	1	2	3	4	5	6	7
Large	9.03	6.91	8.13	7.31	6.96	10.60	10.40

Medium	8.91	7.33	8.15	7.30	7.31	10.83	9.81
Small	8.44	6.35	7.52	6.82	6.66	10.07	9.60

Table VII.

	1	2	3	4	5	6	7
Large	5.45	6.10	6.90	7.39	7.59	11.31	10.83
Medium	5.28	6.02	7.29	7.35	7.49	11.40	10.27
Small	5.13	5.69	6.69	6.92	7.12	11.13	10.13

Table VIII.

		Cluster	Mandible		
			Large	Medium	Small
Maxilla	Females	Large	0.774	-	-
		Medium	0.793	0.776	0.764
		Small	0.789	0.807	0.768
	Males	Large	0.772	-	0.734
		Medium	0.766	0.810	0.733
		Small	-	-	0.785

Table IX

		Cluster	Mandible		
			Large	Medium	Small
Maxilla	Females	Large	0.9036	-	-
		Medium	0.9315	0.9079	0.9137
		Small	0.9233	0.9224	0.9163
	Males	Large	0.9180	-	0.8911
		Medium	0.9018	0.9041	0.8939
		Small	-	-	0.9312

American Journal of Orthodontics and Dentofacial Orthopedics

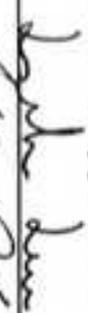
COPYRIGHT STATEMENT

Must be signed by ALL authors

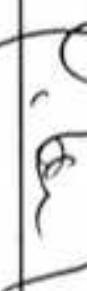
"The undersigned author(s) transfers all copyright ownership of the manuscript [title of article] to the American Association of Orthodontists in the event the work is published. The undersigned author(s) warrants that the article is original, does not infringe upon any copyright or other proprietary right of any third party, is not under consideration by another journal, has not been published previously, and includes any product that may derive from the published journal, whether print or electronic media. The author(s) confirm that they have reviewed and approved the final version of the manuscript. I (we) sign for and accept responsibility for releasing this material.

The corresponding author must be named NIKI ARVEDA 
(Type name) Signature

Each author's name must be typed underneath the signature.

LUCA LOMBARDI  Maurizio PARSONI

NIKI ARVEDA  GABRIELLA LA FALCE Gabriella de Tolles

GIUSEPPE SIERI  ENRICO TORRES Enrico Torres

Date: 07/10/2014

3D models (.ZIP)

[Click here to download 3D models \(.ZIP\): obj models.zip](#)

*ICMJE Statement on Conflict of Interest for each author

[Click here to download ICMJE Statement on Conflict of Interest for each author: coi_disclosure complete Dr Arveda.pdf](#)

*ICMJE Statement on Conflict of Interest for each author

[Click here to download ICMJE Statement on Conflict of Interest for each author: coi_disclosure complete Dr. La Falce.pdf](#)

*ICMJE Statement on Conflict of Interest for each author

[Click here to download ICMJE Statement on Conflict of Interest for each author: coi_disclosure complete Dr. Marcon.pdf](#)

*ICMJE Statement on Conflict of Interest for each author

[Click here to download ICMJE Statement on Conflict of Interest for each author: coi_disclosure complete Dr. Tonello.pdf](#)

*ICMJE Statement on Conflict of Interest for each author

[Click here to download ICMJE Statement on Conflict of Interest for each author: coi_disclosure complete Prof Lombardo.pdf](#)

*ICMJE Statement on Conflict of Interest for each author

[Click here to download ICMJE Statement on Conflict of Interest for each author: coi_disclosure complete Prof Sciliani.pdf](#)