Digital analysis of tooth sizes among individuals with different malocclusions: A study using three-dimensional digital dental models

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Abstract
Objective: It is aimed to examine the tooth sizes of digital models of patients with different malocclusions with the help of three-dimensional measurement software.
Methods: Digital models of 252 patients aged between 13 and 25 years of age were included. According to the Angle classification, three different malocclusion groups were allocated such that there were 84 patients in each group, plaster models of patients scanned with the three-dimensional model browser 3Shape R700 3D Scanner (3Shape A/S Copenhagen, Denmark) and transferred to the digital format. 3Shape Ortho Analyzer (3Shape A/S Copenhagen, Denmark) software was used for making the necessary tooth size measurements.
Results: When the measurements were evaluated, it was determined that significant changes occurred between tooth sizes of individuals with different malocclusions. Generally, higher values were observed in mesiodistal and buccolingual tooth dimensions of class II individuals compared to other groups. There was no difference between the groups in the anterior ratio values, but when the overall ratio values were evaluated among the groups, a statistically significant difference was determined. Class II malocclusion group was found to have a significantly lower overall ratio of occurrence.
Conclusion: Individuals with different malocclusions differ in tooth size.

Keywords
Tooth, malocclusion, dental models

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Introduction

To achieve perfect occlusion during orthodontic treatment, there must be a constant relationship between the size of the maxillary and mandibular teeth. In the early 1900s, Angle determined eight factors that affect occlusion which were: the relationship between the incisors, the size of the teeth, the pattern of the teeth, the length of the teeth, the length of the tubercules, the arch width, the arch shape, and the Spee curve.

In 1902, Black measured the mesiodistal width of human teeth to define the average size of each tooth in the dental arch, and published tables of average tooth sizes that are still used for reference.

Following Black’s studies, many authors focused their investigations on tooth sizes and their possible translation to occlusion. Ballard measured both dental arches to determine the greatest mesiodistal length of each permanent tooth and evaluated the discrepancies between the opposite sides of the upper and lower dental arches. The measurements revealed that 90% of the specimens had a size difference of 0.25–0.50 mm between the teeth on opposite sides of the dental arches.

In 1958, Bolton developed two analyses that evaluated the proportional comparison of tooth sizes. For the overall ratio, the sum of the mesiodistal widths of the 12 mandibular teeth was divided by the sum of the 12 maxillary teeth. For the anterior ratio, the sum of the mesiodistal widths of the six teeth in the mandible was divided by the mesiodistal sum of the six teeth in the maxilla. The results were found to be 91.3% (standard deviation = 1.91) and 77.2% (standard deviation = 1.65) for the overall and anterior ratio, respectively. These two ratios are still considered the gold standard in the evaluation of tooth material.

The prevalence of significant tooth size discrepancies is higher in Class II division 1 and in Class III malocclusions. In the study carried out by Jabri et al., a comparison was done between the tooth-size ratios and malocclusion groups (Class I, II, and III) and no significant difference was found; but, there is an inadequacy in the data particularly related to subgroups of Angle’s classification of malocclusion. Racial variations are also important in the research. If we look at some studies conducted in the Turkish population, Basaran et al. and Akyalcin et al. studied the tooth size in different malocclusion groups, and both reported no significant differences.

Mullen et al. evaluated Bolton ratios on both dental casts and digital models and there was no significant difference between the two methods. It was found that digital measurements were 65 s faster than the manual method. They concluded that digital models are as accurate and even faster than plaster model analysis and are sufficient to replace plaster models.

Cast models are routine diagnostic tools widely used in the evaluation of orthodontic analyses. Now, it is possible to scan and store intraoral models with three-dimensional (3D) scanners, reducing the time required to manage casts. The ability to perform orthodontic analyses on digital platforms makes it easier to access data when needed and eliminates the need for measuring instruments. In the near future, intraoral digital modeling may replace plaster casts, leading to a tremendous shift in analysis procedures. Therefore, our aim in this study was to evaluate digital models of different malocclusion groups in terms of tooth sizes using 3Shape 3D measurement software.
Methods

This study was designed as a retrospective study. The digital models were obtained with the 3D model scanner from the plaster models of the patients before treatment in the archives of the Department of Orthodontics, Faculty of Dentistry, Izmir Katip Celebi University. The study protocol was approved by the Health Research Ethics Board of Izmir Katip Çelebi University, School of Medicine (protocol number: 203, Date: 23.05.2018). The study was conducted in accordance with the principles of the Declaration of Helsinki. According to the Angle classification, models of individuals with Class I, Class II and Class III molar relationships were used in the study.

According to power analysis with 95% power, it was decided to work in three groups of 84 patients each with a total of 252 patients. Individuals included in the study are in the minimum 15 and maximum 40 age range and the age distribution between the groups is shown in Table 1. It was decided that there would be no sex discrimination since there was no difference between genders in the nonparametric test.

The following inclusion criteria were used to select the study models:

1. Models of patients between the ages of 13 and 25 years, who have not received orthodontic treatment, were included.
2. All molars, except wisdom teeth, were present in both jaws,
3. The mesiodistal size of teeth is not affected by caries, loss of substance or fillings,
4. No developmental or structural deformities such as macrodontia or microdontia on the teeth,
5. Models of individuals without mesiodistal wear and all contact points that can be identified are included in the study.

All the good-quality study models that meet the selection criteria were digitalized and transferred to digital format with a 3Shape R700 3D (3Shape A/S Copenhagen, Denmark) scanner. 3Shape Ortho Analyzer (3Shape A/S Copenhagen, Denmark) software was used for image processing and required measurements (Figure 1).

The measurements made on the digital models were (Figures 2–4):

1. Total Maxillary 12: The sum of the mesiodistal widths of the upper 12 teeth from the right first molar to the left first molar tooth.
2. Total Maxillary Front 6: The sum of the mesiodistal width of the upper anterior teeth.

Table 1. The age distribution between the groups.

| Group       | Mean Age | Std. deviation |
|-------------|----------|----------------|
| Class 1 (n: 84) | 20.16   | 2.09           |
| Class 2 (n: 84) | 19.61   | 1.76           |
| Class 3 (n: 84) | 21.26   | 3.6            |
| Total (n: 252) | 20.36   | 2.697          |
3. **Total Mandibular 12**: The sum of the mesiodistal widths of the lower 12 teeth from the right first molar to the left first molar tooth.

4. **Total Mandibular Anterior 6**: The sum of the mesiodistal width of the lower anterior six teeth.
5. **Overall ratio**: The ratio of the mesiodistal width of the lower 12 teeth to the sum of the mesiodistal width of the upper 12 teeth.

6. **Anterior ratio**: The ratio of the mesiodistal width of the lower anterior teeth to the sum of the mesiodistal width of the upper anterior teeth.

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**Figure 3.** Buccolinguval measurements.

**Figure 4.** Mesiodistal measurements.
Statistical analyses were performed using IBM SPSS Statistics 25.0 (IBM Corp., Armonk, New York, USA). For each tooth in each three malocclusions, the anterior ratio and the overall ratio mean value and standard deviation were calculated. Descriptive statistics were reported as the number of units (n), percentage (%), mean ± standard deviation (x ± SD), confidence intervals (95% CI). A normal distribution of numerical variables was assessed using the Shapiro–Wilk normality test and Q-Q plots. Comparisons between groups were performed using a one-way analysis of variance. Tukey’s test was used to determine group differences. Comparisons of the overall ratio and the anterior ratio between the study group and the Bolton group were performed using the two independent samples t-test. p < 0.05 was considered statistically significant. The method error was assessed using Dahlberg’s formula. Intra-class correlation coefficient was used for the evaluation of the reliability of the measurements. To control for individual drawing and measurement errors, 15 subjects were randomly selected from each study group and examined 3 weeks after completion of all analyses to evaluate the reproducibility and measurement consistency of the reference points. A total of 45 patients were re-labeled on the digital model images, and the linear and proportional measurements were repeated, and the data recorded.

Results

Evaluation of the mesiodistal dimensions of permanent teeth in different malocclusion groups

When the mesiodistal dimensions of the upper teeth were evaluated between different malocclusion groups, higher values were observed in the Class II malocclusion group in all other teeth except the first molars in the Class III malocclusion group.

While evaluating the mesiodistal dimensions of the lower teeth between different malocclusion groups, higher values were observed in Class II malocclusion group in all other teeth except first molars, second molars, and the canines in Class III group (Table 2).

Evaluation of buccolingual dimensions of permanent teeth in different malocclusion groups

When the maxillary incisors (U1), maxillary first premolars (U4), and maxillary second premolars (U5) were evaluated between groups, the Class II malocclusion group had a statistically significantly higher values (*p < 0.05) than the Class III malocclusion group. When the buccolingual size of the upper teeth was evaluated between different malocclusion groups, higher values were observed in the Class II malocclusion group (Table 3).

When evaluating the buccolingual size of the mandibular teeth between the different malocclusion groups, the Class II malocclusion group presented higher values except for the first molars in the Class I malocclusion group and the second molars in the Class III
Table 2. Evaluation of mesiodistal dimensions of permanent teeth in different malocclusion groups.

| Jaw   | Tooth | Class I   | Class II  | Class III | p    |
|-------|-------|-----------|-----------|-----------|------|
|       |       |           |           |           |      |
| Maxillary | U1   | 8.25 ± 0.56a | 8.48 ± 0.61b | 8.39 ± 0.60ab | 0.047* |
|       | U2   | 6.35 ± 0.58a | 6.58 ± 0.64b | 6.52 ± 0.60ab | 0.035* |
|       | U3   | 7.44 ± 0.46 | 7.60 ± 0.50 | 7.52 ± 0.50 | 0.108 |
|       | U4   | 6.72 ± 0.44a | 6.89 ± 0.45b | 6.88 ± 0.48ab | 0.033* |
|       | U5   | 6.44 ± 0.47a | 6.66 ± 0.56b | 6.60 ± 0.48ab | 0.018* |
|       | U6   | 9.74 ± 0.56a | 9.91 ± 0.52ab | 9.95 ± 0.47b | 0.025* |
|       | U7   | 9.33 ± 0.68 | 9.50 ± 0.62 | 9.33 ± 0.71 | 0.191 |
| Mandibular | L1   | 4.96 ± 0.49a | 5.23 ± 0.36b | 5.11 ± 0.39b | <0.001** |
|       | L2   | 5.53 ± 0.42a | 5.70 ± 0.53b | 5.63 ± 0.40ab | 0.048* |
|       | L3   | 6.23 ± 0.44a | 6.42 ± 0.40b | 6.46 ± 0.48b | 0.002* |
|       | L4   | 6.71 ± 0.44 | 6.85 ± 0.41 | 6.83 ± 0.48 | 0.113 |
|       | L5   | 6.86 ± 0.59 | 6.97 ± 0.45 | 6.93 ± 0.48 | 0.353 |
|       | L6   | 10.41 ± 0.67 | 10.46 ± 0.56 | 10.62 ± 0.64 | 0.087 |
|       | L7   | 9.76 ± 0.64a | 9.40 ± 0.76b | 9.89 ± 0.63a | <0.001** |

a, b, ab upper icons: The difference between the groups (the same letter in each group shows that there is no difference between the groups). The comparisons between the groups were made by one-way analysis of variance. Tukey multiple comparison test was used to determine the difference groups. *p < 0.05, **p < 0.001.

Table 3. Statistical evaluation of the buccolingual dimensions of permanent teeth in different malocclusion groups.

| Jaw   | Tooth | Class I   | Class II  | Class III | p    |
|-------|-------|-----------|-----------|-----------|------|
|       |       |           |           |           |      |
| Maxillary | U1   | 7.03 ± 0.56ab | 7.10 ± 0.52a | 6.68 ± 0.58b | 0.017* |
|       | U2   | 6.19 ± 0.53 | 6.29 ± 0.55 | 6.17 ± 0.56 | 0.362 |
|       | U3   | 7.59 ± 0.70 | 7.70 ± 0.64 | 7.66 ± 0.63 | 0.557 |
|       | U4   | 8.81 ± 0.58ab | 8.95 ± 0.48a | 8.73 ± 0.54ab | 0.031* |
|       | U5   | 8.94 ± 0.57ab | 9.13 ± 0.50a | 8.87 ± 0.59b | 0.011* |
|       | U6   | 10.21 ± 0.59 | 10.32 ± 0.59 | 10.27 ± 0.62 | 0.512 |
|       | U7   | 9.87 ± 0.72 | 9.90 ± 0.64 | 9.81 ± 0.75 | 0.66  |
| Mandibular | L1   | 5.88 ± 0.48a | 5.96 ± 0.41a | 5.71 ± 0.49b | 0.002* |
|       | L2   | 6.14 ± 0.52a | 6.17 ± 0.44a | 5.89 ± 0.42b | <0.001** |
|       | L3   | 6.91 ± 0.65 | 7.12 ± 0.56 | 6.97 ± 0.52 | 0.055 |
|       | L4   | 7.38 ± 0.53ab | 7.44 ± 0.50b | 7.24 ± 0.47b | 0.029* |
|       | L5   | 8.06 ± 0.54ab | 8.11 ± 0.49a | 7.88 ± 0.52b | 0.016* |
|       | L6   | 9.37 ± 0.60 | 9.35 ± 0.51 | 9.27 ± 0.52 | 0.441 |
|       | L7   | 8.89 ± 0.62 | 8.94 ± 0.58 | 9.01 ± 0.53 | 0.418 |

a, b, ab upper icons: The difference between the groups (the same letter in each group shows that there is no difference between the groups). The comparisons between the groups were made by one-way analysis of variance. Tukey multiple comparison test was used to determine the different groups. *p < 0.05, **p < 0.001.

malocclusion group. The buccolingual size of the lower incisors (L1) and lower laterals (L2) in Class I and Class II malocclusion groups showed no statistically significant difference, but they were significantly lower (*p < 0.05) in the Class III malocclusion group than in the other groups.
Evaluation of Bolton ratios in different malocclusion groups

No statistically significant difference was found when evaluating the anterior ratio values obtained in our study between the groups (Table 4).

When the overall ratio values were evaluated between the groups, the Class II malocclusion group had statistically significantly lower values (*p < 0.05) than the other groups, but there was no statistically significant difference in the Class I and Class III malocclusion groups.

Comparison of Bolton ratios with our study group

Table 4 shows the comparison of overall ratio and anterior ratio values obtained with measurements on digital models and overall ratio and anterior ratio values determined by Bolton (Table 5).

A statistically significant difference (***p < 0.001) was found in overall ratio values. The mean and standard deviation of our study group’s data were statistically higher than Bolton’s ratio. No statistically significant difference was found when comparing the anterior ratio obtained by our study group and Bolton’s.

Discussion

Neff stated that there was a proportional relationship between the mesiodistal dimensions of maxillary and mandibular teeth for an ideal and balanced occlusion. The mesiodistal widths of the lower and upper jaw teeth must be matched for posterior interdigitation, overbite and overjet coordination in neutral occlusion. The importance of these ratios was emphasized to obtain a perfect fit after treatment.

Table 4. Evaluation of Bolton ratios in different malocclusion groups.

|                  | Class I       | Class II      | Class III     | p   |
|------------------|---------------|---------------|---------------|-----|
| Anterior ratio   | 75.87 ± 3.86  | 76.70 ± 4.5   | 76.76 ± 3.16  | 0.252 |
| Overall ratio    | 92.99 ± 2.84a | 91.95 ± 2.49b | 93.29 ± 2.66a | 0.003* |

a, b upper icons: The difference between the groups (the same letter in each group shows that there is no difference between the groups). The comparisons between the groups were made by one-way analysis of variance. Tukey multiple comparison test was used to determine the difference groups. *p < 0.05, ***p < 0.001.

Table 5. Comparison of Bolton ratios with study group.

|                  | Study group Mean ± SS | Bolton’s group Mean ± SS | t value | p value |
|------------------|-----------------------|--------------------------|---------|---------|
| Anterior ratio   | 92.74 ± 2.75          | 91.30 ± 1.91             | 4.64    | <0.001**|
| Overall ratio    | 76.45 ± 3.89          | 77.2 ± 1.65              | −2.27   | 0.025   |

Overall ratio and anterior ratio comparisons between the study group and the Bolton group were done by two independent samples t test.
Tooth size is determined by multifactorial factors such as genetics, environment, race, and sex.\textsuperscript{15,16} Al-Gunaid et al.\textsuperscript{17} found that there was no significant difference between Bolton’s ratio and that of the Yemeni population. Our study included only Turkish individuals. Previously, Al-Khaateb et al.\textsuperscript{18}, measured the maxillary and mandibular mesiodistal tooth dimensions among different malocclusions in both genders and said that patients with Class III malocclusion had larger teeth and females in every malocclusion were prone to have smaller teeth in comparison with males. Oktay and Ulukaya measured the intermaxillary tooth size discrepancies among different malocclusion groups and identified possible gender-related differences in tooth size ratios. According to their study, there were statistically significant gender differences for the posterior ratio, but there were no statistically significant differences among the groups for the anterior ratio.\textsuperscript{19} Bolton did not mention the race of the individuals he included in his study.\textsuperscript{20} Considering the literature that differentiates between populations; we create our study group from citizens of the Republic of Turkey. Hunter and Priest\textsuperscript{21} have investigated the accuracy of measurements performed on dental stone models obtained by alginate impression material and reported that measurements made on stone models were more reliable and sensitive than direct intraoral measurements, and repetitive measurements gave the same results. Lunsdtröm\textsuperscript{6} reported that direct intraoral measurement was more reliable especially for anterior region teeth but the difference between the two methods was insignificant. Tomasetti et al.\textsuperscript{22} were one of the first authors to compare the results of a manual measurement method and computer programs for Bolton analysis and reported that the differences between the methods were not statistically significant. Further research has shown that measurements from digital models are not significantly different from plaster models.\textsuperscript{12,23,24} Evaluations made with digital models have been found to be significantly faster in measuring and verifying enough to allow an orthodontist to make the same diagnostic and treatment planning decisions as with plaster models.\textsuperscript{25} Researchers have argued that the analyses made with computer programs were made in a shorter time and save the clinician time.

Mesiodistal tooth diameters tended to diminish with age.\textsuperscript{26} Mean reductions of 0.15 and 0.32 mm per tooth were described from adolescence to 50 years of age in modern people.\textsuperscript{26} Massaro et al.\textsuperscript{27} reported that from 13 to 17 years of age, no changes were observed for mesiodistal tooth size. They also said that from 17 to 60 years of age, mesiodistal tooth size decreased. Lundström\textsuperscript{6} stated that it would be difficult to find an anatomically correct study material as approximate contacts changed into surface contact with age progress. In the literature, the age of the subjects ranges from 12 to 35 in the studies on tooth size.\textsuperscript{6,28} Taking these into consideration, the individuals included in our study were between adolescence and young adults and not having any tooth material lost was decided as an inclusion criterion.

In a study done by Araujo and Souki, they formed three groups of Angle Class I, Class II, and Class III individuals in the Brazilian population; Angle Class I and III malocclusion groups had significantly larger tooth sizes than the Class II malocclusion group; the average tooth size difference for the Angle Class III group was significantly higher than for the Class I and Class II malocclusion groups.\textsuperscript{9} However, in their study, Mollabashi et al.\textsuperscript{29} investigated anterior, posterior, and overall Bolton values of four malocclusion groups and compared them with the normal Class I occlusion group. They said that the normal occlusion group presented the highest and Class II division 1 group presented
the lowest values for the posterior Bolton value. In another study, Wedrychowska-Szulc et al. compared tooth size ratios of patients with different malocclusion groups (Class I, Class II division 1, Class II division 2, and Class III) and found statistically significant differences in the overall ratio among all groups and in the mean value of the anterior ratio between Class I and Class III groups. In our study, the Class III malocclusion group showed higher overall ratio and anterior ratio values than other groups. When overall ratio values were compared between groups, the Class II malocclusion group had significantly lower values, but no statistically significant difference was observed between Class I and Class III malocclusion groups. As suggested by other authors, ethnic differences might be influential in tooth sizes; therefore, studies conducted on different ethnic groups possibly resulted in different ratio values.

According to the investigation done by Santoro et al. the Bolton tooth size analysis for 56 Dominican American patients resulted in the overall ratio value of 91.3 ± 2.22, which was equivalent to Bolton’s. The anterior ratio, which was 78.1 ± 2.87, was higher than Bolton’s values. Differences between our findings and former findings could be due to the number of subjects, regional and racial differences, individual variations, and types of malocclusion included in the study groups.

Recent advancements in 3D imaging have allowed the digital assessment of dimensional and morphological characteristics of the teeth; in particular, the superimposition and deviation analysis of 3D digital models, or single tooth model, can be used for evaluating right-to-left morphological asymmetries as well as long-term morphological and dimensional changes. Moreover, cone-beam computed tomography (CBCT) technology provides images of the radicular region and, consequently, it is a useful tool for a more comprehensive digital analysis of tooth size discrepancies. In this regard, further studies are warmly encouraged to include this new 3D imaging technology in this field of research.

Conclusions
To achieve a perfect occlusion in orthodontic treatment, there must be a constant ratio between the size of the maxillary and mandibular teeth; however, this ratio differs from case to case. Diversity of tooth sizes contribute to the occurrence of Angle Class I, Class II, and Class III malocclusions; therefore, it is practical to foresee the tooth material excess areas in dental arches. For the best treatment results, tooth size analysis is important in diagnosis and planning and should be considered before initiating orthodontic treatment. The 3Shape Ortho Analyzer digital model analysis software provides reliable, repeatable results when used for the evaluation of tooth sizes. We think that the use of Turkish norms in the orthodontic treatment of patients treated in our country would be more appropriate.

Acknowledgments
We thank Ferhan Elmali for the statistical analysis process.

Declaration of conflicting interests
The authors declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.
Funding
The authors received no financial support for the research, authorship, and/or publication of this article.

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