Original Article

# The Tooth Size Discrepancy among Orthodontic Patients and Normal Occlusion Individuals from Saudi Arabia: A Three-Dimensional Scan Analysis of Diagnostic Casts


## Abstract

**Background/Purpose:** Tooth size discrepancy is one of the causative factors of malocclusion. This study aimed to establish the TDS among various malocclusion classes and normal occlusion subjects in a Southern Saudi population. **Materials and Methods:** The study casts of orthodontic patients from Southern Saudi Arabia (mean age: 19.6 years ± 2.45; $n = 120$) were randomly selected and grouped into eight equal classes based on Angle's classification and gender. An additional 30 study casts, devoid of malocclusion, having excellent intercuspation and class I occlusion, were grouped into two controls ($n = 15$) based on gender. The study casts were three-dimensional scanned to measure mesiodistal widths of all the teeth. The calculated anterior ratios (AR) and overall ratio (OR) were statistically analyzed with analysis of variance and *t*-tests. **Results:** There were no significant differences in "OR" and "AR" between the genders ($P > 0.05$) and among the malocclusion and control subgroups ($P > 0.05$). The mean "OR" (92.01 ± 0.18) and "AR" (78.60 ± 0.27) of the malocclusion group were significantly higher than that of Bolton's ratios ($P > 0.05$). The "AR" of the control group was significantly higher than Bolton's standards ($P = 0.048$). However, "OR" was no different ($P = 0.105$). Malocclusion patients displayed a discrepancy (±2 standard deviation) in "AR" of 22.5% and 'OR' of 6.7% from Bolton's mean (BM). Similarly, the control group displayed a discrepancy in "AR" of 20% and "OR" of 10% from BM. **Conclusion:** The mean "OR" and "AR" of the Southern Saudi population showed no sexual dimorphism and no significant difference among various malocclusion and control subgroups. The "AR" of the malocclusion and control subgroups did not comply with Bolton's standards.


**Keywords:** *Bolton's anterior ratio, Bolton's overall ratio, Malocclusion, odontometric analysis, orthodontics, tooth size discrepancy*

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## Introduction

The maxillary and mandibular tooth sizes should be proportionate to form normal occlusion; size discrepancies may lead to malocclusion.[1] Malocclusion is one of the most prevalent oral disorders; among several malocclusion traits, crowding and spacing are frequent presentations.[2-5] Some studies showed up to 95% of the population have either crowding or spacing.[3] Although the etiology is unclear, intermaxillary tooth size discrepancy (TSD) is one of the factors influencing crowding and spacing;[6] such discrepancy in the patients can vary based on heredity, ethnicity, gender, and secular trends.[7]

Biometric analysis of the tooth size was initially suggested by Dr. Bolton in 1962[1] and endured to be the most commonly used odontometric analysis in orthodontics. It was recommended as a part of routine orthodontic diagnosis and treatment planning charts.[8] Odontometric analysis of tooth size allows the orthodontists to predict the outcome of orthodontic treatment and assists in fine-tuning the finishing phase of the treatment. The ratio between the total mesiodistal widths of six anterior teeth of the mandible and the maxilla is called anterior ratio (AR); a similar ratio between the molar to molar teeth is called the Overall ratio (OR). The nomenclature, formulations, and suggested values of Bolton's analysis are illustrated in Table 1. Bolton proposed that ± 1 standard deviation (SD) from Bolton's means (BM) warranted attention in orthodontic treatment planning; however, Crosby suggested that



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**Table 1: Parameters of Bolton's tooth size ratios and their clinically significant values**

| | AR | OR | Clinical significance |
|---|---|---|---|
| Formula | (MAND6/MAX6) × 100 | (MAND12/MAX12) × 100 | |
| Means (mean±SE) | 77.2%±0.22* | 91.3%±0.26* | |
| SD | 1.65* | 1.91* | |
| >2 SD | >80.5 | >95.12 | Need ortho- $R_x$ for 2-3 mm mandibular tooth size excess† |
| 1-2 SD | 78.86-80.5 | 93.22-95.12 | Need ortho- $R_x$ for mandibular tooth size excess‡ |
| SD | 75.55-78.85 | 89.39-93.21 | No tooth size ratio discrepancy** |
| −(1-2) SD | 73.91-75.54 | 87.48-89.38 | Need ortho- $R_x$ for 2-3 mm maxillary tooth size excess‡ |
| <−2 SD | <73.91 | <87.48 | Need ortho- $R_x$ for maxillary tooth size excess† |

*The Bolton's standards for mean and SD;[1] †According to Crosby's recommendations;[9] ‡According to Bolton's standards but not Crosby's; **According to Bolton's recommendations.[1] AR: Anterior ratio; OR: Overall ratio; MAND12: Total widths of tooth number 36-46; MAX12: Total widths of tooth number 16-26; MAND6: Total widths of tooth number 33-43; MAX6: Total widths of tooth number 13-23; SD: Standard deviation; SE: Standard error

the deviation needed to be ± 2 SD of 'BM' for a clinical significance;[9] several other authors agree with Crosby's suggestion.[10-13]

The tooth size ratios initially proposed by Bolton were based on a small group ($n$ = 55) of the American population and may not apply to other populations across the globe.[14] Some studies on other ethnic groups were in concordance with Bolton's ratios,[11,15,16] while others are not.[17,18] Bolton's study was based on ideal occlusion and may not accurately contemplate the discrepancies in malocclusion cases. Some of the studies on malocclusion groups were in concordance with Bolton's ratios,[9,19] while others are not.[20,21] Besides, some studies reported sexual dimorphism of Bolton's ratio,[22,23] and others did not.[8,13,24] There is a lack of consensus in the literature regarding the universal applicability of Bolton's ratios.

Middle East has a diverse ethnicity, with Arabs, Turks, Persians, and Kurds as major groups and several other minorities. Arabs, specifically from Saudi Arabia, form the largest racial group followed by the Turks.[25] Ethnic diaspora in the region for centuries has led to different genetic profile, especially in the east and west coastal region of Saudi Arabia.[26] However, the geographic location of the Asir region in the south had a minimal opportunity for the ethnic diaspora. A study reported a discrepancy (±2SD) in AR of 28.5% and OR of 26.7% in Libyan children.[27] Similarly, Irani orthodontic patients had a discrepancy (±2SD) in AR of 34.7% and OR of 20.7%.[17] Aldrees *et al*. reported that orthodontic patients from Central Saudi Arabia had a discrepancy (±2SD) in AR of 17.4% and OR of 10.4%.[28] Table 2 illustrates the prevalence of TDS in various parts of the world. To the author's knowledge, there are no studies on Bolton's analysis of the Southern Saudi population.

The current study aimed to determine the variations in the TSD in the Southern Saudi orthodontic patients across the following variables: (i) genders, (ii) normal occlusion against malocclusion, (iii) various Angle's classes of malocclusion, and (iv) comparison of the compounded data with Bolton's standards. The null hypothesis was that there would not be a difference in the TSD across all the variables mentioned above.

## Materials and Methods

### Sample selection of malocclusion groups

After obtaining an ethical clearance (IRB/KKUCOD/ETH/2019-20/001), we obtained 308 diagnostic casts of orthodontic patients from the archives of native Saudi Arabian patients attending King Khalid University dental clinics during 2015–2018. The gender was identified based on the patient's records. All the patients had pretreatment cephalograms. The study casts were categorized into groups of Angle's classification based on molar relationship, canine relationship, and ANB angel on the cephalograms. Each Angle class was subgrouped into male (M) and female (F). The specimens were therefore classified into 1M (Class I male); 1F (Class I female); 2D1M (class II division 1 male); 2D1F (class II division 1 female); 2D2M (class II division 2 male); 2D2F (class II division 2 female); 3M (class III male); and 3F (class III female). The casts were randomly selected to obtain equal subgroups ($n$ = 15), yielding a total malocclusion sample size of 120. Inclusion criteria were as follows: homogenous Saudi nationals; age between 15 and 25 years ($M$ = 19.6; SD = 2.45); a fully erupted component of permanent teeth excluding third molars in both the arches; and diagnostic data containing defect-free casts, orthopantomogram, and lateral cephalograms. Exclusion criteria were as follows: history of orthodontic treatment, history of prosthodontic rehabilitation, congenital abnormalities, mutilation of teeth due to attrition or caries, and proximal restorations.

### Selection of control groups

In addition to the malocclusion group, we made impressions of 47 subjects aging between 15 and 25 years (mean age, 21.2 years ± 4.18) with naturally good occlusion and excellent intercuspation, following the inclusion and exclusion criteria mentioned above. Subjects with class I

**Table 2: Prevalence of tooth size discrepancies in various populations**

| Author | Population/Country | Subjects | AR±2SD (%) | OR±2SD (%) |
|---|---|---|---|---|
| Endo *et al.*[13] | Japan | Class I with mild crowding | 21.6 | 8.3 |
| Tadesse *et al.*[29] | China | Malocclusion | 28.18 | 13.64 |
| Sharma *et al.*[8] | North India | Malocclusion | 24 | 8 |
| Ajami *et al.*[17] | Iran | Malocclusion | 34.7 | 20.7 |
| Aldrees *et al.*[28] | Saudi Arabia | Malocclusion | 17.4 | 10.4 |
| Present study | Saudi Arabia | Malocclusion | 25 | 8.4 |
| Present study | Saudi Arabia | Normal occlusion | 20 | 10 |
| Oktay and Ulukaya[30] | Turkey | Malocclusion | 28.2 | 10.2 |
| | Turkey | Normal occlusion | 28 | 9 |
| Uysal *et al.*[20] | Turkey | Malocclusion | 21.3 | 15.4 |
| Bugaighis *et al.*[27] | Libya | Children | 28.5 | 26.7 |
| Paredes *et al.*[31] | Spanish | Class I Malocclusion | 21 | 5 |
| Wedrychowska-Szulc *et al.*[10] | Polish | Malocclusion | 31.2 | - |
| Bernabé *et al.*[5] | Peruvian | Malocclusion | 20.5 | 5.4 |
| Araujo *et al.*[32] | Brazilian | Malocclusion | 22.7 | - |
| Cançado *et al.*[33] | Brazil | Malocclusion | 23 | 6.5 |
| Johe *et al.*[34] | Caucasians | Malocclusion | 14.4 | 8.9 |
| | African-American | Malocclusion | 29 | 17.7 |
| | Hispanic | Malocclusion | 13 | 11 |
| Santoro *et al.*[35] | Dominican American | Malocclusion | 28 | 11 |
| Crosby and Alexander[9] | American | Malocclusion | 22.9 | - |
| Freeman *et al.*[11] | American | Malocclusion | 30.6 | 13.4 |
| Othman and Harradine[18] | Caucasians | Malocclusion | 17.4 | 5.4 |

AR: Anterior ratio; OR: Overall ratio; SD: Standard deviation

occlusion were randomly selected and subdivided into two equal groups based on gender; "1CM" for males ($n$ = 15) and "1CF" for females ($n$ = 15).

### Scanning the cast and odontometry

We scanned the orthodontic casts using a three-dimensional (3D) surface scanner (D-800, 3-shape, Denmark). First, upper and lower casts were scanned separately, and then they were aligned together and scanned for registration of occlusion [Figure 1]. The resulted STL files were exported to 3D software for measurement and analysis (Meshmixer™ version 3.5, Autodesk®, USA). The images were analyzed to measure the distance between mesial to distal contact points of each tooth separately.

In a top view of the image, initial contact points were marked at the two ends of a mesiodistal line over the occlusal surface. We zoomed the image and coincided the contact points with a guiding sphere drawn from the mesiodistal line; this procedure was done from occlusal and buccal aspects of the tooth, and an accurate position of contact points in both mesial and distal surfaces was determined [Figure 2].

### Measurement of the overall ratio and anterior ratio

We tabulated the determined mesiodistal widths of individual teeth in an excel sheet (Microsoft Excel 2019), and tooth size ratios "OR" and "AR" were calculated according to the formula mentioned in Table 1. To evaluate

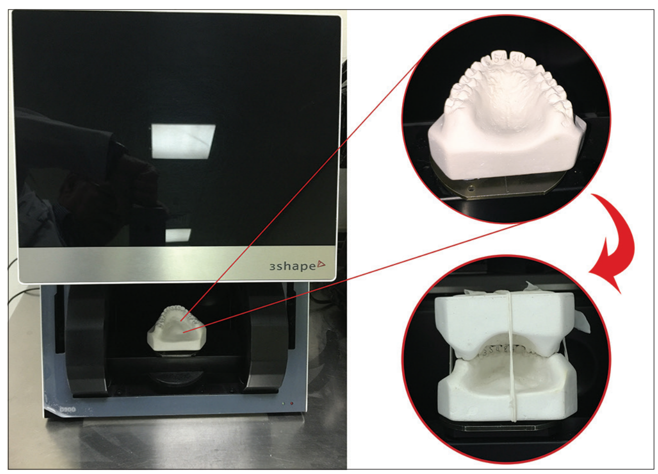


**Figure 1: Three-dimensional optical surface scanning of the casts**

the consistency of the Autodesk Meshmixer measurements, one-third of the samples from each group ($n$ = 5), adding up a sample size of 50, were measured by a second rater. The "OR" and "AR" were obtained using the same formula in an excel sheet.

### Statistical analysis

The data were transferred to the Statistical Package for the Social Sciences software (IBM SPSS statistics version 20, Chicago, IL, USA) for analysis. After determining the interrater reliability ($k$ = 2) by the intraclass correlation coefficient (ICC), the first rater readings were used for the

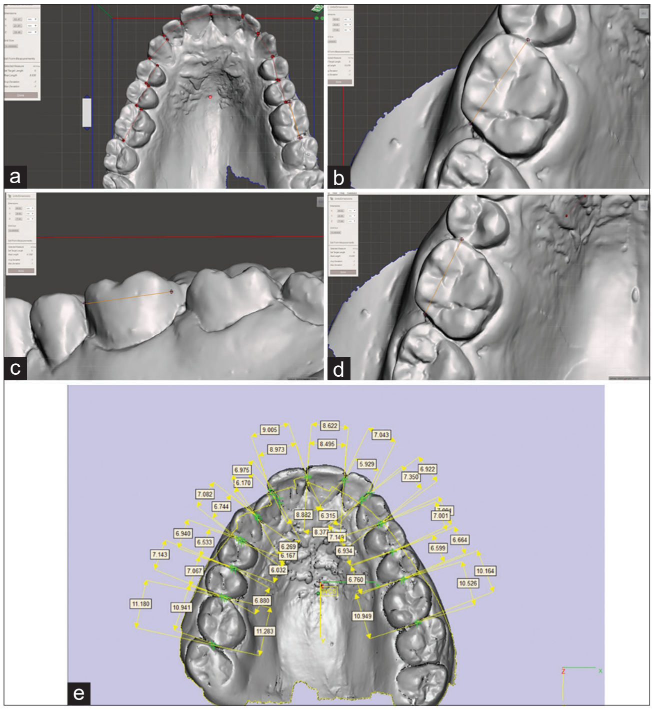

**Figure 2: Measurement technique of the mesiodistal width of the teeth. (a) Marking of initial contact points on a top view (b-d) Coinciding the contact points with the guiding sphere on a zoomed image, buccal view, and occlusal view. (e) Final image displaying three measurements for each tooth**

remaining statistical analysis. The data of the two factors of Bolton's analysis, AR and OR, were initially examined for descriptive statistics and normality of distribution with the Shapiro–Wilk test. The means of each group and subgroup were evaluated for homogeneity with Levene's test. The differences in their mean values were analyzed with analysis of variance and followed up with Tukey's honestly significant difference test. We applied the *t*-test (medcalc.org-online) to compare the mean ratios with BM. The significance level during all the statistical analyses was set at $\alpha = 0.05$. The consolidated data in the excel sheet were further graded according to the amount of discrepancy [Table 1] to determine the prevalence and to compare the results with Bolton's study.

## Results

### The interrater reliability

The ICC, as calculated with SPSS, was estimated at 95% confidence intervals, using an absolute agreement definition, in a two-way mixed effects model. The two rater's readings of AR (ICC = 0.975) and "OR" (ICC = 0.949) displayed an excellent level of agreement. We chose the data of the first rater for subsequent analysis.

### Normality and homogeneity of the data

The Shapiro–Wilk test reported *P* values of 0.118 for AR and 0.715 for OR, indicating that the data were normally distributed. The Levene's homogeneity of variance test reported *P* values of 0.527 for AR and 0.489 for OR, indicating that the data were homogeneously distributed [Table 3]. The histograms, the normal probability, and homoscedasticity plots are illustrated in Figure 3.

### Descriptive statistics

The AR of combined malocclusion subgroups ranged from 68.95 to 85.90 ($M = 78.61$, SD = 2.96), and the OR ranged from 86.39 to 96.57 ($M = 92.01$, SD = 1.98). The combined control group scored AR of 78.23 (SD = 2.52) and OR of 92.02 (SD = 2.02) [Table 3]. The readings of the orthodontic patients and ideal occlusion (control group) were larger than the Bolton's recommendations (AR: $M = 77.2$, SD = 2.11; OR: M = 91.3, SD = 1.91).

### Analysis of variance and Tukey's *post hoc*

All the 10 subgroups showed no statistically significant difference in the tooth size ratios among each other ("AR": $F$ (9, 140) = 0.31, $P = 0.971$; "OR": $F$ (9, 140) = 0.998, $P = 0.444$). Tukey's honestly significant difference indicated no sexual dimorphism of AR and OR among the malocclusion subgroups as well as the control subgroups ($P > 0.05$). The test indicates no statistically significant difference between each subgroup from the rest of the subgroups ($P > 0.05$) [Table 3].

### *T*-test

The comparison of the combined means of the malocclusion subgroups ("AR": $M = 78.61$, SD = 2.96; "OR": M = 92.01, SD = 1.98) with that of the control group ("AR": M = 78.23, SD = 2.52; "OR": M = 92.02, SD = 2.02) revealed no statistically significant difference. The combined AR and OR readings of the malocclusion group was significantly higher than the Bolton's suggested ratios for excellent occlusion ("AR": $P = 0.002$; "OR": $P = 0.027$). There was no statistically significant difference in OR of the control group with Bolton's study ($P = 0.105$). However, the "AR" of the control group was significantly higher than that of Bolton's ($P = 0.048$) [Table 4].

### Grading of consolidated data with regard to Bolton's ratios

The grading of the data indicates, many people, despite having no TSD (33.3% for "AR"; 67.5% for "OR"), suffer from malocclusion. A minority of people in the region exhibited lower than usual Bolton's ARs (17.5% of malocclusion group and 20% of the control group). Despite having proper occlusion, the control group had many subjects with positive deviations of ARs over "BM" (1SD: 40%; 2SD: 20%). A significant number of subjects, irrespective of the gender and type of occlusion, had a positive deviation of AR over Bolton's mean (1SD: 47.3%; 2SD: 22%) [Figure 4].

## Discussion

The intermaxillary tooth size ratio may vary according

**Table 3: Statistical analysis of the tooth size ratios of various malocclusion classes and normal occlusion**

| Factor | Groups | *n* | Mean±SD | 95% CI for mean difference | Homogeneity of variances | | ANOVA | | Tukey's HSD | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | LB-UB | LS | Significant | *F* | *P** | Mean difference | *P** |
| AR malocclusion group | 1M | 15 | 79.08±2.51 | 77.69-80.47 | | | | | 0.74 | 0.998 |
| | 1F | 15 | 78.34±3.83 | 76.21-80.46 | | | | | | |
| | 2D1M | 15 | 78.70±2.85 | 77.12-80.28 | | | | | 0.52 | 1.000 |
| | 2D1F | 15 | 78.18±2.81 | 76.62-79.73 | | | | | | |
| | 2D2M | 15 | 78.75±2.71 | 77.25-80.25 | | | | | 0.74 | 0.998 |
| | 2D2F | 15 | 78.01±2.00 | 76.91-79.12 | | | | | | |
| | 3M | 15 | 79.20±3.70 | 77.15-81.25 | | | | | 0.59 | 0.999 |
| | 3F | 15 | 78.61±3.37 | 76.74-80.47 | | | | | | |
| | Total | 120 | 78.61±2.96 | 78.07-79.14 | 0.96 | 0.465 | 0.28 | 0.960 | | 0.961[a] |
| AR control group | 1CM | 15 | 78.51±2.79 | 76.97-80.06 | | | | | | |
| | 1CF | 15 | 77.94±2.29 | 76.67-79.21 | | | | | | |
| | Total | 30 | 78.23±2.52 | 77.28-79.17 | 0.46 | 0.505 | 0.38 | 0.543 | | |
| AR grand total | | 150 | 78.53±2.88 | 78.07-−78.99 | 0.90 | 0.527 | 0.31 | 0.971 | | 0.975 |
| OR malocclusion group | 1M | 15 | 92.54±2.10 | 91.38-93.70 | | | | | 1.47 | 0.453 |
| | 1F | 15 | 91.07±1.92 | 90.01-92.13 | | | | | | |
| | 2D1M | 15 | 92.33±1.92 | 91.27-93.39 | | | | | 0.50 | 0.997 |
| | 2D1F | 15 | 91.83±2.14 | 90.65-93.01 | | | | | | |
| | 2D2M | 15 | 91.90±1.61 | 91.01-92.79 | | | | | 0.35 | 1.000 |
| | 2D2F | 15 | 91.55±1.06 | 90.96-92.14 | | | | | | |
| | 3M | 15 | 92.85±2.26 | 91.60-94.10 | | | | | 0.83 | 0.942 |
| | 3F | 15 | 92.02±2.39 | 90.69-93.34 | | | | | | |
| | Total | 120 | 92.01±1.98 | 91.65-92.37 | 1.15 | 0.34 | 1.24 | 0.289 | | 0.215[a] |
| OR control group | 1CM | 15 | 92.08±2.13 | 90.91-93.26 | | | | | | |
| | 1CF | 15 | 91.78±1.99 | 90.67-92.88 | | | | | | |
| | Total | 30 | 92.02±2.02 | 91.27-92.78 | 0.17 | 0.681 | 0.44 | 0.514 | | |
| OR grand total | | 150 | 92.01±1.98 | 91.69-92.33 | 0.95 | 0.489 | 1.00 | 0.444 | | 0.300[a] |

[a]Uses harmonic mean sample size=15.00; *α=0.05. *n*: Number of samples; SD: Standard deviation; LB: Lower bound; UB: Upper bound; LS: Levene's statistic; *F*: *F* statistic; *P*: Significance level; M: Male; F: Female; AR: Anterior ratio; OR: Overall ratio; ANOVA: Analysis of variance; CI: Confidence interval; HSD: Highly significant difference; BAR: Bolton's anterior ratio; BOR: Bolton's overall ratio; 1M: Angle's class I (male); 1F: Angle's class I (female); 2D1M: Angle's class II division I (male); 2D1F: Angle's class II division I (female); 2D2M: Angle's class II division II (male); 2D2F: Angle's class II division II (female); 3M: Angle's class III (male); 3F: Angle's class III (female)

**Table 4: *T*-test comparison of the means of malocclusion and normal occlusion subjects between each other and with Bolton's standards**

| Comparisons | Factors | Difference | 95% CI | df | *P** |
|---|---|---|---|---|---|
| Malocclusion to normal occlusion of the current study | AR | −0.38 | −1.54-0.78 | 148 | 0.519 |
| | OR | 0.01 | −0.79-0.81 | 148 | 0.980 |
| Malocclusion groups to Bolton ratios[1] | AR | 1.41 | 0.53-2.28 | 173 | 0.002 |
| | OR | 0.71 | 0.08-1.34 | 173 | 0.027 |
| Control group to Bolton ratios[1] | AR | 1.03 | 0.01-2.05 | 83 | 0.048 |
| | OR | 0.72 | −0.15-1.59 | 83 | 0.105 |

*Significance level (two-tailed); α=0.05. AR: Anterior ratio; OR: Overall ratio; *t*: *t*-statistics; df: Degree of freedom; CI: Confidence interval

to heredity, ethnicity, gender, and secular trends. An acquaintance of TSD in the local population can abet the orthodontists designing a reliable treatment plan. The vastly recognized Bolton's standards refer to the Caucasian population with ideal occlusion; there is a need to establish specific standards for individual population groups with regard to normal occlusion as well as different classes of malocclusion. The current study was a cross-sectional, case–controlled, observational study exploring the prevalence and variation of TSD among various classes of malocclusion, normal occlusion, and gender in the Southern Saudi population. We found no statistically significant difference between the variables: (i) gender, (ii) normal occlusion against malocclusion, and (iii) various Angle's classes of malocclusion. However, the compounded data were significantly different from Bolton's standards. The null hypothesis stating no difference in the TSD across all the variables mentioned above was hence partially

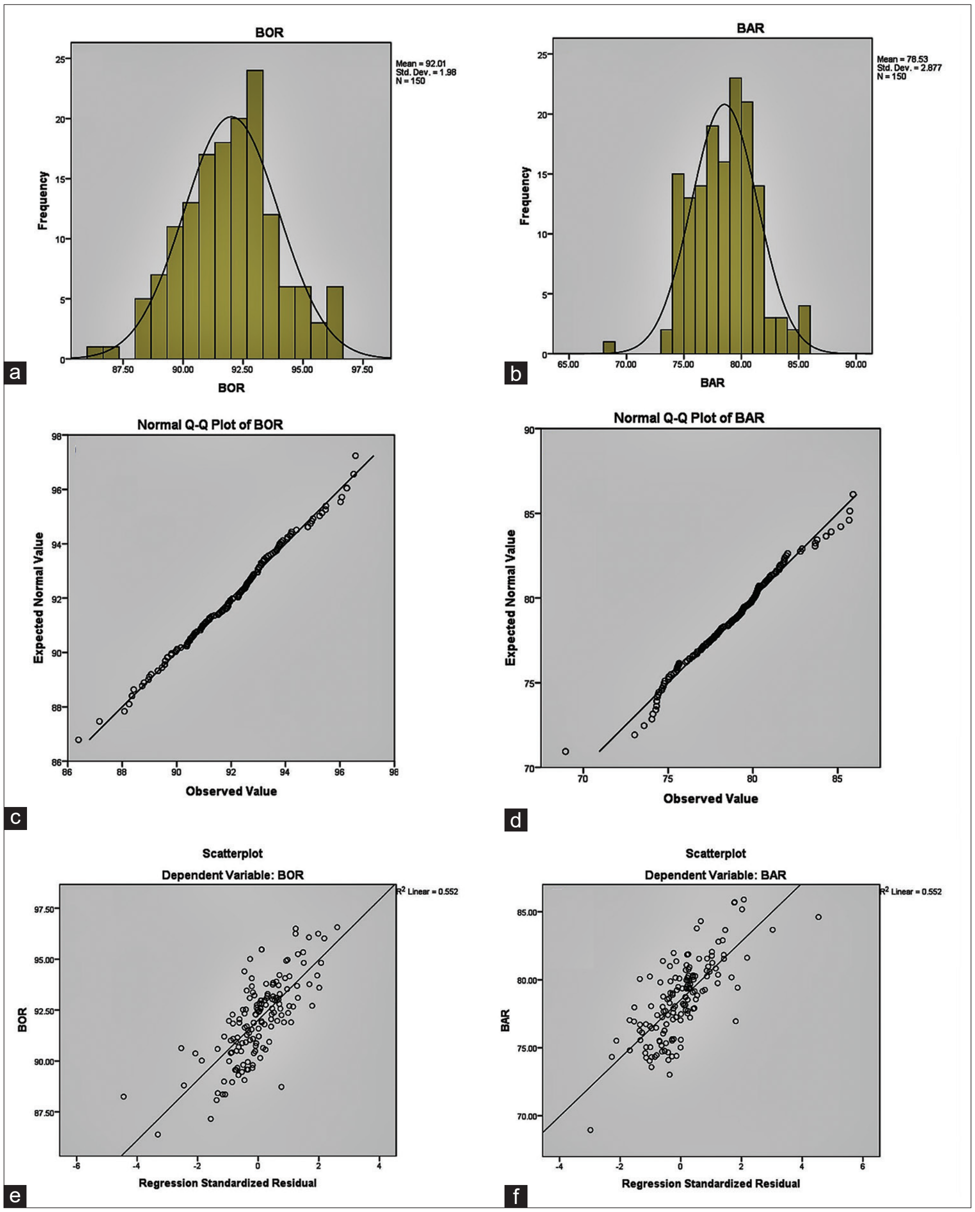


**Figure 3: Normality and homogeneity of the data; (a and b) histograms of Bolton's overall ratio and Bolton's anterior ratio data; (c and d) normal probability plot of Bolton's overall ratio and Bolton's anterior ratio data; (e and f) homoscedasticity of Bolton's overall ratio and Bolton's anterior ratio as variables**

accepted.

In the current study, we found that there was no sexual dimorphism of AR and OR in each class of malocclusion and the control group [Table 3]. The findings are in agreement with most of the populations in other parts of the world, such as North India, China, Japan, America, Turkey, and Libya[8,13,21,27,29,30,34,36,37] with some exceptions.[23] Based on our findings, along with other reports, we can understand that the gender of an individual has an insignificant influence on TSD.

We found that there was no statistically significant difference in AR and OR among the various classes of malocclusion and normal occlusion subgroups in our study. The findings are in agreement with studies in Turkey, America, and North India.[9,20,36-38] Araujo *et al*. found that in the Brazilian population, class III had a significantly higher anterior Bolton's ratio ($M$ = 79.03; SD = 2.35); however, the other two classes had no significant difference between each other.[39] Similar findings were observed in an Iranian population.[40] Furthermore, the Chinese population in a study by Nie and Lin had significant differences among the classes with the anterior tooth ratios in descending order of Class III > Class I > Class II.[21]

There was no significant difference in AR and OR between the malocclusion group and the normal occlusion group of the current study [Table 4]. The finding corroborated with a study on the Turkish and Chinese populations.[30,41] While inferring this finding, a limitation should be kept in mind: the sample size of the normal occlusion group was only 30,

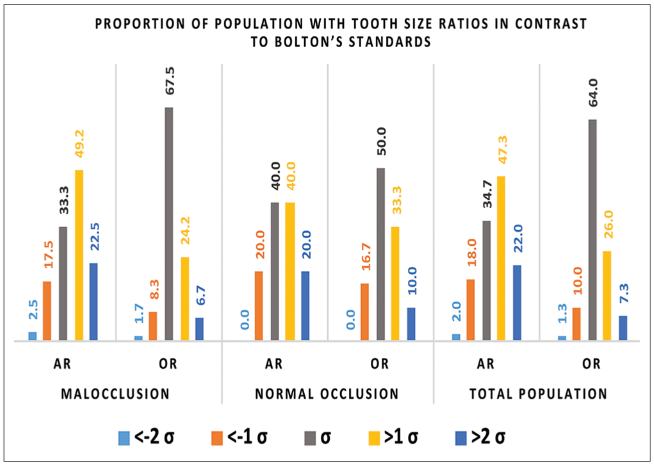


**Figure 4: Graph demonstrating the prevalence of tooth size discrepancy among the malocclusion and normal occlusion individuals**

whereas the malocclusion group was 120. We maintained an equal sample size ($n$ = 15) for all the subgroups in an attempt to minimize the bias when evaluating the sexual dimorphism and other variables. Although this technique rendered comparisons of the groups convenient, further studies on normal occlusion subjects with a large sample size are needed to establish the norms for tooth size ratios.

The "AR" and "OR" of the malocclusion, and the AR of the control group, were significantly higher than Bolton's standards [Table 4]; this signifies the influence of genetics and ethnicity over tooth and jaw size. The finding contrasted with a similar study conducted in the central region of Saudi Arabia, which reported that the normal occlusion subjects complied with Bolton's standards.[16] The difference in the ethnicity of the population and smaller sample sizes in both studies could have influenced the results.

The positive deviation of the "AR" in the Saudi population indicated that most of the people in the region have mandibular anterior tooth size excess. We have noticed that most of the casts displayed crowding in the lower anterior region. The finding is in agreement with a report suggesting excess tooth size to associate with crowding strongly.[4] Furthermore, Bernabé *et al*. reported that tooth size ratios were significantly higher in patients with crowding.[5] The ratios reported in our study were comparable to the standards reported by Lundström in the European Caucasians ("AR": $M$ = 78.5 ± 0.13; "OR": $M$ = 92.3 ± 0.26)[42] and lower than that of Negroid male subjects (AR: $M$ = 79.4; OR: $M$ = 93.5).[22]

The TSD is significantly more dependent on the AR than the OR.[1] The significant deviations in AR in comparison to that of OR in the current study reinforce Bolton's interpretation that AR has greater importance in evaluating the TSD during orthodontic treatment planning.

In the current study, 66.7% of malocclusion subjects had a discrepancy of ± 1SD of BM. This finding signifies the importance of performing an accurate orthodontic diagnosis before treatment. The prevalence of a discrepancy in AR of ± 1SD of BM was substantially greater than that established by Bolton (29%)[1] and by Richardson on American Negroes (33.7%).[24] Our result corroborated with a report on the Brazilian population (56%).[39] In the current study, 60% of normal occlusion subjects displayed a discrepancy of ± 1SD of BM. The finding could signify the factor of ethnicity affecting the tooth size and arch size of the population.

Several authors recommend the TSD to be ± 2SD of BM for clinical significance.[9] A ± 2SD of BM means the AR readings, which are lower than 73.9 and higher than 80.5. We found a significant proportion of malocclusion subjects (25%) irrespective of the type of malocclusion that had AR deviated more than ± 2SD of BM. This finding points out a greater clinical significance in performing an accurate orthodontic diagnosis before treatment. The ± 2SD of BM found in the current study (25%) is alike reported for other populations of the world [Table 2].[9,10,13,17,23,31,32,35] A considerable number of normal occlusion subjects (20%) in the current study had AR deviated more than ± 2SD of BM, which is significantly larger than studies on other populations [Table 2]. This finding could signify the influence of ethnicity on the tooth and jaw size of an individual. Bugaighis and Elorfi have previously demonstrated the ethnic variation of the tooth size.[43]

We have divided the malocclusion group based on Angle's classification; the four classes of malocclusion and the normal occlusion group were split into gender-based subgroups, ending up into a total of 10 proportionate subgroups ($n$ = 15). The equal sample size in each subgroup minimized the bias in the results. We choose the population aged between 15 and 25 years with the object of minimizing the impact of attrition on the tooth size.

The plaster models made from alginate impressions are considered to be dimensionally accurate.[44] The plaster models can produce better accuracy of measurement over the direct intraoral method due to procedural ease, especially in the posterior region.[45] The tooth size measurement on the dental plaster cast gave an additional advantage of repeating the measurements and improving the consistency and accuracy.[43] The measurements on the dental casts were conventionally done by a caliper, with a usual accuracy of 0.1 mm. The 3D surface imaging with measurement software provided a speedy, accurate, verifiable, and reproducible alternative to a caliper. The accuracy of digital measurement is comparable to that of the conventional Vernier caliper.[46] Furthermore, it can provide better accuracy in measuring the dimensions of crowded teeth. An excellent level of agreement between the two raters in the current study proves the reproducibility of Meshmixer method. Although commercially available integrated, 3D surface scanner systems (Ortho Insight 3D Scanner, Motion View, LLC™) were previously used in similar studies,[47] we used Autodesk Meshmixer version 3.5, USA, which is popularly used for 3D printing and has a proven record for dimensional accuracy. The commercially available systems provide convenience by having the 3D surface scanner integrated with measurements and treatment planning software packages; however, it usually allows measurement on the occlusal view only. The Meshmixer allowed tooth size measurements in multiple views to attain averaged values of greater accuracy. However, some commercial systems have an advantage of simultaneous calculation of TDS in mm, which has a better clinical relevance over the ratios. Furthermore, we recommend integrated newer formulae such as Johnson/Bailey's analysis developed by a team at the University of California, San Francisco, which can offer correct ratios applying related clinical parameters such as arch factors and cusp-fossa interdigitation.[48]

## Conclusion

The results of the study enlightened the prevalence of ± 2SD TSD among the Southern Saudi population and reinforced the importance of evaluating the TSD routinely during the initial diagnosis of all the orthodontic patients. Further studies should be carried out on a larger sample size to establish TSD norms for the Saudi population. Within the limitations of the study, we made the following conclusions.

1. There was no sexual dimorphism of tooth size ratios (AR and OR) among Southern Saudi orthodontic patients and population with normal occlusion
2. There was no significant difference in AR and OR among various classes of malocclusions
3. The mean OR among people with normal occlusion was similar to that of Bolton's recommendations; however, the mean AR was significantly higher
4. Significant proportions of Southern Saudi orthodontic patients and people with normal occlusion had ± 2 SD of TSD from Bolton's means.

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### Conflicts of interest

There are no conflicts of interest.

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