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RESEARCH ARTICLE

# Bolton Ratio of Different Angle's Classifications in a School Children Sample of Erbil City: A Cross-sectional Study

**Amanj R. Ibrahim[1], Zana Q. Omer[2], Hasan S. Hasan[1,2]*, Walaa M. Saleem AlMola[3]**

*[1]Department of Orthodontic, Khanzad Polyclinic Teaching Center, General Directorate of Hawler, Ministry of Health, Kurdistan Region, Iraq, [2]Department of Paedodontics, Orthodontics and Preventive Dentistry, College of Dentistry, Hawler Medical University, Kurdistan Region, Iraq, [3]Department Oral Surgery, Faculty of Dentistry, Tishk International University, Erbil, Kurdistan Regional, Iraq*

***Corresponding author:**
Hasan S. Hasan, Department of Orthodontic, Khanzad Polyclinic Teaching Center, General Directorate of Hawler, Ministry of Health, Kurdistan Region, Iraq.
**E-mail:** hsh.ortho@yahoo.com

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## ABSTRACT

Aims of this study were to determine both the Bolton anterior and overall ratios in a representative sample of Erbil schoolchildren of Normal occlusion and Cl I, Cl II div I, div II, and Cl III malocclusion, also to find if there are any gender differences. Numerical data were obtained, comprised of 320 samples study casts of students with a mean age of 13–15 years selected from different schools in Erbil City. The casts were divided into 5 groups according to the type of malocclusion: Normal ($n$ = 64), Cl I ($n$ = 64), Class II div I ($n$ = 64), Class II div II ($n$ = 64), and Class III subjects ($n$ = 64). The measurement of the greatest mesiodistal width of the teeth was performed using digital Vernier directly on the study casts, from the distal surface of the left first molar to the distal surface of the right first molar. The overall and anterior ratios between the maxillary and mandibular teeth were computed and evaluated using Bolton's method. The results revealed that the mean anterior ratio (78.863) was higher and statistically significantly different from anterior Bolton's (77.2) and also the mean overall ratio was not statistically significant different from Bolton's ratio (91.3) ($P$ = 0.239), with respect to the overall and anterior ratios among all the groups, statistically significant differences were found. Differences between genders were analyzed using a $t$-test. The results showed that there were no significant differences between males and females. There were non-significant differences between the findings of the present study and those of Bolton's study for overall ratio and anterior ratio, but among all five classifications, there was a significant difference of Erbil population not similar to Bolton ratio and there was no significant difference between males and females.

**Keywords:** Bolton's ratios; Erbil population; Malocclusion; School children; Tooth size discrepancy

## INTRODUCTION

One of the main tasks of an orthodontist is to obtain a functionally balanced occlusion between the upper and lower dental arches. For an ideal occlusion, the mesiodistal crown diameters of the teeth in both arches should correspond (Oktay and Ulukaya, 2010). The aim of any orthodontic treatment is to determine the best possible aesthetic and functional result, where an inter arch tooth size discrepancy exists, there may still be an excessive overjet, inverse overjet, or an increased overbite following treatment (Muqbil, 2010).

Orthodontists should pay special attention to the presence of tooth size discrepancy because about 60% of orthodontic patients present an anterior Bolton discrepancy (Pizzol et al., 2011; McLaughlin et al., 2002). Failure to identify this disparity during diagnosis and treatment planning can invariably create difficulties for finishing such cases, especially in regard to the ideal relationship of molars and canines, while respecting the ideal overjet and overbite (Pizzol et al., 2011).

Bolton's analysis has had a wide range impact on the field of orthodontics; it is not without controversy (Ebadifar and Taliee, 2013). The importance of harmony between the maxillary and mandibular teeth brought the attention of many investigators over the years; in recent years, much more attention has been paid to tooth size discrepancy because this may be an obstacle to achieving an ideal result in many cases (Ismail and Abuaffan, 2015). Bolton concluded that an overall ratio of 91.3% and an anterior ratio of 77.2% were necessary for proper articulation of maxillary and mandibular teeth. If a ratio lies outside two standard deviations (2 SD) from Bolton's means, then a Bolton's discrepancy is said to exist.

Many studies reported that the incidence of tooth size discrepancy is high, but relatively little literature correlated

malocclusion with the tooth size discrepancy, those studies analyzed the Bolton ratios for groups of Cl I, Cl II, and Cl III cases, they found that Cl III subjects showed greater mandibular tooth size excess than the Cl II and Cl I groups, also they concluded that the Bolton anterior and overall ratios were greater in Cl III patients than in Cl II and Cl I subjects. Al Sulaimani and Afify (2006); Ta et al. (2001a) found that the Bolton standards may be applied to southern Chinese children with Class I occlusion but not to those with Class II or Class III occlusion.

Furthermore, many studies challenged the reliability of Bolton's analysis in predicting malocclusions related to tooth-size discrepancy (Rudolph et al., 1998; Heusdens et al., 2000; Paredes et al., 2006b).

Recently, there is a dearth of information in the literature on the Bolton analysis ratio Erbil City in Kurdistan region of Iraq. The aims of this study were to determine anterior and overall Bolton ratio among randomly selected school children in Erbil city population at different Angle's classification and compered with original Bolton's data, also compare the Bolton ratio between male and female subjects.

## MATERIALS AND METHODS

The sample of 320 of 630 students was chosen consisted of students in the basic, secondary schools and all of schools randomly selected from different geographical areas of Erbil City (16 schools out of 133 basic schools determined using Epi info program with confident interval 95 based on the population size of 41,476). Their ages were between 13 and 15 years old of both genders of basic and secondary level of seven, eight, and nine stages) during the period extended from December 2015 to September 2016. The samples were taken according to inclusion and exclusion criteria that consist of normal occlusion and Cl I, Cl II, and Cl III malocclusions by multi-stage sampling. Erbil city was divided into four geographical areas (north, south, east, and west); from each part, four schools were chosen randomly of both genders (male and female) and from each school, one classroom selected randomly. Twenty students were selected from each school, if in one classroom, the number of subjects did not reached 20 students, another classroom in the same school was chosen.

Occlusal categories classified by Angle's classification, the selection procedure was intentionally biased to produce five groups, normal occlusion and Cl I, Cl II div I, Cl II div II, and Cl III malocclusion, as shown in Table 1.

A disposable mouth mirrors were used to examine each student with the aid of portable light, seated comfortably on a chair. The students' centric occlusion was examined in the upright position with the head slightly moved backward and supported by the wall. Angle molar and canine relationship was recorded. Subsequent, c-type Ormadent silicon impression material (heavy and light body) had used to taken impression for both arches (upper and lower arches) and directly sent to dental laboratory for pouring immediately by stone (Model dental stenotype 4 C.Z). The dental casts were allowed to dry on a table for 1 h, then numbered, trimmed, prepared without being soaped, and articulated regarding student occlusion. Figure 1 showing all material and instrument used in this study, impression taken, and poured trimmed casts.

Study casts were divided into five groups: Group I (Normal occlusion), Group II (Angle's Cl I), Group III (Angle's Cl II div I), Group IV (Angle's Cl II div II), and Group V (Angle's Cl III), normal occlusion was based on Class I molar and a line of occlusion correct, Class I malocclusion on a Class I molar relationship but a line of occlusion is incorrect, Class II on the presence of Class II molar and canine relationship (overjet was a criterion to differentiate between Class II div I and II) and Class III were based on Class III molar relationship (Proffit et al., 2013). Measurements were made directly on the dental casts using digital Vernier, as shown in Figure 2. Mesiodistal tooth width was measured as described by Hunter and Priest (Hunter and Priest, 1960).

The Vernier beaks were gently inserted from the buccal side (mesial and distal contact point) and held parallel to the

**Table 1: The number of subjects in each gender and malocclusion groups**

| Malocclusion groups | Female | Male | Total |
|---|---|---|---|
| Normal occlusion | 32 | 32 | 64 |
| Class I | 32 | 32 | 64 |
| Class II div I | 32 | 32 | 64 |
| Class II div II | 32 | 32 | 64 |
| Class III | 32 | 32 | 64 |
| Total | 160 | 160 | 320 |

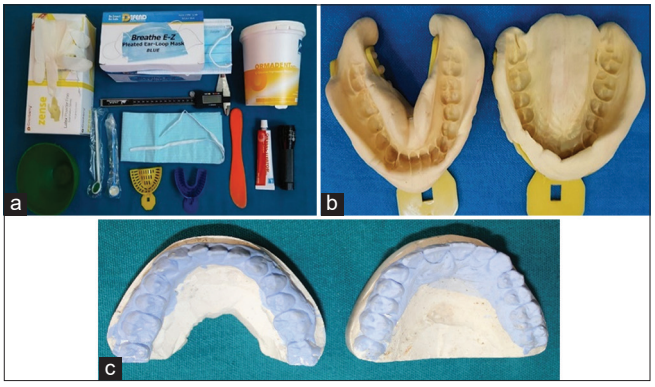


**Figure 1: (a) Instruments and materials used in this study, (b) impression taken, and (c) poured trimmed castes**

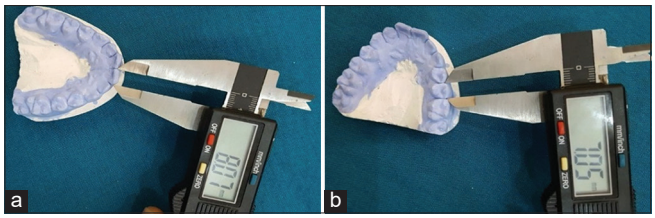

**Figure 2: (a and b) Measurement of tooth width method**

occlusal surface, each tooth measured twice in each arch. If the difference was <0.2 mm, the first measurement was registered. If the second measurement differed by more than 0.2 mm from the first, the tooth was measured again, and only the new measure was registered (Trehan et al., 2012b). Only 12–15 pairs of models were measured each day to prevent visual fatigue.

The method proposed by Bolton (1958a) was adopted for the calculation of tooth size discrepancy. The anterior and overall ratio was calculated as following, respectively:

### Sum of Mandibular and Maxillary 6 Anterior Teeth

The mesiodistal width of all the teeth mesial to the mandibular first premolar was measured and summed up using the Bolton formula:

$$\text{Anterior ratio} = \frac{\text{Sum of mandibular 6 teeth}}{\text{Sum of maxillary 6 teeth}} \times 100 = 77.2\%$$

If the anterior ratio is <77.2%, it indicates maxillary anterior excess. The amount of maxillary anterior excess is determined by the following way:

$$\text{Maxillary 6 teeth} = \frac{\text{Mandibular 6 teeth}}{77.2} \times 100$$

If the anterior ratio is more than 77.2%, it indicates mandibular anterior excess. The amount of mandibular anterior excess is determined by the following way:

$$\text{Maxillary 6 teeth} = \frac{\text{Mandibular 6 teeth}}{100} \times 77.2.$$

### Sum of Mandibular and Maxillary 12 Teeth

The mesiodistal width of all the teeth mesial to the mandibular second permanent molar was measured and summed up using the Bolton formula:

$$\text{Over all ratio} = \frac{\text{Sum of mandibular 12 teeth}}{\text{Sum maxillary 12 teeth}} \times 100 = 91.3\%$$

If overall ratio is <91.3%, it indicates maxillary tooth material excess. The amount of maxillary excess is determined using the formula:

$$\text{Maxillary 12 teeth} = \frac{\text{Mandibular 12 teeth}}{91.3} \times 100$$

If overall ratio is more than 91.3%, it indicates mandibular tooth material excess. The amount of mandibular excess is determined using this formula:

$$\text{Maxillary 12 teeth} = \frac{\text{Mandibular 12 teeth}}{100} \times 91.3$$

Regarding measurement accuracy, a pilot study was conducted to estimate inter-examiner and intra-examiner calibration to ensure the reliability of the quantitative dental arch measurements. All measurements were done by the same investigator. For error assessment, a total of 10 casts were randomly selected from the original sample. Considering that a clinical diagnosis of the reasons contributing to the existence of tooth size discrepancy in casts was not performed, all detected discrepancies were described as a relative excess of maxillary and mandibular tooth size.

### Inclusion Criteria

The following criteria were included in the study:
1. Presence of permanent teeth from the first molar to the first molar in both arches (no permanent tooth/teeth extractions), 2. Age of samples was between 13 and 15 years old, and 3. Both male and female samples must be taken.

### Exclusion Criteria

The following criteria were excluded from the study:
1. Presence of any morphologic dental anomaly, 2. History of previous orthodontic treatment, 3. Extensive proximal caries or extensive proximal restorations on any of the teeth, 4. Supernumerary tooth/teeth, 5. Presence of any deciduous tooth/teeth, 6. Subjects with cleft lip and palate were not taken, 7. Abnormally sized or shaped teeth, and 8. Crown and bridge prosthesis.

## RESULTS

In this study, tooth size ratios (Mean [X], SD, standard error, and sample size) for each occlusion group are summarized.

All subjects had a combined mean anterior ITSD ratio of 78.863, a SD of 2.900, and a range from 73.310 to 86.550. While all subjects had a combined mean overall ITSD ratio of 91.727, a SD of 2.212 and a range from 84.050 to 98.760. When the overall ratio of Cl II div I, compared with Cl III and normal occlusion, there was a significant difference, but when compared with Cl II div I and Cl II

div II malocclusion, the difference was not significant. The overall ratio of Cl II div II was not significantly different from Cl I and CII div I malocclusion and was significantly different from Cl III malocclusion and normal occlusion. Overall ratio of Class III malocclusion group was significantly different from all groups except normal occlusion, as shown in Table 2.

The results of ANOVA. When comparing mean anterior ratio of normal occlusion (mean = 79.640) Class I (mean =78.456), Class II div I (mean = 77.621), CII div II (78.495), and Class III (mean = 80.104) in 320 subjects, significant difference was found among all five classifications ($P$ = 0.002). When comparing the mean overall ratio between groups, a significant difference was found among all five classifications ($P$ = 0.001).

Table 3 shows no sexual dimorphism was observed for the anterior and overall ratio in the sample studied; mean values and SD for maxillary to mandibular anterior tooth-width ratios were 78.859 ± 2.9% and 78.868 ± 3.1% for males and females, respectively, with a $P$ = 0.978. Mean values and standards deviations for the overall tooth-width ratios were 91.696 ± 2.32% and 91.764 ± 2.403% for females and males, respectively, with a $P$ = 0.799. The descriptive statistics demonstrate that male and female ratio in percentage in the present study was 53.75–46.25 for male and female, respectively.

Results from Table 4 show that in Cl I malocclusion, mean anterior ratio for male (78.57 ± 2.79) was higher than females (78.26 ± 3.49). However, there was no statistically significant difference between males and female values ($P$ = 0.694). For Cl II div I, mean anterior ratio for males (77.83 ± 2.84) was higher than females (77.30 ± 2.51). However, there was no statistically significant difference between males and female values ($P$ = 0.445). For CII div II malocclusion mean anterior ratio for male (78.48 ± 2.91) was lesser than females (78.51 ± 3.88). However, there was no statistically significant difference in mean anterior ratio between males and females ($P$ = 0.966). For Cl III, mean anterior ratio for male (80.30 ± 3.10) was higher than female values (79.89 ± 2.26). However, there was no statistically significant difference in mean anterior ratio between males and females ($P$ = 0.548). For normal occlusion mean anterior ratio for male (79.51 ± 2.72) was lesser than female values (79.73 ± 2.65). However, the difference statistically not significant in Bolton's anterior ratio between males (78.85 ± 2.97) and females 78.86 ± 3.10) of normal occlusion and Cl I, Cl II div I and div II, and Cl III malocclusion ($P$ = 0.978).

Results from Table 5 shows that in Cl I malocclusion, mean overall ratio for males (91.85 ± 2.77) was higher than females (91.39 ± 2.44). However, there was no statistically significant difference between males and females ($P$ = 0.500). For Cl II div I, mean overall ratio for males (90.57 ± 1.93) was smaller than females (90.62 ± 2.85). However, there was no statistically significant difference between males and female values ($P$ = 0.929). For Cl II div II, malocclusion mean overall ratio for males (91.29 ± 2.00) was higher than females (91.00 ± 2.53). However, there was no statistically

**Table 2: Descriptive statistics of sample size, mean, standard deviation, and standard error (M, SD, and SE) of anterior and overall Bolton ratios in the normal occlusion and different malocclusion groups**

| Group | Class group | Sample size | Mean | Standard deviation | Standard error | Minimum | Maximum |
|---|---|---|---|---|---|---|---|
| Anterior ratio | CI | 64 | 78.456 | 3.050 | 0.381 | 74.120 | 86.080 |
| | CII div I | 64 | 77.621 | 2.706 | 0.338 | 71.670 | 83.960 |
| | CII div II | 64 | 78.495 | 3.371 | 0.421 | 73.310 | 86.550 |
| | CIII | 64 | 80.104 | 2.712 | 0.340 | 74.710 | 86.440 |
| | Normal | 64 | 79.640 | 2.659 | 0.332 | 75.200 | 86.440 |
| | Total | 320 | 78.863 | 2.900 | 0.3624 | 73.310 | 86.550 |
| Overall ratio | CI | 64 | 91.679 | 2.639 | 0.330 | 84.050 | 98.760 |
| | CII div I | 64 | 90.589 | 2.309 | 0.289 | 84.570 | 95.510 |
| | CII div II | 64 | 91.151 | 2.249 | 0.281 | 85.920 | 97.460 |
| | CIII | 64 | 92.865 | 1.976 | 0.247 | 87.970 | 98.640 |
| | Normal | 64 | 92.354 | 1.886 | 0.236 | 87.630 | 97.350 |
| | Total | 320 | 91.727 | 2.212 | 0.276 | 84.050 | 98.760 |

**Table 3: Analysis of variance (ANOVA) of anterior and overall Bolton ratios between groups**

| | | Sum of squares | Df | Mean square | F | Sig. |
|---|---|---|---|---|---|---|
| Anterior ratio | Between groups | 255.071 | 4.000 | 63.768 | 7.518 | 0.002 |
| | Within groups | 2671.788 | 315.000 | 8.482 | | |
| | Total | 2926.859 | 319.000 | | | |
| Overall ratio | Between groups | 212.204 | 4.000 | 53.051 | 10.688 | 0.001 |
| | Within groups | 1563.552 | 315.000 | 4.964 | | |
| | Total | 1775.756 | 319.000 | | | |

significant difference between males and female values ($P = 0.613$). For Cl III, mean overall ratio for males (93.05 ± 2.26) was higher than females (92.67 ± 1.63). However, there was no statistically significant difference in mean overall ratio between males and female values ($P = 0.446$). For normal occlusion mean overall ratio for males (91.97 ± 1.71) was lesser than females (92.62 ± 1.98). However, the difference statistically was not significant, also means that no statistically significant difference in Bolton's overall ratio between males (91.69 ± 2.32) and females (91.76 ± 2.40) of normal occlusion and Cl I, Cl II div 1 and div II, and Cl III malocclusion ($P = 0.799$).

Regarding absolute values, the overall ratio was significantly larger for the Cl III malocclusion subjects than the other groups, but with no significant difference for either gender. Regarding absolute values, the mean overall ratio for the different groups was in the order of Cl III >Normal >Cl I >Cl II div II >Cl II div I.

To determine the prevalence difference of tooth size discrepancies among the five occlusal categories and the two genders, Chi-square testing was used. No significant differences were determined in the Bolton anterior ($P = 7.869$) and overall ($P = 0.096$) tooth size prevalence between the two genders [Table 6].

The mean of all groups of the anterior ratio of the present study (78.86) compared with original data from Bolton (77.2 ± 1.65) by independent *t*-test which shows that there was a significant difference between them ($P = 0.000$), as shown in Table 7.

The mean of all groups of the overall ratio of the present study (91.72) compared with original data from Bolton (91.3 ± 1.91) by independent *t*-test which shows that there was not a significant difference between them ($P = 0.239$), as shown in Table 8.

The independent *t*-test was used for comparison of the anterior ratios of the malocclusion groups and normal occlusion with the original data from Bolton's ratio (77.2 ± 1.65) showed minimally higher ranges and mean values for the anterior ratio and statistically significant differences in

**Table 4: Student independent *t*-test was used to calculate the *P* value**

| Variable | Class | Sample (n) | Mean±SD | | *P*-value |
|---|---|---|---|---|---|
| | | | Male | Female | |
| anterior ratio | Cl I | 64 | 78.57±2.79 | 78.26±3.49 | 0.694 (NS) |
| | Cl II div I | 39 | 77.83±2.84 | 77.30±2.51 | 0.445 (NS) |
| | Cl II div II | 34 | 78.48±2.91 | 78.51±3.88 | 0.966 (NS) |
| | Cl III | 33 | 80.30±3.10 | 79.89±2.26 | 0.548 (NS) |
| | Normal | 26 | 79.51±2.72 | 79.73±2.65 | 0.746 (NS) |
| Overall ratio | Cl I | 40 | 91.85±2.77 | 91.39±2.44 | 0.500 (NS) |
| | Cl II div I | 39 | 90.57±1.93 | 90.62±2.85 | 0.929 (NS) |
| | Cl II div II | 34 | 91.29±2.00 | 91.00±2.53 | 0.613 (NS) |
| | Cl III | 33 | 93.05±2.26 | 92.67±1.63 | 0.446 (NS) |
| | Normal | 26 | 91.97±1.71 | 92.62±1.98 | 0.177 (NS) |

SD: Standard deviation between genders, NS: Not significant

**Table 5: Student's *t*-test of anterior and overall Bolton ratios between two genders**

| | Gender | | | | | | | | *P* value |
|---|---|---|---|---|---|---|---|---|---|
| | Male | | | | Female | | | | |
| | *n* | Mean | Standard deviation | Standard error mean | *n* | Mean | Standard deviation | Standard error mean | |
| Anterior ratio | 172 | 78.859 | 2.974 | 0.227 | 148 | 78.868 | 3.102 | 0.255 | 0.978 |
| Overall ratio | 172 | 91.696 | 2.328 | 0.178 | 148 | 91.764 | 2.403 | 0.198 | 0.799 |

**Table 6: Results of Chi-square testing demonstrating no Significant difference (*P* > 0.05) in the prevalence of tooth-size discrepancy among all groups between females and males**

| Class group | Gender | | | | Total | Chi-square test | |
|---|---|---|---|---|---|---|---|
| | Male | | Female | | | | |
| | Count | % | Count | % | | *P* value B.A | *P* value B.O |
| Cl I | 40 | 62.5 | 24 | 37.5 | 64 | 7.869 | 0.096 |
| Cl II div I | 40 | 61.5 | 25 | 38.5 | 64 | | |
| Cll div II | 33 | 52.4 | 30 | 47.6 | 64 | | |
| Cl III | 33 | 51.6 | 31 | 48.4 | 64 | | |
| Normal | 26 | 40.6 | 38 | 59.4 | 64 | | |
| Total | 172 | 53.8 | 148 | 46.3 | 320 | | |

Class I ($P = 0.02$), Class II div II (0.02), CIII ($P = 0.000$), and normal groups ($P = 0.000$), whereas Class II div I malocclusion group exhibited not a significant difference. These results are shown in Table 9.

Overall ratio of Cl I, Cl II div I, and CII div II malocclusion showed no significant difference when compared with Bolton ratio by independent *t*-tests. However, overall ratio of Cl III malocclusion and normal occlusion showed a significant difference when compared with Bolton study; these results are shown in Table 10.

Cl I had 0.31% patients with maxillary relative excess and 1.56% patients with mandibular relative excess, and Cl III had 0.00% patients with maxillary relative excess and 1.88% patients with mandibular relative excess, but in normal occlusion (0.25% patients with maxillary relative excess and 0.36% patients with mandibular relative excess), these results are shown Table 11.

In the present study, the number of students of Cl III malocclusion more than 2SD in percentage presented a higher prevalence of anterior Bolton discrepancy greater than other groups of occlusion was 8.13%, followed by normal occlusion (6.88% mandibular excess), followed by Cl I (5% mandibular excess and 1.56% maxillary excess), and then followed by CII div II malocclusion groups (4.38% mandibular excess and 0.63% maxillary), these results are shown in Table 12.

## DISCUSSION

The original Bolton (1958a) and Bolton (1962) norms were calculated using 55 models with excellent occlusion, of

**Table 7: Comparison of the anterior ratio of the combined group with Bolton's ratio (77.2 ± 1.65) by independent *t*-test**

| Group | Mean | Standard deviation | Standard error | Minimum | Maximum | *P*-value |
|---|---|---|---|---|---|---|
| Anterior ratio | 78.86 | 3.03 | 0.16 | 69.67 | 86.55 | 0.000 |

**Table 8: Comparison of the overall ratio of the combined group with Bolton's ratio (91.3±1.91) by independent t-test**

| Group | Mean | Standard deviation | Standard error | Minimum | Maximum | *P*-value |
|---|---|---|---|---|---|---|
| Overall ratio | 91.72 | 2.36 | 0.13 | 84.05 | 98.76 | 0.239* |

**Tables 9: Comparison of the anterior ratio of each group and total anterior ratio with Bolton's ratio (77.2±1.65) by independent *t*-test**

| Group | Class group | Sample size | Mean | Standard deviation | Standard error | Minimum | Maximum | *P*-value |
|---|---|---|---|---|---|---|---|---|
| Anterior ratio | Cl | 64 | 78.456 | 3.05 | 0.381 | 73.12 | 86.08 | 0.020* |
| | Cl II | 64 | 77.621 | 2.706 | 0.338 | 69.67 | 83.96 | 0.550 |
| | Cl II div II | 64 | 78.495 | 3.371 | 0.421 | 71.31 | 86.55 | 0.020* |
| | CL III | 64 | 80.104 | 2.712 | 0.34 | 74.71 | 86.44 | 0.000* |
| | Normal | 64 | 79.64 | 2.659 | 0.332 | 75.2 | 86.44 | 0.000* |
| | Total | 320 | 78.86 | 3.03 | 0.16 | 69.67 | 86.55 | 0.000* |

**Table 10: Comparison of the overall ratio of each group with Bolton's ratio (91.3±1.91) by independent *t*-test**

| Group | Class group | Sample size | Mean | Standard deviation | Standard error | Minimum | Maximum | *P*-value |
|---|---|---|---|---|---|---|---|---|
| Overall ratio | Cl | 64 | 91.679 | 2.639 | 0.33 | 84.05 | 98.76 | 0.420 |
| | CII div I | 64 | 90.589 | 2.309 | 0.289 | 84.57 | 95.51 | 0.060 |
| | CII div II | 64 | 91.151 | 2.249 | 0.281 | 85.92 | 97.46 | 0.645 |
| | CIII | 64 | 92.865 | 1.976 | 0.247 | 87.97 | 98.64 | 0.000* |
| | Normal | 64 | 92.354 | 1.886 | 0.236 | 87.63 | 97.35 | 0.004* |

Student independent *t*-test was used to calculate the *P* value, SD: Standard deviation, NS: Not significant

**Table 11: Frequency of tooth size discrepancy in the overall ratio**

| | Outside 2 SD (%) | 2 SD (%) | 1 SD (%) | Mean (%) | 1 SD (%) | 2 SD (%) | Outside 2 SD (%) |
|---|---|---|---|---|---|---|---|
| | <87.5 | 87.5–89.3 | 89.4–91.2 | 91.3 | 1.4–93.2 | 93.3–95.1 | >95.1 |
| C I | 0.31 | 3.13 | 6.25 | 0.31 | 4.69 | 3.75 | 1.56 |
| CII div I | 1.25 | 5.31 | 5.94 | 0.63 | 4.06 | 2.19 | 0.63 |
| CII div II | 1.25 | 3.44 | 5.31 | 0.00 | 7.50 | 1.56 | 0.94 |
| CIII | 0.00 | 1.25 | 2.50 | 0.00 | 8.75 | 5.63 | 1.88 |
| Normal | 0.25 | 1.25 | 4.06 | 0.94 | 7.19 | 5.31 | 0.36 |
| Total | 3.06 | 14.38 | 24 | 1.33 | 32.19 | 18.44 | 5.46 |

SD: Standard deviation

**Table 12: Frequency of tooth size discrepancy in anterior ratio**

| | Anterior ratio | | | | | | |
|---|---|---|---|---|---|---|---|
| | Outside 2 SD (%) | 2 SD (%) | 1 SD (%) | Mean (%) | 1 SD (%) | 2 SD (%) | Outside 2 SD (%) |
| | <73.9 | 73.9–75.4 | 75.5–77.1 | 77.2 | 77.3–78.8 | 78.9–80.5 | >80.5 |
| C I | 1.56 | 1.25 | 5.00 | 0.63 | 4.06 | 2.50 | 5.00 |
| CII div I | 1.56 | 2.19 | 5.63 | 0.00 | 4.69 | 2.19 | 3.75 |
| CII div II | 0.63 | 4.69 | 2.81 | 0.00 | 1.88 | 5.63 | 4.38 |
| CIII | 0.00 | 0.31 | 2.81 | 0.31 | 2.81 | 5.63 | 8.13 |
| Normal | 0.00 | 0.31 | 4.38 | 0.63 | 2.50 | 5.31 | 6.88 |
| Total | 3.75 | 8.75 | 20.63 | 1.57 | 16.48 | 21.26 | 28.14 |

which 44 were orthodontically treated. Bolton's estimates of variation were underestimated because his sample was derived from perfect Cl I occlusions. The population and sex composition of Bolton's sample were not specified, which implies potential selection bias (Smith et al., 2000). Therefore, our results were different when directly compared with Bolton's norms.

The results of the mean values of anterior and overall ratios from the present study were not statistically significantly different between the two genders in the incidence of tooth-size discrepancies in Cl I, CL II div I and div II, and Cl III malocclusion and in normal occlusion. These findings are in agreement with those reported by other investigators (Nourallah et al., 2005; Al–Sayagh, 2010; Singh and Goya, 2006).

Nie and Lin (1999b) found no statistically significant sex differences in the Chinese sample. Trefa (2011) found that the overall and anterior ratios were consistently larger in males than in females in Sulaimani population, but the difference was not statistically significant, those results that confirm the findings of the present study for the anterior and overall ratio between genders. However, the findings are inconsistent with those of Fattahi et al. (2006), who analyzed tooth size ratios of Angle's Cl I, Cl II div and div II, and Cl III groups with the corresponding skeletal characteristics in an Iranian population and demonstrated significant sex differences in the anterior ratio among the malocclusion groups, but not the overall ratio. Similar to Fattahi et al., the tooth size data reported by Moorrees et al. (2000) and Uysal and Sari (2005a) imply gender differences in the overall ratio. Although those studies demonstrated a tendency for larger Bolton ratios in males, the differences were not statistically significant. The findings of the present study may be due to the tooth size not significantly different between males and females or the same relation of tooth size between maxillary and mandibular arch of males and females.

In the present study, a comparison was made between ITSD in normal, Cl I, Cl II div I, Cl II div II, and Cl III students on study cast based on Angle's classification of malocclusion. The mean total ratio for the whole sample which was very close to Bolton's proposed ideal ratio. However, the anterior ratio for the whole sample, which was higher than Bolton's proposed ideal ratio, which reflected greater mesiodistal widths in the mandibular anterior segment in Erbil population sample. In Cl I group, the mean overall ratio was calculated close to Bolton's proposed ideal ratios and the mean anterior ratio calculated was higher than Bolton's proposed ideal ratios, means that the difference only of the anterior ratio may be due to the mesiodistal tooth dimension of mandibular anterior teeth of Erbil population greater than mesiodistal tooth dimension of mandibular anterior teeth of Bolton's subject. Similarly, the total mean ratio calculated for Cl II div I and Group Cl II div II subjects and the anterior mean ratio for Group II div I subjects was in close agreement with Bolton's proposed ideal ratios. A significantly higher ($P < 0.05$) mean anterior ratio for Group II patients was found and this reflects a tendency toward wider mesiodistal dimensions in the mandibular anterior segment in our study sample. There was a significant difference in the anterior tooth ratios between Group I and Group II patients. No significant difference was found between Group I and Group III or Group II and Group III patients. No correlation was found between Angle's classification of malocclusion and Bolton discrepancy, as shown by Crosby and Alexander (1989b). In fact, Laino et al. (2003) studied (94) dental cast and reported no relationship between the three malocclusion groups and the Bolton index. Hashim (2002) did not find any difference in Bolton's ratios between different malocclusion groups. Uysal and Sari (2005b) compared ITSD in 150 untreated, normal occlusion subjects, and 560 patients of four different malocclusion groups did not find any statistical difference. Several studies have evaluated patients with different malocclusion groups (Cl I, Cl II, and Cl III) that were orthodontically treated and found no statistically significant differences in the prevalence of tooth size discrepancies among the three groups (Basaran et al., 2006a; Edoardo and Giuseppe, 2014).

Al-Khateeb and Abu Alhaija (2006) found no statistically significant differences in Bolton's ratios between the different malocclusions, their sample consisted of 140

orthodontic models of school children aged between 13 and 15 years of Jordanian origin. Lavelle (1972) found that Class III individuals had disproportionally smaller maxillary teeth than Cl I and Cl II subjects when maxillary and mandibular dentition sizes were compared. Furthermore, Araujo and Souki (2003) concluded that individuals with Angle normal occlusion and Cl I and Cl III malocclusions show significantly greater prevalence of tooth size discrepancies than do individuals with Cl II malocclusions and the mean anterior tooth size discrepancy for Angle's Class III subjects was significantly greater than Class I, Cl II div I and CII div II subjects, a significant difference for all the anterior and overall ratios between the groups, the ratios showing that Cl III the highest followed by Cl I and then Cl II (Mujagić et al., 2016). He further added that intermaxillary tooth size discrepancy may be one of the important factors in the cause of malocclusions, especially in Class II and Class III malocclusions and that Bolton analysis should be taken into consideration during orthodontic diagnosis and therapy. However, Xia and Wu (1983) found no significant difference for tooth size ratios between the malocclusion groups and the normal occlusion group after measuring mesiodistal tooth sizes on their models. Thus, the law of nature can be observed only after comparing tooth size ratios among different classified malocclusion groups (Basaran et al., 2006b).

Shah et al. (2015) studied a Gujarat population and found mandibular excess in Angle's Class I and Class III malocclusion. The results of the present study are in partial agreement with some of the above studies considering the fact that no significant difference was found between Bolton's norms and tooth size ratios in Cl I and Cl III patients. However, unlike other studies, Group III did not show a significantly higher anterior tooth ratio as compared to Group I patients. The findings of this may be due to mesiodistal tooth size of the lower arch of Cl III malocclusion greater than other class types of occlusion or mesiodistal tooth size of the upper arch of Cl III malocclusion smaller than other class types of occlusion and means that mesiodistal tooth size related to the class type of occlusion. Tooth size variations exist among various ethnic groups, and it is reported that individuals of black ethnic backgrounds have larger teeth than Caucasians (Basaran et al., 2006b). A comparative study between Jordanians, Iraqi, Yemenites, and Caucasians reported that Jordanians and Iraqi had larger teeth than the other populations (Hattab et al., 1996).

In present study, the means and the SD of the total and anterior ratios were larger than in Bolton's one. The probable reason for this finding may be the type of population that constitutes the sample, subjects with orthodontic problems versus the Bolton individuals who had optimal occlusions and ethnicity has a close association with genetics and hereditary. This is with no doubt that ethnicity will affect the temperature-dependent sex determination (TSD) greatly between population and ethnics (Othman and Harradine, 2007).

The overall Bolton ratio in this present study, was more than that found by Bolton himself. The anterior ratio, from canine to canine, had a larger value when compared with Bolton's anterior ratio. Assuming that an ideal Cl I canine was obtained during treatment and to achieve an acceptable overjet and overbite, an anterior ratio of 78.1% ideally implies the necessity of either removal of tooth structure in the mandibular arch (interproximal striping) or the addition of tooth structure in the maxillary arch (prosthetic procedures to increase the widths the maxillary incisors, usually the lateral incisor, composite buildups or veneers). Both the anterior and overall ratios values were larger than the Bolton standards in all of them, even if total ratios were closer to Bolton's standards. The findings of this study are more similar to those obtained by Paredes et al. (2006a).

Ethnicity has a close association with genetics and hereditary. No doubt that ethnicity will affect the TSD greatly between population and ethnics (Othman and Harradine, 2007).

A more recent study of TSD (1) on Turkish population demonstrated that for both overall and anterior ratios, the means and SD were larger than in Bolton's study. They concluded that the probable reason for the findings may be the types of the population that constituted the samples. Smith et al. (2000) found from his study on (180) pre-orthodontic casts, the Bolton ratio is only applicable to their white female's sample and concluded the ratios should not be indiscriminately applied to white males, blacks, or Hispanics. It is because the relationships between the sizes of the mandibular and maxillary teeth are dependent on population and arch segment lengths. The larger the maxillary arch segment length, the greater the discrepancy between Bolton's ratios and the actual ratios. Although tooth size is strongly influenced by genetic and hereditary, individual variations due to environment and diet may also play an important role in the population variability.

The frequency of tooth size discrepancy outside 2 SD from Bolton's ratio was used as the index of the clinical significance of tooth size imbalance in our sample. With regards to the frequency of patients with anterior Bolton discrepancy higher or smaller than 2 SD, all the studied groups in the present study exhibited relative dental excesses, with predominance in the mandibular arch. This corroborated with several authors, including Freeman et al. (1996); Carreiro et al. (2005); Crosby and Alexander

(1989a); Santoro et al. (2000c); and Wędrychowska-Szulc et al. (2010).

In the present study, using a sample study casts to compare the Bolton ratios in different occlusion groups, found an anterior discrepancy higher than 2 SD in 31.2% of patients when compared with Bolton's standard. Cl III malocclusion presented a higher prevalence of anterior Bolton discrepancy >2 SD followed by normal occlusion followed by Cl I and then followed by Cl II div II malocclusion groups, all groups showed mandibular tooth material excess more than maxillary tooth material excess except Cl II div I showed maxillary tooth material excess more than mandibular tooth material excess. This corroborated with the studies by Nie and Lin (1999a); Sperry et al. (1977); Wędrychowska-Szulc et al. (2010).

On evaluating the frequency of patients with overall Bolton discrepancy greater or smaller than 2 SD (<87.5 or >95.1), that is, the presence and location of tooth excesses with greater clinical significance, Cl I and Cl III malocclusions exhibited a predominance of relative excess in the mandibular arch (Cl I had 0.31% patients with maxillary relative excess and 1.56% patients with mandibular relative excess and Cl III had 0.00% patients with maxillary relative excess and 1.88% patients with mandibular relative excess), which did not occur in normal occlusion (0.25% patients with maxillary relative excess and 0.36% patients with mandibular relative excess), this could be explained by the fact that normal occlusion shows a balance in the distribution of excess between the maxillary and mandibular arches. These results corroborate the findings of Wędrychowska-Szulc et al. (2010); Ta et al. (2001b) found a prevalence of relative excess in the mandibular arch in Cl III malocclusion. Since Bolton's standards were obtained from patients with ideal occlusion, the fluctuation in the distribution of excess between dental arches and the malocclusion type requires the establishment of specific standards for Bolton's ratio in the different malocclusion groups (Uysal and Sari, 2005; Ta et al., 2001b). Generally, in the present study in all groups mandibular excess 5.46% more than maxillary excess 3.06%. (Carreiro et al., 2005) found a prevalence of relative dental excess in the mandibular arch and this corroborated with our results. Carreiro et al. (2005), found a prevalence of relative dental excess in the mandibular arch and this corroborated with our results. The studies conducted by Bolton (1958b) and Proffit et al. (2006) exhibited a low percentage of overall Bolton discrepancy higher than 2 SD, probably because their samples comprised patients with ideal occlusion instead of patients requiring orthodontic treatment. While Cl II div I and Cl II div 2II exhibited a predominance of relative excess in the maxillary arch.

The majority of investigations on ITSD have chosen values outside 2 SD as an indication of a clinically significant TSD. In the present study, the percentages of subjects with clinically significant TSD of the anterior and overall ratio were 31.89% and 8.52%, respectively. Similar results for the anterior and overall ratio have been reported by Al-Omari et al. (2008). Higher percentages for the anterior ratio, however, were found by Freeman et al. (1996) and Santoro et al. (2000b). Both studies were derived from orthodontic populations which may explain the higher percentage of anterior tooth size deviations. On the other hand, the results of the present investigation demonstrated a higher discrepancy in the anterior than the overall ratio. This trend is comparable to the majority of research on ITSD.

It can also be seen that the anterior discrepancy was higher in mandibular excess than maxillary excess; the overall discrepancy was greater in maxillary excess than mandibular excess. The finding for the anterior ratio is similar to those reported by Freeman et al. (1996). In their retrospective study of 157 patient records, they reported that 30.6% of patients had anterior ratios outside 2 SD from Bolton's mean and 13.4% had total ratios >2 SD from Bolton's mean values. 2 SD outside the Bolton's mean ratio have been accepted as a clinically significant ratio for determining tooth size discrepancy (Santoro et al., 2000a; Freeman et al., 1996). However, according to Bernabe et al. (2004), even the 2 SD range from the Bolton standard did not predict clinically significant anterior and total-width ratio discrepancies.

### Limitation

The limitation of the current study is the sample size does not represent the population ratios and further recommendation is to carry out a study on bigger samples and various centers for the data to be valid and to be accepted as a norm for each ethnic.

## CONCLUSION

The following conclusions were drawn.

1. The means of the overall ratio for all groups were found, which were not significant differences between Bolton's mean ratios of the present study and Bolton's study for overall ratio, but the means anterior ratio was significantly different with the means anterior ratio of Bolton's study.
2. There was a significant difference among all five classifications of the anterior ratio and overall ratio between groups was compared.
3. When each group compared with original Bolton ratio showed minimally higher ranges and mean values for the anterior ratio and statistically significant differences of Class I, Class II div I, Cl III, and normal groups,

but only Class II div II malocclusion group exhibited not a significant difference

4. There was no significant difference in Bolton's ratio between males and females of the present study. Therefore, the analysis of and ideal values for a harmonious dentition developed by Bolton can also be used on an Iraqi population or at least on an Erbil population.

### Ethical Approval

The following permissions and approvals were taken before starting:

- Approvals from the College of Dentistry and Hawler Medical University.
- Approval from the Directorate of Education in Erbil City.
- Permission from the educational authorities.
- Permission from the directorate and teachers of all schools that chosen for taking
- A data
- Informed consent from the parents or guardian of the students before examination of each student, written consents were obtained from the parents or guardian of the students of all students who underwent examination and/or impression taking.

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