# OVERALL AND ANTERIOR TOOTH SIZE RATIOS IN A GROUP OF EMIRATIS


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DDS, Ajman University of Science and Technology, 2007

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# ABSTRACT

## OVERALL AND ANTERIOR TOOTH SIZE RATIOS IN A GROUP OF EMIRATIS

**Aims:**

1- To study overall and anterior tooth size ratios in a group of Emiratis with Class I normal occlusion.

2- To estimate overall and anterior tooth size ratios in different malocclusion groups of Emiratis.

3- To compare overall and anterior tooth size ratios of a group of Emiratis, with Class I normal occlusion, with the Bolton standards.

4- To determine the distribution of overall and anterior tooth size ratios ± 2 SD from Bolton mean values in all occlusion groups.

**Materials and Methods:**

Consecutive patients' files, including dental casts, were selected from the archives of the governmental orthodontic clinics of the Dubai Health Authority located in Bur Dubai and Bur Deira. The final sample was formed following the application of specific inclusion criteria: healthy patients, age from 13-18 years, Emirati origin, complete permanent dentition, in which, however, second and third molars may be absent, normal tooth crown morphology, no dental anomalies in tooth shape, tooth size and tooth number, no history of interproximal reduction, no restorations altering mesiodistal tooth crown width, complete record files and excellent quality of study models. The exclusion criteria were: history of systemic diseases, craniofacial anomalies, medical history contributory to dental and jaw development, mixed Emirati origin, mixed dentition, presence of dental anomalies in tooth shape, tooth size and tooth number, history of interproximal

reduction, restorations altering mesiodistal tooth crown width, congenital missing teeth, incomplete record files and poor quality of study models. The sample consisted of 521 pairs of dental casts representing both sexes (males: 188; females: 333) and different occlusion groups (Class I malocclusion: 288; Class II malocclusion 110; Class III malocclusion: 30; Class I normal occlusion: 93). The mean age of patients whose dental casts were utilized in this study was 16.18 years for Class I malocclusion, 15.73 years for Class II malocclusion, 15.83 years for Class III malocclusion and 16.55 years for Class I normal occlusion. The dental casts were selected, scanned using Ortho Insight 3D laser scanner (3D Motion View, Chattanooga, Tennessee, USA) and digitized by the author using the Ortho Insight 3D laser scanner (3D Motion View Software). Measurements were made regarding maxillary and mandibular sums of mesiodistal tooth dimension of the overall (6-6) and anterior (3-3) groups of teeth. In order to test the intra-examiner reliability, the author re-measured 50 pairs of casts, which were randomly selected from the original sample one week after the initial measurement. The intra-examiner reliability was assessed using paired t-test. Statistical analysis included descriptive statistics, paired t-test and analysis of variance (ANOVA). The level of significance was set at $p<0.05$.

**Results:**

No statistically significant differences were found between the first and the second sets of measurements thus, confirming the intra-examiner reliability. The mean values of overall ratios were 91.57 for Class I malocclusion, 91.54 for Class II malocclusion, 90.21 for Class III malocclusion and 91.41 for Class I normal occlusion. In addition, the mean values of anterior ratios were 78.05 for Class I malocclusion, 79.14 for Class II malocclusion, 77.54 for Class III malocclusion and 77.54 Class I normal occlusion. There was a statistically significant difference among malocclusion groups. Comparison of overall and anterior tooth size ratios between the sample of this investigation with Class I normal occlusion and the Bolton standards showed no statistically significant differences. Only five cases in Class II malocclusion presented an anterior tooth size discrepancy outside plus 2 SD from Bolton mean values and one case in Class I malocclusion presented with an overall tooth size discrepancy outside plus 2 SD from Bolton mean values.

**Conclusions:**

Based on the finding of this investigation the following conclusions could be presented regarding the Emirati sample which was studied:

- Class I normal occlusion cases presented similar overall and anterior tooth size ratios to Bolton standards.

- Overall and anterior tooth size ratios among occlusion and different malocclusion groups exhibited statistically significant differences.

- Five cases in Class II malocclusion presented an anterior tooth size discrepancy outside plus 2 SD from Bolton mean values.

- One case in Class I malocclusion presented with an overall tooth size discrepancy outside plus 2 SD from Bolton mean values.

# DEDICATION

***To my first teachers, my amazing father and my wonderful mother, for making me be who I am. Thank you for your endless love and infinite support***

***My dearest mother your help and support in sharing the care of my little baby means a lot to me and it is one of the reasons of what I achieved today***

***To my dearest husband, who has always been there for me***

***To my little prince Zayed, who accompanied me from the middle of this journey***

***To my beloved sisters and brothers, who have been caring and supportive all the way***

***To my best friends Eman, Asma, Hind and Sara thank you for continuous motivation, help and love***

***To all my friends and colleagues in the Department of Orthodontics, thank you for your support and kind wishes.***

## DECLARATION

I declare that all the content of the thesis is my own work. There is no conflict of interest with any other entity or organization.

Name: Moaza Ghuloom Mohammad

Signature:

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# GENERAL PART

## 1. Introduction

Orthodontic finishing is recognized for the multitude of detailed considerations necessary to achieve an excellent occlusal result. In many cases, the finishing phase is very difficult, requiring precise biomechanics to reach an optimal morphologic and functional occlusion. A high percentage of these finishing phases arise because of tooth size imbalances that could have been detected and considered as challenges during initial diagnosis and treatment planning. After completing orthodontic treatment, specific dimensional relationships should exist between the maxillary and mandibular teeth to ensure ideal conditions of interdigitation, overjet, and overbite (Smith et al., 2000).

Since natural teeth match well in most individuals, tooth size discrepancy of less than 1.5 mm is rarely significant, but larger discrepancies create treatment problems and must be included in the orthodontic problem list (Proffit, 2000). Patients with interarch tooth size discrepancies typically require special finishing steps, such as enamel removal (interproximal reduction) or crown material addition (composite buildups or porcelain veneers), to correct this discrepancy so that the teeth occlude properly. Good occlusion needs proportional tooth size relationships between dental arches. If large upper teeth are combined with small lower teeth, as in a denture setup with mismatched sizes, it is impossible to achieve ideal occlusion. The first investigations made in the field of tooth size measured a large number of human teeth and compiled tables of mean dimensions, which are still used as references today (Black, 1902).

Following Black's investigation, many authors studied tooth width in relation to occlusion, especially the 50s and 60s. They included studies of dental asymmetry in tooth size (Ballard, 1944), and the relationship of overbite with the maxillary/mandibular tooth size (Neff, 1949). Another method was also suggested for predetermining the overbite-overjet relationship of the anterior teeth by comparing the width of maxillary four incisors and one-half the width of canines to the full mesiodistal dimension of the six mandibular anterior teeth (Steadman, 1949). A review of existing European literature on intermaxillary tooth width ratio, tooth alignment and occlusion was published by Lundstrom (1954).

The best known study in the 50`s of tooth size disharmony in relation to the treatment of malocclusion was performed by Bolton (1958). He evaluated 55 cases with excellent occlusions. Bolton developed two ratios for estimating tooth size discrepancy by measuring the summed mesiodistal widths of the mandibular to the maxillary anterior teeth. A few years later, the data from this sample was then used to indicate the deviation from the ideal of any measured ratio and thus the size of the discrepancy. Later the same author published a form of his original tooth size analysis in which ratios and their statistical means were presented (Bolton, 1962). Bolton concluded that the anterior and overall ratios should be two of the tools used in orthodontic diagnosis; allowing the orthodontist to gain insight into the functional and esthetic outcome of a given case without the use of a diagnostic setup. During the same period, another method for assessing tooth size disharmonies and localizing them, if present in the posterior region, was introduced by dividing the dental arch into two segments and comparing maxillary and mandibular lengths (Cooper, 1960).

Bolton used a three-inch needle pointed divider to measure the mesiodistal width of all the teeth in each cast excluding second and third molars and the dimensions were taken to the nearest 0.25 mm using a finely calibrated millimeter ruler and recorded (Boley gauge). Dental plaster models have been the gold standard in diagnosis and treatment planning. They are the first and the only true three dimensional replication of the hard and soft tissue of a mouth (Stewart, 2001). Attempts have been made to transform dental plaster models into three dimensional models and currently many software packages are available to perform Bolton analysis electronically.

Digital photographs and radiographs are now routinely used, but digital dental models are still not widely utilized. Bolton tooth size analysis is commonly used as a diagnostic tool in Orthodontics since tooth size discrepancy is present in all populations. As there is no extant relevant data it would be valuable to investigate the overall and anterior tooth size ratios in a group of Emiratis.

# 2. Literature Review

## 2.1 Definition of tooth size discrepancy

The term of tooth size refers specifically to the mesiodistal widths of the teeth (Bolton, 1962). Tooth size discrepancy has conventionally been described as ``a relative excess of tooth structure in one arch, although the actual problem may be the result of localized or generalized reduced tooth size in the opposing arch`` (Fields, 1981).

Tooth size discrepancy has been also defined as disproportion among the sizes of individual teeth. An anomaly in the size of upper lateral incisors is the most common cause but variation in the premolars or other teeth maybe present. Occasionally all the upper teeth will be too large or too small to fit properly with the lower teeth (Proffit, 2007). Tooth size analysis, the degree of disproportional relationships between upper and lower teeth (in total or anterior) with regard to the mesiodistal dimension, often called Bolton analysis after its developer, is carried out by measuring the mesiodistal width of each permanent tooth excluding second and third molars (Proffit, 2007).

## 2.2 Prevalence of tooth size discrepancy

The prevalence of tooth size discrepancy in the general population has been estimated to be 5% (Johe et al., 2010; Bernabe et al., 2004).

The prevalence of tooth size discrepancy in the orthodontic population has been found to vary in overall ratios from 4% to 13.5% and in anterior ratios from 17% to 31% (Crosby and Alexander, 1989; Freeman et al., 1996; Santoro, 2000; Araujo and Souki, 2003; Othman and Harradine, 2006; 2007).

The varying prevalence of tooth size discrepancies in overall and anterior ratios according to different investigators is presented in Table 1 (Othman and Harradine, 2006).

Table 1. Summary of studies of the prevaleance of tooth size discrepancy (modified from Othman and Harradine, 2006).

| Author | Population | Sample size | % Anterior Tooth size discrepancy | % Overall Tooth size discrepancy |
|---|---|---|---|---|
| Crosby and Alexander (1989) | Orthodontic | 109 | 22.9 | - |
| Freeman et al (1996) | Orthodontic | 157 | 30.6 | 13.5 |
| Santoro et al (2000) | Orthodontic | 54 | 28.0 | 11.0 |
| Araujo and Souki (2003) | Orthodontic | 300 | 22.7 | - |
| Bernabě et al (2004) | School | 200 | 20.5 | 5.4 |

## 2.3 Methods of tooth size analysis

Several methods have been described to evaluate the interarch tooth size relationship such as diagnostic set-up (Kesling, 1945), anterior coefficient (Neff, 1949; 1957) and ratios for six anterior teeth (anterior ratios) or for twelve teeth (overall ratios) (Bolton, 1958). The total mesiodistal tooth diameters in the maxillary arch was found to exceed those in the mandibular arch by 8 - 12 mm, and a value greater than this resulted in an excessive overbite (Gilpatric, 1923).

The development of ``anterior coefficient`` which was a proportional measure for the width dimension of the teeth concluded that a ratio of 1.20 – 1.22, when the maxillary mesiodistal sum was divided by the mandibular mesiodistal sum, would result in an optimal overbite (Neff, 1949). Another report studied the relationship between mandibular and maxillary anterior sums, which was termed ``the anterior index``. Its optimal ratio was found to be from 73% to 85% with a mean of 79% for an ideal overbite (Lundstrom, 1954).

Bolton analysis is carried out by measuring the mesiodistal width of each permanent tooth. A standard table is then used to compare the summed widths of the maxillary to the mandibular anterior teeth and the total width of all upper to lower teeth (excluding second and third molars) (Table 2).

Table 2. The standard table comparing the summed widths of maxillary and mandibular teeth and the total width of upper to lower teeth excluding second and third molars (modified from Proffit, 2000).

| **Tooth Size Relationships** | | | |
|---|---|---|---|
| **Maxillary anterior sum of 3-3** | **Mandibular anterior sum of 3-3** | **Maxillary total sum of 6-6** | **Mandibular total sum of 6-6** |
| 40 | 30.9 | 86 | 78.5 |
| 41 | 31.7 | 88 | 80.3 |
| 42 | 32.4 | 90 | 82.1 |
| 43 | 33.2 | 92 | 84.0 |
| 44 | 34.0 | 94 | 85.8 |
| 45 | 34.7 | 96 | 87.6 |
| 46 | 35.5 | 98 | 89.5 |
| 47 | 36.3 | 100 | 91.3 |
| 48 | 37.1 | 102 | 95.0 |
| 49 | 37.8 | 104 | 96.8 |
| 50 | 38.6 | 106 | 98.6 |
| 51 | 39.4 | 108 | 100.4 |
| 52 | 40.1 | 110 | |
| 53 | 40.9 | | |
| 54 | 41.7 | | |
| 55 | 42.5 | | |

The proportion of total sum of mandibular / maxillary teeth (6-6), called the overall ratio, is 91.3 (SD: 1.91). The proportion of anterior sum mandibular / maxillary teeth (3-3), called the anterior ratio, is 77.2 (SD: 1.65). No significant discrepancy exists within 1 SD (Bolton, 1958) or up to 1.5 mm (Proffit, 2000). However, others had suggested that even within 2 SD there should be no abnormality (Crosby and Alexander, 1989; Freeman et al., 1996). Different kinds of forms have been proposed for performing the Bolton analysis (Tables 3 and 4) (Hohlt and Hovijitra, 1999).

Table 3. Bolton analysis measurement form (modified from Hohlt and Hovijitra, 1999).

| | | | |
|---|---|---|---|
| Name: | P.B | D.O.B.: | |
| Sex: | F | Ethnicity: | Caucasian |
| Malocclusion: | I | | |

**Mesio-distal Tooth Measurements in Millimeters**

| Maxillary Tooth # | Trial 1 | Mandibular Tooth # | Trial 1 |
|---|---|---|---|
| 3 | 9.59 | 19 | 10.44 |
| 4 | 6.32 | 20 | 6.73 |
| 5 | 6.59 | 21 | 6.68 |
| 6 | 7.36 | 22 | 6.05 |
| 7 | 5.83 | 23 | 5.35 |
| 8 | 7.77 | 24 | 4.63 |
| 9 | 7.40 | 25 | 4.40 |
| 10 | 5.72 | 26 | 5.32 |
| 11 | 7.05 | 27 | 6.58 |
| 12 | 6.67 | 28 | 6.68 |
| 13 | 6.39 | 29 | 6.82 |
| 14 | 9.68 | 30 | 10.47 |

**Anterior Ratio**: $\frac{\textbf{Mandibular 6} \times \textbf{100}}{\textbf{Maxillary 6}} \qquad \frac{\textbf{32.33 mm}}{\textbf{41.13 mm}} \times \textbf{100} = \textbf{78.60}$

**Posterior Ratio**: $\frac{\textbf{Mandibular 12} \times \textbf{100}}{\textbf{Maxillary 12}} \qquad \frac{\textbf{80.15 mm}}{\textbf{86.37 mm}} \times \textbf{100} = \textbf{92.79}$

Mean anterior ratio 77.2; mean posterior ratio 91.3.

Table 4. Bolton analysis measurement form (modified from Hohlt and Hovijitra, 1999).

**Bolton Analysis Tooth Size Discrepancies**

| **Overall Ratio:** 12 Permanent teeth from first molar to first molar | | | | | |
|---|---|---|---|---|---|
| Sum mandibular "12" ______ mm | | | | S.E.M. | 0.26 |
| ______ + ______ x 100 = ______ % | | | | Mean | 91.3 |
| | | | Overall Ratio | SD | 1.91 |
| | | | | Range | 87.5 to 94.8 |
| | | "12" | | | |
| Max. | Mand. | Max. | Mand. | Max. | Mand. |
| | | | | | |
| 85 | 77.6 | 94 | 85.8 | 103 | 94.0 |
| 86 | 78.5 | 95 | 86.7 | 104 | 95.0 |
| 87 | 79.4 | 96 | 87.6 | 105 | 95.9 |
| 88 | 80.3 | 97 | 88.6 | 106 | 96.8 |
| 89 | 81.3 | 98 | 89.5 | 107 | 97.8 |
| 90 | 82.1 | 99 | 90.4 | 108 | 98.6 |
| 91 | 83.1 | 100 | 91.3 | 109 | 99.5 |
| 92 | 84.0 | 101 | 92.2 | 110 | 100.4 |
| 93 | 84.9 | 102 | 93.1 | | |
| | | | | | |

**Patient Analysis**

**If overall ratio exceeds 91.3:***

$$\frac{80.15}{\text{Actual mand. "12"}} - \frac{78.50}{\text{Correct mand. "12"}} = \frac{1.65}{\text{Excess mand. "12"}}$$

**If overall ratio is less than 91.3:**

$$\frac{\quad}{\text{Actual max. "12"}} - \frac{\quad}{\text{Correct max. "12"}} = \frac{\quad}{\text{Excess max. "12"}}$$

| **Anterior Ratio:** 6 permanent teeth from canine to canine | | | | | |
|---|---|---|---|---|---|
| Sum mandibular "6" ______ mm | | | | S.E.M. | 0.22 |
| ______ + ______ x 100 = ______ % | | | | Mean | 77.2 |
| | | | Anterior Ratio | SD | 1.91 |
| | | | | Range | 74.5 to 80.4 |
| | | "6" | | | |
| Max. | Mand. | Max. | Mand. | Max. | Mand. |
| 40.0 | 30.9 | 45.5 | 35.1 | 50.5 | 39.0 |
| 40.5 | 31.3 | 46.0 | 35.5 | 51.0 | 39.4 |
| 41.0 | 31.7 | 46.5 | 35.9 | 51.5 | 39.8 |
| 41.5 | 32.0 | 47.0 | 36.3 | 52.0 | 40.1 |
| 42.0 | 32.4 | 47.5 | 36.7 | 52.5 | 40.5 |
| 42.5 | 32.8 | 48.0 | 37.1 | 53.0 | 40.9 |
| 43.0 | 33.2 | 48.5 | 37.4 | 53.5 | 41.3 |
| 43.5 | 33.6 | 49.0 | 37.8 | 54.0 | 41.7 |
| 44.0 | 34.0 | 49.5 | 38.2 | 54.5 | 42.1 |
| 44.5 | 34.4 | 50.0 | 38.6 | 55.0 | 42.5 |
| 45.0 | 34.7 | | | | |

**Patient Analysis**

**If anterior ratio exceeds 77.2:***

$$\frac{32.33}{\text{Actual mand. "6"}} - \frac{31.70}{\text{Correct mand. "6"}} = \frac{0.63}{\text{Excess mand. "6"}}$$

**If anterior ratio is less than 77.2:**

$$\frac{\quad}{\text{Actual max. "6"}} - \frac{\quad}{\text{Correct max. "6"}} = \frac{\quad}{\text{Excess max. "6"}}$$

***** The discrepancy is excessive mandibular tooth mass. In the overall ratio chart above left, locate the patient's maxillary "12" measurement; opposite it is the ideal or "correct" mandibular measurement. The difference between the actual and correct mandibular measurement is the amount of excess mandibular tooth mass. The other calculations for excess mandibular and maxillary tooth size are performed similarly.

Peck and Peck (1972) found statistically significant differences in both the mesiodistal (MD) and faciolingual (FL) dimensions of mandibular incisors, between a perfectly aligned and control populations of untreated females. Combining these measures into an index (MD/FL X 100) they formulated ideal size ranges required for central and lateral incisors for them to be well aligned. They recommended mesiodistal reduction of incisors to bring them within this range and prevent further crowding.

It is important to have a method of measurement which is time efficient and easy to use for wide spread application. Equally, no method of measurement is robust without good documentation of its reproducibility. The reliability of the Bolton analysis, when performed with two instruments (needle-pointed dividers and Boley gauges), and the effect of crowding on measurement error have been evaluated. It was found that clinically significant measurement errors could occur when the Bolton tooth size analysis is performed on casts having at least 3 mm of crowding, a factor that should lead clinicians to undertake a tooth size discrepancy analysis in substantially crowded cases only when the teeth have been aligned (Shellhart et al., 1995). Since variations in tooth thickness may produce inaccuracies in the Bolton analysis ratio, a method of predicting anterior tooth size discrepancy that takes into account both tooth thickness and width has been suggested (Rudolph et al., 1998). These methods proved better than Bolton ratios in predicting tooth size discrepancies, indicating that tooth thickness combined with mesiodistal width may be useful in predicting intermaxillary tooth size discrepancies. The same measurement errors may be associated with the positioning of the calipers on the teeth (Ho and Freer,1999). The traditional methods of measuring mesiodistal widths of teeth on dental casts can be described as manual methods and have either employed needle-pointed dividers or Boley gauges or Vernier calipers (Othman and Harradine, 2006).

Technological advances have allowed the introduction of digital calipers, which can be linked to computers for rapid calculation of the anterior and overall ratios and the required correction to produce Bolton ratios. Alternatively, digitized or scanned images of the study casts can be measured on screen. The use of digital calipers with direct input into the computer program can virtually eliminate measurement transfer and calculation errors, compared with analysis that requires dividers, rulers and calculators.

A study comparing manual measurements with a Vernier caliper and three computerized methods showed QuickCeph® was the quickest method followed (in order) by HATS®, OrthoCad® and Vernier calipers. However, QuickCeph® produced results with the greatest mean discrepancy from Vernier calipers, although it was not statistically significant, and which were least correlated with the Vernier caliper results (Tomassetti et al., 2001). Another study compared measurements done with digital calipers and OrthoCad®. It was found that measurements with digital calipers produced the most accurate and reproducible results, but these were not greatly improved relative to the results from OrthoCad®. Digital calipers seem to be a more suitable instrument for scientific work, but OrthoCad® accuracy was considered clinically acceptable (Zilberman et al., 2003).

Arkutu (2004) evaluated commonly used means of assessing a Bolton discrepancy to the gold standard, which was defined as the measurement with a Vernier caliper to 0.1 mm. Anterior and overall ratios were calculated using four methods: (1) eyeballing or simply looking; (2) quick check by comparing the size of the laterals and second premolars; (3) calipers and stainless steel ruler (0.5 mm); and (4) Vernier calipers (0.1 mm). Sensitivity and specificity tests were performed and the study found that, when compared with actual measurement with calipers, these rapid, visual tests are poor at detecting a lack of Bolton discrepancy, and very poor at correctly identifying a significant Bolton discrepancy. This may further explain the subjective clinical view that significant tooth size discrepancy is much less common than several studies have reported.

Some well-known studies of tooth size discrepancy did not report the measurement error at all. Another study reported that if any quantitative investigation is of value, it is imperative that such error analysis be undertaken and reported. The reproducibility of all these methods of measurement has not been adequately explored (Houston, 1983). On the other hand, other studies reported very incomplete measurement of error (Crosby and Alexander, 1989; Araujo and Souki, 2003; Bernabe et al., 2004).

## 2.4 Methodological aspects in using electronic models for assessing dental casts

Successful orthodontic treatment is based on accurate diagnosis and good treatment planning. Dental casts, photographs, radiographs, and clinical examination provide essential information for diagnosis. In fact, dental casts provide a three dimensional view of the patient's occlusion; this enables the clinician to evaluate the malocclusion in more details than by a clinical examination (Grunheid et al., 2014).

In Orthodontics, plaster study models are a standard component of orthodontic records and fundamental for diagnosis, case presentation, treatment planning, evaluation of treatment progress, retention follow up and record keeping. Common diagnostic parameters which are measured on plaster models include tooth size, dental arch space analysis and dimensions, overjet, overbite, occlusal indices and tooth size discrepancy analysis also using the Bolton method.

Historically, orthodontists have used dental models made from plaster, and fabricated by proper impression and poured-up with gypsum. These models provide an accurate representation of a patient's dentition and surrounding structures (Peluso et al., 2004; Naidu et al., 2009). However, plaster models have limitations including risk of breakage, chipping, abrasion, time consuming for their fabrication, cost and need for storage rooms (Peluso et al., 2004; Kau et al., 2011). Even so, the current gold standard for study models analysis involves plaster casts measured with calipers (Akyalcin et al., 2013). In recent years, three dimensional virtual study models have grown in popularity in dentistry. The available literature on three dimensional virtual dental study models has largely focused on those acquired by laser, while others have investigated holographic scanning, stereo-photogammetry capture and more recently, cone-beam computed tomography (CBCT).

Electronic study models were introduced commercially in the late 90s. Ho and Freer (1999) used a computerized version of their Graphical Analysis of Tooth-Width Discrepancy (GATWD) and determined that the use of digital calipers can virtually eliminate measurement transfer and calculation errors. Since many types of digital electronic models are available on the market today, they need to be evaluated in the practice of evidence-based clinical orthodontics and it is the responsibility of the orthodontic community to weight the advantages and disadvantages of these new tools to determine their usefulness. Obviously, the potential advantages of digital models would be negated if the accuracy and efficiency of their measurements were not comparable with those taken on plaster models. Three studies have reached the same conclusion: that digital casts can be an alternative to, or good replacement for conventional plaster models (Santoro et al., 2003; Stevens et al., 2006; El- Zanaty et al., 2010).

Technological advances have allowed orthodontists to perform measurements on digital models which alleviate many of the obstacles encountered with plaster models. Currently, most digital models are made from alginate impressions, which are either scanned directly or poured in plaster and then scanned. Digital models are not subject to physical damage or degradation, the digital file can be easily transferred to other clinicians or retrieved at multiple locations, and digital storage is easy and effective because it eliminates problems related to physical storage of traditional plaster models. As a result of these advantages and their diagnostic versatility as well as, increasing affordability, more orthodontists are incorporating digital models into their practices (Bell et al., 2003; Rheude et al., 2005).

Proffit (2000) stated that one advantage of digitizing tooth dimensions for space assessment is that the computer can quickly provide a tooth size analysis. In a systematic review by Keating et al. (2012) it was concluded that digital models offer a high degree of validity, and measurement differences are likely to be clinically acceptable. Nouri et al. (2014) stated that the reliability of the measurements performed on three dimensional casts was higher than that for measurements on plaster models. No statistically significant differences were found in Bolton anterior ratios and Bolton overall ratios between traditional digital caliper measurement on plaster dental models and stereomicroscopic digital dental models (Shahid et al., 2016). Different technologies can be used to generate electronic study models making standardization issues critically important.

Many studies have compared efficient orthodontic tooth measurements using digital casts and plaster models. Measurement by digital calipers was found to be more rapid than the manual odonto-rule method (Othman and Harradine, 2007). Bolton analysis performed using electronic models can be as accurate as, and significantly faster than, the traditional method of digital calipers and plaster models (Mullen et al., 2007). The occlusal measurement technique for digital models produced the best combination of accuracy, repeatability, and speed of measurement (Horton et al., 2010). Moreover, a clinician who has switched to using electronic model software can be confident in the diagnosis that tooth width measurements on digital models can be as accurate as, and might be more reproducible and significantly faster than, those taken on plaster models (Grunheid et al., 2014).

The diagnostic accuracy and measurement sensitivity of electronic models compared to plaster casts are frequently investigated issues. A systematic review of the literature focused on the comparisons of linear and transverse measurements on digital models and plaster casts using digital calipers. The review was investigating the validity of using digital models to assess tooth size, Bolton ratios, arch length, irregularity index, arch width, inter-arch occlusal features, occlusal indices, crowding and time taken to perform measurements using the two approaches. The absolute mean differences between direct and indirect measurements on plaster and digital models were minor and clinically insignificant. Orthodontic measurements with digital models were comparable to those derived from plaster models. Moreover, the use of digital models offered high degree of validity when compared to direct measurement on plaster casts and could be considered as an alternative to conventional plaster models (Fleming et al., 2011).

The agreement between transverse dimensional readings obtained using digital and plaster models has been verified with the dimensions considered including mandibular and maxillary inter-canine, inter-premolar and inter-molar widths. Mean discrepancies between the two approaches ranged from 0.04 to 0.4 mm. Generally, these differences were small and unlikely to be of clinical significance (Bell et al., 2003; Quimby et al., 2004; Goonewardene et al., 2008; Watanebe et al., 2009).

The reliability of non-specific measurements between various defined occlusal landmarks with both sagittal and transverse components has been also investigated. These studies described similar levels of consistency with mean discrepancies of 0.14 and 0.27 mm reported respectively, between plaster and digital models. Consequently, combinations of anteroposterior and transverse measurements appear to have similar reliability to purely transverse or sagittal measurements by (Bell et al., 2003; Keating et al., 2008).

Differences in individual tooth size with digital and direct plaster methods have been measured in the mesiodistal and vertical dimensions. Tooth size has also been used indirectly to calculate Bolton tooth size ratios, arch length and tooth size–arch length discrepancy. In general minor mean differences in mesiodistal tooth dimension of 0.01–0.3 mm were reported in overall ratios (Santoro et al., 2003; Redlich et al., 2008; Goonewardene et al., 2008; Wantanebe et al., 2009; Horton et al., 2010).

Comparison of Bolton tooth size analysis has been performed on digital and plaster models (Tomassetti et al., 2001; Stevens et al., 2006; Mullen et al., 2007) and an acceptable agreement between the two methods was demonstrated. Stevens et al. (2006) described an anterior discrepancy of 0.6 mm; however, Mullen et al. (2007) reported an overall mean difference of just 0.05 mm. Stevens et al. (2006) found an overall discrepancy of 0.38 mm using electronic models. While Tomassetti et al. (2001) found a more significant difference of 1.02–1.2 mm between direct measurement on plaster models and digital measurement using OrthoCad.

Overall, arch length, crowding and space analysis were measured on digital and plaster casts (Quimby et al., 2004; Stevens et al., 2006; Redlich et al., 2008; Goonewardene et al., 2008; Leifert et al., 2009). With respect to arch length, discrepancies between both techniques ranged from 0.19 to 0.8 mm and the difference between the measurements of crowding obtained with the techniques varied from 0.19 mm to 0.42 mm.

The irregularity index in both the maxillary and mandibular arches was measured by Goonewardene et al. (2008) on digital and plaster casts. Identical mean levels of irregularity were calculated with both techniques using OrthoCad digital models.

Agreement in measurements of overjet and overbite has been found between digital and plaster models (Santoro et al., 2003; Ouimby et al., 2004; Stevens et al., 2006; Watanebe et al., 2009). The concordance of measurement of posterior crossbite and centerline discrepancy was also confirmed by Stevens et al. (2006).

Acceptable concordance between digital and plaster models in relation to the severity of malocclusion using Peer Assessment Rating (PAR), Index of treatment Complexity, Outcome and Need (ICON) and American Board of Orthodontics discrepancy index (ABO) scores has been demonstrated. The agreement between manual and digital measurements was high with respect to both PAR (Mayer et al., 2005; Stevens et al., 2006) and ICON (Veenema et al., 2009). In relation to the ABO score, several studies reported similarities between the techniques and the differences between the measurement methods were small (Costalos et al., 2005; Okunami et al., 2007; Hildebrand et al., 2008).

The difference in the time required to perform a variety of occlusal measurements between digital model and plaster casts has been assessed (Tomassetti et al., 2001; Mullen et al., 2007; Horton et al., 2007). These studies suggest a significant time saving with digital techniques although a significant learning curve and period of adjustment are likely to be required. Relatively minor differences were described by Horton et al. (2007) (2 min) and Mullen et al. (2007) (1 min). The approach to digital measurement is also believed to have an impact, with manipulation of the model being necessary to perform specific measurements. Differences may also arise regarding software and familiarity with the technique.

Another systematic review reported high intra-rater reliability for assessing using two landmark linear parameters including overjet; overbite; maxillary and mandibular mesiodistal tooth sizes from first molar to other first molars as well as maxillary and mandibular inter-molar and inter-canine widths, performed on laser acquired models and CBCT acquired models. They were similar to the measurements acquired on plaster models (Luu et al., 2012). Validity was high for two landmark linear measurements comparing laser acquired models or CBCT acquired models to plaster casts, and the mean differences were clinically insignificant. Agreement of measurements was excellent, with less variability than correlation. Acquisition method had no perceived influences on reliability and validity. Virtual study models are clinically acceptable compared with plaster study models with regard to intra-rater reliability and validity of selected linear measurements (Luu et al., 2012). This review agreed with a previously mentioned study reported by Fleming et al. (2011).

Comparisons of Bolton tooth size analyses were performed between the plaster and digital models and between the CBCT and digital models. Naidu and Freer (2013) reported discrepancies of 0.91 mm for the anterior Bolton ratio and 0.21 mm for the overall Bolton ratio, both of which were statistically significant.

Other studies, however, have noted statistically significant differences between the plaster and digital methods, a report found differences of about 1.02 to 1.2 mm from Bolton mean values using OrthoCad (Tomassetti et al., 2001), similar results comparing measurements from CBCT models and a two dimensional digital measuring technique reported a difference in anterior and overall Bolton ratio of about 0.15 mm and 0.06 mm respectively, (Tarazona et al., 2012; Wiranto et al., 2013), while Nalcaci et al. (2013) reported difference in anterior ratios: 1.8 mm for maxillary anterior teeth and 1.6 mm for mandibular anterior teeth, while difference in overall ratios were 4.3 maxillary 6-6 and 4.5 for mandibular 6-6 from Bolton mean values. Moreover, in the same year Akyalcin et al. (2013) reported a significant difference of 0.4 mm from anterior Bolton ratios in three digital model systems: a stereolithography model obtained from a three dimensional laser desktop scanner using Ortho Insight 3D, electronic model system, and CBCT which can provide diagnostic information similar to caliper measurements with varying degrees of agreement limits. Although all three digital model groups displayed good correlation with caliper measurements, the virtual scan models had the highest intraclass correlation with the manual method (ICC > 0.95). All three digital model systems can provide diagnostic information similar to caliper measurements, with varying degrees of agreement limits.

The differences between plaster and digital models were found to be 0.83 mm for anterior Bolton ratios and 0.87 mm for overall Bolton ratios (Hajeer, 2014).

Margreet et al. (2012) concluded that stereolithographic and digital models made with an intraoral scanner are a valid and reproducible method for measuring distances in a dentition.

Many studies have evaluated the reliability between plaster models and digital casts including the digital casts obtained from CBCT. Hajeer (2014) calculated the Houston coefficient of reliability between methods, with results between 0.96 and 0.99 of high reliability. Akyalcin et al. (2013) calculated a 0.99 ICC for crowding in both the maxillary and the mandibular arches comparing caliper measurements with digital model systems and CBCT casts. High reliability was also confirmed by Lightheart et al. (2012) and by Tarazona et al. (2012) who concluded that CBCT digital models are as accurate and reliable as the digital models obtained from plaster casts.

Abizadeh et al. (2012) found good reliability between methods except for mandibular inter canine width, where digital values were significantly higher than plaster ones. Goonewardene et al. (2008) measured the reliability and validity of tooth size-arch length discrepancies (TALD), irregularity indices and arch lengths (four and six segment analysis) measured directly on study models with digital calipers, with the same measurements measured on digital copies of the study models with proprietary software. There were high ICC values ranging from 98.6-99.9% for both the irregularity indices and the TALDs. The choice of manual over computer and four segment over six segment analysis had a significant effect when measuring lower arch lengths ($p < 0.05$), but they had no effect on the upper arch findings. Reliable measurements of the irregularity index and the TALD can be made on digital models. Computer measurements of TALDs on digital models were more consistent than manual measurements of TALDs on plaster models. Six segment analysis of lower arch lengths on digital and plaster models gave more consistent findings than the four segment analysis.

Only one study observed relevant differences in reliability between measurements. More precisely, the models from CBCT are not sufficiently reliable in reconstructing the occlusal surfaces when producing three dimensional casts. Thus, digital models obtained by an intraoral scanner or a three dimensional scan of plaster models should be better than CBCT models (De Waard et al., 2014). With the increased use of CBCT in orthodontics, several companies have introduced another method of digital model fabrication. Sophisticated software algorithms now allow digital model fabrication from a patient’s CBCT scan thus, eliminating the need for conventional impressions.

## 2.5 Tooth size discrepancy among different types of malocclusion

Studies of the prevalence of tooth size discrepancy among different malocclusion groups, throughout the years, have led to various results. A significant number of investigations concluded that there are no differences in the prevalence of tooth size discrepancy between Class I, Class II and III malocclusion groups (Crosby and Alexander, 1989; Alkofide and Hashim, 2002; Liano et al., 2003; Uysal et al., 2005; Basaran et al., 2006; Akyalcin et al., 2006; Hasija et al., 2014; Cançado et al., 2015; Shastri et al., 2015). Other studies documented the prevalent tendency for intermaxillary tooth size discrepancies for both the anterior and overall ratios among different malocclusion groups (Arya et al., 1974; Nie and Lin, 1999; Qiong and Jiuxiang, 1999; Al-Khateeb and Abu Alhaija, 2006; Oktay and Ulukaya, 2010; Filipović et al., 2010; O'Mahony et al., 2011). Class II malocclusion patients showed a tendency toward wider mesiodistal widths of teeth in the mandibular anterior region or smaller tooth sizes in the maxillary anterior region (Shastri et al., 2015).

One of this type of reports did not include Class III malocclusion samples (Crosby and Alexander, 1989). However, other studies where Class III malocclusion groups were part of the sample concluded significant tooth size discrepancy in this type of malocclusion (Lavelle, 1972; Sperry et al., 1977; Alkofide and Hashim, 2002; Liano et al., 2003; Araujo and Souki, 2003; Alkateeb and Abu Alhaija, 2006; McSwiney et al., 2014; O'Mahony et al., 2011; Wedrychowska et al., 2010; Prasanna et al., 2015). The teeth in the lower arch are larger in Class III malocclusion with the inference that a Bolton discrepancy is likely to be greater in Class III malocclusion than in other malocclusion groups (Lavelle, 1972; Alkofide and Hashim, 2002). Similarly, in another report, mandibular tooth size excess of the overall ratio was greater in cases of mandibular prognathism (Sperry et al., 1977).

A high prevalence of tooth size discrepancies in an orthodontic patient population has been statistically significantly correlated with some dental characteristics. Bolton anterior ratio discrepancies had significant correlations with midline shifts in Class I malocclusion, with U1-SN angle in Class II malocclusion and with L1-APog distance in Class III malocclusion. Tooth size discrepancies related to overall ratios had significant correlations with overjet in Class I malocclusion, with overbite and U1-SN angle in Class II malocclusion, and with IMPA in Class III malocclusion (Akyalcin et al., 2006).

Increased anterior tooth size ratio in subjects with dental midline discrepancy and increased overall ratio in subjects with decreased overjet or overbite have also been observed. These occlusal characteristics might be considered as predictors of tooth size discrepancies (Alam and Iida, 2013).

## 2.6 Tooth size discrepancy in relation to gender

It is important to differentiate gender differences in tooth size discrepancy from differences in absolute tooth size. There is a variation in tooth size between sexes and in relation to different geographical regions. Male teeth are generally recognized to be larger than female teeth (Lavelle, 1972; Arya et al., 1974; Smith et al., 2000; Alkateeb and Abu Alhaija, 2006; Al-Gunaid et al., 2012; Bugaighis et al., 2015).

While research on twins has helped in understanding the genetic contribution on tooth size (Horowitz et al., 1958; Osborne et al., 1959), other investigators have down played the genetic contribution and described the determination of tooth size as multifactorial, with the environment playing an important role in tooth formation (Stewart and Prescott, 1979).

The teeth of Black North American males were larger than those of females for each type of tooth in both arches, but there were no differences in anterior or posterior interarch tooth size proportions (Richardson and Malhotra, 1975), whereas, the same study found that the upper lateral incisors and lower incisors are the most homogenous. Gender differences have also been reported between the upper canines and upper central incisors in primary and permanent dentitions (Doris et al., 1981) and that canines and molars were significantly larger in boys than in girls (Bishara et al., 1989).

With regards to tooth ratios, the 0.7% difference for overall ratios and 0.6% difference for anterior ratios between sexes were small, being much less than 1 SD from Bolton sample (Smith et al., 2000). Some of those studies where a small difference has been found noted that males had slightly larger ratios than females (Lavelle, 1972; Smith et al., 2000). One study found tooth size ratios of females to be higher than those of males (Adeyemi et al., 2010).

Although, significant differences in tooth size between males and females have been reported in general, there is no evidence of a significant gender difference of upper to lower anterior tooth size (Richardson and Malhotra, 1975; Nie and Lin, 1999; Smith et al., 2000; Alkofid and Hashim, 2002; Arujon and Souki, 2003; Al-Tamimi and Hashim, 2005; Endo et al., 2008; Kachoei et al., 2011; Hashim et al., 2015; Shahid et al., 2016).

## 2.7 Tooth size discrepancy among different ethnic/racial groups

Ethnicity has been found to be a factor in tooth size discrepancy. Several studies have concluded that tooth width ratios vary between racial and ethnic groups, and therefore that these should be calculated specifically with regards to each patient's ethnic background (Bishara, 2001). Bolton (1958) based his study upon a heterogeneous Caucasian population sample and, hence, provides no information relating to other ethnic groups.

Tooth size discrepancies are common in orthodontic populations and are evenly distributed among ethnicity categories, with some exceptions. A study reported 50% of the subjects had anterior Bolton tooth-size discrepancies, and 41% had overall Bolton tooth-size discrepancies of ±1 SD. Compared with Caucasian and Hispanic patients, African-American patients had significantly greater chance of having a clinically significant (±2 SD) anterior ratio. When the numbers of subjects above or below the clinically significant ratio were compared, there was equal distribution of maxillary and mandibular excess in Class II and Class III malocclusion patients. Caucasian and African-American patients had equal distributions of maxillary and mandibular excess, whereas Hispanic patients displayed a higher bias toward mandibular excess (Johe et al., 2010).

Investigations on tooth size discrepancy characteristics and trends have been made into different ethnic groups including Caucasoids, Negroids and Mongoloids (Lavelle, 1972), Blacks (Merz et al., 1991), Dominican Americans (Santoro et al., 2000), Blacks, Hispanics and Whites, (Smith et al., 2000), Saudi (Alkofide and Hashim, 2002; Al-Tamimi and Hashim, 2005), Peruvian (Bernabe et al., 2004), Brazilian (Freire et al., 2007), Turkish (Uysal and Sari, 2005), Syrian (Nourallah et al., 2005), Jordanian (Al-Khateeb and Abu Alhaija, 2006), Spanish (Paredes et al., 2006), Moroccan (Regragui et al., 2006), Japanese (Endo et al., 2008), Nigerian (Adeyemi et al., 2010), Thai (Manopatanakul and Watanawirun, 2011), Irish (O'Mahony et al., 2011), Iranian (Mirzakouchaki el al., 2007; Kachoei et al., 2011), South Indian (Doodamani et al., 2011), Black South Africans (Singh et al., 2011), Yemeni (Al-Gunaid et al., 2012), Bangladeshi (Alam and Iida, 2013), North Indian (Shastri et al., 2015), Sudanese (Hashim et al., 2015), Libyan (Bugaighis et al., 2015) and Pakistani (Shahid et al., 2016).

When three ethnic groups were investigated both mean values of overall and anterior ratios were greater in Negroids than in Caucasoids, with those for Mongoloids being intermediate (Lavelle, 1972).

Dominican Americans presented overall ratio equivalent to the Bolton one whereas the anterior ratio was 1 mm larger than Bolton standards. The prevalence of overall tooth size discrepancy was found in 11% (Santoro et al., 2000).

In the study of by Smith et al. (2000) Black people had the highest overall tooth size ratios (93.4%) followed by Hispanics (92.3%) and then Whites (91.2%). The anterior ratios, however, were statistically significantly larger in Hispanics (80.5%) than Blacks (79.3%). Despite, these findings, it has been stated that the trend to larger overall tooth size ratios in Black populations is unlikely to be clinically relevant (Othman and Harradine, 2006).

Saudis presented no statistically significant difference in the incidence of tooth size discrepancies for the overall ratio and anterior ratio between the different malocclusion groups, except for the anterior ratio in Class III malocclusion. Further, no statistically significant difference was observed between males and females when the mean values of their study were compared to Bolton standards (Alkofide and Hashim, 2002).

A few years later another study also on Saudi subjects reported similar results to the previous investigation with no statistically significant differences between the mean values of overall and anterior ratios and the Bolton standards between sexes. Therefore, it was suggested that Bolton prediction tables can be used for Saudis until a large enough representative sample is studied to allow the drawing of prediction tables (Al-Tamimi and Hashim, 2005).

When Peruvian ethnic group was investigated clinically significant tooth size discrepancies in almost one third of the sample were found (Bernabe et al., 2004).

A study on Caucasian Brazilian individuals found no statistically significant tooth size discrepancy among the studied population; with the mean values obtained by overall and anterior ratios being very close to the normal values suggested by Bolton (Freire et al., 2007).

Turkish subjects with normal occlusion reported that the mesiodistal dimensions of maxillary teeth showed greater variability than mandibular teeth, with the first molar dimensions having greater variability. The overall and anterior ratios were found to be 89.88 +/- 2.29 and 78.26 +/- 2.6 respectively. According to Bolton values outside 2 SD found in 18% for the overall ratio and in 21.3% for the overall ratios (Uysal and Sari, 2005).

Analysis of a Syrian sample found mean values similar to those expected from the Bolton ratios (anterior ratio 78.99 with 2.18 SD, overall ratio 92.26 with 2.06 SD), so that these normative standards can be applied in this population (Nourallah et al., 2005).

When Jordanians were studied no statistically significant differences in overall ratio (91.3 with 2.75 SD) and anterior ratio (78.2 with 3.49 SD) from Bolton standards were found (Alkateeb and Abu Alhaija, 2006).

An investigation of Spanish subjects showed results where 21% had a significant anterior discrepancy greater than 2 SD from Bolton standards and 5% had an overall discrepancy. It was concluded that difference between Spanish mean values and Bolton standards were statistically significant and more studies were needed to get specific standards for this ethnic group (Paredes et al., 2006).

A Moroccan ethnic group showed a high percentage of patients with 2 SD outside Bolton values. Several patients presented significant disharmony that could affect their orthodontic treatment and would have to be taken into consideration when establishing proper treatment planning (Regragui et al., 2006).

When a Japanese sample was researched, it was found that Bolton mean values can be used with confidence in this ethnic population since the norms were not significantly different between the two samples (Endo et al., 2008).

A study in a Nigerian population calculated values for overall and anterior ratios (92.5 +/-0.5 and 79.0 +/-0.5) respectively. When the Bolton formula for tooth size discrepancy was applied, the tooth size ratios for females were found higher than those of males (Adeyemi et al., 2010).

When a mixed population of Thai and Chinese groups were investigated, a close correlation between mean values of Thai sample and Bolon standards was detected (Manopatanakul and Watanawirun, 2011).

The prevalence of anterior tooth size discrepancies in Irish orthodontic patients was about 37.9% (O'Mahony et al., 2011).

Iranian Azari and Tabriz subjects presented no significant differences in overall and anterior tooth size ratios with Bolton standards (Mirzakouchaki et al., 2007; Kachoei et al., 2011).

South Indian adults exhibited mean values similar to Bolton standards (Doodamani et al., 2011).

Black South Africans with excellent occlusions were investigated and demonstrated anterior ratios equivalent to Bolton ones, whereas the overall ratio was significantly larger than Bolton overall standards. The results indicate that anterior ratio may be particularly useful when assessing and planning esthetic alignment of the anterior segment (Singh et al., 2011).

Yemeni subjects presented no significant differences in overall and anterior tooth size ratios with Bolton standards (Al-Gunaid et al., 2012).

Observations have been made of increased overall and anterior tooth size ratios in Bangladeshi subjects (Alam and Iida, 2013).

North Indian patients showed tendency toward slight wider mesiodistal width of teeth in the anterior region of Class II malocclusion patients (78.14 with 4.09 SD) while overall ratios were similar to Bolton standards (Shastri et al., 2015).

In Sudanese subjects results of overall and anterior ratio were relatively similar to the values reported by Bolton (Hashim et al., 2015).

Libyan subjects showed significantly wider mesiodistal tooth width in males compared to females except for maxillary first premolars and mandibular central incisors. The mean for anterior tooth size ratios were (78.2 with 2.6 SD) while overall ratios were (91.3 with 2.1 SD) and no significant gender differences were found (Bugaighis et al., 2015).

Pakistani subjects were found to present no significant difference in anterior and overall ratios between males and females compared to Bolton standards (Shahid et al., 2016).

It may be summarized that many different ethnic groups display results similar to Bolton ratio standards. On the other hand, significant discrepancies in the overall and anterior tooth size ratios have been found in other ethnic samples.

## 2.8 Orthodontic management of tooth size discrepancy

The clinician should be aware of discrepancies in tooth size at the initial diagnosis and treatment planning stages if excellence in orthodontic finishing is to be achieved. Andrew's six keys to normal occlusion are a widely quoted set of static occlusal goals for tooth relationships in the maximum intercuspal position (Andrew, 1972). Interarch tooth size discrepancy may influence treatment decisions to obtain an optimal final occlusion, overjet and overbite. A significant variation in the relationship of the total mesiodistal width of maxillary to mandibular teeth should be compensated for in treatment planning by considering esthetic restorations procedures, prosthodontic re-contouring, interproximal enamel reduction, dental extractions, space distribution and changes in overjet and overbite (Freeman et al., 1996).

The intended purpose of the tooth size discrepancy ratio as a diagnostic aid was to gain insight in to the functional and esthetic outcome of a given case without use of diagnostic set-up (Bolton, 1958). A relative mandibular anterior excess may be recognized clinically or by application of the Bolton analysis. The gold standard for identification of tooth size discrepancy is a diagnostic set-up which will approximate closely the true extend of the problem and will give an idea about the most acceptable and achievable measurement procedure. Each tooth size discrepancy might present in localized or generalized way. The localized mesiodistal deficiency is relative to adjacent teeth and can be assessed in anthropometric norms (Grauer et al., 2012).

Several conditions can contribute to a relative mandibular excess including (1) generalized large mandibular anterior teeth relative to maxillary anterior teeth; (2) generalized small maxillary anterior teeth relative to the mandibular anterior teeth; (3) small maxillary lateral incisors; or a peg-shaped maxillary lateral incisor. Patients with mandibular anterior excess usually have either spacing of the maxillary anterior teeth or no interproximal spacing of the maxillary anterior teeth and crowding of the mandibular anterior teeth. The canine relationship, overbite, and overjet vary with the space distribution (Fields, 1981).

Relative mandibular anterior excess problems historically have been resolved by a variety of procedures. The patient may be treated to a reduced overbite and overjet with increased maxillary anterior lingual root torque. There are esthetic limits to this plan, and the anterior teeth may no longer function in protrusive excursions. Another alternative is to treat to an ideal overbite and overjet, leaving spaces distal to the maxillary lateral incisors. This may be esthetically objectionable because of the size of the remaining spaces, or prolonged retention may be required to control post treatment space redistribution (Fields, 1981). The residual spaces may be reduced by accentuation of the distal root tip or "artistic positioning" of the incisors to increase the mesiodistal width of the maxillary incisors, although this plan also has esthetic limits. It has been claimed that artistic positioning of maxillary incisors provides 1mm per tooth by tipping the root 6◦ distally and depends on the shape of incisor (Tuverson, 1980). These adjustments require third order bends in the finishing arch wires. It is also possible to compensate by slightly tipping teeth, or by finishing the orthodontic treatment with mildly excessive overbite or overjet depending on the individual circumstances (Fields, 1981). Moreover, torqueing of maxillary incisors may close small diastema in the front area (Hussels and Nanda, 1987).

More generalized small deficiencies can be masked by altering incisor positions in any of several ways. To a limited extent, torque of upper incisors can be used to compensate. Leaving the incisors slightly more upright makes them take up less room relative to the lower arch and can be used to mask larger upper incisors, while slightly excessive torque can partially compensate for small incisors (Proffit, 2000).

An alternative is to decrease the width of the lower incisors by reducing the enamel thickness. The slenderization technique was descripted for the first time in 1944 (Ballard and Sheridan, 1985). Interproximal reduction may be indicated for patients with good oral hygiene and who have either Class I arch length discrepancies with orthognathic profiles, minor Class II dental malocclusions, particularly in patients who have stopped growing, and Bolton tooth size discrepancies (Stroud et al., 1998). This procedure will often solve some mandibular excess problems, but thin proximal enamel and root proximity may limit its usefulness. Reduction of interproximal enamel is the usual strategy to compensate for discrepancies caused by excess tooth size, Moreover, one of the advantages of bonded appliance is that interproximal enamel can be removed any time. When stripping of enamel is part of original treatment plan most of the enamel reduction should be done initially but final stripping can be deferred until the finishing stage. This procedure allows direct observation of the occlusal relationships before the final tooth size adjustments are made and a topical fluoride treatment is always recommended immediately after stripping (Proffit, 2000). Also, the maxillary anterior teeth can be crowned to increase their mesiodistal width. The esthetic results of this procedure and the reaction of large pulps to tooth preparation are variable. There are other treatment options which address the problem as if it were a maxillary deficiency (Fields, 1981).

The choice of extraction depends on local clinical conditions, which include discrepancy between the dental arches, basal arches, facial profile and the state of the dentition as a whole relative to the cranial base. Normally, there is a variation in the range of normal occlusion, and treatment must adapt to the needs of each patient (Bahreman, 1977).

Orthodontic indications for extracting a mandibular incisor in case of tooth size discrepancies leading to mandibular excess, may include the following clinical scenarios: (1) Class I malocclusions with severe lower anterior crowding; (2) severe lower anterior crowding with lack of space for one lower incisor; (3) Class I malocclusion with anterior dental crossbite due to lower anterior crowding and lower incisor protrusion; (4) Class I malocclusion with severe anterior tooth size discrepancy, small upper or large lower incisors 4-6 mm of mandibular anterior excess; (5) agenesis or previous extraction of maxillary lateral incisor or incisors affected by microdontia; and (6) all other non-orthodontic situations, such as compensatory interproximal stripping or adjusting the axial inclination of incisors in instances of dimensional variability in the canine-incisor region of the arch (Bahreman, 1977; Pujol et al., 2001).

Cases which require upper and lower extractions and /or have any of the following specifications are contraindicated for single mandibular incisor extraction in cases having tooth size discrepancy; (1) deep bite with horizontal growth pattern; (2) cases which require upper first premolar extraction while canines are in Class I relationship; (3) bimaxillary crowding cases which have no tooth size discrepancy in the incisor area; and (4) cases having tooth size discrepancy in the incisors region due to either small lower incisors and/or large maxillary incisors (Bahreman, 1977).

In treatment planning, the decision regarding lower incisor to extract, lateral or central, right or left, the orthodontist must take certain factors into consideration: amount of anterior arch length deficiency, amount of anterior tooth ratio, periodontal and tooth health condition, and upper and lower midline relationship (Bahreman, 1977).

Bolton (1962) correctly stated that premolar extraction would mathematically reduce the suggested overall mean ratio value of 91.3%. After the extraction of four premolars, patients with no tooth size discrepancy existing would have an overall mean ratio of 88%. Two studies have agreed with this opinion, and particularly with the extraction of larger mandibular second premolars, which improves the overall Bolton ratio (Saatci and Yukay, 1997; Tong et al., 2004). In formulating orthodontic treatment plan involving premolar extractions, orthodontist should consider that the overall ratio might decrease and normal clinically significant tooth size discrepancies could change after extraction (Endo et al., 2010). A study reported agreement with removal of all second premolars in mandibular discrepancy and removal of all first premolars in maxillary discrepancy (Gaddam et al., 2015). The clinician should always remember to look on each patient as an individual, and to be aware of other factors in determining what teeth, if any to extract for managing tooth size discrepancy.

# SPECIAL PART

## 3. Research hypotheses

**The hypotheses to be tested are set as:**

1- There are differences between mean values of overall and anterior tooth size ratios in different malocclusion groups of Emiratis.

2- There are differences between mean values of overall and anterior tooth size ratios in a group of Emiratis with Class I normal occlusion, and the Bolton standards.

3- There are differences in the distribution of overall and anterior tooth size ratios ± 2 SD from Bolton mean values in all occlusion groups.

**Null Hypotheses:**

1-There are no differences between mean values of overall and anterior tooth size ratios in different malocclusion groups of Emiratis.

2- There are no differences between mean values of overall and anterior tooth size ratios in a group of Emiratis with Class I normal occlusion, and the Bolton standards.

3- There are no differences in distribution of overall and anterior tooth size ratios ± 2 SD from Bolton mean values in all occlusion groups.

## 4. Aims

The aims of the present investigation are the following:

1- To study overall and anterior tooth size ratios in a group of Emiratis with Class I normal occlusion.

2- To estimate overall and anterior tooth size ratios in different malocclusion groups of Emiratis.

3- To compare overall and anterior tooth size ratios of Emiratis with Class I normal occlusion with the Bolton standards.

4- To determine the distribution of overall and anterior tooth size ratios ± 2 SD from Bolton mean values in all occlusion groups of Emiratis.

# 5. Materials and Methods

## 5.1 Subjects

This is a retrospective cross-sectional study utilizing complete orthodontic records including study models. Consecutive patients' files, including pre-treatment and post-treatment dental casts, were selected from the archives of the governmental orthodontic clinics of the Dubai Health Authority which had been treated during the period from January 2005 to December 2015, located in Bur Dubai (Al Badea Dental Center and Al Barsha Health Center) and Bur Deira (Nad Al Hamar Health Center, Dubai Hospital and Al Mizhar Health Center).

The final sample was formed following application of certain inclusion criteria: healthy patients, aged from 13-18 years; Emirati origin having a United Arab Emirates passport and Emirate identification document; complete permanent dentition, but with second and third molars allowed to be absent; normal tooth crown morphology; no dental anomalies in tooth shape, tooth size and tooth number; no history of interproximal reduction; no restorations altering mesiodistal tooth crown width; complete record files and excellent quality of study models. The exclusion criteria were: history of systemic diseases; craniofacial anomalies; medical history concerning dental and jaw development; mixed Emirati origin regarding at least one of the parents; presence of dental anomalies in tooth shape, tooth size and tooth number; history of interproximal reduction; restorations altering mesiodistal tooth crown width; congenital missing teeth; incomplete record files and poor quality of study models.

The final sample consisted of 521 pairs of dental casts representing both sexes (males: 188; females: 333) and different occlusion groups (Table 5). The 428 pairs of dental casts of various malocclusions derived from pre-treatment study casts and were divided into three malocclusion groups according to Angle classification [(Class I malocclusion: 288; 181 females and 107 males) (Class II malocclusion: 110; 67 females and 43 males) (Class III malocclusion: 30; 20 females and 10 males)] (Table 5). The Class I normal occlusion group derived from post-treatment study casts and consisted of 93 cases (65 females and 28 males). This group of models were characterized by Class I normal occlusion features with regard to molar and canine relationships, overjet, overbite, alignment and levelling.

Table 5. Gender characteristics of the different groups of patients according to occlusion types.

| Gender | Class I malocclusion | Class II malocclusion | Class III malocclusion | Class I normal occlusion | Total | *P*-value |
|---|---|---|---|---|---|---|
| Female | 181 (54.4) | 67 (20.1) | 20 (6) | 65 (19.5) | 333 | 0.459 |
| Male | 107 (56.9) | 43 (22.9) | 10 (5.3) | 28 (14.9) | 188 | |

The mean age of patients whose dental casts were utilized in this study was 16.18 years for Class I malocclusion, 15.73 years for Class II malocclusion, 15.83 for Class III malocclusion and 16.55 years for Class I normal occlusion (Table 6).

Table 6. Characteristics of the different groups of patients according to occlusion types and age.

| Classification | Age | | | | | | |
|---|---|---|---|---|---|---|---|
| | N | Mean | SD | Min | Max | SE | *P*-value |
| Class I malocclusion | 288 | 16.18 | 1.801 | 13 | 18 | 0.106 | 0.008 |
| Class II malocclusion | 110 | 15.73 | 1.807 | 13 | 18 | 0.172 | |
| Class III malocclusion | 30 | 15.83 | 1.931 | 13 | 18 | 0.353 | |
| Class I normal occlusion | 93 | 16.55 | 1.612 | 13 | 19 | 0.167 | |

The dental casts were selected, scanned using Ortho Insight 3D laser scanner (3D Motion View, Chattanooga, Tennessee, USA) and digitized by the author using an Ortho Insight 3D laser scanner (3D Motion View Software). Measurements were made regarding maxillary and mandibular sums of mesiodistal tooth dimension of the overall (6-6) and anterior (3-3) groups of teeth (Table 7). In order to test the intra-examiner reliability, the author re-measured 50 pairs of casts, randomly selected from the original sample, one week after the initial measurement.

Table 7. Digital models variables measured by the software [3-3: Right canine to left canine; 6-6: Right first molar to left first molar].

| Variables |
|---|
| Maxillary 3-3 |
| Mandibular 3-3 |
| Anterior ratio |
| Maxillary 6-6 |
| Mandibular 6-6 |
| Overall ratio |

## 5.2 Materials

All maxillary and mandibular plaster models were scanned using the Ortho Insight 3D laser scanner (Motion View Software LLC, Chattanooga, Tennessee, USA) with scanning resolution being set to ``high`` using the Ortho Insight 3D Software (Version 6.0.7044).

## 5.3 Methods

Following scanning of all the models, the digitization and assessment of the variables of their electronic version included the following stages: (1) ``Separate teeth`` using Ortho Insight 3D, so that each model was separated and each tooth was marked individually; (2) ``Detect landmarks`` without performing changes in the major anatomically detected landmarks in the dentition, so that 21 landmarks were automatically produced on each tooth by the Ortho Insight 3D Software (buccal cusp, gingival buccal groove, occlusal buccal groove, cemento-enamel junction, central fossa, central incisal, central labial, cusp, distal pit, disto-buccal cusp, disto-incisal, disto-labial, disto-lingual cusp, distal marginal ridge, lingual cusp, mesial pit, mesio-buccal cusp, mesio-incisal, mesio-labial, mesio-lingual cusp, mesial marginal ridge), and (3) ``Set FAs (Facial axes) and measure teeth,`` so that the mesial and distal contact points of each tooth were adjusted and checked using the tooth view window which had occlusal, facial and mesial views provided by the software.

Final data produced included patient's information (name, ID, model number, birth date and age of records), sum of mesiodistal dimension of upper and lower twelve teeth (6-6) and sum of mesiodistal dimension of upper and lower six anterior teeth (3-3), and overall and anterior ratios (Table 7).

The author had received instructions from manufacturer and had undergone online training for using the Ortho Insight 3D laser scanner and the software (Motion View Software LLC, Chattanooga, Tennessee, USA). All data were entered in an Excel file and patients' confidentiality was ensured.

# 6. Statistics

## 6.1 Sample size calculation

The previously mentioned sample size was calculated using Cochrane analysis formula that provides sample size and power analysis for hypothesis test, confidence interval and equivalence analysis (Suresh and Chandrashekara, 2012). A total sample size of 595 subjects was calculated and power of 80%, with 95% significant level was given utilizing the following formulas:

$$N = \frac{Z_{\frac{\propto}{2}}^{2} pq}{B^{2}}$$

Where Zα/2 is the quartile of 95% of the confidence interval

P is the prevalence of the disease under study population and q is (1- p)

B is precision or (margin error) and is given by

$$B = \sqrt{\frac{Z_{\propto/2}}{n} pq}$$

Where ``n`` is the sample size from which the prevalence p was calculated.

## 6.2 Statistical methods

Data were elaborated using the special statistical program SPSS (Statistical Package for Social Science for Windows Version 20.0, SPSS Inc., Chicago, Illinois, USA). Measurements per tooth were tested for normality by using the Kolmogorov-Smirnov test which was applied among different occlusion groups. The cross-tabulation test was used to examine the independency between categorical variables. The Chi-square test was performed for assessing associations. Where two or more continuous independent variables were examined, the t-test and analysis of variance (ANOVA) were used to check that the measurements were normally distributed. The Post-HOC to test pairwise comparison was applied if ANOVA showed significant results. A P-value of less than 0.05 was considered significant in all statistical analysis.

## 6.3 Method error

In order to test intra-examiner reliability, the author re-measured 50 pairs of models, randomly selected from the original sample, one week after the initial measurements. The intra-examiner reliability was assessed using the paired t-test, and no statistically significant difference between the first and second measurements was found, thus confirming intra-examiner reliability (Table 8).

Table 8. Reliability test of consistency for readings of investigator by using paired t-test (In the measurement column, R1 indicates 1st measurement and R2 indicates 2nd measurement).

| Measurements | Mean Differences (mm) | Std. Error (mm) | 95% CI | | *P*-value |
|---|---|---|---|---|---|
| | | | Lower | Upper | |
| maxillary 3-3 R1 - maxillary 3-3 R2 | -0.1316 | 0.10144 | -0.33545 | 0.07225 | 0.201 |
| mandibular 3-3 R1 - mandibular 3-3 R2 | -0.1066 | 0.081093 | -0.26956 | 0.056362 | 0.195 |
| anterior ratio R1 - anterior ratio R2 | -0.0102 | 0.006024 | -0.02231 | 0.001905 | 0.097 |
| maxillary 6-6 R1 – maxillary 6-6 R2 | -0.1128 | 0.09691 | -0.30755 | 0.08195 | 0.25 |
| mandibular 6-6 R1 - mandibular 6-6 R2 | -0.0294 | 0.09318 | -0.21665 | 0.15785 | 0.754 |
| overall ratio R1 - overall ratio R2 | 0.0738 | 0.05087 | -0.02843 | 0.17603 | 0.153 |

## 7. Results

The results of testing for normality, performed using Kolmogorov-Smirnov test, are presented in Table 9. Most of the variables were normally distributed and because the sample size within each occlusion group was large (> 50) parametric statistics was chosen for analyzing the data.

Table 9. Results of test of normality using Kolmogorov-Smirnov test.

| Variables | Classification | Kolmogorov-Smirnov | | |
|---|---|---|---|---|
| | | Statistic | df | Sig. |
| Maxillary 3-3 | Class I malocclusion | 0.087 | 288 | 0 |
| | Class II malocclusion | 0.054 | 110 | 0.200* |
| | Class III malocclusion | 0.106 | 30 | 0.200* |
| | Class I normal occlusion | 0.279 | 93 | 0 |
| Mandibular 3-3 | Class I malocclusion | 0.089 | 288 | 0 |
| | Class II malocclusion | 0.047 | 110 | 0.200* |
| | Class III malocclusion | 0.095 | 30 | 0.200* |
| | Class I normal occlusion | 0.114 | 93 | 0.005 |
| Anterior ratio | Class I malocclusion | 0.067 | 288 | 0.003 |
| | Class II malocclusion | 0.068 | 110 | 0.200* |
| | Class III malocclusion | 0.106 | 30 | 0.200* |
| | Class I normal occlusion | 0.093 | 93 | 0.046 |
| Maxillary 6-6 | Class I malocclusion | 0.072 | 288 | 0.001 |
| | Class II malocclusion | 0.494 | 110 | 0 |
| | Class III malocclusion | 0.162 | 30 | 0.044 |
| | Class I normal occlusion | 0.06 | 93 | 0.200* |
| Mandibular 6-6 | Class I malocclusion | 0.089 | 288 | 0 |
| | Class II malocclusion | 0.055 | 110 | 0.200* |
| | Class III malocclusion | 0.087 | 30 | 0.200* |
| | Class I normal occlusion | 0.311 | 93 | 0 |
| Overall ratio | Class I malocclusion | 0.245 | 288 | 0 |
| | Class II malocclusion | 0.13 | 110 | 0 |
| | Class III malocclusion | 0.103 | 30 | 0.200* |
| | Class I normal occlusion | 0.103 | 93 | 0.017 |

Table 10 presents the descriptive statistics data of the all variables among the four occlusion groups.

Table 10. Descriptive statistics of overall and anterior tooth size dimensions and ratios among different occlusion groups.

| Classification | | Maxillary 3-3 | Mandibular 3-3 | Anterior ratio | Maxillary 6-6 | Mandibular 6-6 | Overall ratio |
|---|---|---|---|---|---|---|---|
| Class I malocclusion | N | 288 | 288 | 288 | 288 | 288 | 288 |
| | Mean | 46.92 | 36.62 | 78.05 | 98.45 | 90.18 | 91.57 |
| | SD | 0.70 | 0.53 | 0.52 | 1.29 | 1.28 | 0.38 |
| | Min | 45.3 | 35.27 | 77.13 | 94.28 | 86.16 | 91.13 |
| | Max | 49.69 | 38.72 | 79.42 | 103.51 | 98.62 | 97.01 |
| | SE | 0.04 | 0.03 | 0.03 | 0.07 | 0.07 | 0.02 |
| Class II malocclusion | N | 110 | 110 | 110 | 110 | 110 | 110 |
| | Mean | 48.88 | 38.64 | 79.14 | 100.32 | 91.83 | 91.54 |
| | SD | 1.74 | 1.38 | 0.72 | 3.03 | 2.82 | 0.50 |
| | Min | 44.28 | 34.19 | 77.78 | 91.29 | 83.64 | 90.06 |
| | Max | 54.2 | 42.56 | 82.13 | 107.90 | 99.06 | 92.74 |
| | SE | 0.17 | 0.13 | 0.07 | 0.29 | 0.27 | 0.05 |
| Class III malocclusion | N | 30 | 30 | 30 | 30 | 30 | 30 |
| | Mean | 48.25 | 37.40 | 77.54 | 98.7 | 89.03 | 90.21 |
| | SD | 1.75 | 1.32 | 0.66 | 3.42 | 3.26 | 0.79 |
| | Min | 44.5 | 34.3 | 76.18 | 90.86 | 80.98 | 89 |
| | Max | 52.29 | 40.14 | 78.84 | 104.2 | 94.39 | 91.79 |
| | SE | 0.32 | 0.24 | 0.13 | 0.62 | 0.60 | 0.14 |
| Class I normal occlusion | N | 93 | 93 | 93 | 93 | 93 | 93 |
| | Mean | 48.36 | 37.46 | 77.54 | 99.37 | 90.85 | 91.41 |
| | SD | 2.0 | 1.42 | 0.30 | 2.87 | 2.61 | 0.22 |
| | Min | 44.24 | 34.29 | 77.03 | 92.22 | 84.38 | 91 |
| | Max | 55.10 | 41.28 | 79.24 | 106.77 | 97.91 | 91.99 |
| | SE | 0.21 | 0.15 | 0.03 | 0.30 | 0.30 | 0.02 |

The maxillary 3-3 sum was characterized by a mean value of 46.92 mm in the Class I malocclusion, 48.88 mm in Class II malocclusion, 48.25 mm in Class III malocclusion, and 48.36 mm for Class I normal occlusion, groups respectively.

The mandibular 3-3 sum was characterized by a mean value of 36.62 mm in the Class I malocclusion, 38.64 mm in Class II malocclusion, 37.40 mm in Class III malocclusion, and 37.46 mm for Class I normal occlusion, groups respectively.

For the anterior ratio, the mean value was 78.05 mm in the Class I malocclusion, 79.14 mm in Class II malocclusion, 77.54 mm in Class III malocclusion, and 77.54 mm for Class I normal occlusion, groups respectively.

The maxillary 6-6 sum was characterized by a mean value of 98.45 mm in the Class I malocclusion, 100.32 mm in Class II malocclusion, 98.7 mm in Class III malocclusion, and 99.37 mm for Class I normal occlusion, groups respectively.

The mandibular 6-6 sum was characterized by a mean value of 90.18 mm in the Class I malocclusion, 91.83 mm in Class II malocclusion, 89.03 mm in Class III malocclusion, and 90.85 mm for Class I normal occlusion, groups respectively.

Regarding the overall ratio, the mean value was 91.57 mm in the Class I malocclusion, 91.54 mm in Class II malocclusion, 90.21 mm in Class III malocclusion, and 91.41 mm for Class I normal occlusion, groups respectively.

The gender distribution among different occlusion groups was comparable. The highest number of females was in Class I malocclusion, the Class II malocclusion contained a lower number, as did the Class I normal occlusion group; while the smallest group was that with Class III malocclusion (Table 6) (Figure 1).

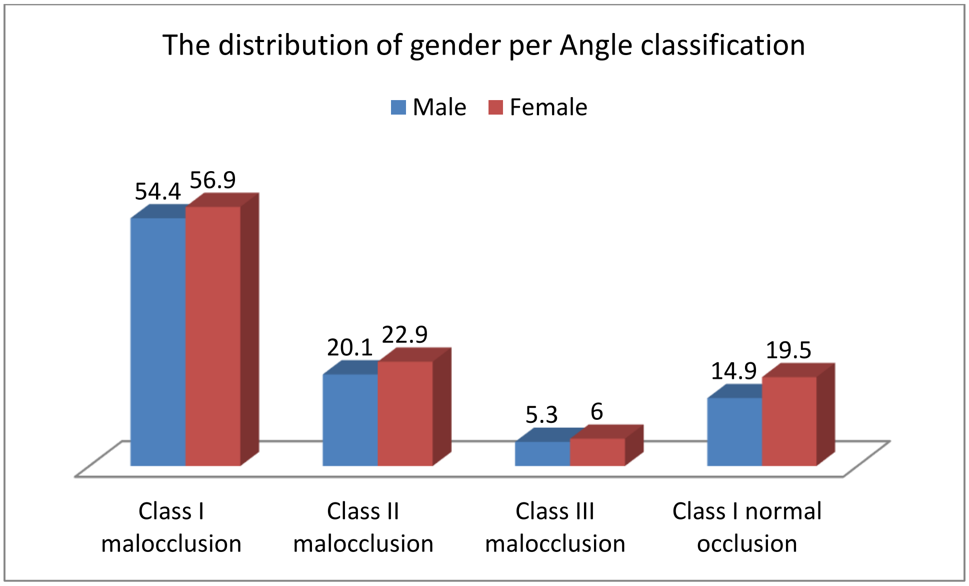


Figure 1. Gender distribution of gender per Angle classification.

There was a statistically significant difference among the different occlusion groups ($P = 0.008$) (Table 6).

Table 11 shows the results of the comparisons between mean values of overall and anterior tooth size dimensions and ratios among different occlusion groups. Statistically significant differences were found in all variables of the various occlusion groups except the maxillary 6-6 sum.

Table 11. Comparison of mean values of overall and anterior tooth size dimensions and ratios among different occlusion groups.

| Variables | Classification | N | Mean | *P*-value |
|---|---|---|---|---|
| Maxillary 3-3 (mm) | Class I malocclusion | 288 | 46.92 (0.70) | 0.001 |
| | Class II malocclusion | 110 | 48.88 (1.74) | |
| | Class III malocclusion | 30 | 48.24 (1.75) | |
| | Class I normal occlusion | 93 | 48.36 (2.0) | |
| Mandibular 3-3 (mm) | Class I malocclusion | 288 | 36.62 (0.53) | 0.001 |
| | Class II malocclusion | 110 | 38.64 (1.38) | |
| | Class III malocclusion | 30 | 37.40 (1.32) | |
| | Class I normal occlusion | 93 | 37.46 ( 1.42) | |
| Anterior ratio (%) | Class I malocclusion | 288 | 78.05 (0.52) | 0.001 |
| | Class II malocclusion | 110 | 79.14 (0.72) | |
| | Class III malocclusion | 30 | 77.54 (0.66) | |
| | Class I normal occlusion | 93 | 77.54 (0.30) | |
| Maxillary 6-6 (mm) | Class I malocclusion | 288 | 98.48 (1.29) | 0.148 |
| | Class II malocclusion | 110 | 100.32 (3.03) | |
| | Class III malocclusion | 30 | 98.70 (3.41) | |
| | Class I normal occlusion | 93 | 99.38 (2.87) | |
| Mandibular 6-6 (mm) | Class I malocclusion | 288 | 90.18 (1.28) | 0.001 |
| | Class II malocclusion | 110 | 91.82 (2.82) | |
| | Class III malocclusion | 30 | 89.04 (3.26) | |
| | Class I normal occlusion | 93 | 90.85 (2.61) | |
| Overall ratio (%) | Class I malocclusion | 288 | 91.56 (0.38) | 0.001 |
| | Class II malocclusion | 110 | 91.54 (0.50) | |
| | Class III malocclusion | 30 | 90.21 (0.79) | |
| | Class I normal occlusion | 93 | 91.41 (0.22) | |

Table 12 shows that there were no statistically significant difference in overall and anterior tooth size ratios in relation to gender.

Table 12. Comparison of overall and anterior tooth size ratios according to gender.

| Ratio | Gender | N | Mean (SD) | *P*-value |
|---|---|---|---|---|
| Anterior ratio (%) | Female | 333 | 78.17 (0.77) | 0.655 |
| | Male | 188 | 78.14 (0.77) | |
| Overall ratio (%) | Female | 333 | 91.46 (0.56) | 0.633 |
| | Male | 188 | 91.44 (0.45) | |

Table 13 shows that there were no statistically significant difference in overall and anterior tooth size ratios between Class I normal occlusion in the group of Emiratis and the Bolton standards.

Table 13. Comparison of overall and anterior tooth size ratios between the Class I normal occlusion in the group of Emiratis and the Bolton standards.

| Ratios | Class I normal occlusion | | | | |
|---|---|---|---|---|---|
| | Present study | | Bolton standard | | *P*-value |
| | N | Mean (SD) | N | Mean (SD) | |
| Anterior ratio | 93 | 77.54 (0.30) | 55 | 77.2 (1.65) | 0.340 |
| Overall ratio | 93 | 91.41 (0.22) | 55 | 91.3 (1.91) | 0.110 |

Table 14 shows that there were statistically significant differences in overall and anterior tooth size ratios among different malocclusion groups ($P = 0.001$).

Table 14. Comparison of overall and anterior tooth size ratios among different malocclusion groups.

| Classification | N | Mean (%) | SD (mm) | SE | *P*-value |
|---|---|---|---|---|---|
| Anterior ratio | | | | | |
| Class I malocclusion | 288 | 78.05 | 0.52 | 0.03 | 0.001 |
| Class II malocclusion | 110 | 79.14 | 0.72 | 0.07 | |
| Class III malocclusion | 30 | 77.54 | 0.66 | 0.13 | |
| Overall ratio | | | | | |
| Class I malocclusion | 288 | 91.56 | 0.38 | 0.02 | 0.001 |
| Class II malocclusion | 110 | 91.54 | 0.50 | 0.05 | |
| Class III malocclusion | 30 | 90.2 | 0.79 | 0.14 | |

The frequency of tooth size discrepancy outside 2 SD from the Bolton mean values for overall and anterior ratios was calculated for all occlusion groups. Table 15 and Figure 2 show the distribution of cases with anterior tooth size discrepancies outside 2 SD from the Bolton mean values (anterior ratio $\bar{X}$ = 77.2 ± 2 SD: 73.9 and 80.5, respectively). Five cases in Class II malocclusion presented anterior tooth size discrepancy outside plus 2 SD from the Bolton mean values.

Table 15. Distribution of cases with anterior tooth size discrepancies outside 2 SD from Bolton mean values (anterior ratio $\bar{X}$ = 77.2 ± 2 SD: 73.9 and 80.5, respectively).

| | Anterior Ratio | | | | | | |
|---|---|---|---|---|---|---|---|
| Classification | Outside SD (%) | SD 2 (%) | SD 1 (%) | Mean (%) | SD 1 (%) | SD 2 (%) | Outside SD (%) |
| | < 73.9 | 73.9-75.4 | 75.5-77.1 | 77.2 | 77.3-78.8 | 78.9-80.5 | >80.5 |
| Class I malocclusion | | | | | 250 (94) | 16 (6) | |
| Class II malocclusion | | | | | 37 (35.6) | 62 (59.6) | 5 (4.8) |
| Class III malocclusion | | | 8 (29.6) | | 19 (70.4) | | |
| Class I normal occlusion | | | 3 (3.7) | 1 (1.2) | 76 (94) | 1 (1.2) | |

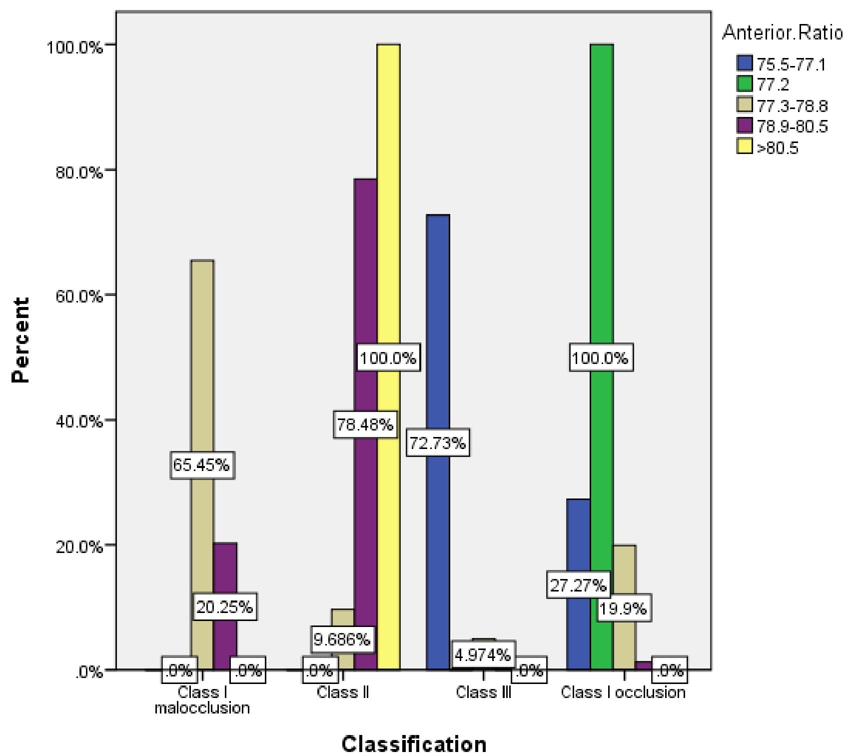


Figure 2. Distribution of cases with anterior tooth size discrepancy outside 2 SD from Bolton mean values (anterior ratio $\bar{X}$ = 77.2 ± 2 SD: 73.9 and 80.5, respectively).

Table 16 and Figure 3 show the distribution of cases with overall tooth size discrepancies outside 2 SD from the Bolton mean values (overall ratio $\overline{X}$ = 91.3 ± 2 SD: 87.48 and 95.12, respectively). There was one case of Class I malocclusion with an overall tooth size discrepancy outside plus 2 SD from the Bolton mean values.

Table 16. Distribution of cases with overall tooth size discrepancies outside 2 SD from Bolton mean values (overall ratio $\overline{X}$ = 91.3 ± 2 SD: 87.48 and 95.12, respectively).

| | Overall Ratio | | | | | | |
|---|---|---|---|---|---|---|---|
| Classification | Outside SD (%) | SD2 (%) | SD 1 (%) | Mean (%) | SD 1 (%) | SD 2 (%) | Outside SD (%) |
| | < 87.4 | 87.4-89.3 | 89.4-91.2 | 91.3 | 91.4-93.2 | 93.3-95.1 | >95.1 |
| Class I malocclusion | | | 1 (0.4) | 1 (0.4) | 222 (98.7) | | 1 (0.4) |
| Class II malocclusion | | | 15 (17.6) | 1 (1.2) | 69 (81.2) | | |
| Class III malocclusion | | 3 (11.5) | 21 (80.8) | | 2 (7.7) | | |
| Class I normal occlusion | | | 16 (25.8) | | 46 (74.2) | | |

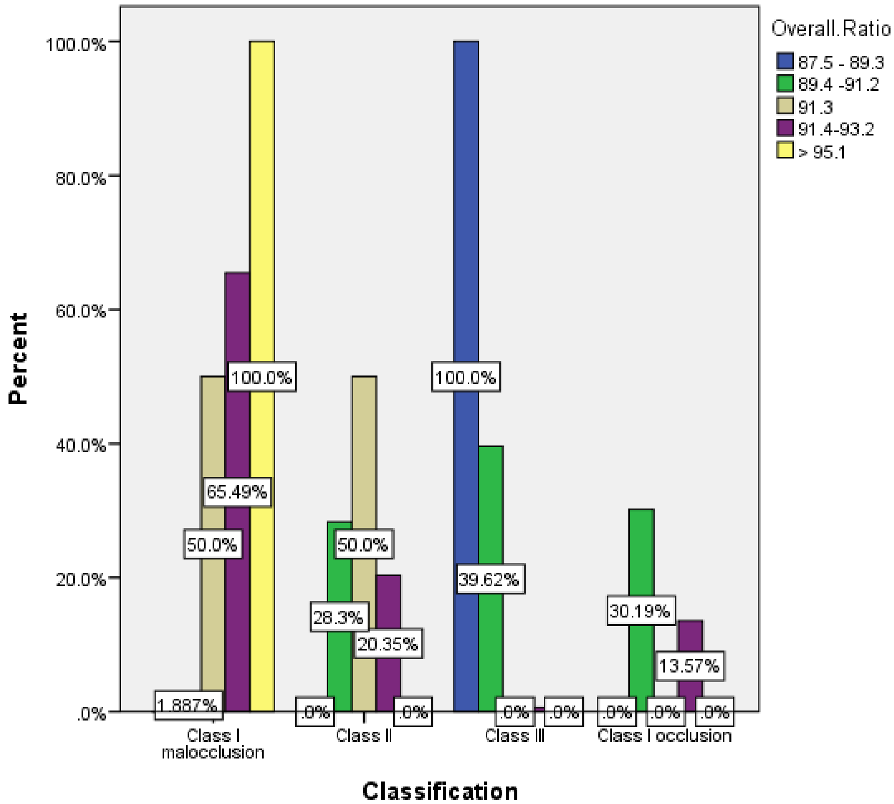


Figure 3. Distribution of cases with overall tooth size discrepancy outside 2 SD from Bolton mean values (overall ratio $\bar{X}$ = 91.3 ± 2 SD: 87.48 and 95.12, respectively).

## 8. Discussion

Although tooth size discrepancy with regard to overall and anterior ratios has been studied in a significant number of ethnic and racial groups as well as malocclusion types, such an investigation is lacking for the Emirati population. Therefore, it is valuable to investigate the tooth size overall and anterior ratios in a group of Emiratis and to compare their values with the Bolton standards.

When plans for forming the Class I normal occlusion group were being made, it was realized that the sample size required by the power analysis calculation (N = 180) would be difficult to find. Individuals with ideal or normal occlusion in such numbers cannot be easily identified, recorded and studied in any population. Therefore, as an alternative, the group of Class I normal occlusion was formed by utilizing orthodontic post-treatment patients' study casts. Special selection criteria were applied in selecting these cases so that factors of tooth morphology and orthodontic treatment characteristics did not influence the mesiodistal dimensions of the teeth which were measured. This is the reason that in this study 521 consecutive cases were included, this being less than the number of 595 which was provided by the sample size calculation.

The inclusion criterion of an Emirati background was checked and assessed utilizing administrative data from patients' files of governmental orthodontic clinics of the Dubai Health Authority.

The traditional way for study model analysis involves plaster casts measured with calipers. However, in recent years, three dimensional virtual study models have become increasingly used in dentistry. The diagnostic accuracy and measurement sensitivity of electronic models compared to plaster models have been thoroughly investigated. In a study focusing on comparisons between measurements on digital models and measurements with digital calipers on plaster models (Fleming et al., 2011) it was concluded that “digital models offer a high degree of validity when compared to direct measurement on plaster models”. Based on this conclusion, the decision was made to perform the present investigation using the Ortho Insight 3D scanner with the resolution set in ``high``, and utilizing the dedicated software provided. The digital models subsequently produced and elaborated were subject to Auto Bolton analysis with the same software.

Many studies have compared orthodontic tooth measurements using digital casts and plaster models. Tooth width measurements on digital models can be as accurate as, more reproducible, and significantly faster than those taken on plaster models (Grunheid et al., 2014). When the diagnostic accuracy and surface matching characteristics of three dimensional digital dental models obtained from various sources were studied, it was concluded that all of them can provide diagnostic information similar to caliper measurements, with varying degrees of agreement limits. The scanner virtual model has the least mean bias. A strong surface match correlation was observed between virtual scanned and electronic models; indicating that these could be used interchangeably. It is important to note that from among the numerous scanning and software systems previously tested, the Ortho Insight 3D scanner and software was the one utilized in the present investigation (Akyalcin et al., 2013).

Several other investigations have compared the findings from plaster casts and those from electronic model measurements reporting dental arch diameters, Bolton index, space analysis and irregularity index. A good reliability of correspondence between both records was found in almost all parameters regarding three dimension for both digital and plaster models compared with plaster models (Goonewardene et al., 2008; Abizadeh et al., 2012; Nouri et al., 2014).

To further confirm the accuracy and consistency of the operator's measurements, a second series of measurements for all variables was conducted with the author/operator blinded for a group of randomly selected sets of models. The results showed consistency between the two series of measurements.

In the present study, where the sample of post-treatment normal occlusion group was compared to the Bolton standards, the results showed that the mean values and standard deviations of anterior and overall ratios obtained were not statistically significantly different. The finding of an absence of statistically significant differences in both ratios of this group with the Bolton values indicated compatibility with the very small sample number of cases presenting values outside the two standard deviation ranges. Bolton (1958) also found a low percentage of overall discrepancy higher than two standard deviations, probably because the sample consisted of patients with ideal occlusions.

Although the normal Class I occlusion group in the present study consisted of orthodontically treated cases with optimal occlusal features and full sets of teeth, it has to be conceded that this is not identical to a normal untreated sample. Obviously, the difficulties in obtaining records of a normal occlusion sample led to the abandoning this option and resorting to the use of orthodontically treated cases. On the other hand, it should be recognized that the strict inclusion criteria implemented for the formation of the present normal occlusion group excluded cases with altered crown morphology resulting from previously performed orthodontic treatment. In addition, all cases with pathological, developmental or therapeutic aspects influencing crown morphology were also excluded from this sample.

Based on existing findings in the relevant literature regarding this kind of investigation, an absence of significant differences with the Bolton standards has been found in other populations from the Middle East region (Alkofide and Hashim, 2002; Al-Tamimi and Hashim, 2005; Nourallah et al., 2005; Al-Khateeb and Abu Alhaija, 2006; Mirzakouchaki el al., 2007; Kachoei et al., 2011; Al-Gunaid et al., 2012; Hashim et al., 2015). The fact that most of the populations surveyed in these studies have Caucasian backgrounds may explain the similarity with the North American Caucasian sample used in the Bolton report.

When anterior and overall tooth size ratios were compered among the four occlusion groups and the three malocclusion groups, respectively, statistically significant differences were found between the groups as has been reported elsewhere (Lavelle, 1972; Sperry et al., 1977; Nie and Lin, 1999; Wedrychowska et al., 2010). Increased values of an overall Bolton ratio for Class III malocclusion patients have been also reported (Sperry et al., 1977; Fattahi et al., 2006). This finding is not unexpected given that one of the etiological factors of malocclusion is deviation in tooth size - jaw size relationships.

No statistically significant differences were observed in the mean values of overall ratios of the teeth between Class I and Class II malocclusions groups. These results agreed with the previous studies' findings of (Crosby and Alexander, 1989; Uysal el al., 2005; O'Mahony et al., 2011).

The results of the current study show that the type of malocclusion is not related to tooth size discrepancy differences between dental arches in the Emirati population. The null hypothesis of present study was accepted because the results showed no differences in the overall and anterior ratios of tooth size discrepancies among different malocclusion groups.

No sexual dimorphism was found when overall and anterior tooth size ratios were compared in reference to gender.

In the present study only five cases in Class II malocclusion presented an anterior tooth size discrepancy outside plus 2 SD from Bolton mean values and one case in Class I malocclusion presented with an overall tooth size discrepancy outside plus 2 SD from Bolton mean values.

Based on the finding of this study, implementation of a detailed, comprehensive and goal-oriented treatment plan in Emirati patients requiring orthodontic therapy should take into account that our group did not exhibited different anterior and overall tooth size ratios from Bolton values. However, there is a possibility that individual variations may exist and this should be considered.

## 9. Conclusions

Based on the findings of this investigation the following conclusions can be presented regarding the Emirati sample which was studied:

- Class I normal occlusion cases presented similar overall and anterior tooth size ratios to Bolton standards.

- Overall and anterior tooth size ratios among occlusion, and different malocclusion groups exhibited statistically significant differences.

- Five cases in Class II malocclusion presented an anterior tooth size discrepancy outside plus 2 SD from Bolton mean values.

- One case in Class I malocclusion presented with an overall tooth size discrepancy outside plus 2 SD from Bolton mean values.

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