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Bolton’s Analysis in Sudanese Sample

By

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Declaration

I declare that every word in this thesis is my own words and any other word taken from other is related to reference.
Dedication

To my family

Friends & colleagues

for their unfailing & selfless love,

support & care for which I will be forever

grateful.
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ABSTRACT

**Background:** Many difficulties encountered during the finishing-phase of orthodontic treatment arise due to lack of intermaxillary tooth-size matching. Bolton ratio is one of the most useful calculations for precise orthodontic diagnosis as it shows if there is a correct ratio between dental proportions.

**Design:** This is a clinical, retrospective study.

**Setting:** The study was done among patients attending the orthodontic clinic at the University of Khartoum, Faculty of Dentistry.

**Objectives:** The purpose of this study was to determined (1) establish tooth size ratio in Sudanese sample with normal occlusion (2) the prevalent of tendency for intermaxillary tooth size discrepancies among different malocclusion groups and genders in a group of Sudanese people.

**Methods:** The sample consisted of 110 (49 Male and 61 Female) study models with normal occlusion, Class I, Class II and Class III malocclusions. Tooth size measurements were performed by electronic digital calipers to an accuracy of 0.01 mm. Tooth size ratios were analyzed as described by Bolton. The incidence of mesio-distal tooth size discrepancies in the malocclusion groups was analyzed and compared between males and females. The anterior and over all ratios were compared with the ratios of some previous studies, principally, Bolton’s study.

**Results:** The results of showed no significant difference in the anterior and overall ratios of normal occlusion sample when compared
to Bolton’s standards. No significant differences were found in gender for the tooth size discrepancies. ANOVA indicated that, no significant difference was determined in the anterior and overall ratio in different malocclusion groups.

**Conclusion:** it’s suggested that Bolton’s values can be used for Sudanease until a large representative sample is studied.
المستخلص

خلفيه:

هناك عدة صعوبات رصدت في طور الانهاء التقويمي وكانت بسبب عدم التناسب السنى الوظيفي بين الفكين. نسب بولتون واحد من القياسات التي تتبع في الوصول إلى التشخيص الصحيح في علاج تقويم الأسنان وهي نسب بين حجم الأسنان العلوى والسفليه (نسب جزئية ومكاني).

تصمم الدراسة: هذه الدراسة سيريراً باثر رجعي. الاعداد: تم الدراسة على المرضى الذين حضرن لعيادة التقويم الأسنان بجامعه الخرطوم كلية طب الأسنان.

أهداف الدراسة:

1- تحديد حجم الأسنان (العرض الانسي والبوحشي) في عينة من السودانيين ذوي الاطباقي الطبيعي.

2- تحديد نسبة التفاوت في عرض الأسنان بين مجموعات سوء الاطباقي المختلفه في الجنسين في مجموعه من الشعب السوداني.

طريق الدراسة:

- تم الدراسة على املتهة حبيصية لعدد 110 فرد منهم 49 ذكور و 61 اثني.
- شملت الامثلة بمختلف اصناف الاطباقي وسوء الاطباقي (الصنف الأول والثاني والثالث).
- تم القياس بقياس رقمي كمترن يدقه 0.01 م.
- تم التحليل التناسب بين الأسنان العلوية والسفلية بالطريقه التي وصفها بولتون.
- حلت نسبة التفاوت في عرض السنى بين المجموعات المختلفه وتم عمل مقارنه بين الاناث والذكور.
- تم عمل مقارنه لنسب بولتون الجزئية ومكانيه في السودانين وبعض الدراسات السابقه خاصه عينة بولتون.
نتائج:
- أظهرت الدراسة أنه لا يوجد اختلافات واضحة في نسبة حجم الأنسان الجنيني والكامل لدى الأطباق الطبيعي عند مقارنتها بنسبة بولتون القياسية.
- لا يوجد اختلافات هامة عند مقارنة نسب العرض السنوي بين الجنسين في السودانين.
- لا يوجد اختلافات هامة في نسب العرض السنوي بين مجموعات سوء الأطباق المختلفة في السودانين.

الاستنتاج:
يمكن استخدام نسبة بولتون لقياس السودانيين حتى إجراء دراسة لعينة أكبر تمثل كل مجموعات الشعب السوداني.
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CHAPTER 1

1.1 Introduction

Correct tooth size relationship between maxillary and mandibular teeth is an important factor to achieve a proper occlusal interdigitation during the final stages of orthodontic treatment.[1]

An excellent orthodontic treatment result with optimal occlusion and ideal intercuspation, overjet and overbite is often jeopardized by tooth size discrepancies or problematical tooth anatomy.[2] For good occlusion, the teeth must be proportional in size. Tooth size discrepancy has been defined as disproportion in the size of teeth between the maxillary and mandibular arches.[3] Difference in tooth size have been associated with different ethnic background and malocclusion.[4]

Dr. Wayne A Bolton [1] in 1952 developed a tooth size analysis that is commonly used today and it is generally referred to as the 'Bolton Analysis'. Bolton's Tooth Size analysis is based on measurement of the mesiodistal widths of permanent teeth. Bolton compared the sum of the widths of lower teeth to the sum of the widths of upper teeth in a sample of excellent occlusions; from this sample Bolton determined two clinically significant ratios which compare the
sizes of the upper to the lower permanent teeth. The first ratio was the overall ratio, involves measurement from first molar to first molar in both jaws inclusively. The second ratio, was the anterior ratio, involves width measurements from canine to canine inclusively in lower and upper jaw.

The importance of harmony between the maxillary and mandibular teeth brought the attention of many investigators over the years, Alexander and Crosby [4] and Freeman [5] reported that there are 22.9% and 30.6% of orthodontic patients who have anterior tooth size discrepancy.
1.2 Justifications

Tooth-size discrepancies are thought to exist frequently in the human dentition. If so, it would benefit the practitioner to be aware of their existence before beginning orthodontic treatment.[6]

Dental literature has many studies comparing tooth size discrepancy and different types of malocclusion in different parts of the world and among different ethnic group. However, no published study has been carried for the Sudanese population analyzing the mesiodistal tooth size ratio between maxillary and mandibular teeth in anterior and posterior segments (Bolton analysis). Therefore, the present study was designed to determine the mean of the tooth size and relationship between the maxillary and mandibular teeth which is an important factor to achieve a proper occlusal interdigitation during final stages of orthodontic treatment, if excellent orthodontic treatment is to be achieved.
1.3 Objectives

General objective:

The aims of the present study were to determine the mean of the mesiodistal tooth width in both anterior and overall Bolton ratios in normal occlusion and different malocclusions groups in a Sudanese sample and compare the obtained result with Bolton’s standard.

Specific objectives;

1. To compare tooth-size ratios of the normal occlusion sample in the present study with those from original data of Bolton's study.

2. To determine whether there is a difference for inter maxillary tooth size discrepancies represented by anterior ratio and overall ratio (Bolton formula) for Angle’s Class I, Class II and Class III cases in a Sudanese sample.

3. To determine whether genders dimorphism for mesiodistal tooth size ratios exists.
1.4 Literature review

1.4.1 Development of tooth size discrepancy (TSD)

Tooth size discrepancies have conventionally been described as a relative excess of tooth structure in one arch in relation to the other arch.[7] And as a disproportion among the size of individual teeth.[3] Specific dimensional relationships must exist between the maxillary and mandibular teeth to ensure proper interdigitation, overbite and over jet and it is important to determine the amount and location of a tooth size discrepancy before starting treatment.[8]

Tooth sizes and their inter arch relationships are fundamental to orthodontic treatment. In the early 1900’s Angle [9] included eight variables in occlusion position, interincisal relation, size of teeth, pattern of teeth, length of teeth, length of cusps, width of arch, arch form, and curve of Spee.

G.V. Black [10] in 1902 published tables of the mean sizes of teeth based on the measurement of many teeth, which still used as references.

Ballard [11] in 1944 measured 500 sets of models to determine the greatest mesiodistal diameter of each permanent tooth on the models, catalogued discrepancies between teeth on opposite sides of the upper and lower arches and compared mean values of each tooth to those in Black's table. The measurements showed a notably increased
range in the sizes of the individual teeth and right to left asymmetry of 0.25 mm or more in 90% of the sample and suggested judicious stripping of proximal surfaces as a practical solution to correct the intra arch disharmony in tooth size.

In a survey of 300 malocclusions Neff [12] reported that the mean anterior ratio was 79% and the range was 73 to 85%. The author stated that tooth size relation of the anterior segments of the dental arches and the degree of overbite did not bear a consistent relationship in malocclusions and orthodontic normal.

Bolton [1] developed two analyses where by the ratio of mandibular to maxillary tooth material was determined. Fifty five sets of dental casts carefully selected and judged to have excellent occlusions, 44 of which were from orthodontically treated non extraction cases and 11 were from untreated subjects. In the study the degree of overbite and over jet, the angle between the maxillary and mandibular central incisors, and the mesiodistal widths of teeth from first molar through first molar in both arches were measured. The overall ratio consisting of the 12 teeth from first molar to first molar and an anterior ratio including six teeth from canine to canine. In the overall ratio, summed the mesiodistal widths of the mandibular twelve teeth and divided it by the sum of the maxillary twelve teeth. For the anterior ratio, summed the mesiodistal widths of the mandibular six teeth and divided it by the sum of the maxillary six teeth. The obtained
results were a means of 91.3% (SD = 1.91) for the overall ratio and 77.2% (SD = 1.65) for the anterior ratio.

The presence of deficiency or excess for each arch identified by applying Bolton's formula to the study case and the calculated value compared to Bolton's Index. The amount of the discrepancy is usually determined by using regression tables or lists which predict the amount of tooth material that the corresponding arch should contain.[1]

Bolton [13] observed that the number arrived were useful only as an aid in developing a treatment plan. However, Bolton found that a significant proportional deviation existed, that is, of more than one standard deviation from the mean ratio and then alteration of mesiodistal tooth dimension in one of the arches had to be considered. This alteration could range from interproximal enamel reduction to extraction and noted that it would be difficult to obtain an excellent occlusion in the finishing phases of treatment without an appropriate mesiodistal tooth size ratio.

The orthodontists should be concerned with tooth size discrepancies as states by Bolton [13] because of their high prevalence among orthodontic patients and reported that 29% of the patients studied in a private practice had a discrepancy in excess of one standard deviation, also noted that each patient required individual consideration. The Bolton analysis can be used to indicate what the anterior and posterior inter arch relationship might be at the conclusion of treatment.
In 1972 Lavelle [14] investigated tooth size ratio in different racial groups (Caucasoid, Mongoloid and Negroid) with different occlusal categories in both genders. The overall and the anterior ratios were found to be greater among the Negroid race than the Caucasoid race with the Mongoloid race being intermediate.

Lundstrom [15] measured tooth widths from randomly selected 264 cast of different malocclusions of which eight were normal or without significant deviations. The mean value for the anterior six teeth was 78.5% with a range of 73 to 84.5%. The mean value of the overall ratio was 92.3%. No strong correlations were found between the anterior index and overjet and overbite in the cases of which these parameters were available. In 1981 Lundstrom [16] reported that the results on the normal cases with slight deviations (slight rotations, crowding or spacing) as 'excellent cases'. In this report the 'excellent' cases had overall ratio of 91.9% and a range from 87 to 93%. No anterior ratio was mentioned for this group.

Stifter [17] carried out a study on 57 models of dental students and eight Navaho Indians. The 65 case sample was reduced to 58 through elimination of cases with missing teeth, obvious peg laterals or other anomalies all were normal Class I occlusions cases with acceptable overjet and overbite. The selected criteria for the ideals occlusion was very close to Bolton's anterior relationship, while the norms did not correlate closely with Bolton's anterior value.
Sperry [18] studied the frequency and magnitude of excess tooth structure in mandibular prognathism by Bolton analysis for 78 cases of Angle Class III malocclusions with varying degrees of severity, 26 class I and 26 class II. The total and anterior Bolton ratios were calculated for the three groups using pretreatment dental casts. Angle Class III subjects had a significantly higher frequency and the magnitude of mandibular tooth-size excess for the overall Bolton ratio but not for the anterior ratio compared to the other malocclusion groups and concluded that tooth-size analysis should be included in diagnostic records for mandibular prognathism.

There is good evidence that populations differ with respect to interarch tooth size relationships because differences in tooth sizes are not systematic. For example, blacks population have larger maxillary canines, premolars, and first molars than whites even though there are no differences for the maxillary central or lateral incisors as reported by Merz et al. [19] Richardson and malhotra [20] reported higher overall ratio on 162 african (94%), the anterior ratio was 77%.

Cosby and Alexander [4] studied the tooth-size discrepancies among different malocclusion groups and compared the findings to Bolton’s published norms, and found that the mean ratios did not differ significantly from Bolton’s, the range of values above and below the mean was significantly greater than that demonstrated by Bolton.

Tayer et al [21] used three diagnostic procedures to assist in the final treatment decisions in four study cases: a Bolton tooth size
analysis; a space available/space needed assessment; and a pretreatment diagnostic set-up. The cases required asymmetric dental extractions in order to achieve the desired treatment results. The Bolton analysis used in the diagnostic predictions supported the treatment plans. The completed treatment results closely approximated the original diagnostic predictions.

Freeman et al [5] conducted a study of orthodontic patients in a military orthodontic training program with a clinically significant interarch tooth-size discrepancy. This study stated that the larger discrepancy could be due to potentially more severe malocclusions encountered in a military residency, as opposed to a private practice. The overall discrepancy was equally likely to be relative excess in the maxilla or the mandible, whereas the anterior discrepancy was nearly twice likely to be due to mandibular excess than a relative maxillary excess.

Santoro et al [22] performed Bolton tooth size analysis on a sample of Dominican Americans. The overall ratio was found to be equivalent to the Bolton overall ratio, whereas the anterior ratio was larger than the Bolton ratio.

Smith et al [8] evaluated Bolton’s interarch ratios extend across populations and genders and concluded that the interarch tooth size relationships are population and gender specific. Bolton ratios apply to white females only; the ratios should not be indiscriminately applied to white males, blacks, or Hispanics.[8]
Al-Tamimi and Hashim [23] carried out a study to determine tooth size ratios in Saudis with class I normal occlusion, and found that the means and standard deviation for the anterior ratio and the overall ratio were very similar to Bolton’s results.

Bernab et al [24] studied tooth size discrepancy in 200 Peruvian adolescents with untreated occlusions. A clinically significant tooth-size discrepancy in almost one third of the sample was found. The 2-standard deviation range from the Bolton standard did not predict clinically significant anterior and total tooth-width ratio discrepancies.

Nourallah [25] calculated the anterior and overall ratios according to Bolton in 55 in Syrian models. The obtained results were similar to the original data by Bolton and stated that the interarch tooth-size analysis developed by Bolton can also be used to an Arabian or at least a Syrian population.

Uysal et al [26] conducted a study in a Turkish population to determine the size of individual permanent teeth, tooth-size ratios for the maxillary and mandibular dentitions, and gender differences, and compare the finding with Bolton’s norms. The results showed greater variability in the mesiodistal dimensions of the maxillary teeth than the mandibular teeth. Significant difference was found between male and female in overall and anterior ratios. The result of the study concluded that Bolton’s original data do not represent Turkish people, and therefore it is appropriate to use Turkish norms in daily orthodontic practice for Turkish patients.
Paredes [27] examined Bolton ratios in Spanish subjects. Both anterior ratio and an overall ratio for the Spanish subjects were significantly greater than Bolton’s ratios, and concluded that the relationship between the sizes of the mandibular and maxillary teeth depends on the population, so specific standards should be established for the Spanish population.

Endo [28] tested the Bolton ratio among Japanese population and stated that the overall ratio showed no statistically significant difference. Bolton's anterior ratio was not applicable to the Japanese population, and specific standard tooth size ratios are needed due to high prevalence rate of an anterior tooth size discrepancy more than 2 standard deviation (SD) above Bolton's mean.

Variation in tooth size is under a high degree of genetic control. There have been difficulties in separation the various genetic and environmental factors [29]. Baydas et al [30] carried out study on subject having orthodontic treatment and their siblings and observed that heritability was effective in tooth size discrepancy.
1.4.2 Tooth-size discrepancies (TSD) and gender

Several studies stated that male teeth are larger than female teeth [14, 20, 31]. Bishara [31] measured tooth size discrepancy in boys and girls among 3 populations from Iowa, Egypt and Mexico and reported that Canines and molars were significantly larger in boys.

Lavelle [14] compared maxillary and mandibular tooth-size ratios between males and females, the total and anterior ratios were found greater in males than in females and gender differences were small. The same result was reported by Smith et al [8] in orthodontic casts of 180 patients, including 30 males and 30 females from each of 3 populations (black, Hispanic, and white groups).

Arya et al [32] studied the tooth size differences between gender. A significant different were observed in the overall ratio. Santoro et al [22] found male crown measurement were slightly larger than female on 54 Dominican American. Uysal et al [26] found significant different in the overall ratio between male and female on 150 Turkish population.

Richardson and Malhotra [20] stated that the teeth of black North American males were larger than those of females for each type of tooth in both arches and no differences were observed in anterior or posterior inter-arch tooth-size proportions.
Al-Tamimi and Hashim [23] reported no gender difference in Bolton ratios in a relatively small sample of 65 Saudi subjects.

Hatteb and AL- khateeb [33] reported that the cumulative tooth widths of males exceeded those of females by a sum of 3.1 mm in the maxilla and 3.6 mm in the mandible, and these differences were statistically significant in Jordanian population. Al-khateeb and Abo Alhaij[34] found that female have smaller teeth than male.

In Japanese orthodontic population with different malocclusion group, Endo [35] found that no statistically significant gender differences were found in anterior or overall ratio in any group.

Iyad K. Al-Omari [36] studied the tooth size discrepancy in Jordanian school children and compared it with gender. The results showed that no significant differences between males and females.

1.4.3 Tooth-size discrepancies in different classes of malocclusion

Lavelle [14] studied 160 subjects to determine anterior tooth sizes. The result showed that Bolton’s discrepancy was greater in Class III subjects than other malocclusion groups. The same results was reported by Sperry et al [18].

Crosby and Alexander [4] studied the prevalence of tooth size discrepancy among different malocclusion groups class I and class II of 20 and 30 subjects respectively. For the anterior ratio, 16.7% of
Class I patients had significant discrepancy, and 23.4% in Class II group and stated that the difference is highlighted because it might be considered potentially significant, but in fact there were no statistically significant differences in the prevalence of tooth size discrepancy among the malocclusion groups.

Nie and Lin [37] studied tooth size discrepancy in a sample of 360 cases. A significant difference was found in all malocclusion groups, for the anterior, posterior and overall ratios which were greatest in Class III and lowest in Class II.

Ta et al [38] compared anterior and overall ratios among different occlusion groups of Southern Chinese children. For the anterior ratio, a statistically significant difference was observed between the Bolton standard and the Class III occlusion group. Whereas overall ratio, statistically significant differences were found between the Bolton standard and Class II malocclusion group, also between Class II and Class III malocclusion groups.

Laino et al [39] reported no relationship across three categories of Angle malocclusions in orthodontic patients from the Campania region of Italy. The patients divided into three groups based on Angle molar classification and the cephalometric ANB value. The result showed no association between tooth size and the malocclusion groups.
Alkofide and Hashim [40] recorded no significant difference in the frequency of tooth-size discrepancies for the overall or anterior ratios between malocclusion groups except for the anterior ratio in Class III malocclusion in 240 pretreatment Saudis casts.

Araujo and Souki [2] investigated Bolton anterior tooth size discrepancies among different malocclusion groups and reported that 56% of the subjects in the study showed Bolton tooth size discrepancy. Clinically significant discrepancies were found in 23% of the sample, and concluded that individuals with Angle Class I and Class III malocclusions have significantly greater frequencies of tooth size discrepancies than individuals with Class II malocclusions and the mean anterior tooth size discrepancy for Angle Class III subjects was much greater than for Class I and Class II subjects. In contrast, no significant difference in Bolton anterior ratios was found between genders.

Al SuIaimani et al [41] studied Bolton analysis in different malocclusion group in Saudi sample and observe that no significant difference between Class I, Class II, and Class III malocclusions and between gender in Bolton anterior and overall ratios.

Uysal et al [42] stated that there no association between tooth size discrepancy and Angle Class I; Class II, division 1; Class II, division 2; and Class III malocclusion groups.
Basaran et al [43] studied the association between tooth-size discrepancies and different malocclusion groups among Turkish youths. No significant difference between subcategories of malocclusion were found, so these groups were combined as Class I, Class II, and Class III. No significant difference also found for all the ratios between the groups.

Akyalcin et al [44] found no significant difference in Turkish population for ratios between the different malocclusion groups (48 Class I, 60 Class II, and 44 Class III) and concluded that tooth size discrepancies were independent of Angle’s classification.

Fattahi et al [45] carried out a study on 200 Iranian patients with different malocclusion groups. The results show that subjects with an Angles Class III malocclusion had a significantly greater prevalence of tooth size discrepancies than those with Class I and Class II malocclusion. The mean anterior tooth size discrepancy for Angle Class III individuals was significantly greater than Class II subjects.

Al-Khateeb and Abu Alhaija [34] conducted a similar study in a Jordanian sample and concluded that subjects with Class III malocclusion exhibited significantly larger teeth than other malocclusion. No significant difference was found in anterior or overall Bolton ratios.
Endo et al [35] studied the tooth size discrepancy in different malocclusion groups in Japanese orthodontic population. No significant differences were found between the distributions of subjects with clinically significant tooth size discrepancies, categorized by the Bolton standard deviation definition and by the actual amount of change calculated for tooth size correction in millimeters, among the malocclusion groups except for the mandibular correction for the overall ratio between Class I and Class III subjects.

Battol et al [46] evaluate the tooth size discrepancy in different malocclusion groups in Pakistani sample. A significant higher mean of anterior tooth ratios were found for Class II malocclusion.

In 2009 Mihovil Strujić et al [47] carried out a study in Croatian sample with different malocclusion. A significant difference in the overall and posterior ratio was observed between Class II and Class III subjects.
1.4.4 Methods of measuring mesiodistal tooth size for Bolton ratios and reproducibility

The methods of measurement of the mesiodistal size should be easy in application. Equally, no method of measurement is robust without good documentation of the reproducibility. The traditional method of measuring mesio-distal widths of teeth on dental casts (manual methods) is either employed needle-pointed dividers or a Boley gauge (Vernier calipers).

Shellhart [48] in 1995 evaluated the reliability of the Bolton analysis when performed by two instruments and investigated the effect of crowding on measurement error, and concluded that clinically significant measurement errors could occur when the Bolton tooth-size analysis is performed on casts with at least 3 mm crowding, a factor that should lead clinicians to undertake a tooth size discrepancy analysis only when the teeth have been aligned.

Recent technological advances have allowed the introduction of digital calipers, which can be linked to computers for rapid calculation of the anterior and posterior ratios and the required correction to produce Bolton’s mean ratio. Alternatively, digitized or scanned images of the study casts can be measured on-screen.

In 1998 Mok et al [49] conducted a study to compare reproducibility of the mesiodistal tooth width given by the DigiGraph Workstation and by digital caliper and found that the sonic
digitalization was not as reproducible as digital caliper and its clinical usefulness should be taken with caution when used in measuring the space condition in malocclusion.

Ho and Freer [50] suggested that 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, although the same measurement error may be associated with the positioning of the calipers on the teeth.

Tomassetti [51] performed a study using manual measurements with a Vernier caliper and three computerized methods in which Quick Ceph was the quickest method followed by Hamilton Arch Tooth System (HATS), OrthoCAD and Vernier calipers. Quick Ceph results had the greatest mean discrepancy than Vernier calipers although not statistically significant and were least correlated with the Vernier caliper results. No measurement of the reproducibility was performed.

Zilberman [52] compared the measurement using digital calipers with OrthoCAD. The result showed that Digital calipers produced more accurate and reproducible results than OrthoCAD and concluded that Digital calipers instrument was suitable for scientific work, and OrthoCAD’s accuracy accepted clinically.
Paredes [53] evaluated the Bolton tooth-size ratios measurement and stated that the digital method provided results comparable with those of the traditional technique.

Othaman and Harradine [54] compare the reproducibility and speed of two methods of performing Bolton's tooth-size analysis. Bolton tooth-size discrepancies and ratios were measured using two methods; one method employed entirely manual measurement and the Odonto rule slide rule, while the other employed digital calipers and the HATS analysis software. The electronic measurement was found to be more rapid than the manual method and both methods demonstrate relatively high random error.

Houston [55] stated that if any quantitative study is to be of value, it is imperative that error analysis be undertaken and reported. The reproducibility of all the methods of measurement has not been adequately explored.
1.4.5 Definition of normal, ideal, excellent and optimal occlusion

To validate Bolton's study, similar ideal occlusion cases were needed. The criteria for the "excellent" occlusions used by Bolton were based on reference to Angle's 1907.[9] Several authors have discussed normal and ideal occlusion of the teeth.

Stifter [17] define normal occlusion as 'occlusion of the teeth is normal when their manifold functions are efficiently performed and the health of the supporting structures is maintained'. The primary functions of the teeth include mastication, esthetics and functions of speech and deglutition. Stiffer wrote that strict adherence to the concept of ideal occlusion had been severely criticized.

Stifter [17] and proffit [3] have referred to Angle's classification as the best way to understand the exact features of normal occlusion and the types of occlusions. Angle's key to occlusion was the position of the upper first permenant molar. The upper and lower molars relate such that the mesiobuccal cusp of the upper molar is situated in the buccal groove of the lower molar. Normal occlusion results in the presence of this molar relationship, if the teeth are aligned on a smooth, catenary’s and curving line of occlusion. Proffit [3] stated that 100 years of experience has proved Angle to be correct except when there are aberrations in the size of teeth.
Brodie [56] stated that “each individual is distinct so far as the morphological characteristics of the head are concerned and just as there are no two sets of identical fingerprints each component part exhibits wide ranges of variation.” The author felt that one could establish a norm by taking an average of all of the variants and combining them, but having done so, the result was not significant for diagnosis.

Current concepts of ideal occlusion are based to a large extent on the principles and teaching of Andrews [57]. Assessment of optimal occlusion, according to Andrews, is based on the presence of the "Six Keys to optimum occlusion" which are:

Key One: Molar relationship - Class 1.

Key Two: Crown angulations (tip) - mesiodistal tip of the long axis of the crown such that the gingival portion is distal to the incisal portion.

Key three: Crown Inclination (torque) - refers to the labiolingual inclination of the long axis of the crown.

Key Four: Absence of tooth rotations.

Key Five: Tight contacts

Key Six: Curve of Spee depth varies from flat to slightly concave.
Andrews established the six keys to optimum occlusion by evaluating the characteristics common to 120 cases, which described as non orthodontic normal (N.O.N.).

Features of the selected cases are:

1. Never had orthodontic treatment,

2. Teeth are straight and pleasing in appearance,

3. had a bite which generally looked correct,


The 120 non-orthodontic normal models studied in the research differed in some respects, but all shared the six characteristics. The absence of any one or more of the six keys results in an occlusion that is proportionately inferior to the naturally optimal sample according to Andrews. Optimal is used for correct; normal is used to mean not abnormal [58] and the six keys can be used as treatment guidelines.

Andrews [58] stated that most of the populations were afflicted with malocclusion and that occlusal deviations are natural, distinguishing the normal malocclusion from abnormal malocclusions as those individuals that can be treated to optimal standards without compromise or help from surgical specialist.
In recent years, much more attention has been paid to tooth size discrepancy, because this may be an obstacle to achieving an ideal result in many cases. Therefore, Bennet and McLaughlin [59] in 1993 recommended a seven key of occlusion ‘correct tooth size’. It is clear that Andrews non-orthodontic normal model had balance tooth size. If not there would be spacing in one arch or crowding in other arch.
CHAPTER 2

Material and methods

2.1 Study design

Cross-sectional descriptive community based study.

2.2 The sample

The total sample consisted of 110 orthodontic study models half of it with normal occlusion and the other half with different malocclusions. The normal occlusion sample obtained from dental student, faculty of dentistry, University of Khartoum 55 normal (25 M, 30 F).

The malocclusion models were selected from the orthodontic department, faculty of dentistry, University of Khartoum, 20 class I (9 M, 11 F), 19 class II (8 M, 11 F) and 16 class III (7 M, 9 F).

The inclusion criteria for normal and malocclusion models were as follows:

- All permanent teeth (from first permanent molar right to first permanent molar left) are erupted and present.

- No mesiodistal or occlusal tooth abrasion.
• No tooth deformity e.g. gemination or peg shape lateral incisor.

• No record of proximal restoration or reduction.

• No residual crown or bridge restoration.

2.3 Materials:

1. Dental mirrors.

2. Disposable gloves.

3. Alginate impression material.

4. Trays.

5. Dental stone.

6. Rubber bowels and Spatulas.

7. Dental casts with different malocclusion.

8. Digital caliper.


10. Recording sheets.
2.4 Methodology:

Intra oral examinations were done for all the final and semi final dental students in the Orthodontic department in period of two months. The selected student who fulfills the previous inclusion criteria and have Class I molar and cuspid relation with good intercuspation and 2-3mm overjet and overbite, were recorded and in the end of screening a set of alginate impression were obtained from each student.

The impressions were washed and poured in the same day with dental stone by the investigator.

The mesiodistal tooth size for the twelve maxillary and mandibular teeth from the right first permanent molars to the left first permanent molars were measured in the study models by the investigator (figure 1). The readings were obtained by measuring the greatest width between the contact points of each crown by the digital calipers (figure 2). The digital caliper was held parallel to the incisal edges or occlusal surfaces. The caliper beaks were inserted from the buccal (labial), and held occlusally parallel to the long axis of the tooth. The beaks were closed until gentle contact with the contact points of the tooth was felt.
Tooth size ratio between upper and lower teeth was calculated as described by Bolton[1]

a- Overall ratio (OR)

\[
O\ R = \frac{\text{Sum of mesiodistal width of mandibular twelve teeth}}{\text{Sum of mesiodistal width of maxillary twelve teeth}} \times 100\%
\]

b- The anterior ratio (AR)

\[
A\ R = \frac{\text{Sum of mesiodistal width of mandibular six teeth}}{\text{Sum of mesiodistal width of maxillary six teeth}} \times 100\%
\]
Figure 1. mesiodistal tooth size measure
Figure 2 Digital caliper
2.5 Statistical analysis

The data were collected, summarized, cleaned and coded; then entered to the statistics package for social science (SPSS) program (version 15).

Frequency tables and descriptive statistic (mean, range and standard deviation) were done for each tooth in normal and malocclusion groups, the anterior and overall ratio and for each group of malocclusion.

The mesiodstal tooth width was compared between right and left side and between male to female using t-test to determine the significance levels.

Analysis of variance (ANOVA) was used to compare between Bolton ratios in different malocclusion groups and Bolton ratio between normal occlusion and different malocclusion groups.

The level of significant was 0.05%
2.6 Error of the method

15 casts randomly selected by the same investigator. The measurements were done twice within 10 days interval period.

The error of method was calculated using Dahlberg’s formula

\[
    ME = \sqrt{\frac{\sum d^2}{2n}}
\]

ME = method error.

n = repeated reading.

d = difference between first and second reading.
CHAPTER 3

RESULTS

3.1 Error of the method

The result from Dahlberg’s method showed the mean of the measurement error of the mesiodistal tooth size for the individual teeth with of 0.28 mm ± 0.136mm. The highest value was 0.86 mm and the lowest value was 0.01 mm.

No significant difference between the two sets of measurement (p < 0.05) was found.
3.2 Mesiodistal tooth Size of the Permanent Teeth

Table 1 showed the means, standard deviations standard error and range for individual tooth. The widest range was observed in the maxillary lateral incisors whereas the narrowest range on the mandibular lateral incisors.

Table 1. Means and standard deviations (mean ± SD) of the mesiodistal tooth size of the sample (measurements are in mm) (n= 110)

<table>
<thead>
<tr>
<th>Arch</th>
<th>Tooth</th>
<th>Mean ± SD</th>
<th>Standard error</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Maxillary</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Central incisor</td>
<td>8.95 ±0.61</td>
<td>0.06</td>
<td>3.11</td>
</tr>
<tr>
<td></td>
<td>Lateral incisor</td>
<td>7.06 ± 0.57</td>
<td>0.05</td>
<td>3.19</td>
</tr>
<tr>
<td></td>
<td>Canine</td>
<td>8.05 ± 0.55</td>
<td>0.05</td>
<td>2.72</td>
</tr>
<tr>
<td></td>
<td>1st premolar</td>
<td>7.42 ± 0.55</td>
<td>0.05</td>
<td>2.66</td>
</tr>
<tr>
<td></td>
<td>2nd premolar</td>
<td>6.65 ± 0.59</td>
<td>0.06</td>
<td>2.49</td>
</tr>
<tr>
<td></td>
<td>Molar</td>
<td>10.12 ± 0.51</td>
<td>0.05</td>
<td>2.74</td>
</tr>
<tr>
<td><strong>Mabdibular</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Central incisor</td>
<td>5.48± 0.52</td>
<td>0.05</td>
<td>2.17</td>
</tr>
<tr>
<td></td>
<td>Lateral incisor</td>
<td>6.00± 0.51</td>
<td>0.05</td>
<td>2.07</td>
</tr>
<tr>
<td></td>
<td>Canine</td>
<td>7.29± 0.60</td>
<td>0.06</td>
<td>2.33</td>
</tr>
<tr>
<td></td>
<td>1st premolar</td>
<td>7.42± 0.55</td>
<td>0.05</td>
<td>2.66</td>
</tr>
<tr>
<td></td>
<td>2nd premolar</td>
<td>7.10± 0.52</td>
<td>0.05</td>
<td>2.5</td>
</tr>
<tr>
<td></td>
<td>Molar</td>
<td>11.02± 0.64</td>
<td>0.06</td>
<td>3.18</td>
</tr>
</tbody>
</table>
Comparisons between the right and left sides of the individual tooth sizes in the same arch showed in Table 2. No significant differences were detected between the contra lateral teeth.

Table 2. Means & stander deviations (mean± SD) of the mesiodistal tooth size of right and left sides (measurements are in mm) (n= 110)

<table>
<thead>
<tr>
<th>Arch</th>
<th>Tooth</th>
<th>Right</th>
<th>Left</th>
<th>P value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maxillary</td>
<td>central incisor</td>
<td>8.95±0.62</td>
<td>8.95±0.64</td>
<td>0.96</td>
</tr>
<tr>
<td></td>
<td>lateral incisor</td>
<td>7.05±0.64</td>
<td>7.06±0.57</td>
<td>0.941</td>
</tr>
<tr>
<td></td>
<td>Canine</td>
<td>8.05±0.59</td>
<td>8.04±0.58</td>
<td>0.936</td>
</tr>
<tr>
<td></td>
<td>1st premolar</td>
<td>7.30±0.48</td>
<td>7.30±0.58</td>
<td>0.995</td>
</tr>
<tr>
<td></td>
<td>2nd premolar</td>
<td>6.66±0.56</td>
<td>6.63±0.74</td>
<td>0.71</td>
</tr>
<tr>
<td></td>
<td>Molar</td>
<td>10.12±0.52</td>
<td>10.11±0.53</td>
<td>0.961</td>
</tr>
<tr>
<td>Mandibular</td>
<td>central incisor</td>
<td>5.47±0.53</td>
<td>5.48±0.55</td>
<td>0.803</td>
</tr>
<tr>
<td></td>
<td>lateral incisor</td>
<td>5.99±0.53</td>
<td>6.01±0.54</td>
<td>0.758</td>
</tr>
<tr>
<td></td>
<td>Canine</td>
<td>7.31±0.51</td>
<td>7.28±0.86</td>
<td>0.754</td>
</tr>
<tr>
<td></td>
<td>1st premolar</td>
<td>7.42±0.58</td>
<td>7.42±0.58</td>
<td>0.973</td>
</tr>
<tr>
<td></td>
<td>2nd premolar</td>
<td>7.09±0.54</td>
<td>7.10±0.56</td>
<td>0.923</td>
</tr>
<tr>
<td></td>
<td>Molar</td>
<td>11.00±0.64</td>
<td>11.04±0.70</td>
<td>0.694</td>
</tr>
</tbody>
</table>

p < 0.05
3.3 Mesiodistal tooth Size Comparison between Gender

Table 3 exhibited the means and standard deviations of the individual mesiodistal tooth sizes of males and females. In general male had larger mesiodistal tooth sizes than female. Significant differences in tooth sizes were recorded in the maxillary lateral incisor and canines (p <0.05) and also in the mandibular canine and first molar (p <0.05).

<table>
<thead>
<tr>
<th>Arch</th>
<th>Tooth</th>
<th>Male n=49</th>
<th>Female n= 61</th>
<th>P value</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Maxillary</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Central incisor</td>
<td>9.05 ±0.65</td>
<td>8.87±0.57</td>
<td>0.127</td>
</tr>
<tr>
<td></td>
<td>Lateral incisor</td>
<td>7.19±0.57</td>
<td>6.95±0.55</td>
<td>0.029*</td>
</tr>
<tr>
<td></td>
<td>Canine</td>
<td>8.21±0.59</td>
<td>7.91±0.48</td>
<td>0.004*</td>
</tr>
<tr>
<td></td>
<td>1st premolar</td>
<td>7.52±0.50</td>
<td>7.35±0.57</td>
<td>0.1</td>
</tr>
<tr>
<td></td>
<td>2nd premolar</td>
<td>6.69±0.68</td>
<td>6.61±0.51</td>
<td>0.475</td>
</tr>
<tr>
<td></td>
<td>Molar</td>
<td>10.15±0.54</td>
<td>10.09±0.48</td>
<td>0.545</td>
</tr>
<tr>
<td><strong>Mandibular</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Central incisor</td>
<td>5.57±0.58</td>
<td>5.4±0.45</td>
<td>0.073</td>
</tr>
<tr>
<td></td>
<td>Lateral incisor</td>
<td>6.1±0.51</td>
<td>5.92±0.5</td>
<td>0.058</td>
</tr>
<tr>
<td></td>
<td>Canine</td>
<td>7.43±0.75</td>
<td>7.19±0.41</td>
<td>0.032*</td>
</tr>
<tr>
<td></td>
<td>1st premolar</td>
<td>7.52±0.5</td>
<td>7.35±0.57</td>
<td>0.1</td>
</tr>
<tr>
<td></td>
<td>2nd premolar</td>
<td>7.15±0.57</td>
<td>7.05±0.49</td>
<td>0.308</td>
</tr>
<tr>
<td></td>
<td>Molar</td>
<td>11.16±0.65</td>
<td>10.91±0.62</td>
<td>0.042*</td>
</tr>
</tbody>
</table>

* Significant difference (p < 0.05).
3.4 Comparison of mesiodistal tooth size different malocclusion groups

Table 4 showed the means and standard deviations of the individual tooth sizes for class I, class II and class III malocclusion group.

Comparison among the individual tooth size of different malocclusion groups showed that class II malocclusion had prevalent tendency toward larger tooth size except for maxillary central incisors, maxillary first molar and mandibular canine in class I and mandibular first molar in class III. The one way analysis of variance indicates that there was significant difference among the different malocclusion classes in the tooth size of maxillary lateral incisors (p < 0.05).
Table 4. Means and standard deviation (mean± SD) of mesiodistal tooth size in different malocclusion groups (measurements are in mm)

<table>
<thead>
<tr>
<th>Arch</th>
<th>Tooth</th>
<th>Class I</th>
<th>Class II</th>
<th>Class III</th>
<th>P value</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>n= 20</td>
<td>n=19</td>
<td>n=16</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Maxillary</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td><strong>Central incisor</strong></td>
<td>9.11±0.69</td>
<td>9.09±0.69</td>
<td>8.71±0.60</td>
<td>0.147</td>
</tr>
<tr>
<td></td>
<td><strong>Lateral incisor</strong></td>
<td>7.03±0.59</td>
<td>7.36±0.56</td>
<td>6.80±0.61</td>
<td>0.023*</td>
</tr>
<tr>
<td></td>
<td><strong>Canine</strong></td>
<td>8.04±0.64</td>
<td>8.24±0.56</td>
<td>8.11±0.50</td>
<td>0.538</td>
</tr>
<tr>
<td></td>
<td><strong>1st premolar</strong></td>
<td>7.50±0.49</td>
<td>7.62±0.55</td>
<td>7.35±0.76</td>
<td>0.43</td>
</tr>
<tr>
<td></td>
<td><strong>2nd premolar</strong></td>
<td>6.55±0.73</td>
<td>6.76±0.58</td>
<td>6.73±0.60</td>
<td>0.56</td>
</tr>
<tr>
<td></td>
<td><strong>Molar</strong></td>
<td>10.23±0.49</td>
<td>10.07±0.65</td>
<td>10.02±0.57</td>
<td>0.516</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mandibular</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td><strong>Central incisor</strong></td>
<td>5.50±0.44</td>
<td>5.84±0.73</td>
<td>5.42±0.58</td>
<td>0.089</td>
</tr>
<tr>
<td></td>
<td><strong>Lateral incisor</strong></td>
<td>5.97±0.52</td>
<td>6.26±0.63</td>
<td>5.85±0.44</td>
<td>0.077</td>
</tr>
<tr>
<td></td>
<td><strong>Canine</strong></td>
<td>7.22±0.5</td>
<td>7.50±0.45</td>
<td>7.5±0.42</td>
<td>0.356</td>
</tr>
<tr>
<td></td>
<td><strong>1st premolar</strong></td>
<td>7.50±0.49</td>
<td>7.62±0.55</td>
<td>7.35±0.76</td>
<td>0.43</td>
</tr>
<tr>
<td></td>
<td><strong>2nd premolar</strong></td>
<td>7.18±0.58</td>
<td>7.18±0.51</td>
<td>7.13±0.47</td>
<td>0.938</td>
</tr>
<tr>
<td></td>
<td><strong>Molar</strong></td>
<td>11.13±0.61</td>
<td>10.93±0.67</td>
<td>11.21±0.7</td>
<td>0.412</td>
</tr>
</tbody>
</table>

* Significant difference (p < 0.05).
3.5 Bolton ratio application in Sudanese sample

Table 5 summarized statistical comparison between the overall ratio and anterior ratio of the present study and Bolton study (1956). The result revealed no statistical a significant difference was observed in tooth size ratio except that the standard deviation in the Sudanese sample is high in both ratios.

Table 5. Means, SD and range of the Sudanese and Bolton’s sample (measurements are in mm)

<table>
<thead>
<tr>
<th></th>
<th>Sudanese sample</th>
<th>Bolton's sample</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean ± SD</td>
<td>Range</td>
</tr>
<tr>
<td>Overall ratio</td>
<td>91.47±2.83</td>
<td>83.85 - 96.81</td>
</tr>
<tr>
<td>Anterior ratio</td>
<td>77.46±3.16</td>
<td>70.97 - 84.17</td>
</tr>
</tbody>
</table>

(p < 0.05)
3.6 comparison Mesiodistal tooth size ratio between genders in different malocclusion group

Means and standard deviation of the anterior ratio the males and the females were 76.64 ± 6.65 and 77.95 ± 2.57 for class I, 80.63 ± 5.56 and 78.46 ± 3.61 for class II, and for class III 79.00 ± 3.40 and 80.03 ± 4.86 respectively. Means and standard deviation of the overall ratio between the males and the female were 92.09 ± 3.79 and 92.39 ± 2.71 for class I, 94.11 ± 3.84 and 92.04 ± 2.63 for class II and 93.39 ± 2.14 and 92.89 ± 3.55 for class III respectively. The anterior and overall ratios were compared between male and female in each classification (figure 3, 4) no significant differences were detected between genders (p< 0.05).

Figure 3. Comparison between male and female overall ratio
3.7 Mesiodistal tooth size ratio between different malocclusion groups

The gender separated samples were combined for each class because no significant sexual dimorphism for tooth size ratio was found. The means and standard deviation for anterior ratio were, $77.36 \pm 4.75$, $79.37 \pm 4.52$ and $79.58 \pm 4.19$ for class I, class II and class III respectively. The means and standard deviation for overall ratio were $92.26 \pm 3.15$, $92.92 \pm 3.27$ and $93.11 \pm 2.94$ for class I, class II and class III respectively. No statistical significant difference was observed in the anterior and overall ratios (figure 5, 6) between the different malocclusion groups (p<0.05)
Figure 5. Comparison of anterior ratios between different malocclusion groups

Figure 6. Comparison of overall ratios between different malocclusion groups
3.8 Comparison of mesiodistal tooth size ratio between normal occlusion and different malocclusion groups

The means and standard deviation of anterior ratio of the normal occlusion and class I were 77.45 ± 3.15 and 77.36 ± 4.75 respectively and for overall ratio were 91.47 ± 2.83 and 92.25 ± 3.15 respectively. No significant differences were found in both ratios (p< 0.05) (figure 7, 8)

Class II malocclusion when compared with normal occlusion the means and standard deviation of anterior ratio were 79.37 ± 4.52 and 77.45 ± 3.15 respectively, and for overall ratio were 92.91 ± 3.26 and 91.47 ± 2.83 respectively. A significant difference was revealed in anterior ratio (p<0.05) where class II exhibited higher mean value.

The means and standard deviation of anterior ratio of the normal occlusion and class III were 77.45 ± 3.15 and 79.58 ± 4.81 respectively, and for the overall ratio were 91.47 ± 2.83 and 93.10 ± 2.93 respectively. Significant difference was observed in the anterior and overall ratio (p<0.05) where class III showed higher mean value.
Figure 7. Comparison of overall ratios between normal occlusion and different malocclusion groups.

Figure 8. Comparison of anterior ratios between normal occlusion and different malocclusion groups.
CHAPTER 4

4.1 Discussion

The mesiodistal tooth size of the maxillary and mandibular arch must relate to each other in order to obtain an optimal occlusion at the completion of the orthodontic treatment.[1] It is one of the important factors that contribute in the inadequate relationship is the tooth size discrepancy.[60]

The wide variation in tooth size for example lateral or the premolar or any other tooth may be the cause of tooth size discrepancy [61]. These variations in tooth size anomaly make it difficult to be detected by clinical examination.

Bolton ratio been developed to help clinicians to diagnose tooth size discrepancy before starting treatment. Identifying such discrepancy from the start of treatment will improve the orthodontic treatment plan and clear the final expectation of both patient and orthodontist. The treatment alternatives of tooth size discrepancies include restoration of relatively small teeth, interproximal striping of relatively large teeth, modification of crown angulation or inclination and extraction. [7]
4.1.1 Mesiodistal tooth size of permanent teeth

In the present study the means of mesiodistal tooth size showed that mesiodistal size of the maxillary lateral incisors had the widest range and the size of the mandibular incisors had the narrowest range. This is in harmony with Hattab et al [33] study in 198 Jordanian sample which indicates that anomaly in the size of maxillary lateral incisor might affect tooth size discrepancy. In contrast; the lower incisors had the narrowest range in the present study whereas Hattab found in the lower molar had the narrowest range. Santoro et al [22] reported that the maxillary teeth showed a higher variability than the mandibular teeth, with the first molar dimensions showing the greatest variability and the size of the maxillary central and lateral incisors also presented high variability which inpartial agreement with the result of the present study.

In comparing the right and left side no significant difference was found. These results were in agreement with those reported by Hattab in Jordanian population groups [33] but contradicting with Alkateeb et al [34] in 140 orthodontic model of Jordanian population which reported significant discrepancy in right to left side tooth size in both upper and lower arches. Ballard [11] found that in 90% of the sample there was a right to left discrepancy and concluded that asymmetry in tooth size is the rule, not the exception.
4.1.2 Tooth size comparison between male and female

The means of tooth size showed that male teeth sizes were larger than female. This is agreed with several studied Lavelle[14], Richardson and Malhotra [20], Bishara [31], AL- khateeb [34], Smith et al[8] and Santoro et al [22].

Arya et al [32] studied (48 M, 47 F) the mesiodistal width of teeth between male and female and reported that all teeth except mandibular incisor were significantly different between male and female. However, the present study showed that there were significant differences in tooth sizes between gender for the maxillary lateral incisor and canines whereas in the mandibular arch were the canine and first molar. These finding are agreed with Hattab et al [33] in Jordanian sample where the most variable tooth in mesiodistal size was the maxillary canine.

4.1.3 Comparison of tooth size in different malocclusion group

No significant difference in tooth size was reported in the present study between different malocclusion groups, only the maxillary lateral incisors showed significant difference. Class II malocclusion showed prevalent tendency toward larger tooth size. However Arya et al [32] in 95 case selected from longitudinal growth records of the Child Study Clinic at the University of Oregon Dental
School found that no consistent pattern to when comparing class I and class II group.

In the present study class III malocclusion revealed the smallest tooth size in both arches except maxillary canine, mandibular molar and canine. However Lavelle [14] reported that maxillary teeth size of class III is the smallest among the others malocclusion groups; but the tooth sizes of class III were the biggest in mandibular teeth.

4.1.4 Compare normal sample with Bolton original sample

No significant different were found in the anterior and the overall ratio between Bolton original sample and the present study. This result is online with Norallah et al [25] in 55 Syrian sample with neutral occlusion (Angle Class I), harmonious overjet and overbite, no reduction of mesiodistal tooth width or missing teeth. In Saudi sample Al-Tamimi and Hashim [23] found no significant difference in Saudi military officers with normal occlusion whereas alkofi and Hashim [40] reported a statistically significant difference.

Bolton’s standards deviation (SD) when compared with the present study a difference was observed. This may be attributed to the difference in the sample criteria. Bolton’s [1, 13] sample was obtained from the models of 55 subjects with perfect Class I occlusions. The population and gender composition of that sample was not specified; the grouping criteria were not explained in detail and it was unclear as
to how many were treated or untreated, which implies potential selection bias[43].

Anterior and overall ratios obtained for the present Sudanese sample were greater than from Bolton’s American population. This is probably due to racial differences. A similar findings of large anterior or overall ratios compared with Bolton’s were obtained by previous studies of different populations (table 6).

Uysal [26] in Turkish population and Paredes [27] in Spanish population concluded that Bolton ratio is not applicable to the samples studied and recommended to have specific ratio for this population.

Table 6. Anterior and total ratios for various populations compared with Bolton standards (%)

<table>
<thead>
<tr>
<th>Population</th>
<th>Study</th>
<th>Anterior ratio</th>
<th>Overall ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>White Americans</td>
<td>Bolton[1, 13]</td>
<td>77.2</td>
<td>91.3</td>
</tr>
<tr>
<td></td>
<td>Crosby and Alexander [4]</td>
<td>77.5</td>
<td>91.4</td>
</tr>
<tr>
<td></td>
<td>Smith et al [8]</td>
<td>79.6</td>
<td>92.3</td>
</tr>
<tr>
<td>Spanish (Spain)</td>
<td>Paredes [27]</td>
<td>78.32</td>
<td>91.97</td>
</tr>
<tr>
<td>Spanish (South America) Blacks</td>
<td>Smith et al [8]</td>
<td>80.5</td>
<td>93.1</td>
</tr>
<tr>
<td>Dominican Americans</td>
<td>Santoro et al [22]</td>
<td>78.1</td>
<td>91.3</td>
</tr>
<tr>
<td>Peruvians</td>
<td>Bernabé et al [24]</td>
<td>78.09</td>
<td>90.79-91.33</td>
</tr>
<tr>
<td>Chinese</td>
<td>Nie and lie [38]</td>
<td>81.95</td>
<td>93.44</td>
</tr>
<tr>
<td>Saudi</td>
<td>Alkofi and Hashim[40]</td>
<td>78.86</td>
<td>92.61</td>
</tr>
<tr>
<td>Japanese</td>
<td>Endo et al [28]</td>
<td>78.39</td>
<td>91.60</td>
</tr>
</tbody>
</table>
4.1.5 Comparison of tooth size ratios between genders

Several studies [2, 25, 27, 44] reported no significant differences in the overall ratio and the anterior ratio between gender. In contrast, Alkofide and Hashim [40] when studying Saudis, observed a significant difference in the anterior ratio between males and females in Class III malocclusion similar to the results reported by Lavelle [14].

Smith et al [8], studied 180 patients, including 30 males and 30 females from each of 3 populations (black, Hispanic, and white). The results showed a gender difference in the overall ratio among different population, which in harmony with Araujo et al [2] result in 300 Brazilian cases and with Uysal et al in 560 Turkish patients [26].

Fatthi et al [45] reported a statistically significant differences in the anterior ratio between males and females in Iranian population. According to the results, the gender difference in the tooth size ratio may be population specific.

4.1.6 Comparison of intermaxillary tooth size ratio in different malocclusion group

In the present study the anterior and overall ratios showed no significant differences between the malocclusion groups. This is in agreement with previous studies carried out by Lanio et al [39] in 94 patients from Italy with different malocclusion, Basaran et al [43] and
Uysal et al [42] in Turkish population, Al SuIaimani and Afify [41] in 160 Saudi sample and Al Khatee b and Abu Alhaija [34] in 140 Jordanian people. However, Crosby and Alexander [4] found no significant difference in class I and class II malocclusion.

In contrast Fattahi et al [45] in the pretreatment models of 200 Iranian patients reported that the anterior tooth size discrepancy for Angle Class III individuals was significantly greater than that in Class II and Nie and Lie [37] in 300 subject in china found significant difference in all the ratios between the malocclusion groups, showing that the anterior, posterior and overall ratios were all greatest in Class III and lowest in Class II.

Battol et al [46] reported in Pakistani sample of different malocclusion groups, a high mean of anterior ratio in class II malocclusion. In Croatian sample Mihovil Strujić et al [47] observed a significant difference between class II and class III.

In class III malocclusion group, the overall ratio reported to be the largest of all the malocclusion groups in the present study; which agreed with previous studied carried out in different populations. Sperry et al [18] concluded that the mandibular tooth size excess was found in class III malocclusion. This statistically significant trend to larger ratios in Class III patients was also reported by Ta et al [38] in Southern Chinese, Alkofide and Hashim [40] in Saudis, Araujo and Souki [2] in Brazilians, and Fatahi et al [45] in Iranians.
Lavelle [14] on 160 subject observed that maxillary teeth were the smallest and mandibular teeth were the largest in the different malocclusions groups. This may indicates that the tooth size ratio of class III group was the greatest among the malocclusion groups.

Difference in the results of comparing the mesiodistal tooth size in different malocclusion between the present study and some previous reported studies as mentioned above may be attributed to the sample size, method of analysis, method of measurement, racial differences and large standard deviation found in the present study.

4.1.7 Comparison of normal occlusion with class I, class II and class III malocclusion groups

No significant difference was observed between normal occlusion and class I malocclusion in anterior and overall ratios. This is in agreement with Nie and Li study on 300 patient in china. In class II significant difference found in overall ratio of class II and both ratios of class III. This is also reported by Hashim and Murshid [62] in a Saudi sample and Al- Tamimi and Hashim [23] on 65 Saudi subject. Alkofide and Hashim [40] in 240 pretreatment orthodontic casts (Sixty cases in each malocclusion class, in addition to normal occlusion) reported a significant difference was found in all malocclusion cases as compared to Bolton’s norms.
Tooth size discrepancy can be detected by using a diagnostic setup or by using the Bolton formulae. If the discrepancy was not detected during the diagnostic stage, it may lead to a postponement in the completion of orthodontic treatment at the finishing stage or to a compromised result. Therefore, in order to evade such problem Bolton analysis should be performed at the initial diagnostic stage preceding orthodontic treatment.

The analysis procedure may seem to be time consuming but the benefits seem to balance this minor inconvenience by allowing more efficient diagnosis of the problem. Populations differ in interarch tooth-size relationships, and differences in tooth sizes are not systematic. The population and gender composition of Bolton’s sample were not specified, but it is likely that the selection was biased.
4.2 Conclusion

1- The male teeth showed a tendency to have larger mesiodistal tooth size than female.

2- The maxillary central and lateral incisor had the great variability in the mesiodistal size; so it may be the cause of tooth size discrepancy.

3- Bolton overall ratio in the present study was 91.47 ± 2.83 and the anterior ratio was 77.46 ± 3.16.

4- No statistically significant difference in the anterior and overall ratio from the Bolton standard and the normal occlusion.

5- There is no significant difference in the anterior and overall ratio between different malocclusion groups and between genders.

6- Class III malocclusion demonstrated significant difference in anterior and overall ratio when compared with normal occlusion.

7- Class II malocclusion exhibited significant difference in anterior ratio when compared with normal occlusion.
4.3 Recommendations

The objectives of the present study were achieved, therefore studies are recommended on a larger sample size of normal occlusion and different malocclusion groups from different parts of the Sudan in order to:

1. Have slandered mesiodistal tooth size for Sudanese population.
2. To verify if the present result can be applied to different ethnic groups in Sudan.
4.4 References


[34] Al-Khateeb SN, Abu Alhaija ES. Tooth size discrepancies and arch parameters among different malocclusions in a Jordanian sample. The Angle orthodontist. 2006 May;76(3):459-65.


### Appendix I

**University of Khartoum**  
Faculty of dentistry  
Department of orthodontic and paedodontic  
Data collection form

1. Model number .........................................................

2. Gender:
   - [ ] 2.1 Male  
   - [ ] 2.2 Female

3. Angle classification:

<table>
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<tr>
<th></th>
<th>3.1 Normal</th>
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<th>3.3 Cl II</th>
<th>3.4 Cl III</th>
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4. Tooth size measurement (measurement in mm):

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<th>16</th>
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Appendix II

Informed consent form

To everyone participating in this study:

This is a scientific research measuring the Bolton tooth size discrepancy in Sudanese sample. I will collect some basic data directly from you to screen for participants. Accordingly, all the participants will be examined with clean dental mirror and dental impression will be taken. There is no harm from the impression material. All the procedures are free of charge.

I, …………………………………………………., would like to participate in this study (evaluated the Bolton ratio in Sudanese sample). I hereby agree to participate in the research.

Signature