Analysis of Bolton's tooth size discrepancy for a referred UK population

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Abstract

Objectives

The aims of this study are:

- To study the incidence of tooth size discrepancy in a UK population
- To establish whether there are differences between males and females.
- To assess racial differences for tooth size discrepancies in different malocclusion categories.

Malocclusion groups included: Class I, Class II division 1, Class II division II, Class III

Racial groups included: Caucasian, Asian, Afro-Caribbean

Method

A retrospective study using dental casts of patients in the orthodontic departments of Birmingham Dental Hospital and Kings College Hospital, London. 30 sets of casts were assessed from each malocclusion group for each race. i.e 30 Class I Caucasian, 30 Class I Asian, 30 Class I Afro-Caribbean, with an equal male to female ratio. In total 360 dental casts were used.

Mesiodistal tooth dimensions were measured from right first molar to left first molar in the maxillary and mandibular arches. Measurements were taken using HATS digital callipers accurate to 0.1mm. Anterior and overall Bolton discrepancies were calculated for each model.

Results

Gender Significant differences between males and females for the overall ratio only existed for the Class II/I Afro-Carribean group. There were significant differences in the anterior ratio for all the racial groups with Class III malocclusion, and for Class I Asian and Class II/II Afro-Carribeans.

Malocclusion group There were significant differences between the means of the malocclusion groups for the combined overall and anterior ratios. These differences arose because of the differences between the Class III subjects and the remaining malocclusion groups. There was also a significant difference in the anterior ratio in the Asian subjects due to the difference between the Class I and Class III groups.

Race Significant differences only arose in the anterior ratio of the Class I group due to the differences between the Asian and the Caucasian groups. No significant differences were found in the combined overall or anterior ratios.

Conclusion

Differences between males and females existed mainly in the anterior ratio for the Class III groups. The Class III groups showed significantly higher combined overall and anterior ratios, compared to the other malocclusion groups. In addition the anterior ratio of the Asian group was higher in Class III than Class I subjects, indicating mandibular tooth size excess in Class III subjects. No significant differences were found when comparing racial groups, except the anterior ratio of the Class I Caucasian group was significantly greater than the Class I Asian group.

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CHAPTER ONE

1.1 Introduction

Malocclusion can be defined as a significant deviation from a normal or 'ideal' occlusion (Andrews, 1972). Many components are involved in the achievement of a normal occlusion, including skeletal, soft tissue and local dental factors. The most important are (a) size of maxilla; (b) size of mandible; (c) factors which determine the relationship between the two skeletal bases, such as cranial base and environmental factors; (d) arch form; (e) size and morphology of the teeth; (f) number of teeth present; and (g) soft tissue morphology and behaviour.

Andrews' study, (1972) was based on 120 casts of non orthodontic patients in which he found six significant characteristics:

- Molar relationship.

  The distal surface of the distobuccal cusp of the upper first permanent molar made contact and occluded with the mesial surface of the mesiobuccal cusp of the lower second molar. The mesiobuccal cusp of the upper first permanent molar fell within the groove between the mesial and middle cusps of the lower first permanent molar.

- Correct crown angulation.

  The gingival portions of the long axes of all crowns were more distal than the incisal portions.

- Correct crown inclination.

  Crown inclination is determined by the resulting angle between a line at ninety degrees to the occlusal plane and a line tangent to the middle of the labial or buccal clinical crown.

- No rotations
- No spaces and tight contact points.
- Flat occlusal plane

Bennett and McLaughlin, (1993) added a seventh key which was correct tooth size. In order to achieve a good occlusion with satisfactory intercuspation of teeth and a correct overjet and overbite, the maxillary and mandibular teeth must be proportional in size. A tooth size discrepancy (TSD), defined as a disproportion among the sizes of individual teeth will affect attainment of an ideal occlusion. Black, (1902) first assessed tooth size and measured the mesio-distal widths of a large number of human teeth in order to establish the mean dimensions for each tooth in the dental arch. Abnormalities in tooth size and shape result from disturbances in development and can lead to a tooth size discrepancy.

1.2 Causes of tooth size discrepancy

Malocclusion is multifactorial in aetiology, being affected by skeletal, dental and soft tissue factors, which in turn are influenced by environmental and genetic components. Whilst measurements of the skeletal craniofacial complex have moderate to high heritability, because of the adaptability of the dentoalveolar region when subjected to environmental factors local malocclusions are often acquired (Mossey, 1999). Harris and Smith, (1982) suggested that some variables pertaining to the position and occlusion of teeth have a stronger environmental than hereditary influence.

Analysis of nature versus nurture in malocclusion concluded that the genetic contribution to dental anomalies was only 40 per cent (Lundstrom, 1984). Other studies however, challenge this view. Lundstrom, (1948) had previously studied 50 pairs of monozygotic twins and 50 pairs of dizygotic twins and concluded that heredity played an important role in determining width and length of arch, crowding and spacing of the teeth, and degree of overbite. In particular twin studies have shown that crown dimensions are strongly determined by heredity (Markovic, 1992). Homeobox genes have particular implications in tooth development. Muscle specific homeobox genes MSX1 and MSX2 appear to be involved in epithelial mesenchymal interactions and are implicated in craniofacial development, in particular concerning the developmental position (Msx-1) and further development (Msx-2) of the tooth buds (Mackenzie et al., 1991; Jowett et al., 1993). Satokata and Maas, (1994) found that mice with a non functional Msx-1 gene had complete failure of tooth development. In addition evolutionary theory suggests that changes in dietary habits have resulted in evolutionary selection with reduced tooth volume in the fields of third molars, second premolars and lateral incisors. Hypodontia of these teeth shows a familial tendency and fits the polygenic model (Gravely and Johnston, 1971)

The most common dental abnormality is variation in size, particularly of maxillary lateral incisors. Alvesalo and Portin, (1969) provided substantial evidence to support the view that missing and malformed lateral incisors may well be the result of a common gene defect. Abnormalities range from peg shaped through microdont to missing lateral incisors, all of which have familial trends, female preponderance and association with other dental anomalies such as ectopic canines.

Size and form of teeth are principally genetically determined. However growth and final morphology of the dentofacial structures is undoubtedly influenced by environmental factors. Therefore in summary the cause of tooth size discrepancy is a classical case of interaction between genetic and environmental factors.

1.3 Methods of assessment of tooth size discrepancy

Since the initial work of Black, (1902), there have been other studies in this field. Steadman, (1952) produced a method to determine the overbite and overjet relationship of anterior teeth and Neff, (1949) examined the three dimensionality of teeth and determined an anterior coefficient value of 1.2 – 1.22 for an ideal anterior ratio between the upper and lower teeth. However the most recognised work is that of Bolton, (1958) who assessed fifty five Caucasian female subjects with excellent occlusions, of which forty four had been treated orthodontically without extraction. Tooth size disharmony was assessed in relation to the treatment of a malocclusion and two mathematical ratios were developed for estimating tooth size discrepancies. The summed mesio distal widths of twelve mandibular to maxillary teeth were measured for the overall ratio, and the six anterior mandibular to the corresponding maxillary teeth for the anterior ratio.

$$\frac{\text{Sum of mesio-distal widths of twelve mandibular teeth}}{\text{Sum of mesio-distal widths of twelve maxillary teeth}} \times 100 = \text{Overall ratio}$$

$$\frac{\text{Sum of mesio-distal widths of six mandibular teeth}}{\text{Sum of mesio-distal widths of six maxillary teeth}} \times 100 = \text{Anterior ratio}$$

Bolton concluded that an overall ratio of 91.3 and an anterior ratio of 77.2 were necessary for proper articulation of maxillary and mandibular teeth. If a ratio lies outside two standard deviations from Bolton's means i.e. 87.47 – 95.13 for the overall ratio and 73.8 – 80.5 for the anterior ratio, then a Boltons discrepancy is said to exist. Bolton concluded that these two ratios could be used as diagnostic tools, allowing clinicians to assess the functional and aesthetic outcome of treatment without the use of a diagnostic wax up (Bolton, 1962).

1.4 Methods for measuring tooth width for Bolton ratios

Several methods are available for measuring tooth width in order to analyse Bolton ratios, and these are continuing to develop with increased technological advances. If a method of measurement is to be widely used, it is important that is quick and easy to use and easily reproducible. The traditional methods for measuring mesiodistal widths of teeth on dental casts have used either needle-pointed dividers or a Boley gauge (Vernier callipers). Shellhart et al., (1995) evaluated the reliability of Bolton analyses using these two instruments. Pre and post treatment casts of 15 patients were analysed by four investigators on two separate occasions two weeks apart. Casts were selected on the basis that there was at least 3mm of pre treatment crowding in one arch and treatment records indicated no inter-proximal tooth reduction. As a result of the pre and post treatment matching, teeth extracted were not included in the measurements. The investigators had all been trained in the use of Bolton analysis but had varying experience. Comparing the recorded Bolton ratios to a clinical standard of significance of 1.5mm (Proffit, 1993) every investigator in the study made at least one error in measurement that was greater than the clinically significant value for tooth size excess. Therefore, even if a patient's teeth were perfectly proportioned, measurement error alone can lead to errors in treatment planning. The authors concluded that significant measurement errors can occur when Bolton tooth size analysis is performed on casts that have at least 3mm of crowding, although there was considerable variation between investigators. This suggests that clinicians should undertake tooth size discrepancy analysis in substantially crowded cases only after the teeth have been aligned. When comparing the two measuring devices, the Boley gauge demonstrated a higher frequency of significantly correlated repeated measures and thus may provide more reliable measurements than needle pointed dividers.

Shellhart et al., (1995) suggested that Bolton's analysis may be appropriate as a screening tool to determine the possible range of discrepancy because of its ease and rapidity, although, if the discrepancy range indicates two treatment alternatives it would be wise to carry out a diagnostic wax up, even though it is more time consuming.

The recent introduction of digital callipers which can be linked to computers allows for rapid calculation of Bolton's ratios. In addition study casts can now be digitized or scanned into a computer so that images can be measured on-screen. The use of digital callipers with direct input into a computer programme can virtually eliminate measurement transfer and calculation errors compared to analyses that require dividers, rulers and calculators (Ho and Freer., 1999). Although measurement error is associated with the placement of computer-linked dividers on the mesial and distal surfaces of the teeth, this method is still more reliable than manual measurement. Computer programmes such as the Ho-Freer Graphic Analysis of Tooth Width Discrepancy (GATWD) (University of Queensland School of Dentistry, Brisbane, Australia 4000) provide a simple graphic description of tooth – width relationships between the arches, a comprehensive representation of tooth-width ratios in various arch segments and a method of localizing tooth size discrepancies. Digital callipers that input data directly into such programmes provide a diagnostic tool that is convenient, consistent and easy to use.

Computer aided analysis of tooth size discrepancy was investigated further by Tomassetti et al., (2001) who compared manual measurements with Vernier callipers to the QuickCeph Image programme, the Hamilton Tooth Arch System software (HATS) and the OrthoCad software. The Quick Ceph image system involved digitising the models in to the Quick Ceph image pro programme, which then measured the casts and calculated Bolton analyses. In contrast the Hamilton Tooth Arch System uses digital callipers to measure the actual study casts, and then transfers the data directly into a computer programme which then calculates the Bolton analysis. The final method using OrthoCad involved shipping the models to CADENT Inc, where they were scanned to make 3-dimensional images, upon which the Bolton analysis was performed. Eleven pre treatment and eleven post treatment models with no more than 3mm of crowding were measured using four methods. Vernier callipers were used to carry out a tooth size analysis three times on each set of casts. Measurements were carried out within a 1 month period, with at least two weeks between each measurement. Each analysis was timed from the first measurement to the final computation, and the data from these measurements were averaged and used as a standard. For the second analysis, models were digitised and measured using the QuickCeph Image programme, which also calculated Bolton analyses. The third analysis used digital callipers which directly inputed data into the Hamilton Tooth Arch System software (HATS). The software calculated the Bolton analysis, and again the entire procedure was timed. Finally the models were scanned to make 3-dimensional images of the casts which were then analysed using the OrthoCad software. Again this was timed. Measurements with the HATS system had the highest degree of correlation to Vernier callipers, with 86.4% of the measurements for the overall ratio being within 1.5mm of the vernier calliper measurements, followed by OrthoCad and QuickCeph. QuickCeph was found to be the fastest method of measurement at 1.85minutes, followed by the HATS system at 3.4minutes, OrthoCad at 5.37minutes and finally Vernier callipers at 8.06 minutes. Although the results were useful, measurements were not replicated to assess reproducibility.

Othman and Harradine, (2007) compared the reproducibility and speed of the HATS digital callipers to the use of manual measurements and the Odontorule slide rule. 150 Caucasian orthodontic patients were randomly selected. Twenty study models were measured twice; a week apart using both methods, and another three investigators also measured twenty sets of models twice with the HATS digital callipers. The results showed that there were small or no systematic errors within or between these two methods. A very significant difference was evident for mean time measurements between the two methods, with the mean time for HATS being 3.5 minutes and for the Odontorule 8.9 minutes. There was relatively high error variance for both methods of measurement as a percentage of the total variance. The authors concluded that On-line electronic measurement was more rapid than manual. Both methods produced high random errors, which may have important consequences for the clinical use of Bolton's ratios

Zilberman et al., (2003) compared the accuracy of model measurement with the aid of Vernier callipers and OrthoCad. Twenty set ups of artificial teeth resembling various malocclusions were created and used to produce plaster and virtual orthodontic models. No more than 5mm of crowding existed in any of the models. The same investigator then performed tooth size measurements of mesiodistal tooth widths as follows:

- Every isolated artificial tooth was measured after removal from the set up, using electronic callipers accurate to 0.01mm
- Teeth on plaster models were measured, again using electronic callipers
- Computerised models were measured using OrthoCad, accurate to 0.01mm

Upper and lower intercanine and intermolar widths were also measured on six set ups, for both plaster and computerised models.

Measurements carried out using all three methods were highly correlated. Measurements made directly on study casts with electronic callipers were however found to be the most accurate and repeatable, although the accuracy of measurements made using OrthCad were considered to be clinically acceptable.

Arkutu, (2004) looked at commonly used methods of assessing Bolton's discrepancy and compared them to the gold standard, which was defined as measurements using Vernier callipers accurate to 0.1mm. The following four methods were used:

- Inspection
- The Quick check method comparing the size of the laterals and second premolars. (Proffit 2000)
- Needle point dividers and stainless steel rule (nearest to 0.5mm)
- Vernier callipers (nearest 0.1mm)

Anterior and overall ratios were calculated on 200 study models. When comparing Inspection and Proffit's method against measurements using Vernier callipers there was poor agreement concerning measurement of Bolton's anterior and overall discrepancies. Assessments made using dividers and a stainless steel rule showed moderate agreement with the Vernier calliper method. In addition sensitivity and specificity tests showed that the inspection and quick check methods were less satisfactory than Vernier callipers for detecting a lack of Bolton's discrepancy and very poor at correctly identifying a significant Bolton's discrepancy. This may explain the clinical opinion that tooth size discrepancy is much less common than many studies report.

The most accurate and reproducible results for studies measuring tooth size discrepancies were achieved using Vernier callipers (Shellhart et al., 1995; Arkutu, 2004.) Vernier callipers digitally linked to computer programmes provide additional accuracy as the error of data recording and transfer is removed (Ho and Freer, 1999). This is supported by Ziebermann et al., (2003) who found that the measurements made using digital callipers such as the HATS system, produced the most accurate and reproducible results. This is probably because investigators can measure more accurately on plaster models as opposed to digitised or scanned 3-dimensional models, and there is less risk of error by inaccurate data recording or analysis. These results suggest that measurements for future studies assessing tooth size discrepancies are best carried out using digital callipers connected to computerised analysis software.

When carrying out quantitative studies, it is important that the reproducibility of measurements is accurately explored. However there have been some well known studies on tooth size discrepancy in which measurement errors were not reported at all (Crosby and Alexander, 1989; Araujo and Souki, 2003; Bernabe et al., 2004). Houston,

(1983) stated that if a study using measurements is to be of value, it is imperative that an error analysis be undertaken and reported. Error analyses serve to improve the quality of results, particularly if models are replicated so that measurements can be averaged.

1.5 The prevalence of tooth size discrepancies

The prevalence of a tooth size discrepancy in the general population is around 5 percent according to the proportion of occlusions that fall outside two standard deviations from Bolton's mean ratios (Proffit, 2000). However studies have reported a higher prevalence of TSD and found that a greater percentage of patients have anterior TSD than an overall TSD. Freeman et al., (1996) found that the overall discrepancy was likely to be a relative excess in the maxilla or the mandible, whereas the anterior discrepancy was nearly twice as likely to be a relative mandibular excess (19.7%) than a relative maxillary excess (10.8%). Further studies which have examined orthodontic patients have produced similar prevalence values (Santoro et al., 2000; Araujo and Souki; 2003).

However Bernabe et al., (2004) assessed a group of 200 Peruvian school children with untreated malocclusions and found an anterior TSD of 20.5% and an overall TSD of 5.4%. Measurement of Bolton's discrepancy is only valid for a fully erupted permanent dentition and orthodontic samples may have a higher prevalence of a Bolton's discrepancy, depending on the proportion of subjects with impacted teeth and hypodontia. This is because impacted teeth are associated with absent or diminutive teeth as illustrated by Brin et al., (1986) who showed that 42.6% of impacted canines were associated with small or developmentally absent lateral incisors.

Othman and Harradine, (2007) investigated how many millimetres of tooth size discrepancy were clinically significant, and what percentage of an orthodontic population had such a tooth size discrepancy. They also aimed to determine the ability of simple visual inspection to detect such a discrepancy. Their sample comprised 150 pre-treatment study casts with fully erupted and complete permanent dentitions from first molar to first molar. The mesiodistal diameter tooth sizes were measured using HATS digital callipers, and the Bolton analysis and the tooth size corrections were calculated by the Hamilton Arch Tooth System (HATS) software. Simple visual estimation of Bolton discrepancy was also performed for comparison. In the sample group 17.4% had anterior tooth-width ratios and 5.4% had total arch ratios greater than 2 of Bolton's standard deviations from Bolton's mean. For the anterior analysis, correction greater than +/- 2 mm was required for 16% of patients in the upper arch or 9% in the lower arch. For the total arch analysis, the corresponding figures are 28% and 24%. A significant percentage of patients had a tooth size discrepancy of +/- 2mm. and it was therefore recommended that 2 mm of required tooth size correction was an appropriate threshold for clinical significance. Visual estimation of TSD had a low sensitivity and specificity suggesting that careful measurement is frequently required in clinical practice than visual estimation would suggest.

1.6 Tooth size discrepancies and malocclusion groups

Studies that have focussed on the prevalence of a Bolton's discrepancy in orthodontic patients have looked at different malocclusions with varying results. Five studies found relative mandibular tooth excess in Class III malocclusions (Sperry et al.,1977; Nie and Lin, 1999; Ta et al., 2001; Alkofide and Hashim, 2002; Araujo and Souki, 2003), relative maxillary excess in Class II malocclusions (Nie and Lin, 1999), whilst other studies found no significant differences (Crosby and Alexander,1989; Liano et al., 2003; Uysal et al., 2005).

The most recent of the studies that found relative mandibular tooth excess in Class III malocclusions was that of Araujo and Souki, (2003). The prevalence of TSD in a Brazilian population from Belo Horizonte was assessed, firstly to measure the prevalence of TSD in the three Angle malocclusion groups according to gender and secondly to investigate differences of Bolton's anterior TSD in the three malocclusion groups. The study sample consisted of 300 patients assigned to a malocclusion group according to Angle's classification. Each group comprised 100 individuals and the distribution between males and females was approximately equal. Each canine and incisor tooth was measured at the largest mesiodistal dimensions using a digital calliper accurate to 0.01mm and all measurements were made by the same examiner. An error analysis was performed by randomly selecting 29 individuals from the original sample and repeating the measurements twice within three weeks. No significant differences were found between the two sets of measurements ($P>0.05$) upon testing using the Wilcoxon nonparametric test. Individual tooth size was firstly assessed using ANOVA to determine whether tooth size was related to gender, malocclusion classification, or both. No significant differences were found between the three groups as a function of Angle's classification. Objectives of the study also involved assessment of the prevalence of TSD compared to those presented by Bolton. Data were classified as 'normal' for Bolton ratios within +/- 1 SD, and 'discrepancy' for ratios greater than +/- 1 SD. Results showed that although 56% of the subjects in the study presented with a Bolton TSD greater than +/- 1 SD, there was no significant difference among the three malocclusion groups or according to gender. 22.7% of the sample showed clinically significant TSD greater than +/- 2SD, and when analysed by Angle's classification, there were significantly greater numbers of Class I and III subjects within this group than Class II subjects. No significant differences were observed between genders. In addition a two by three ANOVA was performed to compare the Bolton anterior ratio as a function of Angle's classification, gender or both. The mean anterior Bolton's ratio was statistically greater for the Class III sample than for the Class I and Class II samples. The Class I and II samples showed no significant differences when compared with each other and no sexual dimorphism was observed.

The results of Alkofide and Hashim, (2002) support the findings of Araujo and Souki, (2003), in that a significant difference in Bolton's ratio was found in females with Class III malocclusions. The purpose of the study by Alkofide and Hashim was to determine if a difference existed in tooth size ratios between the different malocclusion classes and normal occlusion in Saudi patients, and if sexual dimorphism occurred. Their sample comprised of 240 pre-treatment casts with both sexes evenly distributed. Sixty cases had normal occlusion, sixty were Class I malocclusions, sixty Class II malocclusions and 60 Class III malocclusions according to Angle's classification. Mesiodistal tooth widths were measured directly on the dental casts by one examiner using digital callipers with fine tips accurate to 0.01mm. Measurement errors were assessed by remeasuring five sets of study models twice, ten days apart. Pearson correlation coefficient and Dahlberg's method were used for testing the error of the method and results a high correlation between the first and second measurements. However given that the study sample was 240, perhaps more study models should have been measured to confirm reproducibility. Results showed that the average overall ratio for all classes combined was 92.61, with the mean anterior ratio being 78.86. Both of these were higher than the actual Bolton's ratios. Comparison between the three malocclusion groups showed that the mean overall ratio for Class II cases was higher than for Class I and III. This disagrees with Nie and Lin, (1999), who found that the mean ratio in Class III was higher than for both Class I and II in a Chinese population. When the three malocclusion groups were compared in males and females, the results showed that the mean overall and anterior ratios for Class III cases were greater than Class I and II malocclusions in both males and females. This finding is in agreement with Araujo and Souki, (2003). The study also concluded that significant sexual dimorphism existed for the anterior ratio in Class III malocclusion, with males having a significantly higher mean anterior ratio.

Statistically significant differences were found between the anterior ratio of the Bolton standard and the Class III occlusion group a study of 110 Southern Chinese twelve year olds (Ta et al., 2001). 50 Class I, 30 Class II and 30 Class III subjects were randomly selected from 1247 12-year old Southern Chinese children. A digital calliper was used to measure mesiodistal crown diameters to 0.1mm (Moorrees et al., 1957). Twenty dental casts with Class I occlusions were used to determine the method error. Casts were measured twice, with a week between the measurements, and the method described by Dahlberg was used to assess the method error. Unfortunately no Class II or III casts were used when determining the method error which was therefore not representative of the whole sample. No statistically significant sex differences were found between the anterior and overall ratios in the three occlusion groups, and the mean anterior and overall ratios were subsequently combined for males and females. Statistically significant differences for the anterior ratios were found between the Bolton standard and the Class III occlusion group. Statistically significant differences for the overall ratios were found between the Bolton standard and the Class II occlusion group, and between the Class II and Class III groups. The study concluded that Bolton standards applied to southern Chinese children with Class I occlusion but not to those with Class II or III occlusions. Although the young age group in this study was chosen to minimise alteration of mesiodistal tooth dimensions due to caries, attrition or restorations, it was not made clear in the paper whether patients were in the mixed or permanent dentition. This is extremely important as the differences in size between the primary and permanent dentitions will inevitably affect tooth size discrepancy measurements.

Nie and Lin, (1999) assessed intermaxillary tooth size discrepancies among different malocclusion groups in China. The objectives of the study were to determine whether sexual dimorphism exists for tooth size ratios, and to assess whether there is a difference in intermaxillary TSD as represented by the anterior, overall and posterior ratios of Bolton for designated malocclusion groups. The study consisted of 60 subjects who served as the normal group and 300 patients divided into five malocclusion groups based on their skeletal ANB classification (Class I with bimaxillary protrusion, Class II division I, Class II division II, Class III, and Class III surgical cases). The age range was between 13-17 years, except for the Class III subjects who were older at 17-23 years. Tooth size measurements were taken from models of normal occlusion and pre-treatment models of patients using a three dimension measuring machine with an accuracy of 0.01mm. Tooth size ratios were analysed as described by Bolton. T tests showed no sexual dimorphism for the ratios in each of the six groups, so the sexes were combined in each group and compared among different malocclusion groups. No significant differences were found between subcategories of Class II malocclusion. These groups were then combined to produce 120 subjects in each of three categories: Class I, Class II and Class III. Multi comparison was then performed between the three groups and the results showed that Bolton's anterior ratio, posterior ratio and overall ratio was greatest in Class III and least in Class II, with Class I subjects in between. The results support the work carried out by Sperry et al., (1977) which showed that Class III cases with mandibular prognathism had more subjects with mandibular tooth size excess for the overall ratio than did Class I and II subjects. Moreover the findings of Nie and Lin (1999) show that not only Class III surgical but also Class III non surgical groups had a greater frequency of mandibular tooth size excess than other malocclusion groups. In addition the study also concluded that there was a tendency for maxillary tooth size excess in Angle Class II malocclusion.

In contrast Crosby and Alexander, (1989) suggested that there were no significant differences in the incidence of tooth size discrepancies in the four malocclusion groups. When their sample was taken as a whole there was no significant difference in mean mesiodistal tooth size ratios as compared to Bolton's mean, although there were higher standard deviations. The study consisted of 109 patients randomly selected from a private practice and divided as follows: 30 Class I cases, 30 Class II div I cases, 29 Class II div II cases and 20 Class II surgical cases. Measurements were taken with digital callipers accurate to 0.01mm and the procedure was repeated for error analysis on five subjects within each malocclusion group. In this study however, skeletal categories were not mentioned, although some Class II cases were treated surgically. This can be important in sample selection as some skeletal Class II malocclusions can be converted in to dental Class I malocclusions by forward movement of the permanent first molar due to the premature loss of the deciduous second molar, and so a Class I group may contain both skeletal Class I and Class II patients. Also there were no Class III cases in this study, and as shown from the previous studies these cases tend to display a high degree of anterior tooth size discrepancy, which may well have affected the results. In addition Crosby and Alexander did not differentiate between sexes and did not mention the ratio of sexes in each group. The study did however show a large number of subjects within each group with discrepancies greater than 2 SD from the mean, as defined by Bolton's study,   indicating the importance of tooth size analysis before treatment.

Liano, (2003) and Uysal, (2005) also found no association between TSD and different malocclusion groups. However in the study by Liano there were only 13 subjects in the Class III group, which meant that the statistical analysis was dubious. Although Uysal's study showed no differences between malocclusion types, all malocclusion groups had significantly higher average ratios than the group of 150 untreated normal occlusions.

Summary

In summary much of the evidence suggests that mandibular tooth size excess is greatest in Class III malocclusions (Arauyo and Souki,2003; Nie and Lin, 1999; Ta et al., 2001, Sperry et al.,1977). Sperry et al., (1977) also showed that there was maxillary tooth excess in Class II malocclusions. In the Chinese populations studied, both anterior and posterior ratios were greatest in Class III malocclusions, (Nie and Lin, 1999; Ta et al., 2001) and in fact Ta et al., (2001) concluded that Bolton's ratios only applied to Chinese subjects who were Class I. Although Crosby and Alexander, (1989) concluded there was no difference in tooth size discrepancy between the malocclusion groups, they did note the high proportion of subjects with ratios greater than 2SD of Bolton's ratio within each group.

1.7 Tooth size discrepancies and racial variation

The incidence of a Bolton's discrepancy differs between racial groups (Santoro et al., 1970; Lavelle, 1972; Smith et al, 2000). Bolton's original 1958 study was carried out on a group of 55 Caucasian females, and provides no information relating to other racial groups. The Bolton standards may therefore not necessarily be applicable to other racial groups.

Lavelle, (1972) compared mesiodistal crown diameters of the maxillary and mandibular teeth in the three major racial groups, Caucasoid, Mongoloid and Negroid. These three terms for racial groups are anthropological and are based on skull dimensions. They can be considered equivalent to white, black and far eastern, as used in many English speaking countries today (Harradine, 2006). A total of 120 casts with excellent occlusion were included in the study, 40 from each racial group. Male to female distribution was equal and all subjects were within the age range 18 to 28 years. Subjects were chosen to have excellent occlusions, so the means are a good guide to the norms for a racial group. Mesiodistal crown diameters and percentage overbite were determined. Tooth dimensions were greater in males than females, and the average mesio- distal crown diameter was greater in Negroids than in Caucasoids, with that for Mongoloids being intermediate. This applied to maxillary and mandibular dentitions in both males and females. In addition both the overall and anterior ratios were greater in Negroids than in Caucasoids, with Mongloids again being intermediate. Percentage overbite was greater in Caucasoids than Mongoloids and that for Negroids was intermediate. These results suggest that there is a greater degree of conformity between the maxillary and mandibular tooth dimensions in Negroids than in Caucasoids, with that for Mongoloids being intermediate.

Merz et al., (1991) assessed tooth diameters and arch perimeters in both black and white populations. Records of 51 black and 50 white patients were selected and mesiodistal diameters were measured for all teeth in the lower left quadrant, first molar to central incisor. In addition arch width and depth were measured. The mean mesiodistal crown diameters of the canines, premolars and molars in the black population were all significantly larger than for the corresponding teeth in the white population. Mean mesiodistal diameters of the central and lateral incisors showed no significant difference between the two groups. Maxillary intercanine and intermolar arch widths were significantly greater in the black subjects than the white subjects. Mandibular intercanine and intermolar widths were also greater in the black sample, although the difference was not statistically significant. In addition both the mean maxillary and mandibular arch depths were significantly greater in the black sample. The increased dental arch width and arch depth in the black sample resulted in an increase in arch perimeter more than sufficient to accommodate larger tooth space requirements.

Smith et al., (2000) support the evidence of racial variation with respect to tooth size, since they found significant differences in tooth size discrepancy in negroid, caucasoid and hispanic samples. 60 study models from each racial group with an equal male to female ratio were measured and anterior, posterior and overall ratios were compared. There were significant gender and racial differences in the ratios between upper and lower arch segments. The overall ratio was smallest in caucasoids followed by hispanics and negroids, and the difference between caucasoids and negroids was highly significant. The posterior ratio was greatest in negroids, who had larger mandibular teeth than either caucasoids or hispanics. The difference in the overall ratio between caucasoids and negroids was primarily due to size differences in the posterior teeth, with the posterior maxillary segment being 2.3mm larger in negroids and the posterior mandibular segment 3.6mm larger than the caucasoid sample. The anterior ratio was significantly larger in hispanics than negroids, with caucasoids showing no significant difference from the other two groups. The anterior ratio showed that caucasoids had larger anterior mandibular teeth than negroids, a finding which differed from that of Lavelle et al., (1972) who showed that overall and anterior ratios were greater in Negroids than Caucasoids.

Other studies have looked more specifically at single population groups, such as the Dominican Americans (Santoro et al., 2000) and Peruvians (Bernabe et al., 2004). Santoro et al., (2000) examined 54 Dominican Americans and aimed to establish normative data on the mesiodistal crown dimensions of this population group. The 36 male and 18 female orthodontic patients were second or third generation Dominicans residing in New York who were racially mixed subjects with homogeneous skin pigmentation and craniofacial features. Mean, range and standard deviations were calculated for the sizes of the teeth, and the coefficients of variation were obtained for the tooth size ratio. Generally the results showed that male crown measurements were slightly larger and showed a higher variability than female measurements, but followed the same distribution pattern. When the results were compared to that of the African American sample and the white sample, they showed a closer resemblance to the former. Maxillary and mandibular tooth dimensions in Dominicans were slightly smaller than those in the African American sample, with the exception of the mandibular central and lateral incisors, which were larger. The crown widths of the Dominicans were however consistently larger than the crown widths of the North American whites. The American Dominican tooth ratios were then compared to the Bolton ratios, and it was noted that in both the overall and anterior ratios the range, standard deviations and coefficients of variation were larger than in the Bolton study. This may have been due to the fact that the sample was of patients with orthodontic problems, whereas Bolton's sample was of individuals with optimum occlusions. The overall tooth size ratio was equivalent to the original Bolton overall ratio, but the anterior tooth size ratio was larger than the Bolton anterior ratio ($P < 0.05$). In addition a statistically significant overall tooth size discrepancy was found in 11% of the subjects, whereas 28% exhibited a statistically and clinically significant anterior discrepancy. The differences shown from the results of this sample compared to the Bolton ratios, suggest the need for more specific standards for the Dominican population.

The Dominican population had a close ethnic relationship with the Peruvian population, and it may therefore be expected to show significant differences in anterior tooth width ratios (Santoro et al., 2000). However Flores-Mir et al., (2003) found no clinical differences in tooth widths in a Peruvian population compared with white samples. Bernabe, (2004) studied 200 Peruvian school children to determine maxillary to mandibular tooth size ratios. Two standard deviations from the Bolton mean did not predict clinically significant anterior and total tooth width ratio discrepancies. A tooth size discrepancy of less than 1.5mm is rarely significant (Proffit, 2000) and only larger discrepancies create problems in treatment planning. If the mandibular arch is defined as normal, then a tooth size discrepancy would be described as maxillary tooth width deficiency or excess. According to this definition 32.5% of this sample had a clinically significant anterior tooth size discrepancy, and 36.5% had a clinically significant total tooth size discrepancy, although this was not predicted by the 2 SD range from the Bolton mean.

Bishara et al., (1989) compared mesio-distal and bucco-lingual crown dimensions in populations from Egypt, Mexico and the United States. The sample from each population group was similar in size and matched for age and male to female proportion. Mesio-distal crown dimensions were measured on casts using pointed callipers. The findings indicated the presence of sexual dimorphism between the three populations, and in general sex differences was more pronounced in Mexicans. Comparisons made between the three groups indicated consistent differences in the maxillary central incisors for boys, with the Egyptian boys having larger mesiodistal diameters than the US and Mexican boys. Egyptian girls had significantly larger mesiodistal widths for all first premolars, mandibular second premolars and first molars than girls from Mexico and the US. In general there were fewer differences in mesiodistal crown widths between the boys in the three groups than between the girls, and overall the average differences found were considered small and not of clinical significance. The differences in tooth dimensions detected between these different groups could have been related to the degree of admixture within the population groups. The genetic pool in the Mexicans was largely of Spanish Caucasian and North American Indian Mongolian descents, whereas as the US population was an admixture of various Caucasian groups, mainly English, Scandinavian and German. The Egyptian population seemed to be the least mixed.

Summary

Studies that have assessed tooth size discrepancies with regard to race have shown differing results. Lavelle et al., (1972) concluded that mesiodistal crown widths were greater in Negroid, than Caucasoid populations with Mongoloid subjects being intermediate. This is supported by Merz et al., (1991), who found the mesiodistal widths of canines, premolars and molars in a black sample to be significantly greater than the corresponding teeth in a white sample. Smith et al., (2000) also suggested that there was a trend to larger overall and posterior ratios in black populations compared to white and hispanic groups, although in contrast to Lavelle et al., (1972), anterior ratios were shown to be greater in caucasians than negroids. Bernabe et al., (2004) concluded that 2 SD from the Bolton mean was not sufficient to detect tooth size discrepancies in a Peruvian population. This certainly suggests that there is much racial variation with respect to tooth size. However Flores-Mir, (2003) assessed tooth size discrepancy in a Peruvian population and found no significant differences compared to Bolton, whilst Bishara et al., (1989) compared tooth size discrepancies in populations from Mexico, Egypt and the United States and found that differences detected were of small magnitude and not clinically significant.

1.8 Tooth size discrepancy and gender

Bishara et al., (1989) assessed tooth dimensions in populations from Egypt, Mexico and the United States and as well as assessing racial variation, compared female to male dimensions within each population. Maxillary and mandibular canines and first molars were larger in Egyptian males than females. The sum of the maxillary right canine and first and second premolars was also significantly greater in boys. In the Mexican sample the canines, first premolars, second premolars and first molars were significantly larger in males than in females, although there was no significant difference between the sexes regarding incisors. The subjects from the US showed significantly larger canines and first molars in males than females, with no significant differences between the incisors. Unfortunately tooth size discrepancy ratios were not measured in this study

Lavelle, (1972) compared maxillary and mandibular tooth size ratios between males and females. The overall and anterior ratios were both greater in males than females, although the differences were small, all being less than 1%.

Richardson et al., (1975) sampled 162 American negroes with an equal male to female distribution. The mean mesiodistal crown dimensions of each type of tooth in the maxillary and mandibular arches were greater in males than females. The anterior and overall mandibular to maxillary arch ratios were the same for both males and females. Other studies have also found no significant differences between tooth size discrepancies in males and females (Aroujo and Souki, 2003; Alkofide and Hashim, 2002; Nie and Lin, 1999). Smith et al., (2000) however found that overall and posterior ratios were significantly larger in males than females, although the differences were small (0.7% for the overall and 0.9% for the posterior ratio).

There is much variation in the literature regarding tooth size discrepancy and gender. Richardson et al., (1975) showed that tooth dimensions were greater in American Negro males than females, and this was supported by Bishara et al., (1989), who looked at populations in Mexico, Egypt, and the United States. However much of the evidence suggests that gender makes no significant difference to tooth size discrepancy.

1.9 Clinical relevance of tooth size discrepancy

Tooth size discrepancies must be taken into account when treatment is planned since they are a principal factor in accurate space analysis. At the planning stage it is important to quantify the space required in each arch to correct a malocclusion. Crowding or spacing, arch width change and incisor anteroposterior changes can have substantial space implications. Space analysis can be used to assess the need for extractions, to determine anchorage requirements and to plan mechanics during treatment.

Crowding or spacing should be related to an arch form that reflects the majority of teeth, not necessarily the imaginary arch that passes through the incisal edge of the most prominent central incisor in each arch (Kirschen et al., 2000). Assessment of arch width and the anteroposterior position of the labial segment is essential when deciding the line of the arch upon which to base treatment objectives. A diagnostic wax up can be a useful aid when planning management of tooth size discrepancies as planned tooth movements, composite additions and prosthetics can be visualised. In addition it also allows a number of treatment options to be explored prior to deciding upon a definitive plan.

1.10Management of tooth size discrepancy

The goal of orthodontic treatment is to determine the best possible aesthetic and functional result. Where a tooth size discrepancy exists, there may still be residual spaces or an excessive overjet or an increased overbite following treatment. Management will of course depend on whether there is excess space or a shortage of space and this is discussed in more detail below.

1.11 Tooth tissue reduction

Although tooth size discrepancy problems are usually evaluated during treatment planning, it not usually until the finishing phase that they are actually dealt with. Inter proximal dental stripping or "slenderisation" is the usual method to compensate for discrepancies caused by tooth excess. Space can be gained from reduction of the mesiodistal width of an unusually broad tooth or from approximal enamel reduction. When stripping of enamel is part of the original treatment plan, most of the stripping should be done initially, but final stripping can be deferred until the finishing stage. This would allow direct observation of the occlusal relationships before the final adjustments are made (Proffit, 2007).

1.12 Incisor angulation (mesiodistal tip)

Generalised small size deficiencies can be masked by altering the position of the incisors in several ways, including mesiodistal angulation, inclination and rotation. If upper incisors are too vertical they take up less space in the arch than if they are correctly angulated Kirschen et al., (2000). Tuverson, (1980) demonstrated the use of diagnostic wax ups to show that 2mm of excess space can be absorbed by mesial angulation of upright upper incisors. However incorrect angulation does not necessarily signify that a space requirement exists, although, if incorrectly angulated teeth are corrected, space is gained by correcting them to normal angulation. The space gained is small and it is important to balance this with the anchorage implications of mesiodistal and apical movements, which are likely to be of greater clinical relevance.

1.13 Incisor inclination (torque)

Andrews, (1972) pointed out the importance of correct labio-lingual inclination of the upper incisors if they are to occupy the correct amount of space. Failure to establish correct inclinations would lead to either an incorrect buccal occlusion or spacing and would compromise the final aesthetic result (Bass, 1991). Torque of the upper incisors can be used to compensate for larger or smaller upper incisors. Leaving the incisors slightly more upright makes them take up less space relative to the lower arch and hence masks large upper incisors. On the other hand slightly excessive torque can partially compensate for small upper incisors. Tuverson, (1980) suggested that 1mm of excess maxillary space could be absorbed by applying palatal root torque to maxillary incisors.

1.14 Building up small teeth

When tooth size discrepancy problems are caused by small teeth, the maxillary lateral incisors are often to blame. A small space distal to the lateral incisors can be aesthetically pleasing and functionally acceptable, although the amount of tooth material in both arches must be proportional to achieve an excellent occlusion. A composite resin restoration of small lateral incisors is usually the best plan and this can either be carried out towards the end of treatment or as soon as possible once the patient is in retention. This would require an initial retainer to hold the space and a new retainer once the restoration is completed. Alternatively an indirect restoration can be provided, and again this can be carried out once orthodontic treatment has been completed. The main advantage of waiting until after orthodontic appliances have been removed is to allow gingival inflammation to resolve (Proffit, 2007).

1.15 Premolar extractions and their effect on tooth size discrepancy

The decision to extract teeth is a critical one in relation to orthodontic treatment and may affect the Bolton overall ratio. Premolar teeth are usually the extractions of choice and Bolton, (1962) discussed the affect of premolar extraction on the overall ratio, which was reduced from a mean of 91.3% to 86% by extraction of four premolars. Saati and Yuckay, (1997) investigated whether the extraction of four premolars was a factor in the creation of a tooth size discrepancy. They assessed 50 pre-treatment casts and determined the overall Bolton ratio for each. The difference between the pre-treatment and post-extraction Bolton ratios was found to be statistically significant following first premolar extractions but not significant for other combinations. Tong et al., (2004) also found that the overall Bolton ratio decreased after premolar extractions. The effect of a combination of premolar extractions on tooth size discrepancy was assessed for 213 plaster casts, divided in to those with a small Bolton ratio (89.39% - 1sd), normal Bolton ratio (between 89.39% and 93.21%) and a large Bolton ratio (93.21% + 1sd). A tooth size discrepancy occurred in normal overall ratios after premolar extractions, but tooth size discrepancy might be corrected with big overall ratios after premolar extractions.

Summary

Tooth size discrepancy must be taken in to consideration when planning orthodontic care. Its impact on an overall case varies with the severity of the discrepancy, although even small mismatches between maxillary and mandibular arches will affect the overall orthodontic finish. It is therefore imperative for the accurate planning of cases that an assessment of any discrepancy is made at this initial phase. Bolton's ratio is a quick method to use, however it is uncertain whether the ratios apply to all populations, since Bolton's original study was based only upon measurements of white females with excellent occlusions. The literature is certainly inconclusive on many of these issues. Although the effects upon Bolton's ratios of gender, race and malocclusion have been studied to some extent, there is little evidence in the literature to compare the incidence of intermaxillary tooth size discrepancy in different racial groupings with similar malocclusions (Nie, 1999). This is the area that I intend to investigate in the present study. Within the West Midlands population and the referred population at Birmingham Dental Hospital many of patients are of Caucasian, Asian or Afro-Caribbean origins, and therefore I will analyse the Bolton ratio for these three population groups.

CHAPTER TWO

2.1 Objectives

The objectives of the study are to determine:

1. The incidence of a tooth size discrepancy in a referred orthodontic population in the UK

2. To establish whether there is a difference in tooth size discrepancies between males and females.

3. To assess racial differences for tooth size discrepancies in different malocclusion categories.

2.2 Null Hypotheses

There is no difference in the incidence of tooth size discrepancies in a referred orthodontic population from that of the general population

1. There is no difference in intermaxillary tooth size discrepancy between males and females

2. There is no difference in intermaxillary tooth size discrepancy between different racial groups and malocclusion classes

CHAPTER THREE

Materials and Method

3.1 Sampling

360 casts of patients treated at The Birmingham Dental Hospital, Russells Hall Hospital and Kings Dental Hospital were analysed retrospectively.

3.2 Ethical approval

Ethical approval was obtained from South Staffordshire PCT, Research and Development approval was obtained from South Birmingham and King's College London Research and Development Committees.

3.3 Selection Criteria

Inclusion Criteria

- Orthodontic patients aged between 13 and 25 years.
- All permanent teeth, except for third molars, erupted and present.
- Good quality pre-treatment models
- No severe mesiodistal tooth abrasions
- No restorative treatment affecting mesial and distal surfaces.

Exclusion Criteria

- Subjects with congenitally missing teeth, extracted teeth, broken or chipped teeth or carious lesions that could affect the mesio-distal crown width.
- Poor quality study mode

3.4 Subject selection

360 casts were required for the study. These were retrospectively selected dental casts of patients treated at various UK hospitals. All casts were stored within the hospital departments.

The variables assessed at were:

Gender

Racial group

Malocclusion

Racial group

The racial groups were Caucasian, Asian and AfroCaribbean. This was determined using the facial views of the clinical photographs that had been taken as part of each patient's routine orthodontic records. These photographs were stored on a secure hospital computer and were accessible only to clinical staff. The Term Asian in this study is used to define people from the Indian sub continent and included those of Indian, Pakistani and Bangladeshi origins. The term AfroCaribbean was used to define patients that originated from the Caribbean. Patients of Middle Eastern and African origins were not included in the study, as well as patients of mixed racial origin. Identifications were determined by contacting the clinicians responsible for their care.

Malocclusion group

This was determined using both intra-oral photographs and study models. Both methods were used to try and eliminate inaccuracies due to photographs being postured or models incorrectly trimmed. Use of both types of records allowed subjects to be categorised into a malocclusion group with more confidence.

Subjects were divided in to four malocclusion groups based on the British Standards Institute's Incisor Classification (1983), Class I, Class II/I, Class II/II and Class III. The intra-oral photographs also helped to identify patients who had restorations affecting their mesial and distal tooth surfaces. This would have prevented accurate measurements of tooth widths. These patients were not included in the study.

Gender

This was determined using the clinical photographs. Equal numbers of males and females were selected for each malocclusion class.

Lists were produced for all patients under the care of each clinician, with their basic information such as date of birth. The ages of the patients could then be determined to ensure that they were within the required age criteria for the study. The photographs of all patients that fell in to the required age criteria for the study were then assessed. The clinical photographs were used to systematically select the final study sample by physical randomisation; patients were selected sequentially until each group was filled.

Quality of study casts

Prior to carrying out measurements on study models of the selected patients, these models were firstly assessed to ensure that they were of adequate quality. In a few cases models were damaged to the extent where it was not possible to carry out accurate mesiodistal tooth width measurements, these were therefore not used.

3.5 Sample size calculation

The number of subjects required was based on sample size calculations carried out using an Altmans nomagram.

Significance level	= 0.05
Clinically relevant difference CRD (Tooth size discrepancy)	= 2.0mm
Power	= 0.8
Standard difference	=CRD/SD = 2/2 = 1

The normogram, (Altman, 1991 p456) suggests that a sample size of 30 to give 0.8 power at 0.01 significance level

30 casts per racial group and malocclusion group were therefore used for the study, giving a sample of 120 casts per racial group and a total of 360 casts. Each group had an equal gender distribution.

3.6 Reproducibility study

Prior to the main study 30 casts were randomly selected for an initial reproducibility study to evaluate and assess the accuracy of a single operator. The measurements were then repeated four weeks later

3.7 Model measurement

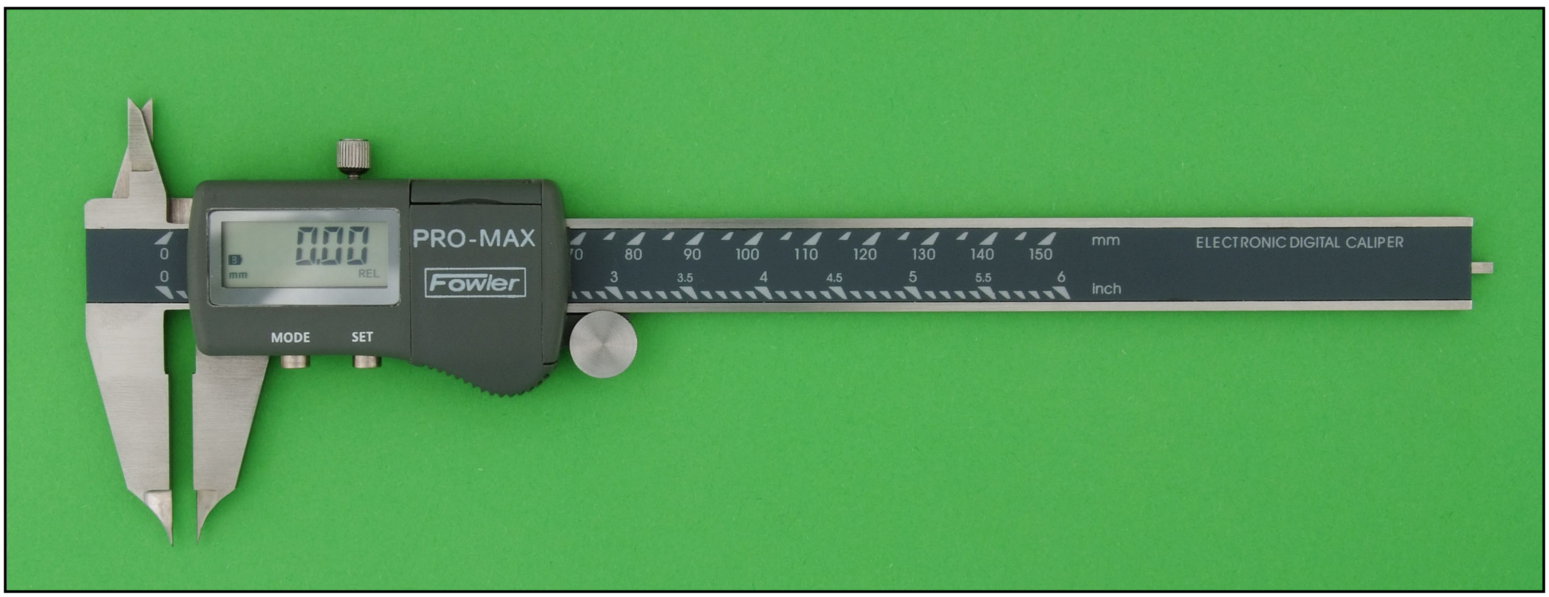
All measurements were carried out by a single operator (I M). Measurements on the casts were made using HATS digital callipers to the nearest 0.01mm. (Figure 2.1)

Measurements of individual mesiodistal tooth widths were taken from first molar to first molar in each arch. In a well aligned dentition measurements were made from mesial contact point to distal contact point. Where teeth were rotated their mesial and distal points in the de-rotated positions were measured. Measurements taken with the callipers were automatically recorded by the HATS software onto a computer screen and the sum of the upper and lower teeth was generated. The data was then transferred on to an Excel spreadsheet for further analysis (Figure 2.2)

3.8 Data analysis

Data were analysed using the Minitab statistical package

Figure 2.1



The Hamilton Arch Tooth System (HATS) digital calipers.

Developed by Dr David Hamilton of Pennsylvania and supplied by Dentsply GAC.

Figure 2.2

The HATS computer screen

The HATS computer screen above shows the data recorded by the HATS software. Individual tooth widths are automatically inputted in to the table and the sum of the upper and lower teeth, and the recommended tooth size corrections are calculated.

CHAPTER FOUR

4.1 Results

Table 4.1 Descriptive Results for Reproducibility Testing

Paired t Test and Confidence Interval

Tooth	**1st Mean**	**2nd Mean**	**P Value**	**Significance of difference**
UR6	10.57	10.59	0.51	NS
UR5	7.08	7.02	0.54	NS
UR4	7.24	7.31	0.51	NS
UR3	7.95	7.95	0.85	NS
UR2	7.11	7.09	0.66	NS
UR1	8.75	8.77	0.62	NS
UL1	8.65	8.66	0.61	NS
UL2	6.91	6.92	0.74	NS
UL3	7.83	7.83	0.98	NS
UL4	7.35	7.37	0.70	NS
UL5	7.00	6.98	0.53	NS
UL6	10.65	10.64	0.89	NS
LL6	10.92	10.92	0.99	NS
LL5	7.58	7.56	0.55	NS
LL4	7.49	7.48	0.78	NS
LL3	6.89	6.89	1.00	NS
LL2	6.19	6.22	0.61	NS
LL1	5.61	5.61	0.97	NS
LR1	5.51	5.52	0.63	NS
LR2	6.06	6.09	0.56	NS
LR3	6.83	6.82	0.84	NS
LR4	7.46	7.47	0.78	NS
LR5	7.50	7.49	0.70	NS
LR6	10.97	10.95	0.63	NS

Key: NS= Not significant

Table 4.2 Descriptive Statistics for Main Study

Variable	N	Mean	StDev	Minimum	Maximum
111OR	15	91.38	1.97	88.81	94.61
111AR	15	76.24	1.54	73.89	78.87
112OR	15	92.41	2.62	87.46	96.11
112AR	15	80.46	4.03	74.63	87.84
113OR	15	92.40	1.75	88.88	94.45
113AR	15	78.81	3.07	74.13	86.78
121OR	15	91.68	1.57	89.49	94.03
121AR	15	78.36	2.21	76.17	81.76
122OR	15	91.53	2.08	88.00	94.83
122AR	15	78.20	3.12	73.46	83.91
123OR	15	93.42	1.90	90.78	96.75
123AR	15	78.86	3.22	76.18	85.62
131OR	15	91.23	1.24	89.30	92.65
131AR	15	78.90	2.85	74.74	82.43
132OR	15	92.06	2.79	87.32	96.43
132AR	15	79.93	2.61	76.25	84.17
133OR	8	92.73	1.66	90.72	94.45
133AR	8	79.34	1.90	77.09	81.58
141OR	15	93.98	1.46	92.09	96.86
141AR	15	80.98	2.05	77.83	83.60
142OR	15	92.09	1.94	88.13	94.94
142AR	15	79.22	1.87	74.76	84.16
143OR	15	93.19	2.02	89.16	96.11
143AR	15	80.99	2.08	75.15	83.91
211OR	15	91.83	1.17	90.22	94.07
211AR	15	77.40	1.00	76.17	80.19
212OR	15	92.22	1.98	88.99	95.47
212AR	15	79.38	3.20	74.07	84.69
213OR	15	91.95	1.94	87.38	94.39
213AR	15	77.50	2.66	72.23	81.01
221OR	15	91.70	3.59	87.43	96.37
221AR	15	78.98	3.83	72.98	83.77
222OR	15	90.58	5.26	73.62	95.45
222AR	15	78.44	5.14	61.91	84.82
223OR	15	91.10	1.73	86.98	93.47
223AR	15	76.99	1.72	71.79	79.46
231OR	15	91.63	1.87	88.52	94.53
231AR	15	78.73	2.27	75.13	83.85
232OR	10	91.36	1.98	87.63	94.53
232AR	10	77.01	2.53	74.15	80.64
233OR	15	91.36	1.98	87.63	94.53
233AR	15	77.01	2.53	74.15	80.64
241OR	15	93.23	9.61	88.54	127.57
241AR	15	77.44	2.04	75.31	81.79
242OR	15	91.33	2.49	86.32	94.50
242AR	15	76.95	2.63	71.74	81.35
243OR	15	92.62	1.93	88.73	94.74
243AR	15	77.89	1.82	74.83	80.04

Key:
Variable ABC-OR or ABC-AR,

Where A is gender, 1= Male and 2= Female
B is malocclusion, 1=Class I, 2=Class II/I, 3=Class II/II, 4=Class III
C is Race, 1= Asian, 2= Caucasian, 3= Afro-Caribbean
OR = Overall ratio, AR = Anterior ratio

4.1 Statistical Analysis

Two- Sample T tests were used to investigate differences between male and female subjects in the following twelve categories:

Class I Asian	Class I Caucasian	Class I Afro Caribbean
Class II/I Asian	Class I//I Caucasian	Class II/I Afro Caribbean
Class II/II Asian	Class II/II Caucasian	Class II/II Afro Caribbean
Class III Asian	Class III Caucasian	Class III Afro Caribbean

ANOVA was used to test for differences between blocks of data as grouped with regard to anterior or posterior ratio; racial group; and malocclusion Class.

The following comparisons were made:

Combined overall ratios by malocclusion group
Combined overall ratios for Asians by malocclusion group
Combined overall ratios for Caucasians by malocclusion group
Combined overall ratios for Afro Caribbeans by malocclusion group

Combined anterior ratios by malocclusion group
Combined anterior ratios for Asians by malocclusion group
Combined anterior ratios for Caucasians by malocclusion group
Combined anterior ratios for Afro Caribbeans by malocclusion group

Combined overall ratios by racial groups
Class I overall ratios by racial group
Class II/I overall ratios by racial group
Class II/II overall ratios by racial group
Class III overall ratios by racial group

Combined anterior ratios by racial group
Class I anterior ratios by racial group
Class II/I anterior ratios by racial group
Class II/I anterior ratios by racial group
Class III anterior ratios by racial group

Table 4.3 Paired T test values for differences in overall ratios by gender

Race/Malocclusion	Class I	Class II/I	Class II/II	Class III
Asian	0.45	0.98	0.56	0.77
Caucasian	0.82	0.52	0.63	0.36
Afro-Caribbean	0.52	0.002*	0.13	0.44

Table 4.4 Paired T test values for differences in anterior ratios by gender

Race/Malocclusion	Class I	Class II/I	Class II/II	Class III
Asian	0.02*	0.59	0.24	0.00*
Caucasian	0.42	0.88	0.19	0.01*
Afro-Caribbean	0.23	0.06	0.04*	0.00*

Key- * denotes values of significance ($p < 0.05$)

Significant differences between males and females for the overall ratio only existed for the Class II/I Afro- Caribbean group. There were significant differences in the anterior ratio for all the racial groups with Class III malocclusions, and for Class I Asians and Class II/II Afro-Caribbeans.

Table 4.5 ANOVA for combined overall ratios by malocclusion group

```
                                Individual 95% CIs For Mean Based on
                                   Pooled StDev
Occlusion     N     Mean  StDev    --+---------+---------+---------+-------
I             90    92.03  1.93        (------*-------)
II/I          90    91.67  3.04   (-------*-------)
II/2          108   91.78  2.06     (------*------)
III           60    93.12  4.97                   (---------*--------)
                                  --+---------+---------+---------+-------
                                 91.20     92.00     92.80     93.60

One way ANOVA R-Sq (Adj)= 1.98%; F= 3.34; p < 0.05
```

Key

I   - Class I incisor occlusion
II/I- Class II division I incisor malocclusion
II/2- Class II division II incisor malocclusion
III – Class III incisor malocclusion

There were significant differences between the means of the four malocclusion groups. This difference arose due to the difference between the mean for the Class III subjects (93.12) and both the Class II division I (91.67) and Class II division II subjects (91.78).

A print out for ANOVA results can be interpreted in terms of overlapping between the confidence intervals of the respective groups. Space between confidence intervals is indicative of significance. Overlapping of the confidence intervals for different groups indicates absence of significant difference between them

.

Table 4.6 ANOVA for Overall Asian ratios by malocclusion group

```
                              Individual 95% CIs For Mean Based on Pooled StDev

Occlusion    N    Mean  StDev     +---------+---------+---------+---------
I            30  91.61  1.609       (--------*--------)
II/I         30  91.69  2.720       (--------*--------)
II/2         30  91.41  1.613     (--------*---------)
III          30  93.60  6.763                    (--------*--------)
                                  +---------+---------+---------+---------
                               90.0      91.5      93.0      94.5

One way ANOVA R-Sq (Adj)=2.81%; F= 2.15; P <0.098
```

There were no significant differences between the means of the malocclusion groups

Table 4.7 ANOVA for Overall Caucasian ratios by malocclusion group

```
                          Individual 95% CIs For Mean Based on Pooled StDev

Occlusion   N    Mean  StDev     +---------+---------+---------+---------
I           30   92.32  2.29                 (---------*---------)
II/I        30   91.05  3.96     (----------*---------)
II/2        30   91.85  2.34             (---------*----------)
III         30   91.71  2.23            (---------*---------)
                                 +---------+---------+---------+---------
                              90.0      91.0      92.0      93.0

One way ANOVA R-Sq (Adj)=0.10%; F= 1.04; P <0.377
```

There were no significant differences between the means of the malocclusion groups

Table 4.8 ANOVA for Overall Afro-Caribbean ratios by malocclusion

```
                          Individual 95% CIs For Mean Based on
                          Pooled StDev

Occlusion   N   Mean  StDev  ---------+---------+---------+---------+
I           30  92.17  1.83        (---------*---------)
II/I        30  92.26  2.14         (---------*---------)
II/2        18  91.97  1.92   (------------*------------)
III         30  92.91  1.97                 (---------*---------)
                             ---------+---------+---------+---------+
                                91.70     92.40     93.10     93.80

One way ANOVA R-Sq (Adj)=0.34%; F= 1.12; P <0.344
```

There were no significant differences between the means of the malocclusion groups

Table 4.9 ANOVA for Combined anterior ratios by malocclusion group

```
                                  Individual 95% CIs For Mean Based on
                                  Pooled StDev

Occlusion     N    Mean  StDev      +---------+---------+---------+---------
I             90   78.30  3.046     (--------*-------)
II/I          90   78.30  3.360     (--------*-------)
II/2          108  78.28  2.658     (-------*-------)
III           60   79.66  2.454                   (----------*----------)
                                    +---------+---------+---------+---------
                                  77.70     78.40     79.10     79.80
```

One way ANOVA R-Sq (Adj)= 2.21%; F=3.61; P< 0.05

There were significant differences between the means of the malocclusion groups. This difference arose due to the difference between the mean for the Class III subjects (79.66) and the Class I (78.30), Class II division I (78.30) and Class II division II subjects (78.28).

Table 4.10 ANOVA for anterior Asian ratios by malocclusion

```
                          Individual 95% CIs For Mean Based on
                          Pooled StDev

Occlusion    N    Mean  StDev  --------+---------+---------+---------+-
I            30  76.82  1.41   (-------*-------)
II/I         30  78.67  3.09                   (-------*-------)
II/2         30  78.24  3.02               (-------*-------)
III          30  79.21  2.70                       (-------*-------)
                               --------+---------+---------+---------+-
                                   76.8      78.0      79.2      80.4
```

One way ANOVA R-Sq (Adj)= 8.11%; F=4.5; P< 0.005

There were significant differences between the means of the malocclusion groups. This difference arose due to the difference between the mean for the Class I subjects (76.82) and the Class II/I (78.67) and Class III subjects (79.21)

Table 4.11 ANOVA for anterior Caucasian ratios by malocclusion

```
                          Individual 95% CIs For Mean Based on
                          Pooled StDev
Occlusion   N    Mean  StDev  ---------+---------+---------+---------+
I           30  79.917  3.617                (---------*---------)
II/I        30  78.317  4.179    (---------*---------)
II/2        30  79.328  2.477            (---------*---------)
III         30  78.085  2.518  (---------*---------)
                               ---------+---------+---------+---------+
                                     78.0      79.2      80.4      81.6

One way ANOVA R-Sq (Adj)= 2.61%; F= 2.06; P <0.109
```

There were no significant differences between the means of the malocclusion groups

Table 4.12 ANOVA for anterior Afro-Caribbean ratios by malocclusion

```
                          Individual 95% CIs For Mean Based on
                          Pooled StDev

Occlusion   N    Mean  StDev  --+---------+---------+---------+-------
I           30  78.15  2.90       (---------*--------)
II/I        30  77.92  2.71     (--------*---------)
II/II       18  78.05  2.51   (-----------*------------)
III         30  79.44  2.49                    (--------*---------)
                              --+---------+---------+---------+-------
                              77.0      78.0      79.0      80.0

One way ANOVA R-Sq (Adj)= 2.76%; F= 2.01; P <0.117
```

There were no significant differences between the means of the malocclusion groups

Table 4.13 ANOVA for Combined overall ratios by racial group

```
                                    Individual 95% CIs For Mean Based on
                                    Pooled StDev
Race            N    Mean  StDev    ------+---------+---------+---------+---
Asian           120  92.076  3.873         (----------*---------)
Caucasian       120  91.731  2.800  (----------*---------)
Afro-Caribbean  108  92.366  1.977              (----------*-----------)
                                    ------+---------+---------+---------+---
                                       91.50     92.00     92.50     93.00

One way ANOVA R-Sq (Adj)= 0.15%; F= 1.27; P <0.283
```

Key
A = Asian
C = Caucasian
AC= Afro Caribbean

No significant differences were found between the means of the racial groups

Table 4.14 ANOVA for Class I overall ratios by racial group

```
                                    Individual 95% CIs For Mean Based on
                                    Pooled StDev
Race              N    Mean  StDev  -----+---------+---------+---------+----
Asian            30  91.608  1.609  (-----------*----------)
Caucasian        30  92.315  2.287              (-----------*----------)
Afro-Caribbean   30  92.174  1.833            (----------*-----------)
                                    -----+---------+---------+---------+----
                                      91.20     91.80     92.40     93.00

One way ANOVA R-Sq (Adj)= 0.29%; F= 1.13; P <0.328
```

No significant differences were found between the means of the racial groups

Table 4.15 ANOVA for Class II/I overall ratios by racial groups

```
                           Individual 95% CIs For Mean Based on Pooled StDev

Level            N    Mean  StDev   +---------+---------+---------+---------
Asian            30  91.69  2.72          (----------*----------)
Caucasian        30  91.05  3.96    (----------*----------)
Afro-Caribbean   30  92.26  2.14                (----------*----------)
                                    +---------+---------+---------+---------
                                 90.0      91.0      92.0      93.0

One way ANOVA R-Sq (Adj)= 0.41%; F= 1.18; P <0.312
```

No significant differences were found between the means of the racial groups

Table 4.16 ANOVA for Class II/II overall ratios by racial groups

```
                                  Individual 95% CIs For Mean Based on
                                  Pooled StDev

Race            N    Mean  StDev  ---------+---------+---------+---------+
Asian          30  91.41  1.61   (-----------*------------)
Caucasian      30  91.85  2.34           (-----------*-----------)
Afro-Caribbean  18  91.97  1.92         (---------------*--------------)
                                  ---------+---------+---------+---------+
                                       91.20     91.80     92.40     93.00

One way ANOVA R-Sq (Adj)= 0.00%; F= 0.57; P <0.57
```

No significant differences were found between the means of the racial groups

Table 4.17 ANOVA for Class III overall ratios by racial groups

```
                                   Individual 95% CIs for Mean Based on
                                   Pooled StDev

Race             N    Mean  StDev  ---------+---------+---------+---------+
Asian            30   93.60  6.77              (---------*---------)
Caucasian        30   91.71  2.23  (---------*----------)
Afro-Caribbean   30   92.91  1.97          (---------*----------)
                                   ---------+---------+---------+---------+
                                         91.5      93.0      94.5      96.0

One way ANOVA R-Sq (Adj)= 1.13%; F= 1.51; P <0.23
```

No significant differences were found between the means of the racial groups

Table 4.18 ANOVA for Combined anterior ratios by racial groups

```
                                    Individual 95% CIs for Mean Based on
                                    Pooled StDev

Race             N     Mean   StDev  ------+---------+---------+---------+---
Asian            120   78.23  2.757  (----------*---------)
Caucasian        120   78.91  3.323               (---------*----------)
Afro-Caribbean   108   78.43  2.711     (-----------*----------)
                                     ------+---------+---------+---------+---
                                        78.00     78.50     79.00     79.50

One way ANOVA R-Sq (Adj)= 0.393%; F= 1.67; P <0.19
```

No significant differences were found between the means of the racial groups

Table 4.19 ANOVA for Class I anterior ratios by racial group

```
                          Individual 95% CIs For Mean Based on
                          Pooled StDev
Race   N    Mean  StDev  -----+---------+---------+---------+----
A      30   76.82  1.41  (------*------)
C      30   79.92  3.62                      (------*------)
AC     30   78.15  2.90           (------*------)
                          -----+---------+---------+---------+----
                            76.5      78.0      79.5      81.0

One way ANOVA R-Sq (Adj)= 15.65%; F= 9.26; P < 0.01
```

There were significant differences between the means of the three racial groups. This difference arose due to the difference between the mean for the Asian subjects (76.82) and that for the Caucasian subjects (79.92).

Table 4.20 ANOVA for Class II/I anterior ratios by racial group

```
                                     Individual 95% CIs For Mean Based on
                                     Pooled StDev

Race             N    Mean    StDev  ---+---------+---------+---------+------
Asian           30   78.67   3.09           (------------*-----------)
Caucasian       30   78.32   4.18         (-----------*-----------)
Afro-Caribbean  30   77.92   2.71    (-----------*------------)
                                     ---+---------+---------+---------+------
                                     77.0      78.0      79.0      80.0

One way ANOVA R-Sq (Adj)= 0.00%; F= 0.36; P < 0.696
```

No significant differences were found between the means of the racial groups

Table 4.21 ANOVA for Class II/II anterior ratios by racial group

```
                          Individual 95% CIs For Mean Based on
                          Pooled StDev

Race            N    Mean  StDev   --+---------+---------+---------+-------
Asian           30  78.24  3.024        (--------*---------)
Caucasian       30  79.33  2.477                  (---------*---------)
Afro-Caribbean  18  78.05  2.511   (-----------*------------)
                                   --+---------+---------+---------+-------
                                  77.0      78.0      79.0      80.0
```

One way ANOVA R-Sq (Adj)= 1.85%; F= 1.73; P < 0.185

No significant differences were found between the means of the racial groups

Table 4.22 ANOVA for Class III anterior ratios by racial group

```
                                 Individual 95% CIs For Mean Based on
                                 Pooled StDev

Race           N    Mean  StDev  --------+---------+---------+---------+-
Asian          30  79.21  2.70              (--------*--------)
Caucasian      30  78.09  2.52   (--------*--------)
Afro-Caribbean 30  79.44  2.49                (--------*---------)
                                 --------+---------+---------+---------+-
                                      78.0      79.0      80.0      81.0
```

One way ANOVA R-Sq (Adj)= 3.03%; F= 2.39; P < 0.098

No significant differences were found between the means of the racial groups

CHAPTER FIVE

5.1 Discussion

The prevalence of Bolton's tooth size discrepancy in the sample population was 6.6% for the overall ratio and 26.7% for anterior ratio. This was comparable to many of the existing studies (Proffit, 2000; Freeman et al., 1996; Santoro et el., 2000; Araujo and Souki; 2003). The prevalence of Bolton's tooth size discrepancies in different racial and malocclusion groups has been studied extensively for a number of populations, and the studies have generated varying results. Bolton's original study was carried out on a group of 55 Caucasian females with excellent occlusions, and so its application to males, non Caucasian populations, and different malocclusion groups has been questioned.

The majority of studies comparing Bolton's ratios have tried to establish whether or not differences existed between males and females. The results of these studies have varied. Bishara et al., (1989) looked at three groups of children from the United States, Egypt and Mexico and found that there were gender differences within each racial group, with males showing large mesio distal tooth widths for different teeth. This supported the work of Richardson et al., (1975) who showed that tooth size dimensions were greater in a group of Negro males than females. Lavelle, 1972 compared the overall and anterior ratios for males and females and found both to be greater in males, although the difference was less than 1%. Strujic et al., (2009) have assessed the presence of tooth size discrepancy in a sample of 301 Croatian subjects, assessing variation with regard to

Angle's classification and looking at sexual dimorphism. Their results showed a statistically significant gender difference in the anterior ratio (P= 0.017). The results of the present study support these findings as most of the significant tooth size discrepancies between males and females in the existing sample were in the anterior ratios.

T tests were carried out to compare overall and anterior ratios by gender. Significant differences in the overall ratios were found only in the Class II division I Afro-Caribbean subjects. There were significant differences in the anterior ratios of all Class III malocclusions, and for Class I Asians and Class II/II Afro-Caribbeans. From the existing study it appears that on the whole, tooth size discrepancies between males and females is largely limited to the anterior ratio and particularly affects Class III subjects.

Much of the research assessing the association between malocclusion and tooth size discrepancy suggests that mandibular tooth size excess is greatest in Class III malocclusions (Arauyo and Souki, 2003; Nie and Lin, 1999; Ta et al., 2001, Sperry et al.,1977). This was supported by the findings of the current study, as significant differences existed for the overall and anterior ratios in Class III subjects. ANOVA was used to compare combined overall ratios by malocclusion groups, and significant differences were found between the means of the four malocclusion groups due to differences between the means for the Class III subjects and those of the Class II/I and Class II/II subjects. The mean for the Class III subjects was significantly greater than that of the Class II groups, suggesting overall mandibular tooth size excess in the Class

III group. No significant differences were found for the overall ratios of individual racial groups. Data for the combined anterior ratios showed significant differences between the means of some malocclusion groups. These differences arose due to difference in the means between Class III subjects and the other three groups, with that of the Class III group being significantly greater. Again this suggests that a mandibular tooth size excess exists in Class III subjects. When comparing anterior ratios for individual racial groups by malocclusion, significant differences were found between the means of the Class I Asian subjects and the Class III Asian subjects. Again the mean ratio for the Class III group was greater, suggesting that mandibular tooth size excess existed in the Class III Asian group compared to the Class I group.

Different racial groups were compared in the work carried out in the United Kingdom by Lavelle, (1972). A local white population was compared to Far eastern immigrants from Hong Kong and black immigrants from Africa. All groups had excellent occlusions and the mesio-distal tooth widths of their teeth were compared. The average mesio- distal crown diameter was greater in the black group than in the white, with that for far eastern group being intermediate. This applied to maxillary and mandibular dentitions in both males and females. In addition both the overall and anterior ratios were greater in Black group than in the white, with far eastern again being intermediate.

This was supported by Smith et al., (2000) who found significant differences in tooth size discrepancy in negroid, caucasoid and hispanic samples. The overall ratio was smallest in caucasoids followed by hispanics and negroids, and the difference between caucasoids and negroids was highly significant. The posterior ratio was greatest in negroids, who had larger mandibular teeth than either caucasoids or Hispanics. The anterior ratio was significantly larger in hispanics than negroids, with caucasoids showing no significant difference from the other two groups. The anterior ratio showed that caucasoids had larger anterior mandibular teeth than negroids, a finding which differed from that of Lavelle et al., (1972) who showed that overall and anterior ratios were greater in Negroids than Caucasoids.

Merz et al, (1991) assessed tooth diameters in both black and white populations in the United States. The mean mesiodistal crown diameters of canines, premolars and molars in the black population were all significantly larger than for the corresponding teeth in the white population, which supports the results of Lavelle et al., (1972). In addition both the mean maxillary and mandibular arch depths were significantly greater in the black sample resulting in an increase in arch perimeter more than sufficient to accommodate larger tooth space requirements; therefore the black population did not have significantly more crowding.

Other studies have not found racial variation to be a significant factor in the presence of tooth size discrepancies. Flores-Mir, (2003) assessed tooth size discrepancy in a Peruvian population and similar results to those of Bolton, (1958). Bishara et al., (1989) compared tooth size discrepancies in populations from Mexico, Egypt and the United States and found that differences were small magnitude and not clinically significant.

The present study assessed three racial groups, Asians, Caucasians and Afro Caribbeans. ANOVA was used to test for differences in anterior and overall ratios in the three racial groups. No significant differences were found in the overall ratios for the three racial groups for combined ratios or any malocclusion Class. In addition, no significant differences were found between the combined anterior ratios of individual malocclusion Classes, except for the Class I group where significant differences were found between the anterior ratios of the Asian and Caucasian Class I groups. The mean anterior ratio for the Caucasian group (79.92) was significantly larger than the mean of the Asian group (76.82). The anterior ratio for the Afro-Caribbean group was intermediate (78.00), although did not differ significantly from the other two groups. This supports the work of Smith et al., (2000) in which there was no significant difference in the anterior ratios of Caucasians and negroids. No significant differences existed between the means of the combined overall and anterior ratios of Asians and Caucasians and the only significant difference was in the Class I group. No study has examined Caucasian and Asian (Indian sub-continent) populations and so it is not possible to make comparisons with the present findings.

On the whole the results of the current study suggest that differences in tooth size discrepancies are affected by gender and malocclusion group, particularly in Class III subjects. The anterior ratios of all Class III subjects showed significant differences between males and females. This was the only malocclusion group to show such gender differences for all three racial groups. When the malocclusion groups were compared, both the overall and anterior ratios were greatest in the Class III groups suggesting mandibular tooth size excess. Only one significant difference was found when comparing racial groups. This was between anterior ratios in Class I Asian and Class I Caucasian subjects.

CHAPTER SIX

6.1 Conclusions

- The prevalence of tooth size discrepancy in the sample population was 6.03% in the overall ratio and 26.7% for the anterior ratio

- Significant differences between males and females for overall ratios existed only for Class II/I Afro- Caribbean subjects.

- There were significant differences between males and females in the anterior ratios for all racial groups with Class III malocclusions. Differences also were found for Class I Asians and Class II/II Afro- Caribbeans

- There were significant differences between the means of the combined overall ratios for the four malocclusion groups. These differences arose due to the mean for the Class III subjects being significantly greater than the means for both Class II division I and Class II division II subjects

- There were significant differences between the means of the combined anterior ratios for the four malocclusion groups. These differences arose due the mean for the Class III subjects being significantly greater than those of the other malocclusion groups.

- There were significant differences between the means of the anterior ratios for the Asian subjects by malocclusion class. The mean for the Class I subjects was significantly lower than for the Class II/I and Class III subjects

- There were significant differences between the means of the three racial groups. This difference arose due to difference between the means for the Asian subjects and that Caucasian subjects.

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