BOLTON COMPARISON BETWEEN CAUCASIAN AND CHINESE POPULATIONS.

By

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Dedication

I dedicate this thesis to my husband, parents and sisters. Thank you for your support and endless love.

CONTENTS

ABSTRACT

INTRODUCTION: An ideal occlusion with the correct overbite and overjet, good alignment and Class I canine and molar relationship, can only be obtained if the upper and lower teeth are proportional in size.[1]

A tooth size discrepancy can result in spacing, crowding and incorrect intercuspation or interdigitation of the upper and lower teeth. [2]

Bolton norms were generated using Caucasoid norms and may not be reliable nor clinically applicable to other ethnic groups.

OBJECTIVES: To determine the preferred management approach before commencing orthodontic treatment, the clinician should do a Bolton calculation to detect tooth size discrepancies. The aim of this study was to use the Bolton calculations to compare and detect any tooth size discrepancies which may exist between Caucasian and Chinese subjects, and between males and females.

MATERIALS & METHODS: Fifty Caucasians and fifty Chinese subjects' casts (25 male and 25 female) were selected who had a complete permanent dentition up to the first molars, without interproximal restorations or caries, and had no previous orthodontic treatment. Casts were measured with a Digital Caliper (accurate to 0.01mm), Boley

Gauge Vernier Caliper and OrthoCAD®. The measurements were used to do the Bolton calculations for the over-all ratio (Overall 12) and for the anterior ratio (Anterior 6). Linear regression models with main effects for race and gender as well as an interaction effect between them were used.

RESULTS: No significant difference ($p > 0.05$) was found amongst the gender groups for the Overall 12 and the Anterior 6. A significant difference ($p = 0.007$) was found amongst the different ethnic groups for the Overall 12 but not for the Anterior 6 ($p > 0.05$). For the Anterior 6 there was a significant difference ($p = 0.04$) in the group variances with the Caucasian group showing more variance.

CONCLUSIONS: Based on the findings in this study, for improved accuracy it will be advisable to generate Chinese- specific Bolton tables.

Key Words: Tooth size discrepancy, Anterior ratio, Posterior ratio

List of Tables and Figures

CHAPTER 1

1.0 Introduction

1.1 Preamble

In 1958, Wayne A. Bolton, presented a study in which he outlined the importance of tooth size, which refers to the mesio-distal diameter of a tooth. (Bolton, 1958) He wanted to convey that an evaluation of tooth widths in the initial diagnostic phase could assist in the diagnosis and treatment planning of orthodontic cases. It could also affect the functional and aesthetic results of these cases (Bolton, 1962). In 1962, Bolton published a second paper, in which he presented clinical cases to investigate if his study was an accurate diagnostic tool.

It has been found that an ideal occlusion with the correct overbite and overjet, good alignment and Class I canine and molar relationship, can only be obtained if the upper and lower teeth are proportional in size (Othman & Harradine, 2006). Harmony between the arches allows for structural and functional stability in an orthodontic case (Judica, 2004).

A tooth size discrepancy (TSD) can be seen as an excess of tooth structure in one arch in relation to the other arch (Alkofide & Hashim, 2002).

A TSD results in spacing, crowding and incorrect intercuspation or interdigitation of the upper and lower teeth (Baydas et al.,2005). It can therefore be defined as a disproportion among the sizes of individual teeth and roughly 5% of the population have some variation among the sizes of the individual teeth (Proffit et al., 2013).

Other variables that are important in achieving proper occlusal relationships are: - Maxillary incisor thickness, incisor inclinations and arch form (Kayalioglu et al., 2005).

Bolton's study was important as it allowed for the analysis of intermaxillary permanent tooth size discrepancies (Alkofide & Hashim, 2002). The Bolton analysis is therefore not a space analysis. It is not used to calculate tooth size: arch length discrepancies. Space analysis involves two processes: the calculation of space within the dental arches and the determination of the amount of space required to align the teeth. The arch perimeter is measured from one first molar to the other, over the posterior teeth contact points and the incisal edges of the anterior teeth in order to determine the space available in the arches. The sum of the measurements of the mesiodistal widths of individual teeth are calculated in order to determine the required space. This measurement can then be compared to the measurement for space availability. An arch perimeter space deficiency exists if the space required for the permanent teeth is greater than the available space, this will result in crowding. There will be spaces between teeth if the space available is greater than the required space (Proffit et al., 2013).

A mixed dentition space analysis is available in order to estimate the mesiodistal dimensions of the unerupted permanent teeth and therefore calculate the space required. This can then be compared with the available space (as with the permanent dentition) in order to calculate if there is a space excess or deficiency. Both these analyses are done on orthodontic study models (Proffit et al., 2013).

Tooth size measurements can be conducted via various methods such as with needle-pointed dividers, Boley gauges, Digital Calipers and digital models in a software program.

The Boley gauge showed more clinically significant repeated measurements than the needle-pointed dividers and thus is more reliable. (Shellhart et al., 1995).

A comparison between digital caliper measurements on dental plaster models (current golden standard) vs 3D digital models measured using a software program showed no significant differences.(Correia et al., 2014; Stevens et al., 2006; Whetten et al., 2006; El-Zanaty et al., 2010; Radeke et al., 2014; Lippold et al., 2015; Paredes et al., 2006); Wan Hassan et al., 2016)

Zilberman et al 2003 evaluated the validity of measurements made by digital callipers and OrthoCad®. Digital callipers produced the most accurate measurements, but the measurements made with OrthoCad® were not much different. Digital callipers seem to be a more suitable instrument for scientific work, but OrthoCad's® accuracy was considered clinically acceptable. (Zilberman et al., 2003)

The literature review will discuss various aspects of the Bolton study. It will highlight the prevalence, importance and the reliability and validity of the Bolton ratios with regards to different genders, cultures and malocclusion groups.

1.2 Purpose

To determine the preferred management approach before commencing orthodontic treatment, the clinician should do a Bolton calculation to detect tooth size discrepancies. The purpose of this study was to use the Bolton calculations to compare and detect any tooth size discrepancies which may exist between Caucasian and Chinese subjects, and between males and females.

1.3 Null Hypotheses

The null hypotheses for this study state that:

1. There is no statistically significant difference in the Bolton tooth size discrepancies amongst the different populations.

2. There is no statistically significant difference in the Bolton tooth size discrepancies amongst the different genders.

3. There is no statistically significant difference in the Bolton tooth size discrepancies amongst the different genders within an ethnic group.

CHAPTER 2

2.0 Literature Review

2.1 Tooth size analysis

Tooth size has been a topic of interest since the late nineteenth century. There have been many studies done in order to determine the dimensions of teeth, such as (Lysell & Myrberg, 1982; Afb et al.,1994; Otuyemi & Noar, 1996; Condon et al., 2011) . The researchers believed that mathematical ratios could be set up between the total length of the arches and even segments of the arch. Bolton himself, believed that these mathematical formulas could play a role in diagnosis, treatment, function and aesthetics of certain clinical cases (Bolton, 1958, 1962). In 1962, Bolton published a second paper, in which he presented clinical cases to investigate if his study was in fact, an accurate diagnostic tool (Tomassetti et al., 2001)

G.V. Black measured human teeth which resulted in the establishment of tables with mean values. These tables are still used presently (Bolton, 1962).

In 1944, Ballard investigated asymmetry in tooth size by comparing the mesiodistal diameters of a tooth with the corresponding tooth on the opposite side of the dental arch. He found that there was a right- left discrepancy in mesio-distal width in 90 % of his sample. This was considered to be a 0,25mm discrepancy. He concluded that interproximal reduction could solve this imbalance (Ballard, 1944; Bolton, 1962).

C.W Neff created an "anterior coefficient" by dividing the sum of the mandibular teeth into the sum of the maxillary teeth. This coefficient was then related to the degree of overbite. A 20% overbite was deemed ideal (Neff, 1949; Bolton, 1962).

S.R Steadman compared the width of the four maxillary incisors and a half of the width of the canines to the mesiodistal diameter of the complete six mandibular anterior teeth. He wanted to formulate a method to determine the overbite-overjet relationship of the anterior teeth. Half the thickness of the Maxillary central incisor (measured at the incisal third) is subtracted from the Maxillary measurement, and half the thickness of the Mandibular lateral incisor (measured at the incisal third) is added to the mandibular measurement. If the sums are equal and the canines are in an ideal Class I relationship, a good overbite-overjet would exist. A -2.0mm value would result in an edge-to-edge incisor relationship. A+2.0mm value would result in an enlarged overbite and overjet. (Steadman, 1949; Bolton, 1962)

R.C Wheeler also did a study which consisted of tooth dimensions, so that ideal tooth dimensions could be achieved during carving and articulation of teeth. When his figures were used and the ratios were computed, the results were found to be 91.4 for the over-all ratio and 77.8 for the anterior ratio. (Wheeler, 1940; Bolton,1958, 1962)

Recently, there have also been numerous studies on tooth size and its importance in attaining an ideal occlusion. R.S Johe et al 2010 found in their sample size (Caucasian, African American and Hispanic) that 50% of their sample had anterior Bolton tooth-size discrepancies and 41% had a Bolton tooth size discrepancy overall (R.S Johe et al., 2010). M. Heusdens et al 2000 compared four studies and concluded that the maxillary and mandibular mesiodistal tooth size must have a relationship in order to achieve a good occlusion after orthodontic treatment. One study had the sample populations

Caucasian, African American and another study had the sample populations as Caucasian, African American and Mongoloid. The other two studies did not state which population groups casts were used. (Heusdens et al., 2000)

A controversial study by Redahan & Langerstrom 2003 in the Journal of Orthodontics studied the anterior inter-arch tooth size ratio pre- and post-treatment and found that the measurement of the anterior tooth size ratio pre-treatment was not clinically beneficial for determining anterior dental relations post-treatment (Redahan & Langerstrom, 2003).

Bernabé et al 2004 found that the 2-standard deviations range from the Bolton standard did not predict clinically significant anterior and total tooth-width ratio discrepancies. Therefore, it is evident that tooth dimensions and TSD remain topics of interest. (Bernabé et al., 2004)

If a TSD exists, clinically it may present in a variety of ways. If the maxillary anterior teeth are too large relative to the mandibular anterior teeth, then there may be a deep overbite or a larger overjet or a crowded anterior segment (Baydas et al., 2005).

If the mandibular anterior teeth, are relatively larger and not proportional in size to the maxillary anterior teeth a few clinical presentations may occur. There may be an end-to-end relationship of the teeth or spacing in the maxillary anterior segment or crowding of the mandibular incisors or improper occlusion of the posterior teeth (Baydas et al., 2005).

If the clinician fails to identify these discrepancies, it may lead to a delay in the finishing stages of treatment as the TSD will need to be rectified. If left untreated, an orthodontic result that is compromised may ensue (Alkofide & Hashim, 2002).

2.2 Prevalence of Tooth Size Discrepancy

The prevalence of TSD remains undefined as numerous studies have been done to determine it and the results have been variable:

Proffit states that the prevalence of disproportion among the sizes of teeth is approximately 5% (Proffit et al., 2013)

In 1989, Crosby and Alexander found that 22.9% of the sample of 109 patients (mixed population) with different malocclusions had an anterior TSD, and that there was a higher percentage of people with an anterior TSD than with an overall TSD. This fact was also found in studies conducted by Freeman et al 1996 and Santoro et al 2000. They found that there was an equal chance of there being an excess in the maxilla or mandible for the overall discrepancy, whereas with the anterior discrepancy, there was double the possibility that the excess lay in the mandible (19.7%) compared to the maxilla (10.8%).

In 1996, a study done by Freeman et al on 157 orthodontic patients (115 white patients, 27 black patients, and 15 patients of other ethnic origin) concluded that 30.6% of patients had an anterior discrepancy and 13.5% of patients had an overall discrepancy.

In a study in Turkey (2005), there was an overall ratio discrepancy in 18% of the Turkish sample and a discrepancy in anterior ratio in 21.3% of the sample.(Uysal & Sari, 2005)

Despite the varying conclusions that have been obtained from each study, the general view amongst clinicians is that TSD is a relatively infrequent problem in patients, but it should not be ignored (Othman & Harradine, 2006)

Table 1: Authors of Study and Population/Ethnic groups studied.

Author	Population/Ethnic group
Crosby and Alexander (1989)	Mixed
Freeman et al (1996)	White, Black and Other
Santoro et al (2000)	Dominican
Araujo and Souki (2003)	Brazilian
Bernabé et al (2004)	Peruvian

Table 2: Summary of different studies and the prevalence of TSD.

Author	Population	Sample size	% Anterior TSD	% Overall TSD
Crosby and Alexander[10]	Orthodontic	109	22.9	–
Freeman *et al.*[11]	Orthodontic	157	30.6	13.5
Santoro *et al.*[12]	Orthodontic	54	28.0	11.0
Araujo and Souki[13]	Orthodontic	300	22.7	–
Bernabě *et al.*[14]	School	200	20.5	5.4

(Othman & Harradine, 2006)

2.3 Bolton's Study

In 1958, Bolton (Bolton, 1958) analysed fifty –five cases, which had excellent occlusions. Of these cases, forty-four had been treated orthodontically and eleven had not. These cases were selected from the orthodontic department of the University of Washington and surrounding private practices. The measurements of the mesiodistal widths of the maxillary and mandibular teeth were recorded with three-inch needle point dividers. The second and third molars were excluded from the study. With this data he formulated 2 ratios; the *"Over-all ratio"* and the *"Anterior ratio"*. His aim was to determine if mathematical ratios could be established between the total length of the dental arches and the dental arch segments (Bolton, 1958; Othman & Harradine, 2006)

Bolton felt that these two ratios could assist clinicians in determining the expected overbite and overjet at the completion of treatment. This would eliminate the need for a diagnostic setup. It would also assist in determining; the effects of proposed extractions on the posterior occlusion, the relationship of the incisors and assist in identifying occlusal misfits due to inter-arch tooth size discrepancies. He found that these two ratios were necessary for proper coordination of the mandibular and maxillary teeth.

The over-all ratio depicts the percentage ratio of the sum of the mesiodistal widths of the mandibular teeth (mandibular arch length) to the sum of the mesiodistal widths of the maxillary teeth (maxillary arch length). From the data collected, a mean ratio of 91.3% and a standard deviation (SD) of 1.91%, will result in an ideal overbite-overjet relationship and an ideal posterior occlusion.

Simplified this is:

$$\text{Overall Ratio} = \frac{\text{Sum of Mandibular 12 Teeth}}{\text{Sum of Maxillary 12 Teeth}} \times 100 = 91.3\%$$

The clinical significance of the over-all ratio is that if it is larger than 91.3%, the discrepancy results from an excess of mandibular tooth material or that the maxillary arch is too small for the mandibular arch. There is a table which Bolton devised so that the TSD can be calculated. This table works as follows: the patient's maxillary tooth size is located in the table. Across from this figure is another figure which is the ideal mandibular measurement. The amount of excess mandibular tooth material is calculated by determining the difference between the actual and the ideal mandibular measurement (Moyers, 1988) [Refer to Table 3]

If the ratio is less than 91.3%, the discrepancy is as a result of an excess in maxillary tooth material, which is determined by the difference between the actual and the ideal maxillary size (Moyers, 1988)

The Anterior- ratio depicts the percentage relationship of the sum of the mandibular anterior teeth to the sum of the maxillary anterior teeth (Bolton, 1958; Othman & Harradine, 2006)

The mean anterior ratio, which produced an ideal overbite and overjet relationship, was 77.2% and the standard deviation was 1.65%. This occurs, provided that the incisor angulations are correct and the labiolingual thicknesses of the incisal edges are suitable. If the anterior- ratio is greater than 77.2%, there is an excess of mandibular tooth

material, but if the ratio is less than 77.2%, then there is an excess of maxillary tooth material (Moyers, 1988; Paredes et al., 2006)

The other factors that were investigated in this study include: measurement of the buccal segments to localize tooth discrepancy; degree of overbite and overjet; angles of the maxillary and mandibular incisor to the occlusal plane, incisal length and cusp height (Bolton, 1958)

Simplified:

$$\text{Anterior Ratio} = \frac{\text{Sum of Mandibular 6 Teeth}}{\text{Sum of Maxillary 6 Teeth}} \times 100 = 77.2\%$$

The data which Bolton collected was used to highlight the deviation from the ideal of a particular ratio, thereby highlighting the discrepancy size. A significant discrepancy is indicated when there is a standard deviation greater than one from Bolton's values (Othman & Harradine, 2006; Paredes et al., 2006). Other studies have found that a significant discrepancy exists when there is a standard deviation greater than two from Bolton's values, as approximately 95% of Bolton's sample fell in this range (Othman & Harradine, 2006).

Therefore, for the overall ratio, values that were less than 87.5% or greater than 95.1%, were considered a significant discrepancy. Ratios in between 87.5% and 95.1% fell within 2 standard deviations (2×1.91) of Bolton's mean. In the same way, a significant discrepancy for the anterior ratio exists when the values are less than 73.9% and greater than 80.5%. Ratios in between 73.9% and 80.5% fell within 2 SD (2×1, 65) of Bolton's mean (Paredes et al., 2006; Uysal & Sari, 2005). The deviation from this

ratio leads to a disharmony between the arches and a resultant malocclusion (Laino et al., 2003).

The significance of Bolton's standard deviation is that it can be used in clinical practice to determine if there is a need to reduce or increase tooth structure. Reduction can be done by interdental stripping of the enamel. Addition can be done with a restoration (Bolton, 1962; Othman & Harradine, 2006).

Bolton's second paper, was published in 1962, and involved clinical cases in order to demonstrate the use and significance of the Bolton' ratios.

The aim of the ratios was to allow one to see if a diagnostic setup is necessary and how it should be approached. It allows one to determine if extractions are necessary.

Bolton's study today is still a well-recognized valid research topic. The study itself has paved the way for continuing research.

Table 3: An analysis sheet for the Over-all and Anterior ratio (Bolton, 1962)

ANALYSIS OF TOOTH-SIZE DISCREPANCIES

Over-all Ratio

Sum mandibular 12 _____ mm. / Sum maxillary 12 _____ mm. = _____ × 100 = _____ % Over-all ratio

Mean 91.3 = 0.26
S.D. (o) 1.91
Range 87.5-94.8

Maxillary 12	Mandibular 12	Maxillary 12	Mandibular 12	Maxillary 12	Mandibular 12
86	77.6	94	85.8	103	94.0
86	78.5	95	86.7	104	95.0
87	79.4	96	87.6	105	95.9
88	80.3	97	88.6	106	96.8
89	81.3	98	89.5	107	97.8
90	82.1	99	90.4	108	98.6
91	83.1	100	91.3	109	99.5
92	84.0	101	92.2	110	100.4
93	84.9	102	93.1		

Patient Analysis

If the over-all ratio exceeds 91.3 the discrepancy is in excessive mandibular arch length. In above chart locate the patient's maxillary 12 measurement, and opposite it is the correct mandibular measurement. The difference between the actual and correct mandibular measurement is the amount of excessive mandibular arch length.

Actual mandibular 12 _____ − Correct mandibular 12 _____ = Excess mandibular 12 _____

If over-all ratio is less than 91.3:

Actual maxillary 12 _____ − Correct maxillary 12 _____ = Excess maxillary 12 _____

Anterior Ratio

Sum mandibular 6 _____ mm. / Sum maxillary 6 _____ mm. = _____ × 100 = _____ % Anterior ratio

Mean 77.2 = 0.22
S.D. (o) 1.65
Range 74.5-80.4

Maxillary 6	Mandibular 6	Maxillary 6	Mandibular 6	Maxillary 6	Mandibular 6
40.0	30.9	45.5	35.1	50.5	39.0
40.5	31.3	46.0	35.5	51.0	39.4
41.0	31.7	46.5	35.9	51.5	39.8
41.5	32.0	47.0	36.3	52.0	40.1
42.0	32.4	47.5	36.7	52.5	40.5
42.5	32.8	48.0	37.1	53.0	40.9
43.0	33.2	48.5	37.4	53.5	41.3
43.5	33.6	49.0	37.8	54.0	41.7
44.0	34.0	49.5	38.2	54.5	42.1
44.5	34.4	50.0	38.6	55.0	42.5
45.0	34.7				

Patient Analysis

If anterior ratio exceeds 77.2:

Actual mandibular 6 _____ − Correct mandibular 6 _____ = Excess mandibular 6 _____

If anterior ratio is less than 77.2:

Actual maxillary 6 _____ − Correct maxillary 6 _____ = Excess maxillary 6 _____

2.4 Variables of Bolton Study:(Gender, Ethnicity, Malocclusion, Crowded vs. Non-crowded dentitions)

2.4.1 Malocclusions

Tooth size may be a factor in the cause of a certain Angle malocclusion (Lavelle, 1972). Crosby et al 1989 found that there was no significant difference in the incidence of tooth size discrepancies among different malocclusion groups from a sample of 109 patients with different malocclusions (Class I, Class II Div 1 and Div2, Class II surgery).

A study by Nie & Lin 1999 found that there was no significant difference between the malocclusion groups (Class I bimaxillary protrusion, Class II Div 1 and 2, Class III and Class III surgery) but when they combined the groups (Class I, Class II, and Class III) there was a statistically significant difference as follows: Class III having the most discrepancies, Class I second most and Class II malocclusion third most discrepancies. They concluded that tooth size discrepancies may be an important factor for malocclusions. Araujo et al 2003 had the same findings as Nie & Lin in 1999. Basaran et al 2006 found no differences between the malocclusion groups or combined malocclusion groups. Laino et al 2003 found no difference amongst the malocclusion groups and concluded that there is no predisposition for a tooth-size discrepancy in any of the malocclusion groups.

A study conducted in Hong Kong China found that there was a difference found between the Bolton standard and the Class II malocclusion group, and between the Class II and Class III groups. The Bolton Standard applied to the Class I occlusion group. Tooth-size discrepancies were more prevalent in the Class III malocclusion group (Ta et al., 2001).

Posterior Bolton ratios were significant for the different malocclusion groups and anterior Bolton ratios were insignificant amongst the different malocclusion groups. (Oktay & Ulukaya, 2010)

2.4.2 Crowded vs. Non-crowded

Clinically significant measurement errors can occur when using cases with a minimum 3mm of crowding when conducting a Bolton tooth-size analysis (Shellhart et al., 1995).

No clinical differences, but statistically significant tooth size discrepancies were found between crowded and non-crowded groups (Bernabé et al., 2004).

2.4.3 Ethnicity

Bolton based his study on a Caucasian population(Bolton, 1958).

More tooth size discrepancies were found in the Caucasian population compared to the Mongoloid population. (Lavelle, 1972)

A study by Smith et al 2000 found that whites displayed the lowest overall ratio compared with to Hispanics and Blacks.(Othman & Harradine, 2006)

2.4.4 Gender

Male teeth are larger in general then female teeth.

Lavelle 1972 found that the sex differences were small (<1%). (Othman & Harradine, 2006)

No overall differences were found amongst the different gender groups but posterior Bolton ratio differences were found amongst males and females. (Oktay & Ulukaya, 2010). No Bolton tooth-size differences were found amongst the different gender groups. (Bernabé et al., 2004; Basaran et al., 2006)

Most studies have found no difference in the mean Bolton ratios between males and females. If a difference was found it was small and clinically insignificant.

Table 4: Summary of studies with clinically significant tooth size discrepancies according to gender, malocclusion and racial/ethnicity. (Othman & Harradine, 2006)

Author	Country	Gender difference	Malocclusion differences	Racial/ethnicity
Sperry et al.[21]	USA		Yes	
Corby and Alexander[10]	USA		No	
Nie and Lyn[22]	China	No	Yes	
Araujo and Souki[13]	Brazil	No	Yes	
Ta et al.[23]	China		Yes	
Alkofide and Hashim[24]	Saudi Arabia	No	Yes	
Liano et al.[25]	Italy		No	
Uysal et a.[26]	Turkey		No	
Lavelle[28]	USA	Yes		Yes
Richardson and Malhotra[29]	USA	No		
Al-Tamimi and Hashim[30]	Saudi Arabia	No		
Smith et al.[9]	USA	Yes		Yes

2.5 Management of a Tooth Size Discrepancy

TSD must be considered in the initial treatment plan so as to avoid unexpected errors in the finishing stage of treatment (Proffit et al., 2013)

In Ballard's study, he found that 90% of the sample had a mesio-distal discrepancy between the teeth on the opposite side of the arch and despite the fact that the discrepancy was small, it could not be ignored. He felt that if a TSD was not handled correctly, it would lead to a relapse in treatment. He stated that it did not matter if the contact points had an ideal relationship in both arches and there was a good arch to arch relationship on one side, the other side could be imperfect due to a discrepancy in the size of teeth (Ballard, 1944)

A tooth size discrepancy that is less than 1,5 millimetres (mm) is not significant, but larger discrepancies do lead to treatment problems (Kayalioglu et al., 2005; Proffit et al., 2013)

To decide on the correct management approach, one must differentiate if the cause of the TSD is a single tooth anomaly or a general size difference that occurs between the maxillary and mandibular teeth. This can be done by using the Bolton analysis or by a diagnostic cast setup (Proffit et al., 2013)

A setup requires the use of mounted dental study models in order to remove the anterior teeth and then wax them onto the cast in their ideal position. The clinician can then compare the amount of space that will occur at the finishing stages of orthodontic treatment. This will allow the clinician to plan the appropriate management of such occurrences (Oesterle & Shellhart, 1999).

According to Proffit, there are five ways in which a larger TSD can be handled. These procedures are generally carried out in the finishing stages of treatment (Proffit et al., 2013).

The incisor inclination or crown angulation can be altered to compensate for a small differential size Proffit et al., 2013; Ha et al., 2005; Ramos et al., 1996 stated that such changes would alleviate anterior Bolton discrepancies and allow for an ideal incisor relationship. (Araujo et al., 2003)

Interproximal reduction of the enamel can be done to decrease the widths of the teeth. Most of the stripping is done in the initial stage and later in the finishing stage so as to monitor the occlusal relationships before the final tooth size modifications are made. This is especially beneficial in the anterior segments as there are many surfaces that can be stripped successfully (Ballard, 1944; Proffit et al., 2007).

Composite material, a crown or a veneer can be used to increase the width of a smaller tooth or teeth (Proffit et al., 2013).

The normal extraction technique (extraction of the first premolars) can be changed in order to compensate for size discrepancies. The larger second lower premolars could be extracted instead (Proffit et al., 2013).

A small space in one of the arches could exist and be considered acceptable. The space is normally found distal to the lateral incisors (Proffit et al., 2013).

The presence of an anomaly in tooth size tends to create a TSD. This usually occurs with the upper lateral incisor when it is not 12-14% wider than the lower lateral incisor. (Baidas & Hashim, 2005; Proffit et al., 2013) A clinician can look for a discrepancy by comparing the size of the upper and lower lateral incisors clinically. As stated, there is

usually a small space distal to these incisors, which may be acceptable to the patient and it can be left untreated. However, if the patient finds it unappealing, it can be built up with composite material (Proffit et al., 2013).

2.6 Effect of absent teeth on Tooth Size Discrepancy

Proffit et al., 2013 stated that the most to less common congenitally missing teeth are as follows: 1. Third molars ,2. Mandibular second premolars ,3. Maxillary lateral incisors and 4. Maxillary second premolars. Excluding 3rd molars, maxillary lateral incisors are the most common missing teeth when one or two teeth are absent whereas 2nd premolars are the most frequent missing teeth when more than two teeth are absent.

The incidence of absent maxillary lateral incisors is 5%. Agenesis of one lateral incisor is often accompanied by a small lateral on the contralateral side

The aetiology of their absence is multifactorial. The problems arising from the missing lateral incisors include a higher incidence of impactions of the canines, reduced tooth size and ultimately tooth size discrepancies in both arches. Delayed tooth development can also occur in patients with hypodontia of the permanent teeth (Baidas & Hashim, 2005; Proffit et al., 2013).

In a study conducted by Baidas and Hashim, they used the Bolton anterior ratio and the divine proportion to compare the widths of the anterior teeth in people who had congenitally absent upper lateral incisors. Their sample population consisted of patients with unilateral and bilateral absence of teeth. In patients with unilateral absence of the incisor, the other incisor was usually malformed and smaller than a normal lateral

incisor (peg- shaped lateral incisor). This anomaly in size would result in a TSD (Baidas & Hashim, 2005).

The measurements of the tooth widths were collected and inserted into the anterior ratio. From their results, they concluded that the mean value of the Bolton ratio, in those cases with unilateral missing lateral incisors, was not as closely correlated to the Bolton mean value as the cases with bilateral absent lateral incisors. In both cases however, the Bolton ratio did show maxillary insufficiency (Baidas & Hashim, 2005).

2.7 Clinical Assessment of Tooth Size Discrepancy

Proffit suggested that a fast evaluation for anterior tooth size discrepancy can be done by comparing the size of upper and lower lateral incisors. He proposed that unless the upper lateral incisors are larger, a discrepancy almost with certainty exists (Othman & Harradine, 2006; Proffit et al., 2007).

For posterior tooth size discrepancy, he suggests that a quick visual check be done by comparing the size of upper and lower second premolars, which should be of approximately equal size (Othman & Harradine, 2006).

(Andrews & Diego, 1964) Andrews defied the six keys to a normal occlusion as:

1. The Molar relationship. The distal surface of the distobuccal cusp of the upper first permanent molar makes contact and occludes with the mesial surface of the mesiobuccal cusp of the lower second molar. The mesiodistal cusp of the upper first permanent molar falls within the groove between the mesial and middle cusps of the lower first permanent molar.

2. Crown Angulation. The angulation or tip of the long axis of the crown. (Refer to Figure 1)

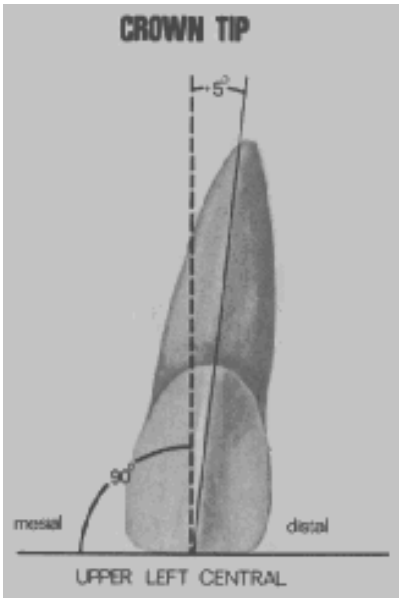


Figure 1: Crown angulation (Andrews,1972)

3. Crown Inclination. The labiolingual or buccolingual inclination of the long axis of the crown.
   A. Anterior teeth (Central and buccolingual inclination). The inclination of the crowns are sufficient to resist overeruption of the anterior teeth and also to allow proper distal positioning of the contact points of the upper teeth in their relationship to the lower teeth, permitting proper occlusion of the posterior crowns. (Refer to Figure 2)

   B. Upper posterior teeth (canines to molars). A lingual crown inclination. Constant inclinations for all posteriors but more pronounced in the molars. (Refer to Figure 3 nr B)

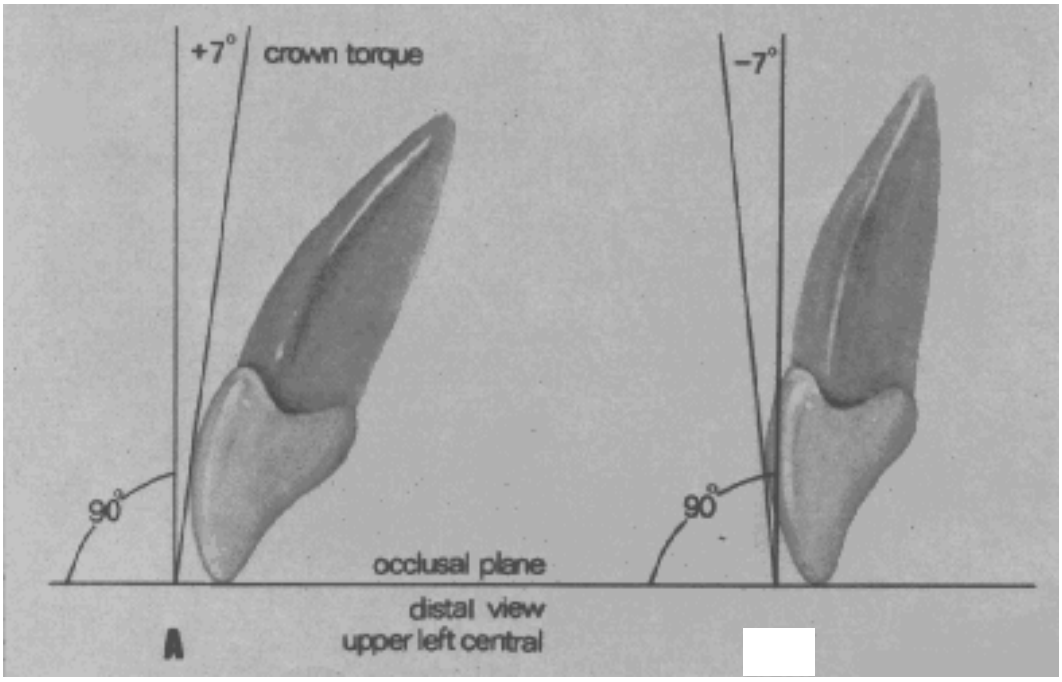


Figure 2. Crown inclination (Andrews,1972)

B

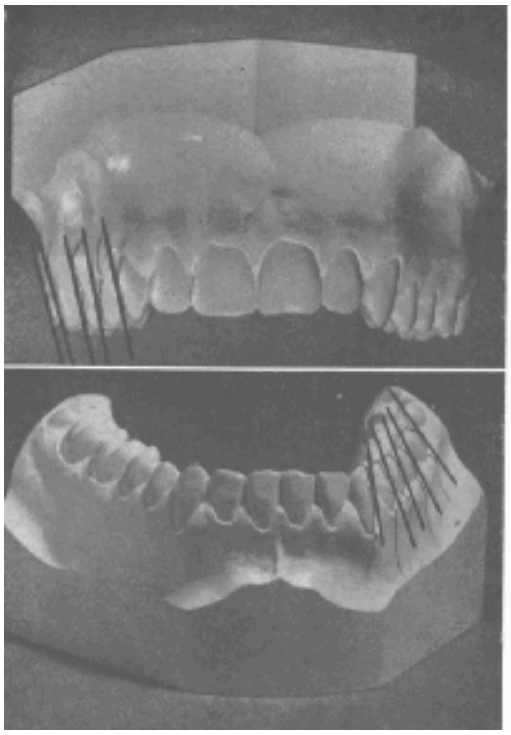


Fig. 9

C

Fig. 10

Figure 3. Posterior crown inclinations (canines through to the molars) (Andrews,1972)

C. Lower posterior teeth (canines to molars). The Inclinations progressively increased from the canines to the 2nd molars. (Refer to Figure 3 nr C)

4. Rotations. No rotations present (Refer to Figure 4)

Figure 4. Rotations. Rotations will occupy more space (Andrews,1972)

5. Spaces. No spaces present and contacts are tight

6. Occlusal plane. Should be from generally flat to a semi curve of Spee. (Refer to Figure 5)

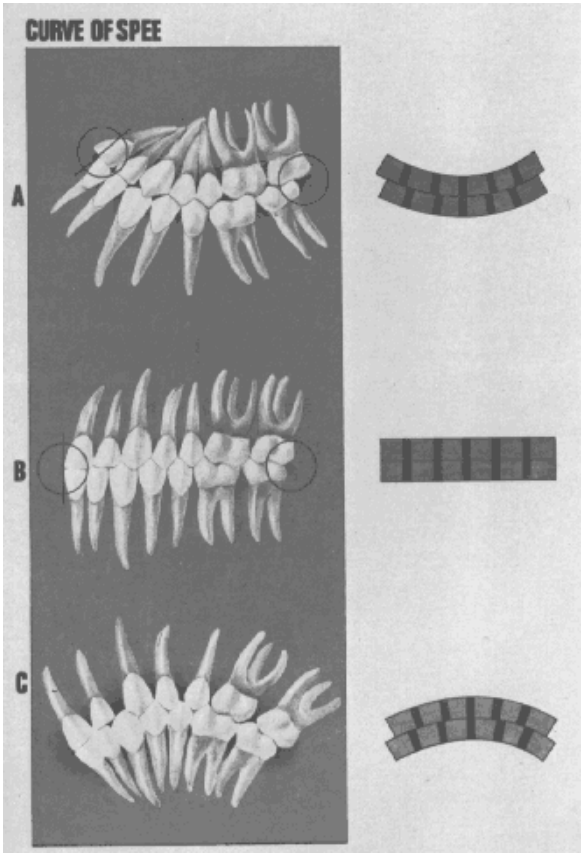


Figure 5. Curve of Spee (Andrews,1972)

When a Class I molar meets all the criteria of Andrew's six keys of normal occlusion and the Canines appear in a Class II relationship a Bolton discrepancy can be the reason and should be investigated.

2.8 Aims and Objectives

The Bolton study is important as it allows for the analysis of intermaxillary permanent tooth size discrepancies. The Bolton analysis is therefore not a space analysis, but it is used to calculate tooth size and not arch length discrepancies. Harmony between the arches allows for structural and functional stability in an orthodontic case. An ideal occlusion with the correct overbite and overjet, good alignment and Class I canine and molar relationship, can only be obtained if the upper and lower teeth are proportional in size. Recent studies have shown that the data collected by Bolton may not apply to all people of different ethnic and culture groups, gender and different malocclusion groups. (Lavelle, 1972; Othman & Harradine, 2006; Oktay & Ulukaya, 2010). Therefore, each population should use standards that are specific to it. This will ensure accuracy and a form of standardization amongst different populations.

The Aim of this study was to use the Bolton calculations to compare and detect any tooth size discrepancies that may exist between Caucasians and Chinese in Manitoba.

Immigrants from China grew 63.9% from 2001 to 2011. Ontario had the highest population of Chinese immigrants (>49%) in 2001 and 2011.

Manitoba where the study will be conducted showed a 51,6% increase of Chinese immigrants from 2001 – 2011.http://canadaimmigrants.com/chinese-immigrants-to-canada/

The 2016 Census recorded 1,577,060 Chinese people. Chinese are the highest minority group in Canada. Chinese immigrants from 2011-2016 were 142,110. Filipino

immigrants were the highest for the period 2011-2016 with 182,890 immigrations. (Refer to Table 7) (http://www.statcan.gc.ca).

Table 6: Chinese Immigrants to Canada in the different Provinces 2001 and 2011. http://canadaimmigrants.com/chinese-immigrants-to-canada/

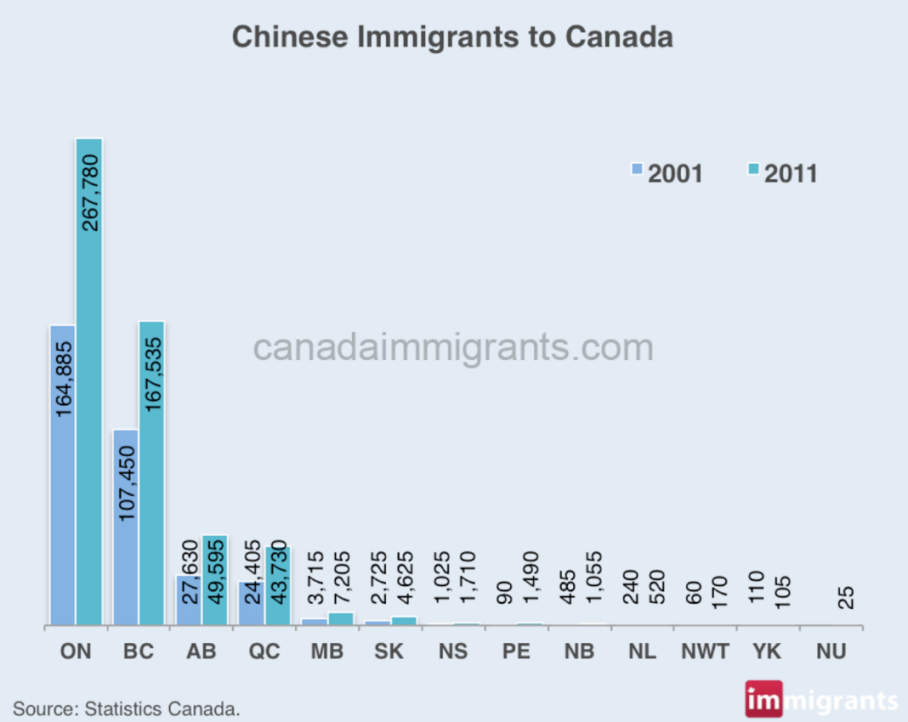


Table 7. Ethnicity Immigrants and Non-Immigrants (http://www.statcan.gc.ca).

Ethnicity	Total—Immigrants status and period of immigration	Non-Immigrants	Immigrants	Before 1981	1981-1990	1991-2000	2001-2010	2001-2005	2006-2010	2011-2016	Non-permanent residents
Chinese	1,577,060	438,290	1,029,730	145,835	148,860	290,415	302,515	160,420	142,095	142,110	109,040
Black	1,198,545	531,070	623,190	110,805	75,835	113,965	180,850	73,860	106,995	141,735	44,280
Filipino	780,130	183,610	562,145	44,050	46,030	104,655	184,520	63,240	121,280	182,890	34,370
Latin American	447,320	101,900	319,310	27,685	61,125	63,160	110,100	45,580	64,515	57,240	26,115
Arab	523,235	145,015	352,420	19,765	31,460	67,215	130,500	52,435	78,060	103,455	25,800

Chinese has the highest First Generation minority group in Canada. Third Generation Chinese are the second largest third generation minority group. Blacks has the highest third Generation group, more than double the Chinese third Generation group. (Refer to Table 8)

Table 8. Visible Minority groups.(http://www.statcan.gc.ca).

Visible Minority group	Total	First Generation	Second generation	Third generation
Chinese	1,577,060	1,147,475	381,680	47,900
Black	1,198,545	675,475	419,845	103,225
Filipino	780,130	598,960	168,045	13,125
Latin American	447,320	348,340	95,125	3,860
Arab	523,235	381,900	137,470	3,865

CHAPTER 3

3.0 Materials and Methods

3.1 Ethics

Ethics approval was obtained on December 3rd, 2015 from the Human Research Ethics Board (Bannatyne Campus, University of Manitoba) prior to commencement of this retrospective study.

3.2 Sample

Study models of 25 females and 25 males in each of the population/ethnic groups were obtained from the archives of the University of Manitoba Graduate Orthodontic clinic, and from the private office of Dr. Herman Lee an instructor at the University of Manitoba. All permanent teeth free of interproximal caries and restorations, up to the first permanent molars were present. All the models selected had no chipped or broken teeth. All patients did not have had any previous orthodontic treatment.

Models were used from the Orthodontic Graduate clinic at the University of Manitoba and a private office in Manitoba. The Graduate clinic and the private office used the same Orthodontic white stone namely Whip Mix® to make the study models. All models were cast using the recommended mixing and handling technique given by the manufacturer. Whip Mix® undergo a 0.09% setting expansion and a 8500psi compressive strength when dry at 48 hours. (Rock, ND.)

All the models were not older then 5 years.

3.3 Methods

The measurements of the mesiodistal widths of the maxillary and mandibular teeth on the plaster models were recorded with a Digital Caliper (accurate to 0.01 mm) by the principal investigator. The second and third molars were excluded from the study.

3.4 Reliability

50% of the models were re-measured using a Boley Gauge to detect any error of >5%.

40% of the sample size were scanned using the iTero® Digital scanner and digitally measured using the OrthoCad® software from iTero® to detect any error of >5% by the principal investigator.
20% of the sample were re-measured by another clinician (inter-rater) Dr. Alvaro Salles an Orthodontist, and re-measured by the principal investigator (intra-rater).

For intra and inter-examiner reliability, the measurements were assessed using an interclass correlation coefficient (ICC) test on 10 % of the sample (measured at four week intervals) included in the study to identify any measurement errors.

Figure 6. Digital Caliper and plaster models

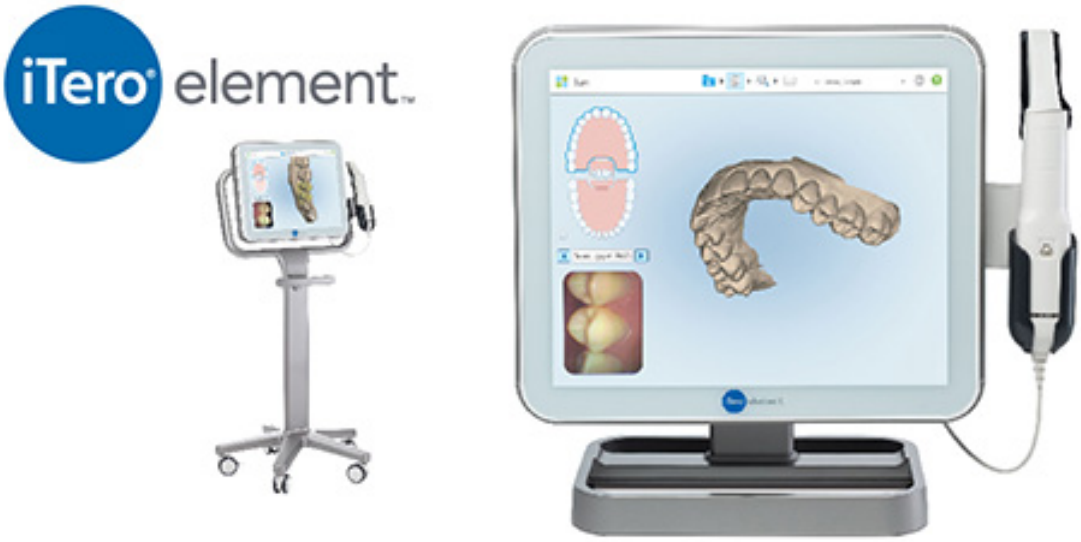


Figure 7. iTero® Digital scanner

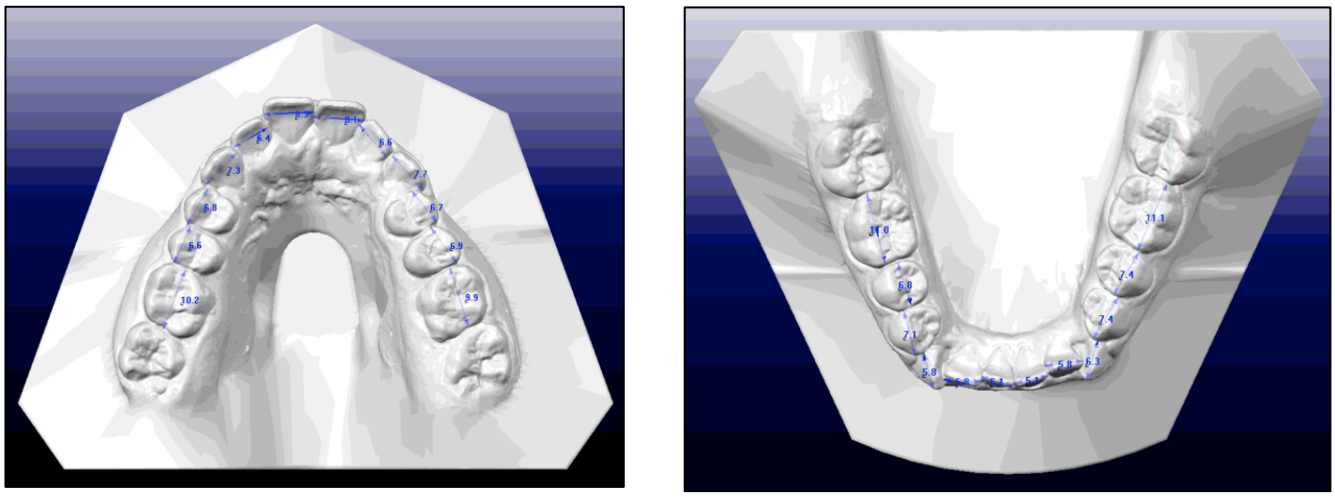


Figure 8. OrthoCad® models

20% of the sample were re-measured by another clinician (inter-rater) Dr. Alvaro Salles an Orthodontist, and re-measured by the principal investigator (intra-rater).

With the data gathered from the Digital Calliper the 2 ratios; the *"Over-all ratio"* and the *"Anterior ratio"* were evaluated against the Bolton standards.

"Over-all ratio" = All 12 = $\frac{\text{Sum mandibular 6-6 MD widths}}{\text{Sum maxillary 6-6 MD widths}} \times 100$

"Anterior ratio" = Anterior 6 = $\frac{\text{Sum mandibular 3-3 MD widths}}{\text{Sum maxillary 3-3 MD widths}} \times 100$

3.5 Statistical Analysis

3.5.1 Sample size calculation

Using S.A.S Version 9.3 for sample size calculation, using $\alpha<0.05$ and with 80% power, it dictated a minimum sample size of 47 subjects per group. Therefore, 50 subjects per group were chosen and included. 25 Male and 25 Female in each group were selected.

Statistical software SAS 9.3 was utilized to evaluate the data.

CHAPTER 4

4.0 Results

4.1 Summary Statistics for All 12 teeth

Linear regression models with main effects for race and gender as well as an interaction effect between them were calculated for all 12 teeth.

The data set did not contain any outliers.

The mean values and the standard deviations for the investigated pre-treatment study models in the two ethnic groups and the gender groups within each ethnic group for the All 12 teeth are shown in Table 9.

Caucasian Females had a mean Bolton of 92.54% ± 1.74%.

Caucasian Males had a mean Bolton of 91.98% ±2.07%

Chinese Females had a mean Bolton of 90.96% ± 1.58%

Chinese Males had a mean Bolton of 91.57% ± 1.73%

Significant discrepancy exists when there is a standard deviation greater than two from Bolton's values, as approximately 95% of Bolton's sample fell in this range. Therefore,

for the overall ratio, values that were less than 87.5% or greater than 95.1%, were considered a significant discrepancy (Laino et al., 2003; Uysal & Sari, 2005; Othman & Harradine, 2006; Paredes et al., 2006).

Caucasian Females (90.8%- 94,29%) and Caucasian Males (89,91% - 94,05%) mean ratios and SD for all 12 teeth (overall-ratio) fell within the 2 x SD Bolton ratio (87,5%-95,1%).

Chinese Females (89,41% – 92,54%) and Chinese Males (89,84% – 93,30%) mean Bolton ratio and SD for all 12 teeth also fell within the normal Bolton ratio and 2 x SD (87,5%-95,1%).

The mean and median values for Caucasian and Chinese male subjects were very similar (91.98% vs 91.77%/ 91.62% vs 91.77%).

For Caucasian females the tooth size was close to 2mm larger than the Chinese females.

Table 9: Summary Statistics by Ethnicity and Gender for All 12 teeth.

Ethnicity	Gender	Mean	Median	Minimum	Maximum	SD
Caucasian	Female	92.54	92.25	89.40	97.13	1.74
	Male	91.98	91.62	88.25	96.15	2.07
Chinese	Female	90.96	90.8	87.62	94.05	1.58
	Male	91.57	91.77	88.08	95.4	1.73

Ethnicity (Caucasian vs Chinese)

P value = 0.0066

Gender (Combined Caucasian and Chinese Males vs Females)

P value = 0.95

Ethnicity Gender (Caucasian Males vs Chinese Males / Caucasian Females vs Chinese Females)

P value = 0.11

P<0.05 is statistically significant

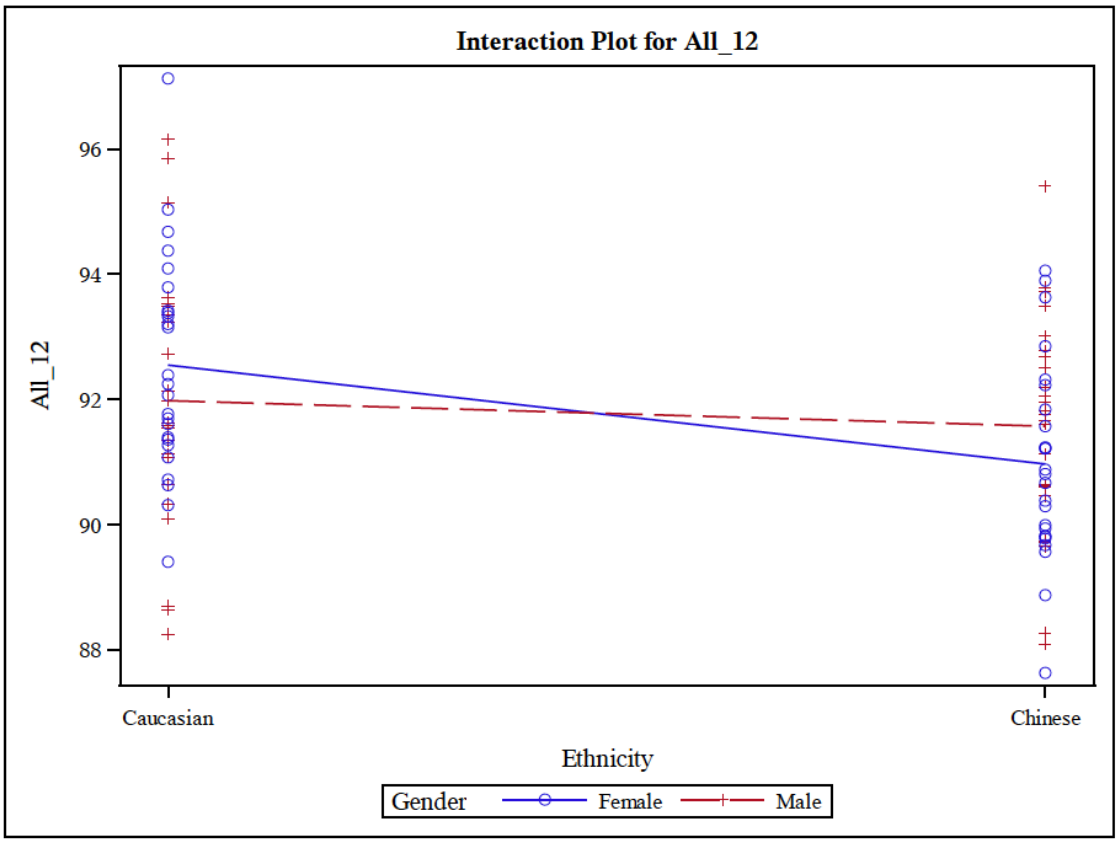
A significant difference ($p<0.05$) was found between the two ethnic groups for all 12 teeth (overall-ratio) as seen in Table 9 ($p = 0.006$). The null hypothesis is rejected.

No significant difference ($p>0.05$) was found between the genders for all 12 teeth as seen in Table 9 ($p = 0.95$). The null hypothesis is accepted.

No significant difference ($p>0.05$) was found between the gender groups within each ethnic groups for all 12 teeth as seen in Table 9 ($p = 0.11$). The null hypothesis is accepted.

No significant variances are seen between the Ethnic groups as seen in Figure 9.

Figure 9. Distribution for each Ethnic and Gender group for All 12 teeth



4.2 Summary Statistics for the Anterior 6 teeth.

Linear regression models with main effects for race and gender as well as an interaction effect between them were calculated for the Anterior 6 teeth.

The data set did not contain any outliers.

The mean values and the standard deviations for the investigated pre-treatment study models in the two ethnic groups and the gender groups within each ethnic group for the Anterior 6 teeth are shown in Table 10.

Caucasian Females had a mean Bolton of 77.91% ± 2.55%.

Caucasian Males had a mean Bolton of 78.05% ±2.73%

Chinese Females had a mean Bolton of 76.97% ± 1.98%

Chinese Males had a mean Bolton of 77.53% ± 1.90%

Caucasians' teeth are larger than the teeth of the Chinese population. Males' teeth are larger than females' teeth.

A significant discrepancy exists when there is a standard deviation greater than two from Bolton's values, as approximately 95% of Bolton's sample fell in this range. Ratios

in between 73.9% and 80.5% fell within 2 SD (2×1, 65) of Bolton's mean (Laino et al., 2003; Uysal & Sari., 2005; Othman & Harradine, 2006; Paredes et al., 2006).

Caucasian Females (75,36% – 80,46%), Chinese Females (74,99% – 78,95%), Chinese Males (75,63% – 79,43%) mean Bolton and SD for the anterior 6 teeth fell within the 2 x SD mean Bolton ratio (73.9% - 80.5%).

Caucasian Males mean Bolton and SD (75,32% - 80,78%) for the anterior 6 teeth had an 0,28% increase of the 2 x SD mean Bolton ratio (73.9% - 80.5%), indicating a prevalence for increased mandibular tooth size discrepancies for the anterior 6 teeth.

No significant difference ($p>0.05$) was found between the Caucasians and Chinese for the anterior 6 teeth as seen in Table 10 ($p = 0.12$). The null hypothesis is accepted.

No significant difference ($p>0.05$) was found between the genders for the anterior 6 teeth as seen in Table 10 ($p = 0.45$). The null hypothesis is accepted.

No significant difference ($p>0.05$) was found between the gender groups within each ethnic group for the anterior 6 teeth as seen in Table 10 ($p = 0.65$). The null hypothesis is accepted.

Table 10: Summary Statistics by Ethnicity and Gender for Anterior-6 teeth

Ethnicity	Gender	Mean	Median	Minimum	Maximum	SD
Caucasian	Female	77.91	77.88	72.04	83.77	2.55
	Male	78.05	78.43	72.04	82.93	2.73
Chinese	Female	76.97	76.4	74.48	81.59	1.98
	Male	77.53	77.71	73.92	80.7	1.90

Ethnicity (Caucasian vs Chinese)

P value = 0.12

Gender (Combined Caucasian and Chinese Males vs Females)

P value = 0.45

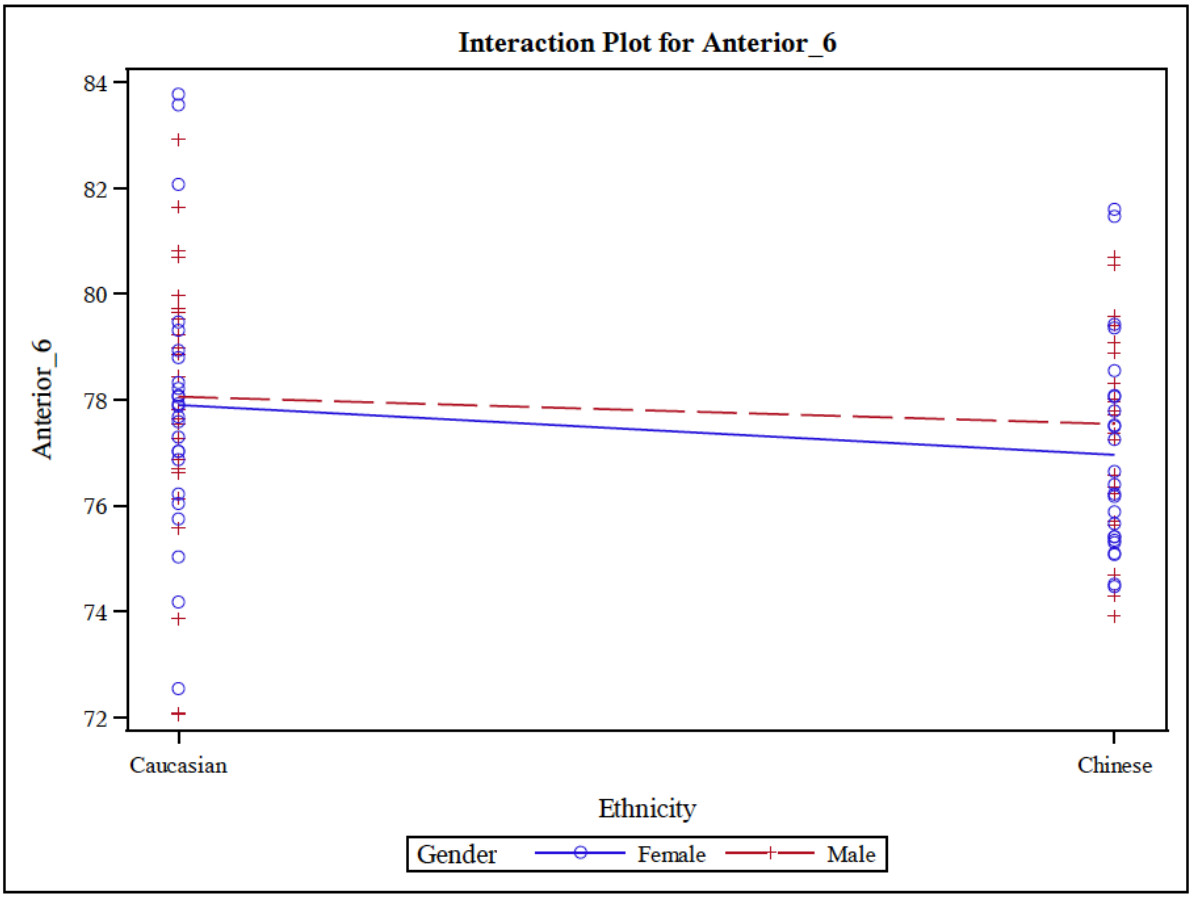
Ethnicity Gender (Caucasian Males vs Chinese Males / Caucasian Females vs Chinese Females)

P value = 0.65

P<0.05 is statistically significant

The Caucasian group has a much larger spread of the Anterior 6 ratio than the Chinese group as seen in Figure 10. The F-test was calculated for comparing the variances and a significant difference ($p<0.05$) in group variances are seen between the Ethnic groups for the Anterior 6 teeth (Caucasian SD = 2.61; Chinese SD = 1.94 ; $p = 0.04$).

Figure 10. Distribution for each Ethnic and Gender group for the anterior six teeth.



CHAPTER 5

5.0 Discussion

5.1 Discussion

An ideal occlusion with the correct overbite and overjet, good alignment and Class I canine and molar relationship, can only be obtained if the upper and lower teeth are proportional in size (Othman & Harradine, 2006). Harmony between the arches allows for structural and functional stability in an orthodontic case (Judica, 2004). A tooth size discrepancy (TSD) can be seen as an excess of tooth structure in one arch in relation to the other arch (Alkofide & Hashim, 2002). It can therefore be defined as a disproportion among the sizes of individual teeth and roughly 5% of the population have some variation among the sizes of the individual teeth (Proffit, Fields, & Sarver, 2013)

Other variables that are important in achieving proper occlusal relationships are: - Maxillary incisor thickness, incisor inclinations and arch form (Kayalioglu et al., 2005).

A TSD results in various problems such as spacing, crowding, deep overbite, larger overjet, end-to-end relationship of teeth etc. of the upper and lower teeth (Baydaş et al., 2005).

Various interventions can be used to deal with the TSD such as: Interproximal reduction of enamel (Ballard, 1944; Proffit et al., 2007), composite material, a crown or a veneer can be used to increase the width of a smaller tooth or teeth (Proffit et al., 2013). Incisor inclination or crown angulation can be altered to compensate for a small

differential size. Furthermore, extractions and changing extraction patterns, could also be considered (Proffit et al., 2013).

If the clinician fails to identify these discrepancies, it may lead to a delay in the finishing stages of treatment as the TSD will need to be rectified. If left untreated, an orthodontic result that is compromised may ensue (Alkofide & Hashim, 2002).

In 1958, Bolton (Bolton, 1958) analysed fifty –five cases and with this data he formulated 2 ratios; the *"Over-all ratio"* and the *"Anterior ratio"*. His aim was to determine if mathematical ratios could be established between the total length of the dental arches and the dental arch segments. From the data collected, a mean ratio of 91.3% and a standard deviation (SD) of 1.91%, will result in an ideal overbite-overjet relationship and an ideal posterior occlusion. The mean anterior ratio, which produced an ideal overbite and overjet relationship, was 77.2% and the standard deviation was 1.65%. (Bolton, 1958; Othman & Harradine, 2006).

Other studies have found that a significant discrepancy exists when there is a standard deviation greater than two from Bolton's values, as approximately 95% of Bolton's sample fell in this range. Ratios in between 73.9% and 80.5% fell within 2 SD (2×1, 65) of Bolton's mean (Laino et al., 2003; Uysal & Sari, 2005; Othman & Harradine, 2006; Paredes et al., 2006).

A tooth size discrepancy that is less than 1,5 millimetres (mm) is not significant, but larger discrepancies do lead to treatment problems (Kayalioglu et al., 2005; Proffit et al., 2013)

Various studies found no difference in the tooth size discrepancies amongst the different malocclusion groups. (Al-Khateeb & Abu Alhaija, 2006; Crosby et al., 1989; Basaran et al., 2006; Laino et al., 2003; O'Mahony et al.,2011)

Al-Khateeb & Abu Alhaija 2006 used 140 Jordanian subjects with different malocclusions (Class I, Class II division 1, Class II division 2, and Class III malocclusions) in their study.

Crosby et al conducted their study on 109 patients of various ethnicities from a private practice with the following malocclusions: Class I, Class II Division 1, Division 2 and Class II surgery. (Crosby et al., 1989)

Basaran et al conducted their study on 60 Turkish subjects who served as the normal occlusion group and 300 patients divided into five malocclusion groups (Class I, Class II, Class II division 1, Class II division 2, and Class III). (Basaran et al., 2006)

O'Mahony et al conducted their study on 240 Irish subject models. 30 Female and 30 male sets for each malocclusion (Class I, Class II division 1, Class II division 2, and Class III).

Because Bolton used Caucasian study models to obtain his Bolton tables it was of interest to us to do a Bolton comparison between Caucasian and Chinese populations.

Chinese immigration to Canada has increased in the past decade making them one of the largest minority groups in Canada.

A highly statistically significant difference ($p<0.01$) was found between the Caucasian and Chinese populations for all 12 teeth (overall ratio) ($p = 0.006$). Caucasians had more Bolton tooth discrepancies for all 12 teeth then the Chinese.

No statistically significant difference ($p>0.05$) was found between the combined genders ($p = 0.95$) and genders within an ethnic group ($p = 0.11$) for the overall 12 teeth.

No statistically significant difference ($p>0.05$) was found between the Caucasian and Chinese ($p=0.12$), combined genders ($p = 0.45$) or genders within an ethnic group ($p = 0.65$). ($p = 0.12$). for the anterior 6 teeth.

Caucasian Males mean Bolton and SD (75,32% - 80,78%) for the anterior 6 teeth had a 0,28% increase of the 2 x SD mean Bolton ratio (73.9% - 80.5%), indicating a prevalence for increased mandibular tooth size discrepancies for the anterior 6 teeth.

Even though male teeth are generally larger then female teeth. In this study no statistically significant mean Bolton ratio difference was found between males and females for both the "all 12 teeth" and "anterior 6 teeth". These findings agree with

studies done by: Bernabé et al., 2004; Basaran et al., 2006; Oktay & Ulukaya, 2010; 2010 and Othman & Harradine, 2006.

5.2 Assessment of the Null Hypothesis

1. The first null hypothesis states that there is no statistically significant difference in the Bolton tooth size discrepancies amongst the different populations. This study proved that there is a highly significant difference ($p = 0.006$; $p<0.01$) between the two ethnic groups for all 12 teeth (overall-ratio) thus rejecting the null hypothesis.

   This study found no significant difference ($p = 0.12$; $p>0.05$) between the Caucasians and Chinese for the anterior 6 teeth thus accepting the null hypothesis.

2. The second null hypothesis states that there is no statistically significant difference in the Bolton tooth size discrepancies amongst the different genders. This study found no significant difference ($p = 0.95$; $p>0.05$) between the combined genders for all 12 teeth, thus accepting the null hypothesis.

   This study also found no significant difference ($p = 0.45$; $p>0.05$) between the combined genders for the anterior 6 teeth and thus accepting the null hypothesis.

3. The third null hypothesis states that there is no statistically significant difference in the Bolton tooth size discrepancies amongst the different genders within an ethnic group. The study found no significant difference ($p = 0.11$; $p>0.05$) between the gender groups within each ethnic group for all 12 teeth, thus accepting the null hypothesis.

   There is no significant difference ($p = 0.65$; $p>0.05$) found in this study between the gender groups within each ethnic group for the anterior 6 teeth, thus accepting the null hypothesis.

CHAPTER 6

6.0 Conclusions and Recommendations

6.1 Conclusions

The conclusions obtained from this study are as follows:

1. There is a highly significant difference between the Caucasian and Chinese overall 12 teeth Bolton tooth size discrepancy.

2. There is no significant Bolton tooth size ratio difference between males and females within each ethnic group.

3. There is no significant Bolton tooth size ratio difference between males and females in the combined Caucasian and Chinese groups.

4. Caution should be exercised when doing a Bolton tooth size analysis on other ethnic groups using the Bolton tooth size calculations, based on Caucasian norms.

6.2 Future Studies

1. Generating Chinese- specific Bolton tables with a bigger sample size.

2. Comparing Bolton's Caucasian based tooth size discrepancy with other ethnic groups. Example: Filipinos

CHAPTER 7

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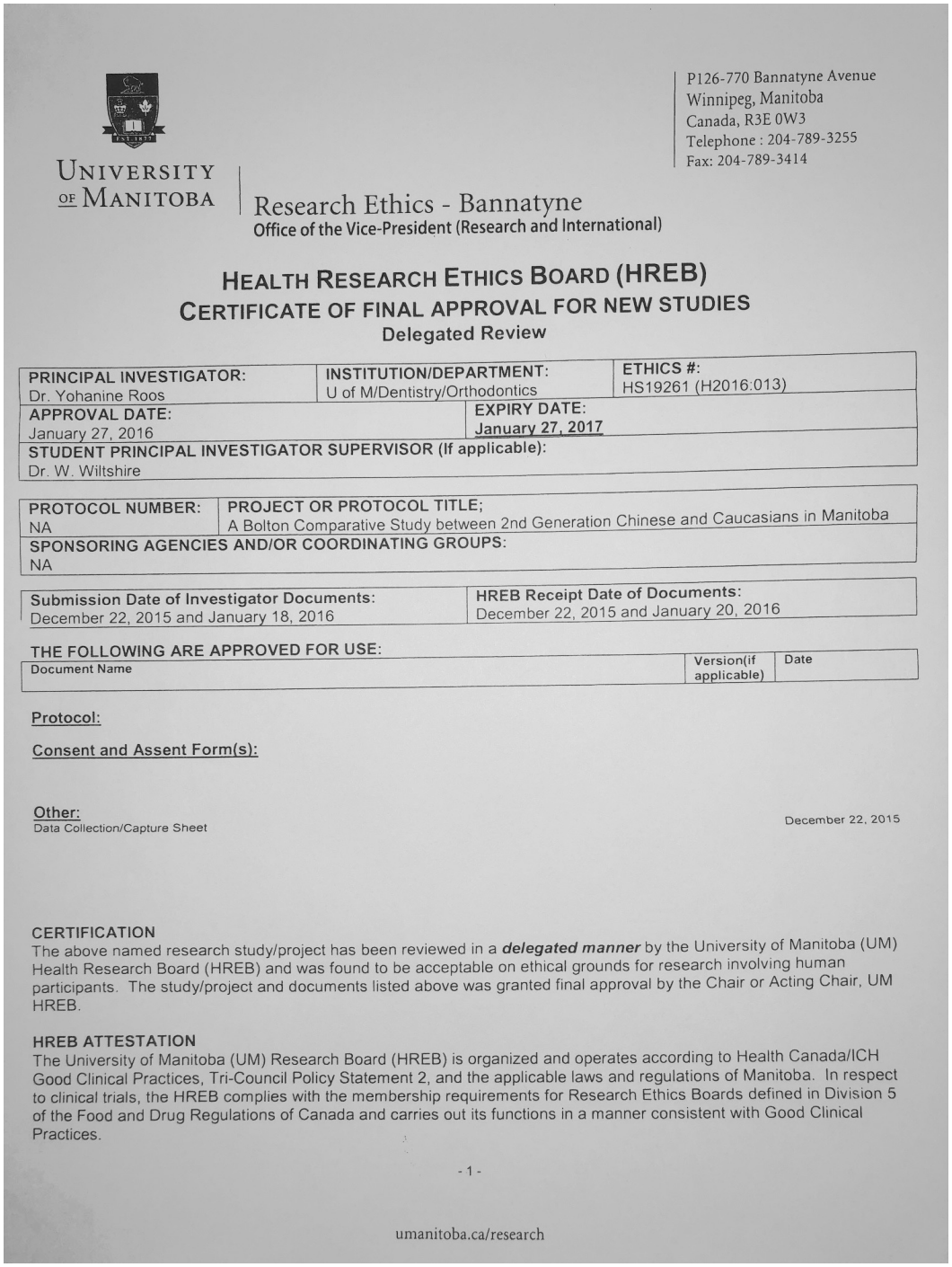
CHAPTER 8

8.0 Appendices

8.1 Ethics Approval



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HEALTH RESEARCH ETHICS BOARD (HREB)
CERTIFICATE OF FINAL APPROVAL FOR NEW STUDIES
Delegated Review

PRINCIPAL INVESTIGATOR: Dr. Yohanine Roos	INSTITUTION/DEPARTMENT: U of M/Dentistry/Orthodontics	ETHICS #: HS19261 (H2016:013)
APPROVAL DATE: January 27, 2016	EXPIRY DATE: January 27, 2017	
STUDENT PRINCIPAL INVESTIGATOR SUPERVISOR (If applicable): Dr. W. Wiltshire		

PROTOCOL NUMBER: NA	PROJECT OR PROTOCOL TITLE; A Bolton Comparative Study between 2nd Generation Chinese and Caucasians in Manitoba
SPONSORING AGENCIES AND/OR COORDINATING GROUPS: NA	

Submission Date of Investigator Documents: December 22, 2015 and January 18, 2016	HREB Receipt Date of Documents: December 22, 2015 and January 20, 2016

THE FOLLOWING ARE APPROVED FOR USE:

Document Name	Version(if applicable)	Date
Protocol:		
Consent and Assent Form(s):		
Other: Data Collection/Capture Sheet		December 22, 2015

CERTIFICATION
The above named research study/project has been reviewed in a ***delegated manner*** by the University of Manitoba (UM) Health Research Board (HREB) and was found to be acceptable on ethical grounds for research involving human participants. The study/project and documents listed above was granted final approval by the Chair or Acting Chair, UM HREB.

HREB ATTESTATION
The University of Manitoba (UM) Research Board (HREB) is organized and operates according to Health Canada/ICH Good Clinical Practices, Tri-Council Policy Statement 2, and the applicable laws and regulations of Manitoba. In respect to clinical trials, the HREB complies with the membership requirements for Research Ethics Boards defined in Division 5 of the Food and Drug Regulations of Canada and carries out its functions in a manner consistent with Good Clinical Practices.

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8.2 Journal Article

BOLTON COMPARISON BETWEEN CAUCASIAN AND CHINESE POPULATIONS.

ABSTRACT

OBJECTIVE: The aim of this study was to use Bolton calculations to compare and detect tooth size discrepancies which may exist between Caucasian and Chinese subjects.

MATERIALS & METHODS: Fifty Caucasians and fifty Chinese subjects' study casts (25 male and 25 female) were selected who had a complete permanent dentition up to the first molars, without interproximal restorations or caries, and had no previous orthodontic treatment. Casts were measured with a Digital Caliper (accurate to 0.001"). The measurements were used to do the Bolton calculations for the over-all ratio (Overall 12) and for the anterior ratio (Anterior 6). Linear regression models with main effects for race and gender as well as an interaction effect between the groups, were used.

RESULTS: No significant gender difference ($p > 0.05$) was found for the Overall 12 and the Anterior 6. A highly significant difference ($p = 0.007$) was found amongst the two ethnic groups for the Overall 12, but not for the Anterior 6 ($p > 0.05$). For the Anterior 6 there was a significant difference ($p = 0.04$) in the group variances, with the Caucasian group showing more variance.

CONCLUSIONS: Based on the findings in this study, for improved accuracy, it is advisable to generate Chinese- specific Bolton tables.

Introduction

An ideal occlusion with the correct overbite and overjet, good alignment and Class I canine and molar relationship, can only be obtained if the upper and lower teeth are proportional in size.[1] Harmony between the dental arches allows for structural and functional stability.[2]

A Tooth Size Discrepancy (TSD) is defined as an excess of tooth structure in one arch in relation to the other arch, and a disproportion among the sizes of individual teeth.[3]

A TSD results in either spacing or, crowding and incorrect intercuspation or interdigitation of the upper and lower teeth.[4] Approximately 5% of the population have some variation among the sizes of the individual teeth.[5]

Bolton (1958), outlined the importance of tooth size, referring to the mesio-distal diameter of teeth. With his data, he formulated 2 ratios; the *"Over-all ratio"* and the *"Anterior ratio"*. [6]

$$\text{Overall Ratio} = \frac{\text{Sum of Mandibular 12 Teeth}}{\text{Sum of Maxillary 12 Teeth}} \times 100 = 91.3\%$$

$$\text{Anterior Ratio} = \frac{\text{Sum of Mandibular 6 Teeth}}{\text{Sum of Maxillary 6 Teeth}} \times 100 = 77.2\%$$

Overall Ratio: Ratios between 87.5% and 95.1% fall within 2 standard deviations (2×1.91) of Bolton's mean and any percentage outside this range is considered a significant discrepancy.

Anterior Ratio: Ratios between 73.9% and 80.5% fall within 2 SD (2×1, 65) of Bolton's mean and any percentage outside this range is also considered a significant discrepancy. [7,8] Deviation from this ratio leads to a disharmony between the arches and a resultant malocclusion.[9]

Bolton's study allows for the analysis of intermaxillary permanent tooth size discrepancies, important in accurate treatment planning.[3]

The significance of Bolton's standard deviation is that it can be used in clinical practice to determine if there is a need to reduce or increase tooth structure. Reduction can be done by interdental stripping of the enamel and addition can be done with a restoration, veneer or crown. [1,10]

Bolton's second paper, was published in 1962, and involved clinical cases' review, in order to demonstrate the use and significance of the Bolton' ratios.

Bolton based his study on a Caucasian population, and may not be applicable to all ethnic groups.[6] Various studies showed a significant difference in TSD between Caucasians and other ethnic groups such as Mongoloids, Hispanics and Blacks. [1,11]

Chinese are the largest minority group in Canada. The 2016 Census in Canada recorded 1,577,060 Chinese people. The number of Chinese immigrants between 2011-2016 were 142,110.[12]

Epidemiologically, male teeth are generally larger then female teeth.[13,14] In addition, Lavelle (1972) found that the gender differences were small (<1%).[1]

Although no overall differences were found amongst different gender groups, posterior Bolton ratio differences were found amongst males and females in a Turkish population.[15] However no Bolton tooth-size differences were found amongst the different gender groups in the Southeastern Turkish and Peruvian populations. [16,17]

Due to variations observed in the literature, the aim of this study therefore was to use the Bolton calculations to compare and detect any tooth size discrepancies which may exist between Canadian Caucasian and Chinese subjects, and between males and females.

Materials and Methods

Plaster study casts of 25 females and 25 males in each of the population/ethnic groups (Chinese and Caucasian) were obtained from the archives of the University of Manitoba Graduate Orthodontic Clinic, and from a private Orthodontic office.

Inclusion criteria:

- Study casts in a good condition with no broken teeth.
- All permanent teeth were erupted up to the first permanent molars.
- No interproximal caries or restorations present, up to the and including first permanent molars.
- No previous Orthodontic treatment (Interproximal reduction might have been performed during treatment).

The measurements of the mesiodistal widths of the maxillary and mandibular teeth on the plaster casts were recorded by the principal investigator with a Digital Caliper (Ortho-Pli) (accurate to 0.001”). The second and third molars were excluded from the study.

Figure 1. Digital Caliper and plaster models

With the data gathered from the Digital Calliper the 2 ratios; the *"Over-all ratio"* and the *"Anterior ratio"* were evaluated against the Bolton standards using Linear regression models with main effect for race and gender as well as an interaction effect between them.

Statistical analysis

For intra and inter-examiner reliability, the measurements were assessed using an interclass correlation coefficient (ICC) test on 10 % of the sample (measured at four week intervals) included in the study to identify any measurement errors. With the data gathered from the Digital Calliper the 2 ratios; the *"Over-all ratio"* and the *"Anterior ratio"* were evaluated against the Bolton standards using Linear regression models ($p<05$) with main effect for race and gender as well as an interaction effect between them. The p-value was considered significant at $\alpha<0.05$. For all statistical tests, the statistical software SAS 9.3 was utilized to evaluate the data.

Results

Linear regression models with main effects for race and gender as well as an interaction effect between them were calculated for all 12 teeth (over-all ratio) and anterior 6 teeth (anterior ratio).

The mean values and the standard deviations for the investigated pre-treatment study models in the two ethnic groups and the gender groups within each ethnic group for the over-all Bolton ratio (all 12 teeth) are shown in Table 1.

Caucasian Females had a mean Bolton of 92.54% ± 1.74%.

Caucasian Males had a mean Bolton of 91.98% ±2.07%

Chinese Females had a mean Bolton of 90.96% ± 1.58%

Chinese Males had a mean Bolton of 91.57% ± 1.73%

Caucasian Females (90.8%- 94.29%) and Caucasian Males (89.91% - 94.05%) mean ratios and SD for all 12 teeth (overall-ratio) fell within the 2 x SD Bolton ratio (87.5%-95.1%).

Chinese Females (89.41% – 92.54%) and Chinese Males (89.84% – 93.30%) mean Bolton ratio and SD for all 12 teeth also fell within the normal Bolton ratio and 2 x SD (87.5%-95.1%).

The mean and median values for Caucasian and Chinese male subjects were very similar (91.98% vs 91.77%/ 91.62% vs 91.77%).

For Caucasian females, tooth size was close to 2mm larger than the Chinese females.

Ethnicity	Gender	Mean	Median	Minimum	Maximum	SD
Caucasian	Female	92.54	92.25	89.40	97.13	1.74
	Male	91.98	91.62	88.25	96.15	2.07
Chinese	Female	90.96	90.8	87.62	94.05	1.58
	Male	91.57	91.77	88.08	95.4	1.73
Ethnicity (Caucasian vs Chinese) P value = 0.006* Gender (Combined Caucasian and Chinese Males vs Females) P value = 0.95 Ethnicity Gender (Caucasian Males vs Chinese Males / Caucasian Females vs Chinese Females) P value = 0.11 P<0.05 is statistically significant*						

Table 1: Summary Statistics by Ethnicity and Gender for the Overall Bolton ratio.

A significant difference ($p<0.05$) was found between the two ethnic groups for all 12 teeth (overall-ratio) as seen in Table 1 ($p = 0.006$).

No significant gender differences ($p>0.05$) were found for all 12 teeth (Table 1).

No significant gender differences ($p>0.05$) were found within each ethnic group for all 12 teeth (Table 1).

No significant variances are seen either between the Ethnic groups (Figure 2).

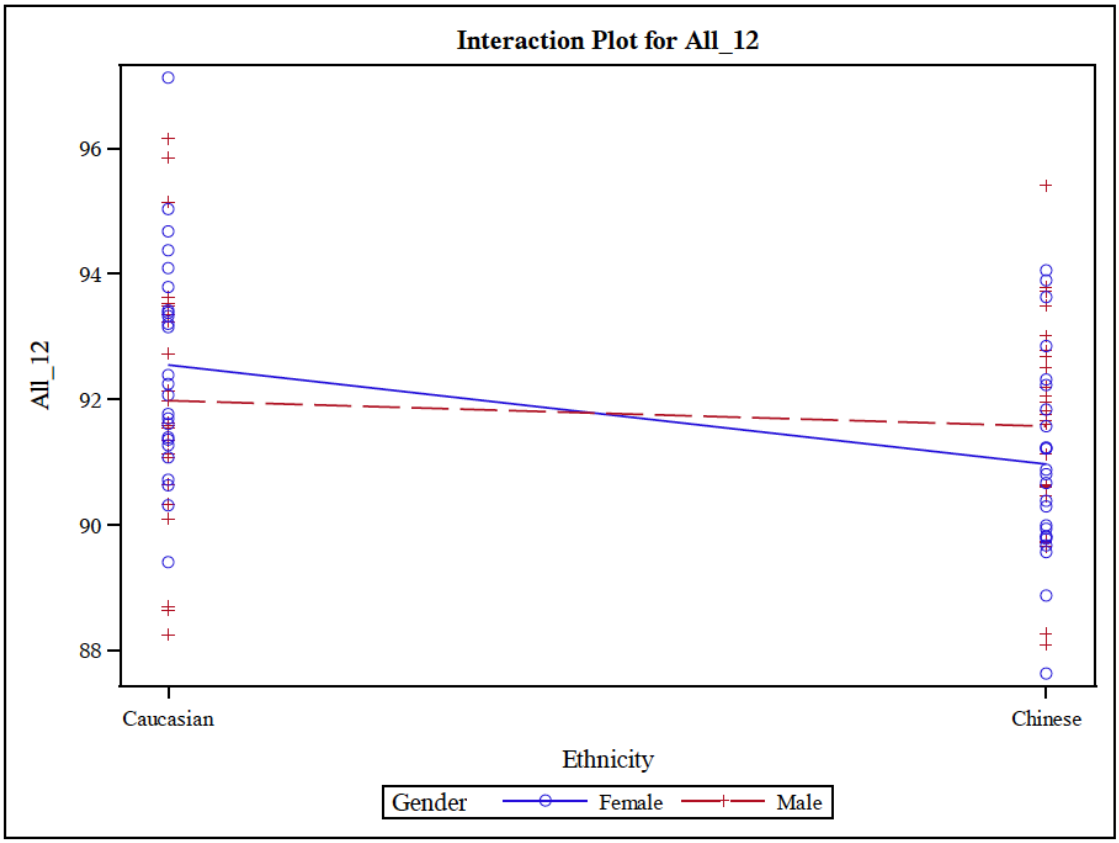

Figure 2. All 12 teeth (overall) Bolton ratio distribution for each Ethnic and Gender group.

The mean values and the standard deviations for the pre-treatment study casts in both ethnic and gender groups within the Caucasian and Chinese groups for the Anterior 6 teeth, are shown in Table 2.

Caucasian Females had a mean Bolton of 77.91% ± 2.55%.

Caucasian Males had a mean Bolton of 78.05% ±2.73%

Chinese Females had a mean Bolton of 76.97% ± 1.98%

Chinese Males had a mean Bolton of 77.53% ± 1.90%

For the anterior six teeth, the Caucasians' teeth are larger than the teeth of the Chinese population. Males' teeth are larger than females' teeth. Caucasian males' teeth are the largest and Chinese females' teeth the smallest.

Caucasian Females (75.36% – 80.46%), Chinese Females (74.99% – 78.95%), and Chinese Males (75.63% – 79.43%) mean Bolton and SD for the anterior 6 teeth fell within the 2 x SD mean Bolton ratio (73.9% - 80.5%).

Caucasian Males mean Bolton and SD (75.32% - 80.78%) for the anterior 6 teeth had a 0.28% increase of the 2 x SD mean Bolton ratio (73.9% - 80.5%), indicating a prevalence for increased mandibular tooth size discrepancies for the anterior 6 teeth.

No significant difference ($p>0.05$) was found between the Caucasians and Chinese for the anterior 6 teeth (Table 2) ($p = 0.12$).

No significant difference ($p>0.05$) was found between the genders for the anterior 6 teeth (Table 2) ($p = 0.45$).

No significant difference ($p>0.05$) was found between the gender groups within each ethnic group for the anterior 6 teeth (Table 2) ($p = 0.65$).

Ethnicity	Gender	Mean	Median	Minimum	Maximum	SD
Caucasian	Female	77.91	77.88	72.04	83.77	2.55
	Male	78.05	78.43	72.04	82.93	2.73
Chinese	Female	76.97	76.4	74.48	81.59	1.98
	Male	77.53	77.71	73.92	80.7	1.90

Ethnicity (Caucasian vs Chinese)

P value = 0.12

Gender (Combined Caucasian and Chinese Males vs Females)

P value = 0.45

Ethnicity Gender (Caucasian Males vs Chinese Males / Caucasian Females vs Chinese Females)

P value = 0.65

$P<0.05$ is statistically significant

Table 2: Summary Statistics by Ethnicity and Gender for the Anterior-6 teeth Bolton ratio.

The Caucasian group has a much larger spread of the Anterior 6 ratio than the Chinese group (Figure 3). The F-test was calculated for comparing the variances and a significant difference ($p<0.05$) in group variances are seen between the Ethnic groups for the Anterior 6 teeth (Caucasian SD = 2.61; Chinese SD = 1.94 ; p = 0.04).

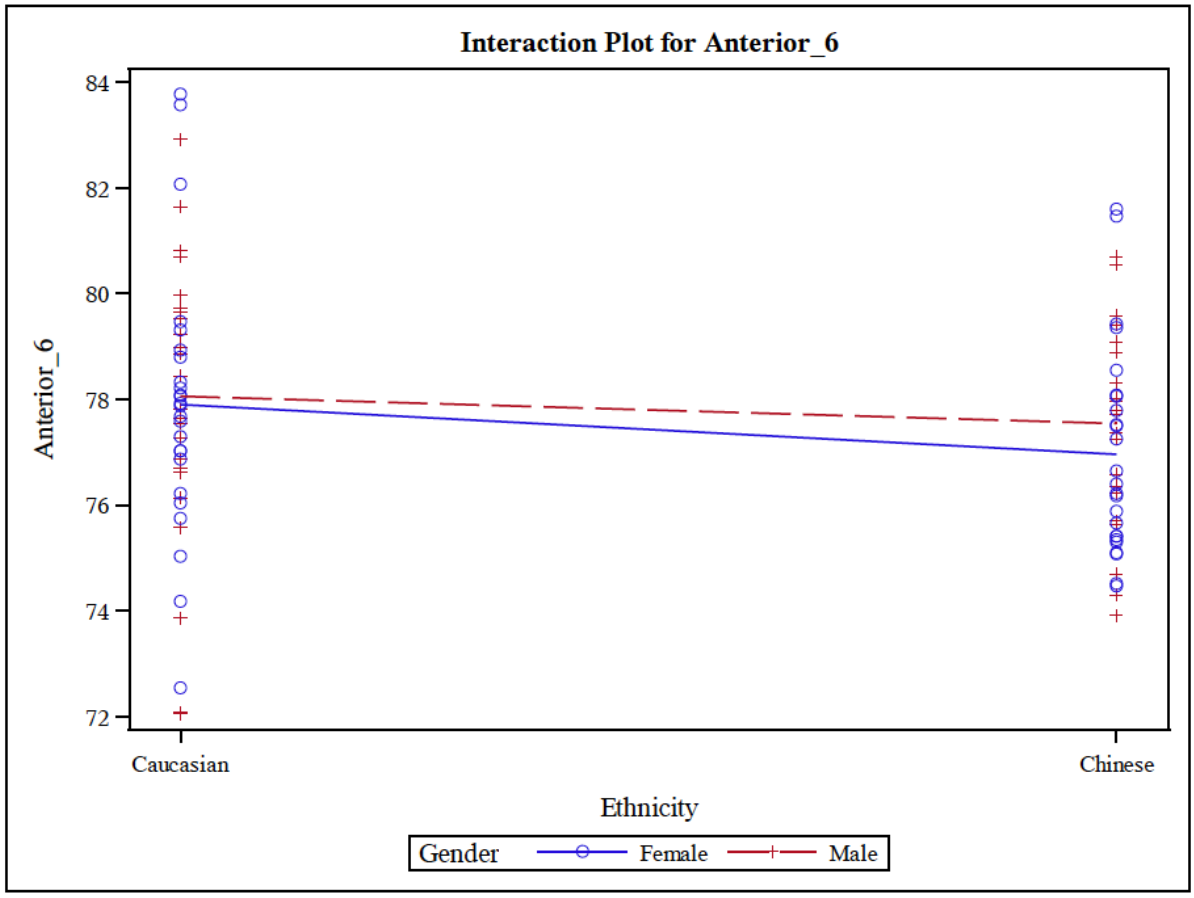

Figure 3. Anterior six teeth Bolton ratio distribution for each Ethnic and Gender group for the anterior six teeth.

Discussion

A TSD results in various problems such as spacing, crowding, deep overbite, enlarged overjet, end-to-end relationship of the anterior teeth inter alia.[4]

Various interventions can be used to deal with the TSD such as: Interproximal reduction of enamel [5,18], composite material buildup, a crown or a veneer which may all be used to increase the width of a smaller tooth or teeth.[5] Incisor inclination or crown angulation can also be altered to compensate for a small differential size. Furthermore, extractions and varying extraction patterns, could also be considered.[5]

Additional variables effecting proper occlusal relationships are: -Maxillary incisor thickness, incisor inclinations and arch form.[19]

A tooth size discrepancy that is less than 1.5 millimetres (mm) is not significant, but larger discrepancies may lead to treatment problems.[5, 19]

Results from this study found that there are greater tooth size discrepancies in the Caucasian population for the over-all ratio compared to the Chinese population. Lavelle 1972 had a similar finding comparing Black and Caucasian ethnic groups tooth size discrepancies. His study found more discrepancies in the Caucasian population.[11]

Our study demonstrated no significant anterior six ratio differences between the Caucasian and Chinese populations. Whereas Lavelle 1972 found more discrepancies in the Caucasian population compared to the Black population.[11]

Furthermore, our study demonstrated no gender differences for the overall and the anterior six ratios. This is in line with studies done by Bernabé et al. (2004)[17], Basaran et al. (2006)[16] and Tadesse et al. (2008)[20.] which found no differences amongst the gender groups. Tadesse et al. (2008)[20] based their study on a Chinese population in Central China, whereas Bernabé et al. (2004)[17] conducted their study on a Peruvian population. Basaran et al.'s (2006)[16] study was based on a Turkish population.

The Caucasian population has more variance for the anterior six ratio.

These results suggest that there is a better balance in the inter-arch tooth sizes for Chinese compared to Caucasians. In the clinical orthodontic setting ,a better Class I buccal and canine relationship can be achieved without the need for IPR, restorative buildups, crowns or veneers more in the Chinese population.

Conclusions

When using standard Bolton Ratio analysis to compare the tooth size differences between Caucasian and Chinese populations, less size variances were found in the Chinese population. Establishing Bolton ratios unique to a particular ethic group will improve the clinical assessment and render improved final inter-arch harmony.

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8.3 Journal article submission received

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Date: 28 April 2018 at 11:52
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