

## Research Article

# Reliability Study of the Bolton Analysis using Dental Models from Cases Passed by the American Board of Orthodontics Clinical Examination

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2017; **Published:** March 13, 2017**Abstract**

**Background:** In treatment planning the correction of malocclusions, a challenge is of tooth size discrepancy to predict the fit of the maxillary and mandibular arches to be proportionate to accomplish an excellent occlusion. Bolton's tooth analysis has been a gold standard. In this study, the Bolton ratios were analyzed on dental models that have passed the rigorous testing of the American Board of Orthodontics (ABO) in their clinical examination for diplomate status. Along with this, a second objective was to determine the correlation between the Bolton ratios and overjet, overbite, anterior teeth inclination, interincisal angle and upper tooth thickness.

**Methods:** The sample size was 94 sets of dental models along with their cephalometric radiographs that had passed the ABO clinical examination. The sets of models (n=52) that were Class I full permanent dentitions were measured from 6-6 for the overall ratio while the sets of models (n=94) were measured for the anterior ratio along with their overjet, overbite and upper anterior teeth thickness. Measurements of the cephalometric radiographs recorded were interincisal angle, upper and lower incisor inclinations as U1-SN, U1-NA, L1-MP and L1-NB.

**Results:** The overall (91.3%) and anterior (77.2%) ratios of the Bolton study and the study sample were the same. The test of correlation between the Bolton ratios and the variables overjet, overbite, and upper tooth thickness showed statistically significant correlations but inverse correlations. The anterior teeth inclinations and the interincisal angle did not show significant correlation. The level of significance was set at 0.05.

**Conclusions:** The Bolton analysis was shown to be a reliable diagnostic tool for assessing tooth size discrepancy and an aid in orthodontic treatment planning. This study has shown that the Bolton analysis is not the only measurement in predicting clinically significant tooth size discrepancies that would achieve good occlusions with ideal overjet, overbite and good interdigitation. Other factors such as incisor angulation and thickness are contributing factors. A diagnostic set-up could indicate IPR to correct the tooth size discrepancy or IPR could be performed at the end of orthodontic treatment to achieve good overjet and overbite. A final recommendation would be for cosmetic bonding to correct the tooth with size discrepancy.

**Keywords:** Bolton analysis; Anterior tooth ratio; Overall tooth ratio; Tooth size discrepancy; Tooth size ratio; Tooth size disharmony; American board of orthodontics

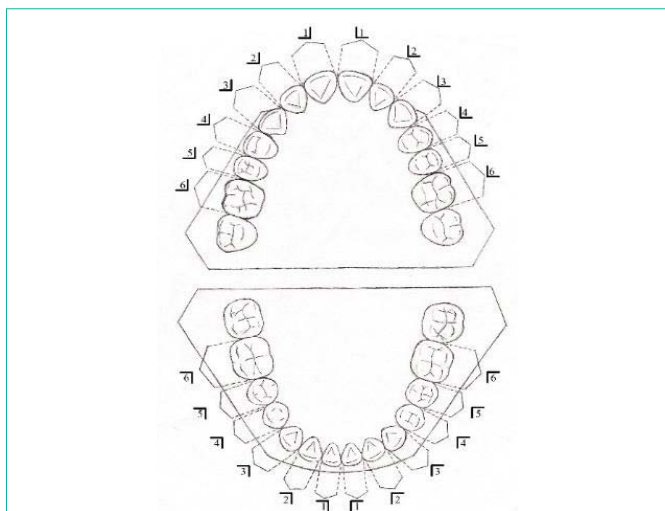
## Introduction

In treatment planning the correction of malocclusions, a common problem is tooth size discrepancy of upper and lower teeth to accommodate an excellent occlusion. It is frequently accepted that the sizes of the maxillary and the mandibular teeth must be proportionate to accomplish excellent occlusal interdigitation with ideal overjet and overbite [1,2].

Any significant malocclusion is a challenge for the practitioner to predict whether the maxillary and the mandibular dental arches will fit ideally in an excellent occlusion. Before the discovery of

mathematical formulas to evaluate tooth size discrepancy as described by Neff in 1949, [3] and subsequently by Bolton in 1958 [1], clinicians used diagnostic plaster set-ups as the main tool to evaluate tooth size discrepancy [4] for diagnosis and treatment planning [1,5].

Bolton's Master's Thesis of 1952 and published in 1958 [1] of inter-maxillary tooth size discrepancy and its relation to malocclusion described an analysis, which is still used presently, that would aid in identifying inter-arch tooth size discrepancies. He developed two formulas for inter-arch tooth size ratios based on a sample of fifty-five patients with excellent occlusions. The first ratio is the overall



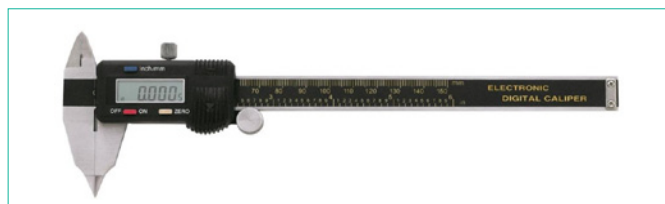
**Figure 1:** An illustration of maxillary and mandibular tooth width measurements. (Used by permission from Angle Orthodontist from Bolton, 1958).

ratio which includes teeth from first molar to first molar of upper and lower arches and the second ratio is the anterior ratio which includes teeth of both arches from canine to canine [1].

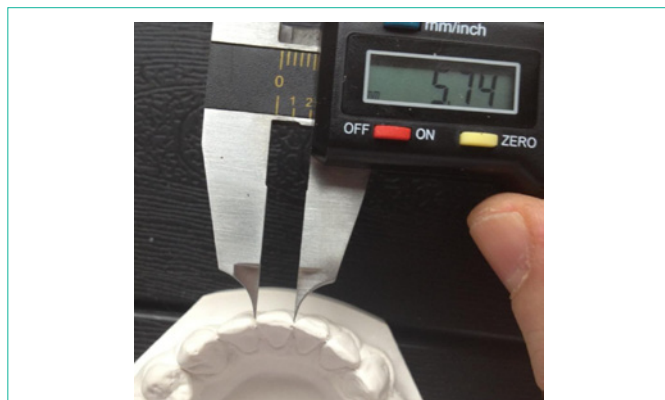
The concept of having an ideal tooth size ratio for the general population has been challenged [5,6]. Cases with significant Bolton discrepancies have been shown to have good occlusion while on the other hand cases with normal Bolton ratios has been shown to have a difficulty achieving a good occlusal relationship. Some speculated that, tooth dimensions exhibit significant difference for both mesio-distal width and labio-lingual thicknesses when comparing different ethnicities and different genders which may affect the ideal tooth size mean ratios of the general population [7-10]. Many studies have suggested that the overbite [1], overjet, [11] tip of incisors [12], torque of incisors [13], inter-incisal angles [11,12], and lastly tooth thickness [11,14] may affect ideal tooth size ratios in order to achieve an acceptable occlusal result in a given case. It has been shown using diagnostic set-ups that changes in the incisal angulation of the anterior teeth may result in an increase or a decrease of arch length suggesting a change in the ideal tooth size ratios [12]. Furthermore, when a dentition has excess labio-lingual thickness of upper incisors, the ideal tooth size ratios may be decreased [11].

Cordato [15] developed a mathematical model on an extensive computer generated spreadsheet showing changes in anterior dental relations in the anterior and transverse as tooth width, arch form and inter-arch perimeters changed. Then, the model was extended with hypothetical measurements to show the changes [16]. The benefit would then be to understand inter-arch relations to be used for diagnosis or in treatment. The third part showed the effect of vertical overlap with overbite influenced by overjet, tooth thickness and tooth angulation [17].

The main objective of this study is to determine the applicability and the accuracy of Bolton tooth size discrepancy analysis by evaluating cases that passed the American Board of Orthodontics (ABO) clinical examination requirements of cases presented for Board certification. These cases passed the criteria for alignment of



**Figure 2:** Digital Caliper with Pointed Tips with an accuracy of 0.05mm.



**Figure 3:** Measuring the lower central incisor mesial-distal width.



**Figure 4:** Measuring molar mesial-distal width.



**Figure 5:** Measuring overjet with the slide out center ruler.

the marginal ridges, bucco-lingual inclination, occlusal relationships, occlusal contacts, overjet, interproximal contacts and root angulation. Since the standards set by the American Board of Orthodontics have

been carefully documented and tested by Board examiners, [8,19] using ABO tested models would eliminate investigator bias by providing an objective sample of excellent dental occlusions.

The second objective is to determine the correlation between the Bolton ratios and any of the following factors: overjet, overbite, anterior teeth inclination, inter-incisal angle, and upper anterior tooth thickness.

This study is intended to provide a better understanding of ideal inter-arch tooth size ratios relative to many other factors contributing to a good occlusion. To have such an understanding, a diagnostic tool for clinicians such as the Bolton Analysis would be providing a reliable mathematical formula for the treatment of malocclusions.

### Materials and Methods

Ninety-four cases with final dental study models and cephalometric radiographs that had successfully passed the American Board of Orthodontics clinical exam were obtained from ABO diplomates as the sample size. The Office for the Protection of Research Subjects of the University of Illinois at Chicago determined in July 2012 that this study (approval number for protocol 2012-0640-69258-1) did not meet the definition of human subject researches defined by 45CFR46.102(f); therefore, permission to conduct research without further submission to the institutional review board was granted. All Personal Health Information (PHI) was excluded from the research material.

Exclusion criteria were cases with buccal to lingual contact discrepancy of more than 0.5mm, anterior tooth extraction or missing anterior teeth or any spacing between teeth. All cases included had the upper canine occluding in the embrasure between lower canine and first premolar.

The mesio-distal width of each tooth was recorded as per the study of Bolton1 (Figure 1) using a pointed head fractional digital caliper with an internal ruler (Baileigh Industrial Manufacturing Co., Manitowoc, WI with an accuracy of 0.05 mm) (Figure 2-4).

Both overall and anterior tooth size ratios were computed using the Bolton equations1:

$$\text{Sum mandibular "12"} \times 100 = \text{overall ratio (\%)}$$

$$\text{Sum maxillary "12"}$$

$$\text{Sum mandibular "6"} \times 100 = \text{anterior ratio (\%)}$$

$$\text{Sum maxillary "6"}$$

The cases that had a full permanent dentition, Class I molar relationship from first molar to first molar and no missing teeth excluding third molars were chosen for the overall ratio (n=52).

All the cases (n=94) were used for the anterior ratio. These were Class I (n=52) with full permanent dentition, Classes I, II and III molar relationships with possible various premolar extraction sequences (n=42). All had upper and lower arches with six anterior teeth. A statistical power analysis indicated that the number of cases in this study would provide significance for correlations and achieving statistically significant results.

A pilot study was conducted for intra- and inter-reliability using

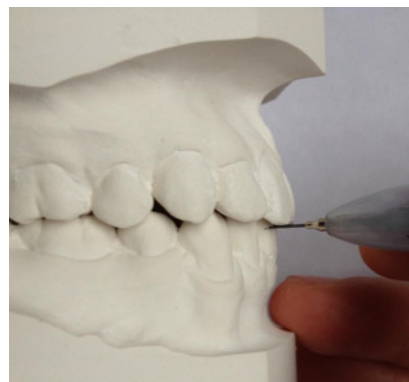


Figure 6: Measuring overbite by marking the overbite.



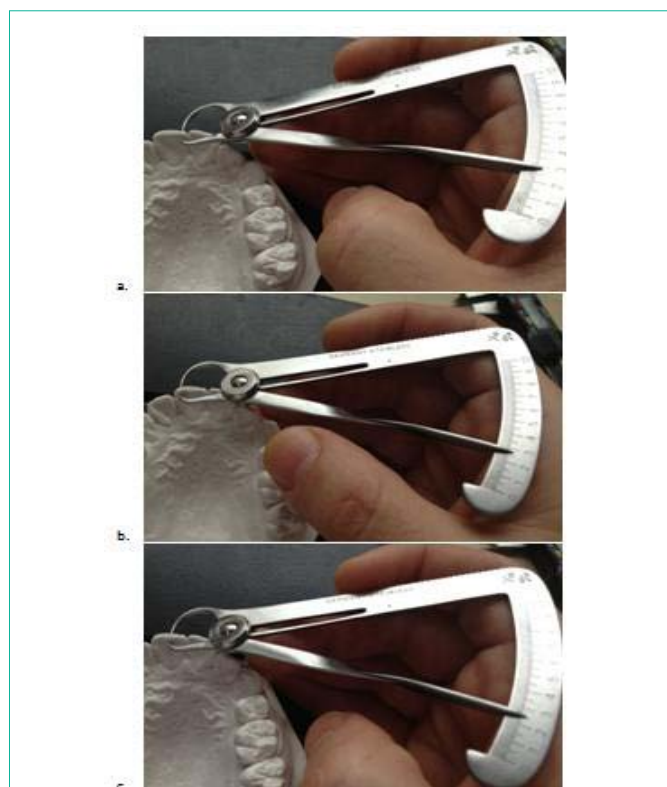
Figure 7: Measuring overbite with the digital caliper.



Figure 8: Crown Thickness Gauge measuring up to 0.1mm.

10 ABO cases. A paired samples t-test was computed to evaluate the statistical difference between the two measurements. The results indicated that the correlation coefficient of the variables in the study was a high positive correlation ( $r > 0.80$ ) which provided validation for the research method used.

Overjet was measured as the distance from the labial surface of the upper central incisor to the labial surface of the corresponding lower central incisor in maximum intercuspation. This was measured with the slide out center ruler of the digital caliper held parallel to the base



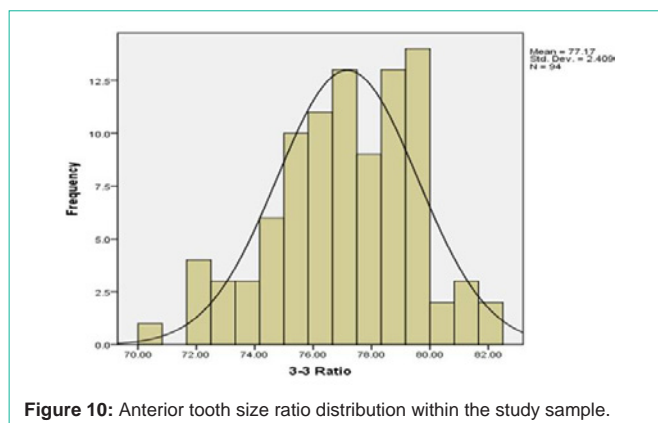
**Figure 9:** Measuring crown thickness 2mm from incisal edge: a. 1mm from mesial proximal surface; b. 1mm from distal proximal surface; c. middle of the mesial-distal distance.

of the ABO trimmed models and read on the digital screen (Figure 5). Overbite was measured as the distance from the incisal edge of the lower central incisor to the projection of the corresponding upper incisal edge on the labial surface of the same lower incisor. Marks were made on the teeth on the models with an architect's very fine pointed lead pencil (Figure 6). The pointed portion of the caliper was used for this measurement holding the caliper perpendicular to the base of the models (Figure 7). Overjet and overbite were recorded as linear measurements on the screen of the digital caliper with the study models in maximum inter-cuspatation.

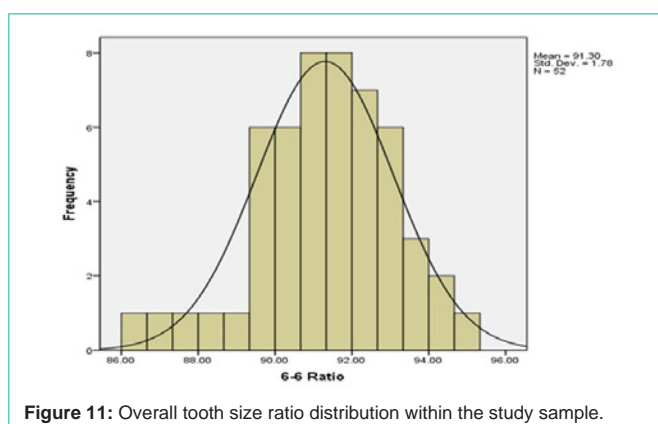
Since a requirement of the trimmed ABO models is to have the occlusal plane most parallel to the base of the models and in measuring overjet and overbite the digital caliper is held parallel for overjet and perpendicular for overbite to the base of the models in maximum inter-cuspatation, in effect, the measurements are made either parallel or perpendicular to the occlusal plane.

A crown thickness gauge (Integra®Miltext®, York, PA) (Figure 8) measuring up to 0.1mm accuracy was used to record the upper incisor's incisal edge thickness. There were three measurements from pencil markings 2mm from the incisal edge per tooth: 1) 1mm from the mesial proximal surface, 2) 1mm from the distal proximal surface and 3) middle of the mesial-distal distance. Demonstrated in figure (Figure 9). The canines were excluded and not used because of their great variation in size and shape.

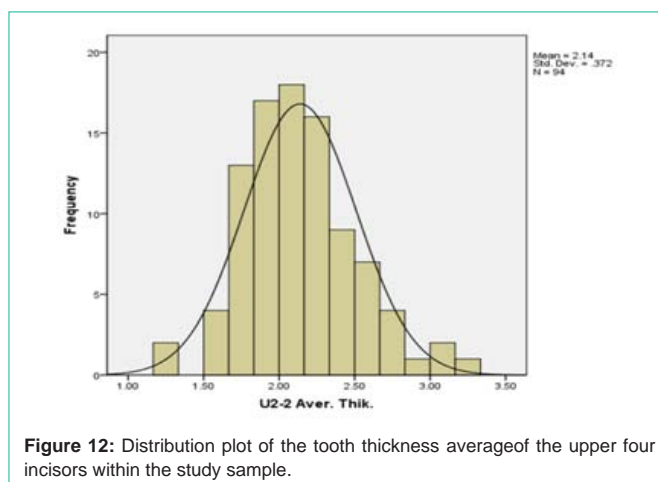
All cephalometric radiographs (n=94) were traced and recorded by one operator. These were the inter-incisal angle and upper and



**Figure 10:** Anterior tooth size ratio distribution within the study sample.



**Figure 11:** Overall tooth size ratio distribution within the study sample.

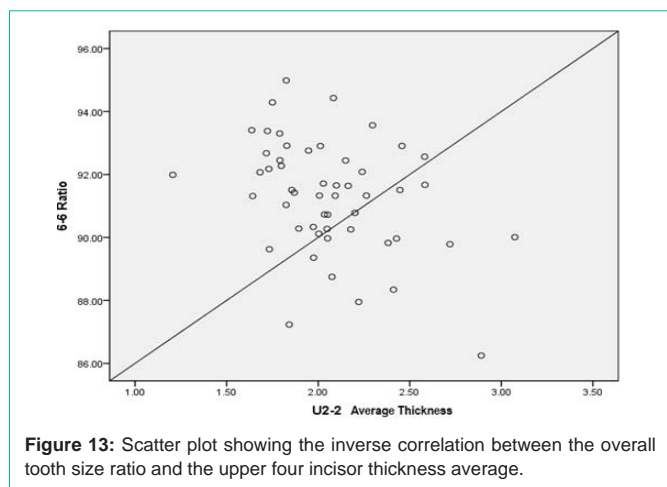


**Figure 12:** Distribution plot of the tooth thickness average of the upper four incisors within the study sample.

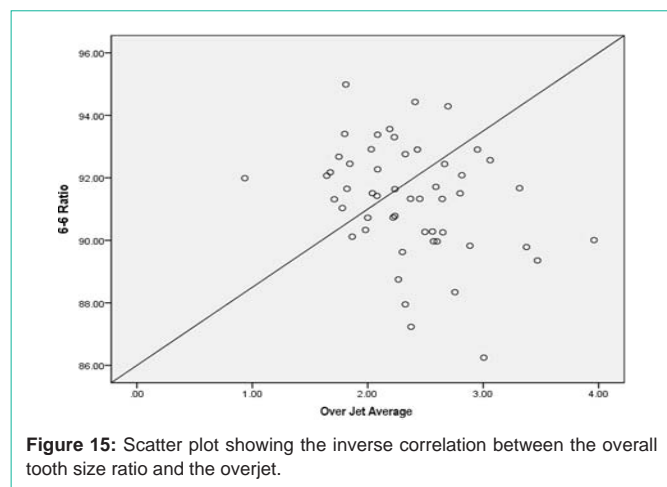
lower incisor inclinations. The latter were recorded as U1-SN, U1-NA, L1-MP and L1-NB. The mandibular plane used was the best fit tangent to the lower border of the mandible.

**Statistical analysis**

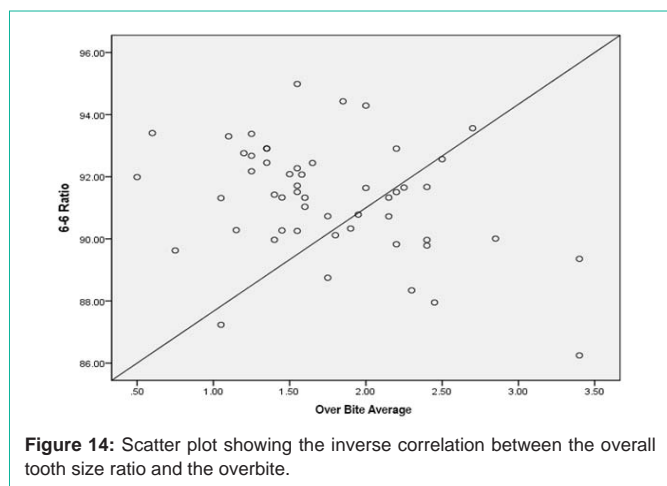
The data was analyzed using SPSS version 19.0 (Chicago, IL, USA). Descriptive statistics are shown for all the variables of this study. Bivariate statistics utilizing the t-test shows the relationship and association between the variables. The probability distribution of the data derived from this study was compared with the probability of the reference probability distribution by the Kolmogorov-Smirnov test and refined for more specificity of the normality of the data by the



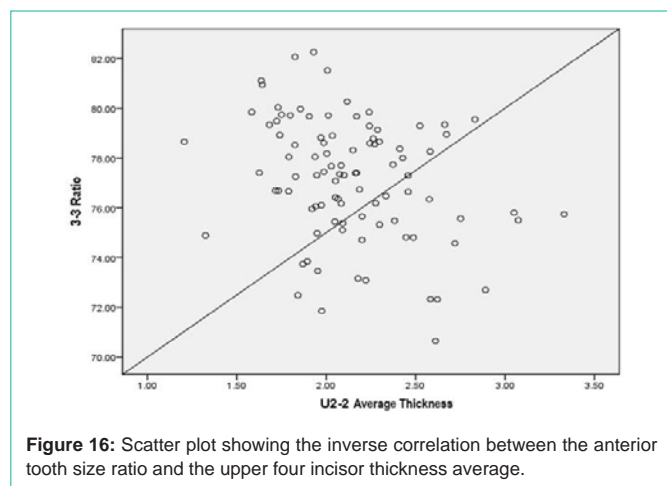
**Figure 13:** Scatter plot showing the inverse correlation between the overall tooth size ratio and the upper four incisor thickness average.



**Figure 15:** Scatter plot showing the inverse correlation between the overall tooth size ratio and the overjet.



**Figure 14:** Scatter plot showing the inverse correlation between the overall tooth size ratio and the overbite.



**Figure 16:** Scatter plot showing the inverse correlation between the anterior tooth size ratio and the upper four incisor thickness average.

Shapiro-Wilk test.

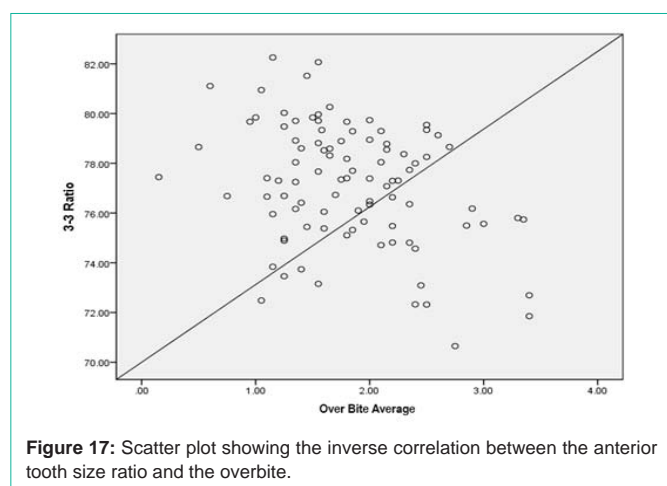
Statistical plots were generated to show the distribution of the study sample by anterior tooth size ratio and the overall tooth size ratio (Figure10,11). Similarly plots were generated for overjet, overbite, upper four incisor tooth thickness (Figure 12), U1 angle to S-N plane, U1 angle to N-A plane, L1 to MP, L1 to N-B plane and the inter-incisal angle.

Scatter plots of the overall tooth size ratio to the upper four incisor thickness, overbite and overjet were generated (Figures 13-15) as were scatter plots for the anterior tooth size ratio to these same variables (Figures 16-18).

The level of significance was set at 0.05.

## Results

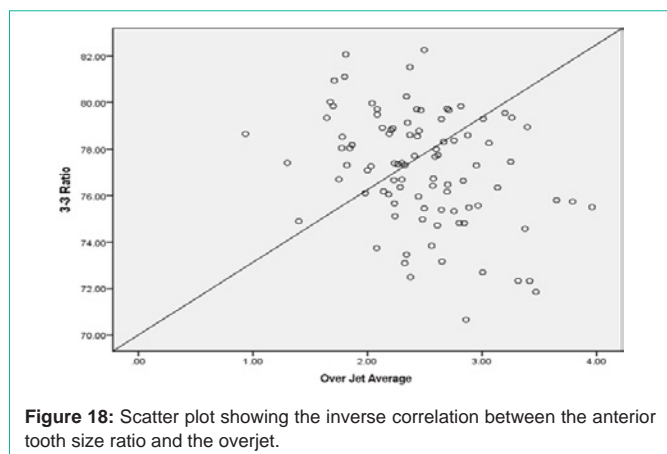
The results of overall tooth ratio and anterior tooth ratio as per the Bolton study of 19581 compared to the present study are demonstrated in table (Table I). This shows that the mean of the overall ratio and mean of the anterior ratio of the two studies are identical with a very small standard of error. The coefficient of variation of the anterior tooth size ratio in the current study is 1.61 times the coefficient of variation in the overall tooth size ratio (3.12%/1.94%=1.61). In Bolton's original study, the same ratio is only



**Figure 17:** Scatter plot showing the inverse correlation between the anterior tooth size ratio and the overbite.

1.02, representing similar data dispersion in overall and anterior ratios (2.14%/2.09%=1.02). In the Bolton study, coefficient of variation of overall tooth size ratio is 1.08 times higher (2.09%/1.94%=1.08) than in the present study sample. However, the anterior tooth ratio variation of the study sample is 1.46 times higher (3.12%/2.14=1.46) than the original Bolton study.

A one-sample t-test comparing the overall tooth ratio of this study



**Figure 18:** Scatter plot showing the inverse correlation between the anterior tooth size ratio and the overjet.

**Table 1:** Comparison of the overall and anterior ratios as reported by Bolton1 with the data derived from this study.

	Overall ratio (Bolton, 1958)	Overall ratio (This study)	Anterior ratio (Bolton, 1958)	Anterior ratio (This study)
<b>Range</b>	87.5%-94.8%	86.3%-95.0%	74.5%-80.4%	70.7%-82.3%
<b>Mean</b>	91.30%	91.30%	77.20%	77.20%
<b>Standard Deviation</b>	1.91	1.78	1.65	2.41
<b>Standard error of the mean</b>	0.26	0.25	0.22	0.25
<b>Coefficient of variation</b>	2.09%	1.94%	2.14%	3.12%

**Table 2:** One sample t-test comparing the mean of the overall tooth size ratio derived from the study sample and its equivalent mean value of 91.3 suggested by the 1958 Bolton Study.

One-Sample Test				
Test Value = 91.3				
	P value	Mean Difference	95% Confidence Interval of the Difference	
			Lower	Upper
6-6 Ratio	0.998	-0.00073	-0.4963	0.4948

Coefficient of variation: (100 x std. deviation)/ mean = 1.94%.

**Table 3:** One sample t-test comparing the mean of the anterior tooth size ratio derived from the study sample and its equivalent mean value of 77.2 suggested by the 1958 Bolton Study.

One-Sample Test				
Test Value = 77.2				
	P value	Mean Difference	95% Confidence Interval of the Difference	
			Lower	Upper
3-3 Ratio	0.906	-0.02945	-0.5228	0.4639

to the Bolton1 study and the same test comparing the anterior tooth size ratio showed that both comparisons did not show any statistical difference (Tables 2,3).

The measurements for overjet, overbite, anterior teeth inclination, inter-incisal angle, and upper anterior tooth thickness are normally distributed (Table 4), (p>0.05).

A Pearson correlation test (Table 4) was computed to investigate if there was a statistically significant association between the anterior tooth size ratio and each of the other variables in the study. The

**Table 4:** Pearson correlation test comparing the anterior (n=94) and overall (n=52) tooth size ratios with each of the following variables: overjet, overbite, upper four incisor thickness, upper and lower incisor angulations and inter-incisal angle.

		Anterior 3-3 Ratio	Overall 6-6 Ratio
<b>Overjet Aver.</b>	Pearson Correlation	-.338*	-.310*
	P value	0.001	0.025
<b>Overbite Aver.</b>	Pearson Correlation	-.342*	-.342*
	P value	0.001	0.013
<b>U2-2 Aver. thickness</b>	Pearson Correlation	-.300*	-.376*
	P value	0.003	0.006
<b>U3-3 Aver. thickness</b>	Pearson Correlation	0.004	-0.155
	P value	0.973	0.273
<b>U1 SN</b>	Pearson Correlation	0.105	0
	P value	0.313	1
<b>U1 NA</b>	Pearson Correlation	0.176	0.02
	P value	0.09	0.886
<b>L1 MP</b>	Pearson Correlation	-0.067	-0.056
	P value	0.519	0.692
<b>L1 NB</b>	Pearson Correlation	-0.135	-0.183
	P value	0.194	0.193
<b>Inter incisal Angle</b>	Pearson Correlation	-0.035	0.169
	P value	0.74	0.232

\*Correlation is significant.  
Correlation of 0.1 to 0.3 or -0.1 to -0.3 is small.  
Correlation of 0.3 to 0.5 or -0.3 to -0.5 is medium.  
Correlation of 0.5 to 1.0 or -0.5 to -1.0 is strong.

same was done for the overall tooth size ratio. The test of correlation suggested that three pairs of variables: overall tooth size ratio with overjet, overbite and upper anterior teeth thickness showed a statistically significant correlation. The coefficient of correlation was negative with a range from -0.376 to -0.310, (p<0.05). The same three pairs of variables when correlated to the anterior tooth size ratio also showed statistically significant correlation. The coefficient of correlation was again negative with a range from -0.342 to -0.300, p<0.05 (Table 4). The other variables did not show statistical significance of correlation (p>0.05).

## Discussion

The one-sample t-test results showed that no statistical significant difference exists between Bolton’s inter-arch tooth size mean ratios as published in Bolton’s 1958 study [1] and the corresponding mean ratios drawn from the present study of ABO passed orthodontic cases (p>0.05).

Another aspect of the study was to investigate possible association between either the overall tooth size ratio or the anterior tooth size ratio and each of the following variables: overjet, overbite, anterior teeth inclination, inter-incisal angle, and anterior teeth thickness. The test of correlation suggested that both the overall tooth size ratio and the anterior tooth size ratio showed a statistically significant association with each of the following variables: overjet, overbite, and

upper anterior teeth thickness (the average of the upper anterior four teeth only, without including the upper canines). The correlations were negative and ranged from -0.376 to -0.300, ( $p < 0.05$ ), indicating medium strength relationships. Anterior teeth inclination, and inter-incisal angle did not show statistical significant correlation with the overall tooth size ratio or the anterior tooth size ratio ( $p > 0.05$ ).

Thicker upper anterior teeth would correspond with having a lower tooth size ratio to accommodate for it. On the other hand having a smaller tooth size ratio may increase the possibility of finishing a given orthodontic case with an increase of overjet, overbite or a combination of both. Having a low tooth size ratio and yet achieve good treatment results may be explained with an occlusion that has a deeper overbite and subsequently an increased overjet to allow the lower incisal edges to touch the lingual surface of the upper incisors.

Tuverson [12] discussed inter-occlusal relations of anterior teeth affected by the tip and torque of teeth or how the anatomy of teeth such as “shovel shaped incisors” need to have marginal ridges reduced or tooth size discrepancies which need interproximal reduction. The sample of this study did show the variation to demonstrate these factors.

The mathematical model that Cordato [16] developed is verified by the clinical changes that are seen in this study when overbite is influenced by overjet, tooth thickness and tooth angulation. Although the sample of this study showed a direct correlation of the overall tooth size ratio and anterior tooth size ratio to the overbite, overjet and upper anterior tooth thickness, there was also a great variability in both the upper and lower incisor angulation to produce an excellent occlusion along with acceptable ABO standards in overbite and overjet requirements.

A diagnostic set-up is recommended in malocclusions showing a significant tooth size discrepancy, especially if the treatment plan includes having to do reshaping of teeth or selective Dental Interproximal Reduction (IPR). To avoid any misinterpretations of the analytic readings, another way to determine the need for IPR would be to align both upper and lower dental arches orthodontically to the finishing stages having achieved Class I canine relationship. Then, if it is difficult to achieve a good overbite and overjet relationship, it would be prudent to perform selective IPR or dental buildups (cosmetic bonding) to correct the tooth size discrepancy. Even tooth thickness and/or torque are factors to contemplate improving arch coordination.

Consideration would be to examine any of these four factors or in combination with each other.

For treatment results that passed the ABO examination requirements, cases had a range of variability between 0.2 to 3.4 mm for overbite and 0.94 to 3.96 mm for overjet and finally a range of 1.8-2.9 mm for upper incisal thickness. This variation nonetheless reflects the acceptable overbite, overjet and tooth thickness achieved for cases to meet the ABO standards.

## Conclusions

The Bolton analysis has been routinely used for predicting whether upper and lower dentitions will match with good occlusion. Good occlusion is usually defined as an occlusion with proper overbite and

overjet relationship for the anterior teeth and good interdigitation for the posterior teeth. American Board of Orthodontists has a set of well-defined criteria for determining good occlusion. Using cases that passed the ABO clinical examination constitute a good sample to test the reliability of the Bolton analysis.

The present study demonstrated the accuracy of the Bolton analysis. It also affirmed the correlation of Bolton tooth ratios with the amount of overbite, overjet and thickness of the upper incisors. However, this study also indicated that the Bolton ratios are not the only measurements in predicting clinically good occlusion. Factors such as incisor angulation, tooth tip and torque of teeth must be considered as affecting the arch perimeter and occlusion.

It is important to consider overjet, overbite, incisor angulation and upper incisor tooth thickness, as influencing factors that would affect the final occlusion in orthodontic cases due to the inverse correlation that has been demonstrated in this study.

## 8. Acknowledgment

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## References

- Bolton WA. Disharmony in tooth size and its relation to the analysis and treatment of malocclusion. *Angle Orthod.* 1958; 28:113-30.
- Smith SS, Buschang PH, Watnabe E. Interarch tooth size relationships of 3 populations: “Does Bolton’s analysis apply?”. *Am J Orthod & Dentofacial Orthop.* 2000; 117: 169-174.
- Neff CW. Tailored occlusion with anterior coefficient. *Am J Orthod.* 1949; 35: 309-313.
- Kesling HD. The philosophy of the tooth positioning appliance. *Am J Orthod.* 1945; 31: 297-340.
- Fields H. Orthodontic restorative treatment for relative mandibular anterior excess size problems. *Am J Orthod.* 1981; 79: 176-183.
- Freeman JE, Maskeroni AJ, Lorton, L. Frequency of Bolton tooth-size discrepancies among orthodontic patients. *Am J Orthod & Dentofacial Orthop.* 1996; 110: 24-27.
- Gillien RJ, Schwartz RS, Hilton TJ, Evans DB. An analysis of selected normative tooth proportions. *Int J Prosthodont.* 1994; 7: 410-417.
- Merz ML, Isaacson, RJ, Germane N, Rubenstein LK. Tooth diameters and arch perimeters in a black and white population. *Am J Orthod Dentofacial Orthop.* 1991; 100: 53-58.
- Lavelle CL. Maxillary and mandibular tooth size in different racial group and in different occlusal categories. *Am J Orthod.* 1972; 61: 29-37.
- Moorrees CFA. *The Aleut dentition.* Cambridge, Mass; Harvard University Press. 1957.
- Bolton WA. The clinical application of a tooth size analysis. *Am J Orthod.* 1962; 48: 504-529.
- Tuverson D. Anterior occlusal relations: Part I. *Am J Orthod.* 1980; 78: 361-370.
- Sangcharearn Y, Ho C. Maxillary incisor angulation and its effect on molar relationships. *Angle Orthod.* 2007; 77: 221-225.
- Rudolph DJ, Dominguez PD, Ahn K, Thinh T. The use of tooth thickness in

- predicting intermaxillary tooth-size discrepancies. *Angle Orthod.* 1998; 68: 133-138.
15. Cordato MA. A simple mathematical study of anterior dental relations: Part I. *Aust Orthod J.* 1995; 13: 249-253.
16. Cordato MA. A mathematical study of anterior dental relations: Part II incisor and canine overjet. *Aust Orthod J.* 1996; 14: 143-149.
17. Cordato MA. A simple mathematical study of anterior dental relations: Part III incisor and canine overbite. *Aust Orthod J.* 1998; 15: 75-84.
18. Casco JS, Vaden JL, Kokich VG, Damone J, James RD, Cangialosi TJ, et al. Objective grading system for dental casts and panoramic x-rays. *Am J Orthod Dentofacial Orthop.* 1998; 114: 589-599.
19. American Board of Orthodontics Grading System of dental casts and radiographs.