The Influence of Labio-lingual and Mesio-distal Anterior Tooth Dimensions on Inter-arch Relationships: A Modified Anterior Bolton Analysis

Yelena Akselrod Beygelman

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Committee:
Anne-Marie Bollen
Roozbeh Khosravi
Mohammed Masoud
David Turpin

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Abstract

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Yelena Akselrod Beygelman

Chair of the Supervisory Committee:
Anne-Marie Bollen, Graduate Program Director
Department of Orthodontics

Introduction: Tooth size and morphology of anterior teeth influence inter-arch relationships. The Bolton analysis uses tooth width to calculate a sum of mandibular to maxillary tooth widths ratio necessary for proper occlusion. Several parameters not factored in the Bolton analysis influence occlusion such as tooth thickness. This study sought to use 3D modeling to develop and assess a tooth size analysis that encompasses labio-lingual thickness as well as mesio-distal width of anterior teeth.

Methods: The role of tooth thickness in inter-arch relationships was studied using simulations in a 3D modeling software (Suresmile^{TM}). To develop a new chart of inter-arch ratios based on tooth thickness, a series of simulations were produced with varying tooth thicknesses and widths. The new ratios were evaluated on records from 50 patients.

Results: Findings from the simulations suggest that the ideal tooth thickness remains approximately 2mm if the overall tooth width of the dentition increases and the inter-arch anterior ratio is maintained. The thickness-adjusted anterior mandibular to maxillary tooth ratio ranges from 0.70 to 0.79 depending on the tooth thickness. This thickness-adjusted ratio provides a superior prediction for the sum of anterior tooth width compared to the Bolton analysis.

Conclusion: Tooth thickness does affect inter-arch tooth width ratios and anterior occlusion. A thickness-adjusted ratio can be used to more accurately predict anterior tooth dimensions necessary to achieve proper occlusion.

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1. INTRODUCTION

Tooth size and morphology play a key role in the occlusion between maxillary and mandibular teeth. Wayne Bolton introduced the idea of an ideal tooth width ratio of mandibular to maxillary teeth. He measured the mesio-distal width of maxillary and mandibular teeth in models that demonstrated excellent occlusion to find an ideal ratio between the sum of maxillary and mandibular tooth widths (Bolton 1958). He stated that if an ideal ratio is present, maxillary and mandibular teeth are capable of proper interdigitation with good anterior coupling and no excess spacing or overlap. Bolton also noted that extreme anterior labio-lingual thickness is rare and may require a larger maxillary anterior sum (Bolton, 1962). In today's diverse population of orthodontic patients, there is greater variation in tooth morphology. The Bolton ratios have been re-examined among different ethnicities and populations.

Many studies have evaluated the reliability of the Bolton ratios among different racial groups. In Middle Eastern populations, Syrian, Saudi, and Iranian samples showed the anterior ratio to be comparable to Bolton's (Nourallah et al. 2005; Al-Tamimi and Hashim, 2005; Kachoei, 2011). On the other hand, the mean anterior ratio was found to be significantly greater than Bolton's in Indian, Black, and Hispanic populations (Subbarao et al, 2014, Smith et al. 2000). It suggests that the anterior ratio may need to be adjusted for different racial groups. Other studies have further examined the challenges of the Bolton analysis and found that overbite, overjet, tooth angulation, and tooth thickness contribute greatly to inter-maxillary relationships (Alamir 2013; Bolton 1958; Rudolph et al. 1998).

Caucasian females with ideal occlusion comprised the sample population for Bolton's study. The models displayed a mean overjet of 0.74mm, suggesting that these cases were representative of thinner teeth in the labio-lingual dimension. It is interesting to note that there is variation in tooth morphology among different ethnicities and populations, with some demonstrating higher prevalence of thicker anterior marginal ridges and overall increased thickness of anterior teeth. There is greater variation in the labio-lingual dimension than in the mesio-distal dimensions between populations (Bishara et al. 1989). Furthermore, marginal ridge thickness of anterior teeth was analyzed in a study of 120 pre-treatment

patient models in the Department of Orthodontics at Marquette University School of Dentistry. They found that males tend to have thicker marginal ridges than females, non-Caucasians show higher frequency of thicker marginal ridges than Caucasians, and there is a high correlation between marginal ridge thickness and the Bolton index (Foster 2011). Patients in which the labio-lingual thickness ranges outside the norm may pose a challenge for the orthodontist attempting to achieve ideal occlusion.

In 1998, Rudolph et al evaluated the influence of tooth thickness on the inter-arch ratio. He used 44 positioner setup models of patients who completed orthodontic treatment to evaluate the relationship between tooth thickness and the tooth width of upper and lower anterior dentition. Tooth thickness was measured using a crown gauge at the level of occlusal contact. Based on these models, he developed a prediction equation for a new ratio of lower to upper teeth that accounts for the labio-lingual thickness. The proposed formula states that if the average anterior tooth thickness is less than 2.75mm, then the predicted ideal inter-arch anterior ratio can be calculated by the following formula:

$$\text{Predicted Ratio} = -7.054\ (\text{tooth thickness}) + 95.024$$

If anterior tooth thickness is greater than or equal to 2.75mm, then the predicted ratio is calculated by the following formula:

$$\text{Predicted Ratio} = -1.928\ (\text{tooth thickness}) + 81.874$$

The mean absolute error for this predicted ratio is 0.84 +/- 0.46, which is smaller compared to Bolton's error of 1.29 +/- 0.81 (Rudolph et al. 1998). However, there are limitations to this study. All patients had previously received orthodontic treatment, so tooth thickness may have been adjusted by enameloplasty and tooth width may have been adjusted by interproximal reduction to improve anterior coupling. Furthermore, the prediction model was developed and tested using the same sample group, which may not have produced an accurate evaluation of the results.

In the growing digital world, 3D virtual treatment planning is becoming more popular with advancing technologies such as Suresmile™, Invisalign™, Orthocad™, and e-models (Favero, 2009). These software technologies can be useful in comparing various treatment plans (Hou, 2015) as well as predicting the challenges that may show up as treatment progresses. Tooth size analysis is already incorporated in 3D modeling software to plan for strategies to address discrepancies during the early stages of treatment. Integrating tooth thickness in this analysis can add an additional degree of customization to each patient. The first goal of this study was to use 3D modeling to develop a tooth size analysis that evaluates both the labio-lingual thickness and mesio-distal width of anterior teeth. The second goal was to test the formula on a separate sample of patients characterized by a range of tooth thicknesses.

2. MATERIALS AND METHODS

2.1. Maxillary Incisor Tooth Thickness

Overall maxillary incisor tooth thickness can be defined as the distance from the labial surface of the maxillary incisor to the lingual point of contact with the lower dentition. However, the distance from the incisal edge to the labial surface of the tooth does not influence the occlusion. This leaves the distance from the incisal edge to the lingual surface of the tooth at point of contact with mandibular incisors as the most functional definition for tooth thickness. This definition coincides with the measurement of overjet, which we used for the purpose of this study to measure tooth thickness.

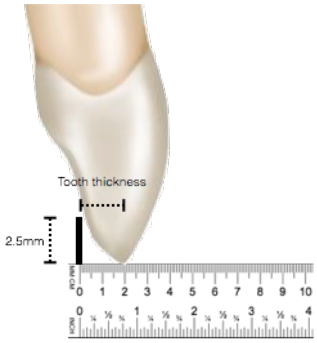


Figure 1. Custom ruler measuring tooth thickness.

2.2. Simulations

2.2.1. Typodont and Modeling Software Used for Simulations

The Hamaguchi model was designed by a lab technician to represent proper tooth size proportions and occlusal relationships. A stone model of the Hamaguchi occlusion was chosen to represent a practical model of dentition. This model was first scanned into digital form using Ortho Insight 3D (MotionView, Hixson, TN/USA), and then imported into Suresmile (OraMetrix, Richardson, TX), the 3D modeling software used for this study. The scanned model was adjusted in Suresmile to an ideal occlusion. Anterior clinical crowns were adjusted to average mesio-distal widths. Class I canine relationship was defined by mesial and distal contact on the maxillary canines. Overbite was adjusted to 2mm for the centrals and 1.5mm for the laterals, with an overjet of 2-3mm. Light occlusal contact was present on each anterior tooth, as well as the interproximal contact.

2.2.2. The First Set of Simulations: Does Tooth Width Affect Tooth Thickness Needed for ideal Occlusal Relationship in the Anterior Region?

The first set of simulations evaluated how changes in mesio-distal tooth width of the upper anterior teeth affect their bucco-lingual tooth thickness necessary to maintain ideal occlusion. The tooth widths of centrals, laterals and canines were changed on the typodont model, and the ideal thickness associated with the upper centrals and laterals was measured. For each simulation, the lower incisor tooth

widths were adjusted to maintain an ideal Bolton ratio. Several studies were referenced to determine the range of tooth widths found among different races, and a reasonable range to use for the simulations (Orozco-Varo et al., 2015; Parciak, 2015; Troncoso-Pazos et al., 2017). Based on the findings, in each simulation the tooth width of both upper and lower incisors was changed by an increment of 2%. A total of 15 simulations were produced ranging from 84% to 110%, and 118% of the average tooth width. 84% and 118% sizes served as the two extremes, at the two standard deviation boundary (Orozco-Varo et al., 2015; Parciak, 2015; Troncoso-Pazos et al., 2017). Detailed steps in producing the simulations are presented in the Appendix (Appendix I). Overall, with the width adjusted across a wide range, the tooth thickness necessary to achieve proper occlusion did not exceed 2mm. For teeth with a thickness less than 2mm, the occlusion would be minimally effected.

2.2.3. The Second Set of Simulations: How Does Change in Tooth Thickness Affect Inter-Arch Relationships?

The goal of the next set of simulations was to examine how changing the tooth thickness affects occlusion. When tooth thickness is increased, and if a Class I posterior occlusion is maintained, the result is interproximal spacing in the maxillary arch unless adjustments are made in the tooth width. This means that either the tooth width of the maxillary anterior segment must increase or the width of the mandibular anterior segment must decrease. In the next set of simulations, tooth thickness was changed and for each thickness, a new ideal mandibular/maxillary ratio was calculated (thickness-adjusted anterior Bolton ratio).

The Hamaguchi typodont was used with average tooth widths. To eliminate error and variation in the Class I canine position, in each simulation the mandibular arch and the canine position were held constant. Then to increase tooth thickness, the maxillary anterior teeth were moved labially and to decrease tooth thickness they were moved lingually. Therefore, the change in tooth thickness was reflected in the perimeter of the maxillary anterior arch because labial movement created interproximal spaces and lingual movement created interproximal overlap. This new perimeter was defined as the new

anterior maxillary sum for each simulation as a function of tooth thickness. Detailed steps in producing the simulations are presented in the Appendix (Appendix II). The modified anterior sum was calculated by considering the anterior widths canine-to-canine, interproximal spaces produced by labial movement, and the interproximal overlap produced by maxillary anterior lingual movement:

Modified Maxillary Anterior Sum=

(Sum of anterior dental widths) + (inter-proximal spaces produced by labial movement)

or

(Sum of anterior dental widths) - (inter-proximal overlap produced by lingual movement)

The simulations with changing tooth thickness were then repeated in dentitions with narrower teeth and wider teeth to determine if the findings were specific to the average tooth widths. The same protocol was followed as above, except that all tooth widths of the typodont were 110% of the original model representing wider teeth and 84% of the original model representing narrower teeth. A new mandibular/maxillary ratio was recorded for each tooth thickness.

2.2.4. Evaluating the Thickness-Adjusted Ratios on Patients

The next goal was to test the thickness-adjusted ratios on a sample of patients. As seen in previous simulations, changing tooth thickness consequentially requires adjustment in the width of either mandibular or maxillary teeth to maintain proper occlusion. Both techniques were used to evaluate the thickness-adjusted ratios. In 25 cases the width of the maxillary anterior teeth was adjusted, and in the next 25 cases the mandibular width was adjusted to accommodate tooth thickness.

Fifty patient casts were gathered from a University Orthodontic department as well as from faculty private practices. The inclusion criteria required dentition with fully erupted maxillary and mandibular permanent anterior teeth, and a variation of maxillary incisor tooth thicknesses and widths. Each cast was scanned into Suresmile, and adjusted to proper occlusion. In the first 25 models, the lower anterior

dentition was aligned ideally with interproximal contact. The upper teeth were aligned to the lower teeth, with canines in a Class I position and occlusal contact. As a result spaces or inter-proximal overlap was recorded to calculate the simulation-based ideal upper anterior sum. In the next 25 cases, the upper anterior teeth were aligned ideally and the lower teeth were moved to accommodate a Class I canine position and occlusal contact. The resulting simulation-based ideal mandibular anterior sum was recorded (See Appendix III for detailed steps). The ideal mandibular/maxillary anterior sum ratios were compared to the Bolton ratio and the thickness-adjusted anterior ratios.

3. RESULTS

3.1. The First Set of Simulations: Does Tooth Width Affect Tooth Thickness Needed for ideal Occlusal Relationship in the Anterior Region?

Fifteen simulations were prepared with tooth widths ranging from 84% to 110%, and 118% of the average tooth width. The mandibular/maxillary width ratio was maintained in all simulations. The resulting ideal tooth thickness was similar for tooth widths greater than the average. The tooth thickness was slightly smaller for tooth widths less than the average (Table 1). It appears that if the inter-arch ratio remains the same, then increasing tooth widths does not have significant affect on tooth thickness.

Table 1. The Affect of Changing Tooth Width on Tooth Thickness

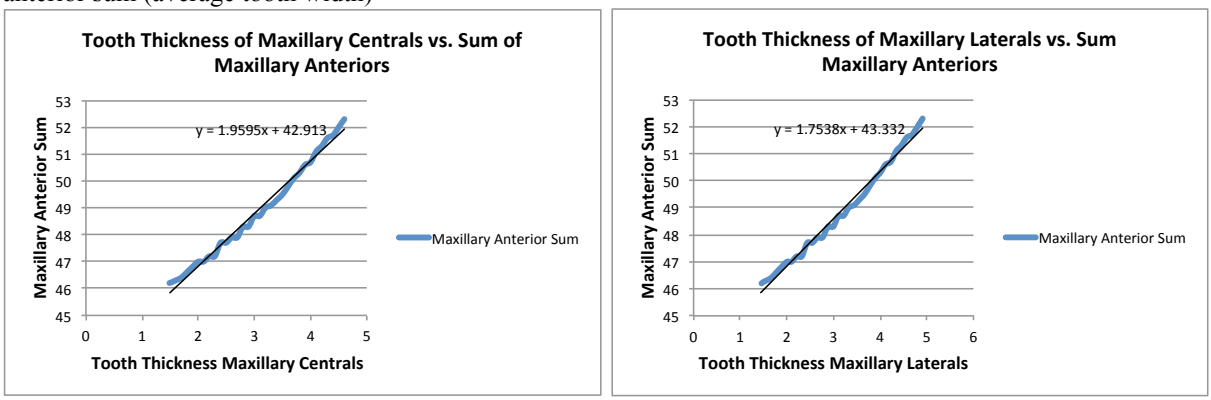
Simulation	Tooth Width (%)	Width U3s (mm)	Width U2s (mm)	Width U1s (mm)	Width L3s (mm)	Width L2s (mm)	Width L1s (mm)	*Thickness U1s (mm)*	*Thickness U2s (mm)*	*Avg. (mm)*
1	84	6.55	5.80	7.39	5.80	4.96	4.54	1.56	1.58	1.57
2	86	6.71	5.93	7.57	5.93	5.07	4.64	1.67	1.64	1.66
3	88	6.86	6.07	7.74	6.07	5.19	4.75	1.67	1.72	1.70
4	90	7.02	6.21	7.92	6.21	5.31	4.86	1.78	1.68	1.73
5	92	7.18	6.35	8.10	6.35	5.43	4.97	1.78	1.72	1.75
6	94	7.33	6.49	8.27	6.49	5.55	5.08	1.84	1.74	1.79
7	96	7.49	6.62	8.45	6.62	5.66	5.18	1.73	1.70	1.72
8	98	7.64	6.76	8.62	6.76	5.78	5.29	1.74	1.88	1.81
9	100	7.80	6.90	8.80	6.90	5.90	5.40	2.00	2.00	2.00
10	102	7.96	7.04	8.98	7.04	6.02	5.51	1.99	1.99	1.99
11	104	8.11	7.18	9.15	7.18	6.14	5.62	1.99	1.98	1.99
12	106	8.27	7.31	9.33	7.31	6.25	5.72	1.99	1.98	1.98
13	108	8.42	7.45	9.50	7.45	6.37	5.83	1.90	1.89	1.90
14	110	8.58	7.59	9.68	7.59	6.49	5.94	2.00	1.98	1.99
15	118*	9.20	8.14	10.38	8.14	6.96	6.37	2.03	2.01	2.02

* Tooth width 2SDs above average

3.2. The Second Set of Simulations: How Does Change in Tooth Thickness Affect Inter-Arch Relationships?

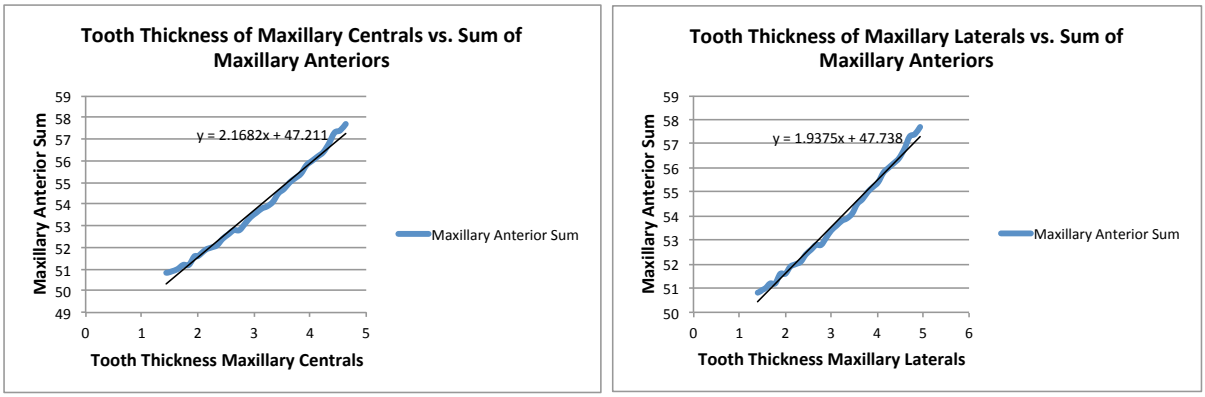
Thirty-two simulations were prepared using the Hamaguchi typodont with average tooth widths. Tooth thickness ranged from 1.4mm to 4.9mm in increments of 0.1mm. The resulting maxillary anterior sum ranged from 46.2mm to 52.3mm. As tooth thickness increased, the maxillary anterior arch length increased. The sum of the anterior maxillary arch increased by 1.96mm for every millimeter of tooth thickness of the central incisors. The sum of the maxillary arch increased by 1.75mm for every millimeter of tooth thickness of the lateral incisors (Graphs 1a, 1b). The resulting ratio of mandibular anterior arch length to maxillary anterior arch length ranged from 0.70 to 0.79 (Appendix IV).

Figure 2. Relationship of (a) upper central incisor thickness and (b) upper lateral incisor thickness to maxillary anterior sum (average tooth width)



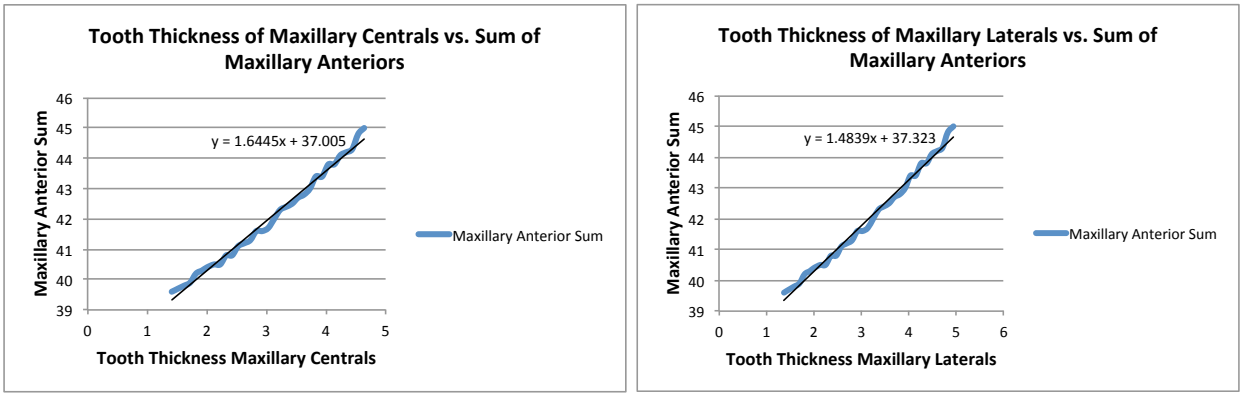
Thirty-three simulations were repeated on a typodont with tooth widths greater than the average. The resulting maxillary anterior sum ranged from 50.8mm to 57.7mm. The anterior maxillary arch length increased by 2.2mm for every millimeter of tooth thickness of the central incisors. The arch length increased by 1.9mm for every millimeter of tooth thickness of the lateral incisors (Graphs 2a, 2b). The resulting ratio of mandibular anterior arch length to maxillary anterior arch length ranged from 0.70 to 0.79 (Appendix V).

Figure 3. Relationship of (a) upper central incisor thickness and (b) upper lateral incisor thickness to maxillary anterior sum (wider tooth width)



Thirty-three simulations were repeated with tooth widths smaller than average. The resulting maxillary anterior sum ranged from 39.6mm to 45mm. The anterior maxillary arch length increased by 1.6mm for every millimeter of tooth thickness of the central incisors. The arch length increased by 1.6mm for every millimeter of tooth thickness of the lateral incisors (Graphs 3a, 3b). The resulting ratio of mandibular anterior arch length to maxillary anterior arch length ranged from 0.70 to 0.79 (Appendix VI).

Figure 4. Relationship of (a) upper central incisor thickness and (b) upper lateral incisor thickness to maxillary anterior sum (narrower tooth width)



The data collected with average, narrow, and wide tooth widths was combined to calculate the average values (Appendix VII, Table 2). The inter-arch ratio remained in a range of 0.70-0.79.

Table 2. Thickness-Adjusted Anterior Mandibular/Maxillary Ratios

Tooth Thickness Centrals (mm)	Mandibular/Maxillary Anterior Sum
1.4	0.787
1.5	0.785
1.7	0.784
1.8	0.781
1.9	0.778
2.0	0.774
2.0	0.773
2.2	0.770
2.3	0.770
2.4	0.765
2.5	0.763
2.6	0.759
2.7	0.758
2.8	0.755
2.9	0.752
3.0	0.748
3.1	0.747
3.2	0.742
3.3	0.740
3.4	0.737
3.5	0.734
3.6	0.730
3.7	0.727
3.8	0.724
3.9	0.720
4.0	0.717
4.1	0.712
4.2	0.711
4.3	0.707
4.4	0.704
4.5	0.700
4.6	0.696

3.3. Evaluating the Thickness-Adjusted Ratios on Patients

A sample of 50 pre-treatment patient models was collected from a University Orthodontic department and faculty private offices. Treatment simulations were made to an ideal occlusion. In the first 25 cases, the maxillary anterior sum was adjusted to accommodate occlusion. Thus, the ideal maxillary anterior sums were compared to the maxillary sum predicted by Bolton (Appendix VIII), the thickness-adjusted ratios referencing maxillary centrals (Appendix X) and maxillary laterals (Appendix XII). In the

next 25 cases, the mandibular anterior sum was adjusted to accommodate the occlusion. Thus, the ideal mandibular anterior sums were compared to that predicted by Bolton and the thickness-adjusted ratios. The average discrepancy of the Bolton was 2.3mm in the maxillary arch and 1.8mm in mandibular arch (Appendix IX). The average discrepancy of the thickness-adjusted ratio based on maxillary centrals was 0.7mm in the maxillary arch and 0.2mm in the mandibular arch (Appendix XI). The average discrepancy of the new ratio based on maxillary laterals was 1.0mm in the maxillary arch and 0.7mm in the mandibular arch (Appendix XII). See a summary in Table 3,4.

Table 3. Discrepancies in Maxillary Anterior Width Sum

	Bolton Ratio	Thickness-adj. Ratio (Centrals)	Thickness-adj. Ratio (Laterals)
Median (mm)	2.2	-0.7	1.1
Average (mm)	2.3	-0.7	1.0
Range Min (mm)	0.4	-3.9	-0.9
Range Max (mm)	4.4	2.8	3.1

Table 4. Discrepancies in Mandibular Anterior Width Sum

	Bolton Ratio	Thickness-adj. Ratio (Centrals)	Thickness-adj. Ratio (Laterals)
Median (mm)	-1.8	0.2	-0.8
Average (mm)	-1.8	0.2	-0.7
Range Min (mm)	-3.1	-1.5	-2.0
Range Max (mm)	-0.5	2.2	1.0

4. DISCUSSION

Maxillary anterior tooth thickness is not commonly discussed or measured during initial treatment planning. In fact, there is no standard method of measuring tooth thickness. Yet there is often a degree of variation in incisor morphology. In addition to commonly found thick anterior marginal ridges, there are incisors with talon cusps, barrel shaped morphology, and microforms. They all introduce a challenge to achieve ideal anterior coupling and posterior occlusion. This study focused on the influence of maxillary anterior tooth thickness on occlusion.

Many studies have re-evaluated the anterior Bolton ratio and suggested that the ratio should be adjusted to different races. However, very few studies have introduced another variable to the ratio that

can be applied to dentitions with different morphology. Past studies have evaluated anterior tooth thickness on physical models, but there are no studies that have used 3D modeling to decipher the interplay of maxillary incisor tooth thickness and occlusion. The first goal of this study was to understand how thickness and width relate. The first set of simulations measured ideal maxillary incisor tooth thickness in dentitions of different widths. All other factors were held constant, including the anterior ratio of mandibular to maxillary teeth, to eliminate any tooth width discrepancy between the arches. These controlled settings helped to determine if the ideal tooth thickness changes for different tooth widths. The results showed that in wider teeth, the functional tooth thickness of maxillary incisors remains about 2mm. On the other hand in narrower teeth, the ideal tooth thickness is slightly smaller. Interestingly, this may explain why the average overjet in Bolton's study was 0.7mm, significantly smaller than the average today. His Caucasian female patient sample may have had narrower teeth. Overall, the findings suggest that tooth thickness greater than 2mm may affect the occlusion.

The next set of simulations evaluated the effect of changing tooth thickness beyond 2mm. When maxillary incisor tooth thickness is increased, and if tooth width is maintained, the posterior segments must compensate with a Class II canine and molar tendency. If a Class I occlusion is maintained, the result is interproximal spacing in the maxillary arch. Therefore as tooth thickness is increased, tooth width must be adjusted to restore a balanced occlusion. This means that either the maxillary anterior arch length must increase or the mandibular anterior arch length must decrease. Change in tooth thickness leads to a new ratio of mandibular to maxillary anterior widths.

Similar simulations were produced using a typodont with overall narrower and wider teeth, and the results showed that the ratio of mandibular to maxillary anterior sums was consistent in all three scenarios. It is therefore logical that in wider teeth, increasing tooth thickness demands slightly greater amount of increase in tooth width compared to the change necessary in average teeth. Similarly, dentitions with average tooth width demand a slightly greater change in width compared to narrower teeth. It suggests that a thickness-adjusted ratio can be applied to dentitions with differing tooth widths.

The thickness-adjusted ratios were evaluated on a sample of patients. Ratios that reference tooth thickness of centrals were able to predict the ideal anterior mandibular to maxillary sum ratio better than the Bolton ratio. On average, the Bolton ratio predicted a maxillary sum that was 2.3mm less than the sum necessary while the thickness-adjusted ratio on average predicted a maxillary sum 0.7mm greater than the ideal. It is difficult to compare the findings of this study to the previous study by Rudolph et al because tooth thickness was not measured in the same manner.

The thickness-adjusted tooth size analysis must be easy and applicable in both a clinical and digital setting. To do so, a method of measuring tooth thickness is necessary. If there is contact between the mandibular incisors and maxillary central at a proper overbite (generally considered to be 2.5 mm), tooth thickness can be measured as overjet using a standard ruler. It can also be easily measured in 3D digital software. However if there is lack of anterior contact, a custom ruler can be used to measure tooth thickness clinically 2.5mm from the incisal edge (Figure 1).

This study had several limitations. Specifically, using the Suresmile software posed some challenges. Although change in tooth inclination can be measured in Suresmile, the initial tooth inclination of patient dentition was not possible to evaluate without a CBCT. To address this issue, tooth inclination was adjusted based on lateral cephalographs when possible. Therefore, there was no method of recording the final tooth inclination. Another limitation is that the typodont simulations assumed that the thickness of maxillary centrals and laterals are uniform, while clinically there may be variation in morphology such as the presence of barrel-shaped laterals. The thickness-adjusted ratio considering the central incisors may not be relevant in patients with this variation. Future studies should evaluate additional parameters that play a large role in anterior coupling and occlusion such as tooth inclination and arch shape.

5. CONCLUSION

Findings of the 3D simulations suggest that maxillary incisor tooth thickness does affect occlusion and inter-arch tooth width ratios. Larger teeth appear to be slightly more affected by variation in anterior tooth thickness than smaller teeth. Considering a range of maxillary anterior tooth thicknesses, the ratio of anterior mandibular/maxillary arch length changes from 0.70 to 0.79 as a function of change in thickness. Our preliminarily analysis of 50 patients indicated that the sum of mandibular or maxillary widths predicted by the thickness-adjusted ratios is more accurate compared to sums calculated by the Bolton ratio. Therefore, a thickness-adjusted ratio can be used in dentitions with variation in maxillary anterior tooth thickness.

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APPENDICES

Appendix I.

The following adjustments were made for each simulation with tooth width greater than the model:

I. Increased tooth width of each mandibular anterior tooth by 2% (created interproximal overlap).

II. Eliminated mandibular interproximal overlap by distal tooth movement of teeth along the arch form to achieve interproximal contact.

III. Increased tooth width of maxillary anterior teeth by 2% (creates interproximal overlap).

IV. Adjusted maxillary interproximal overlap FIRST by distal tooth movement around the arch form until canine Class I relationship was reached (at which point there may be remaining interproximal overlap).

V. Eliminated the remaining maxillary interproximal overlap by uniform buccal movement of maxillary anterior teeth.

VI. Adjusted overbite to 2mm at centrals and 1.5mm at laterals (if necessary) by intrusion/extrusion.

VII. Measured and recorded the resulting tooth thickness (measured as overjet).

A similar protocol was followed for simulations with tooth widths less than the model:

I. Decreased tooth width of each mandibular anterior tooth by 2% (creates interproximal spaces).

II. Eliminated mandibular interproximal spaces by mesial tooth movement of teeth along the arch form to achieve interproximal contact.

III. Decreased tooth width of maxillary anterior teeth by 2% (creates interproximal spaces)

IV. Adjusted maxillary interproximal spaces FIRST by mesial tooth movement around the arch form until canine Class I relationship is reached (at which point there may be remaining interproximal spaces).

V. Eliminated the remaining maxillary interproximal spaces by uniform lingual movement of maxillary anterior teeth.

VI. Adjusted overbite to 2mm at centrals and 1.5mm at laterals (if necessary) by intrusion/extrusion.

VII. Measured and recorded the resulting tooth thickness (measured as overjet).

Appendix II

The following protocol was followed to adjust tooth thickness:

I. Mandibular anterior teeth were held constant

II. Mandibular and maxillary canine position were held constant

III. **Increased** tooth thickness of maxillary incisors by buccal movement of maxillary centrals and laterals in increments of 0.1mm, up to thickness 4.6mm

    a. Tooth thickness was measured from the incisal edge to contact with labial surface of lower incisor

    b. Buccal tooth movement in Suresmile creates interproximal **spaces**

Similarly, when decreasing tooth thickness:

I. Mandibular anterior teeth were held constant

II. Mandibular and maxillary canine position were held constant

III. **Decreased** tooth thickness of maxillary incisors by lingual movement of maxillary centrals and laterals in increments of 0.1mm, up to thickness 1.4mm

    a. Tooth thickness measured from incisal edge to contact with labial surface of lower incisor

    b. Lingual tooth movement in Suresmile creates inter proximal **overlap**

Appendix III

Protocol for patient model simulations:

I. 1-25 cases:

   a. Aligned **lower** dentition with no overlap or spacing along the arch form

   b. Aligned the **upper** dentition along the lower arch form to a canine Class I position (defined by lingual mesial and distal contact points)

      i. **Upper** arch will have inter proximal spaces or overlap if the tooth thickness is too small or too large

   c. Adjusted the upper dentition to achieve a light occlusal contact on all teeth

   d. Measured the interproximal spacing or overlap in the upper arch to calculate a "new" maxillary anterior sum

   e. Compared the patient "new" upper anterior sum to the predicted upper anterior sum based on our findings

II. 25-50 cases:

   a. Aligned **upper** arch with no overlap or spacing along the arch form

   b. Aligned the **lower** dentition along the upper arch form to a Class I canine position (defined by lingual mesial and distal contact points)

      i. Lower arch will have inter proximal spaces or overlap if the tooth thickness is too small or too large

   c. Adjusted the lower dentition to achieve a light occlusal contact on all teeth

   d. Measured the spacing or overlap in the lower arch to calculate a "new" mandibular anterior sum

   e. Compared the patient "new" lower anterior sum to the predicted lower anterior sum based on our findings

Appendix IV

Effect of change in anterior tooth thickness on inter-arch ratios. Average tooth widths.

Simulation	Tooth Thickness Centrals (mm)	Tooth Thickness Laterals (mm)	Anterior Mn Sum (mm)	Anterior Mx Sum (mm)	Anterior Sum Mn/Sum Mx
1	1.5	1.4	36.4	46.2	**0.788**
2	1.6	1.6	36.4	46.3	**0.786**
3	1.7	1.7	36.4	46.4	**0.784**
4	1.8	1.8	36.4	46.6	**0.781**
5	1.9	1.9	36.4	46.8	**0.778**
6	2.0	2.0	36.4	47	**0.774**
7	2.1	2.1	36.4	47	**0.774**
8	2.2	2.2	36.4	47.2	**0.771**
9	2.3	2.3	36.4	47.2	**0.771**
10	2.4	2.4	36.4	47.7	**0.763**
11	2.5	2.5	36.4	47.7	**0.763**
12	2.6	2.7	36.4	47.9	**0.760**
13	2.7	2.8	36.4	47.9	**0.760**
14	2.8	2.9	36.4	48.3	**0.754**
15	2.9	3.0	36.4	48.3	**0.754**
16	3.0	3.1	36.4	48.7	**0.747**
17	3.1	3.2	36.4	48.7	**0.747**
18	3.2	3.3	36.4	49	**0.743**
19	3.3	3.4	36.4	49.1	**0.741**
20	3.4	3.6	36.4	49.3	**0.738**
21	3.5	3.7	36.4	49.5	**0.735**
22	3.6	3.8	36.4	49.8	**0.731**
23	3.7	3.9	36.4	50.1	**0.727**
24	3.8	4.0	36.4	50.3	**0.724**
25	3.9	4.1	36.4	50.6	**0.719**
26	4.0	4.2	36.4	50.7	**0.718**
27	4.1	4.3	36.4	51.1	**0.712**
28	4.2	4.5	36.4	51.3	**0.710**
29	4.3	4.6	36.4	51.6	**0.705**
30	4.4	4.7	36.4	51.7	**0.704**
31	4.5	4.8	36.4	52	**0.700**
32	4.6	4.9	36.4	52.3	**0.696**

Appendix V

Effect of change in anterior tooth thickness on inter-arch ratios. Larger tooth widths.

Simulation	Tooth Thickness Centrals (mm)	Tooth Thickness Laterals (mm)	Anterior Mn Sum (mm)	Anterior Mx Sum (mm)	Anterior Sum Mn/Sum Mx
1	1.4	1.4	39.9	50.8	**0.785**
2	1.5	1.5	39.9	50.9	**0.784**
3	1.6	1.6	39.9	51	**0.782**
4	1.7	1.7	39.9	51.2	**0.779**
5	1.8	1.8	39.9	51.2	**0.779**
6	1.9	1.9	39.9	51.6	**0.773**
7	2.0	2.0	39.9	51.6	**0.773**
8	2.1	2.1	39.9	51.9	**0.769**
9	2.2	2.2	39.9	52	**0.767**
10	2.3	2.3	39.9	52.1	**0.766**
11	2.4	2.4	39.9	52.4	**0.761**
12	2.5	2.6	39.9	52.6	**0.759**
13	2.6	2.7	39.9	52.8	**0.756**
14	2.7	2.8	39.9	52.8	**0.756**
15	2.8	2.9	39.9	53.1	**0.751**
16	2.9	3.0	39.9	53.4	**0.747**
17	3.0	3.1	39.9	53.6	**0.744**
18	3.1	3.2	39.9	53.8	**0.742**
19	3.2	3.3	39.9	53.9	**0.740**
20	3.3	3.5	39.9	54.1	**0.738**
21	3.4	3.6	39.9	54.5	**0.732**
22	3.5	3.7	39.9	54.7	**0.729**
23	3.6	3.8	39.9	55	**0.725**
24	3.7	3.9	39.9	55.2	**0.723**
25	3.8	4.0	39.9	55.4	**0.720**
26	3.9	4.1	39.9	55.8	**0.715**
27	4.0	4.2	39.9	56	**0.713**
28	4.1	4.4	39.9	56.2	**0.710**
29	4.2	4.5	39.9	56.4	**0.707**
30	4.3	4.6	39.9	56.8	**0.702**
31	4.4	4.7	39.9	57.3	**0.696**
32	4.5	4.8	39.9	57.4	**0.695**
33	4.6	4.9	39.9	57.7	**0.692**

Appendix VI

Effect of change in anterior tooth thickness on inter-arch ratios. Smaller tooth widths.

Simulation	Tooth Thickness Centrals (mm)	Tooth Thickness Laterals (mm)	Anterior Mn Sum (mm)	Anterior Mx Sum (mm)	Anterior Sum Mn/Sum Mx
1	1.4	1.4	31.2	39.6	**0.788**
2	1.5	1.5	31.2	39.7	**0.786**
3	1.6	1.6	31.2	39.8	**0.784**
4	1.7	1.7	31.2	39.9	**0.782**
5	1.8	1.8	31.2	40.2	**0.776**
6	1.9	1.9	31.2	40.3	**0.774**
7	2.0	2.0	31.2	40.4	**0.772**
8	2.1	2.1	31.2	40.5	**0.770**
9	2.2	2.2	31.2	40.5	**0.770**
10	2.3	2.4	31.2	40.8	**0.765**
11	2.4	2.5	31.2	40.8	**0.765**
12	2.5	2.6	31.2	41.1	**0.759**
13	2.6	2.7	31.2	41.2	**0.757**
14	2.7	2.8	31.2	41.3	**0.755**
15	2.8	2.9	31.2	41.6	**0.750**
16	2.9	3.0	31.2	41.6	**0.750**
17	3.0	3.1	31.2	41.7	**0.748**
18	3.1	3.3	31.2	42	**0.743**
19	3.2	3.4	31.2	42.3	**0.738**
20	3.3	3.5	31.2	42.4	**0.736**
21	3.4	3.6	31.2	42.5	**0.734**
22	3.5	3.7	31.2	42.7	**0.731**
23	3.6	3.8	31.2	42.8	**0.729**
24	3.7	3.9	31.2	43	**0.726**
25	3.8	4.0	31.2	43.4	**0.719**
26	3.9	4.1	31.2	43.4	**0.719**
27	4.0	4.3	31.2	43.8	**0.712**
28	4.1	4.4	31.2	43.8	**0.712**
29	4.2	4.5	31.2	44.1	**0.707**
30	4.3	4.6	31.2	44.2	**0.706**
31	4.4	4.7	31.2	44.3	**0.704**
32	4.5	4.8	31.2	44.8	**0.696**
33	4.6	4.9	31.2	45	**0.693**

Appendix VII

Effect of change in anterior tooth thickness on inter-arch ratios. Average of all simulations.

Simulation	Tooth Thickness Centrals (mm)	Tooth Thickness Laterals (mm)	Anterior Mn Sum (mm)	Anterior Mx Sum (mm)	Anterior Sum Mn/Sum Mx
1	1.4	1.4	35.8	45.5	0.787
2	1.5	1.5	35.8	45.6	0.785
3	1.7	1.6	35.8	45.7	0.784
4	1.8	1.7	35.8	45.9	0.781
5	1.9	1.8	35.8	46.1	0.778
6	2.0	1.9	35.8	46.3	0.774
7	2.0	2.0	35.8	46.3	0.773
8	2.2	2.2	35.8	46.5	0.770
9	2.3	2.3	35.8	46.6	0.770
10	2.4	2.4	35.8	46.9	0.765
11	2.5	2.5	35.8	47.0	0.763
12	2.6	2.6	35.8	47.2	0.759
13	2.7	2.7	35.8	47.3	0.758
14	2.8	2.8	35.8	47.5	0.755
15	2.9	2.9	35.8	47.7	0.752
16	3.0	3.0	35.8	47.9	0.748
17	3.1	3.2	35.8	48.0	0.747
18	3.2	3.3	35.8	48.3	0.742
19	3.3	3.4	35.8	48.4	0.740
20	3.4	3.5	35.8	48.6	0.737
21	3.5	3.6	35.8	48.8	0.734
22	3.6	3.7	35.8	49.1	0.730
23	3.7	3.8	35.8	49.3	0.727
24	3.8	3.9	35.8	49.5	0.724
25	3.9	4.1	35.8	49.8	0.720
26	4.0	4.2	35.8	50.0	0.717
27	4.1	4.3	35.8	50.3	0.712
28	4.2	4.4	35.8	50.4	0.711
29	4.3	4.5	35.8	50.7	0.707
30	4.4	4.6	35.8	50.9	0.704
31	4.5	4.7	35.8	51.2	0.700
32	4.6	4.9	35.8	51.5	0.696

Appendix VIII

Measuring the accuracy of the Bolton ratio on a patient sample

	Patient Measurements				Simulation Measurements		Comparison with Bolton ratios	
Patient	Anterior Mx Sum (mm)	Anterior Mn Sum (mm)	Thickness Centrals (mm)	Thickness Laterals (mm)	Ideal Anterior Mx Sum (mm)	Discrepancy in Sum	Bolton Mx Sum	Discrepancy in Sum
1	50.2	39.2	4.1	4.0	53.4	3.2	50.8	2.6
2	50.7	39.9	3.6	2.8	53.6	2.9	51.7	1.9
3	51.7	39.6	4.4	3.8	55.6	3.9	51.3	4.3
4	51.1	41.8	4.3	2.6	56.8	5.7	54.1	2.7
5	50.3	38.6	3.6	3.0	52.1	1.8	50.0	2.1
6	49.5	38.6	4.1	3.5	54.4	4.9	50.0	4.4
7	47	35.6	3.9	3.4	50.3	3.3	46.1	4.2
8	50.2	37.8	4.1	3.1	51.4	1.2	49.0	2.4
9	43.3	34.9	3.4	2.7	46.7	3.4	45.2	1.5
10	51.7	40.5	3.8	3.1	55.2	3.5	52.5	2.7
11	46.6	36.7	4.4	2.7	49.7	3.1	47.5	2.2
12	45.9	35.9	3.1	2.7	48.8	2.9	46.5	2.3
13	48.6	36.6	1.9	1.9	47.8	-0.8	47.4	0.4
14	50.4	37.5	3.6	3.5	50.8	0.4	48.6	2.2
15	50.8	39.2	3.0	2.9	55.2	4.4	50.8	4.4
16	50.5	39.2	3.1	2.8	53.1	2.6	50.8	2.3
17	50.7	39.4	4.3	2.4	53.6	2.9	51.0	2.6
18	42.6	35.4	3.1	3.4	47.9	5.3	45.9	2.0
19	46.4	36.8	3.0	2.3	49	2.6	47.7	1.3
20	49.9	37.8	3.2	2.5	51.6	1.7	49.0	2.6
21	49.2	40.2	4.3	3.2	53	3.8	52.1	0.9
22	42.1	33.6	2.4	2.8	43.9	1.8	43.5	0.4
23	46.7	38.2	3.8	2.4	51.3	4.6	49.5	1.8
24	49.8	38.9	4.1	3.1	51.8	2	50.4	1.4
25	47.7	38.5	3.5	2.0	50.9	3.2	49.9	1.0

Patient	Anterior Mx Sum (mm)	Anterior Mn Sum (mm)	Thickness Centrals (mm)	Thickness Laterals (mm)	Ideal Anterior Mn Sum (mm)	Discrepancy in Sum	Bolton Mn Sum	Discrepancy in Sum
26	49.4	39.3	4.1	3.7	35.8	-3.5	38.1	-2.3
27	51.4	40.1	4.0	3.1	37.4	-2.7	39.7	-2.3
28	48.7	39.2	3.2	2.9	36.8	-2.4	37.6	-0.8
29	51	40.1	3.6	3.5	38.6	-1.5	39.4	-0.8
30	52.4	40.6	3.3	3.0	38.7	-1.9	40.5	-1.8
31	47.7	31.9	4.3	3.3	35.2	3.3	36.8	-1.6
32	47.7	38.1	3.9	3.0	33.7	-4.4	36.8	-3.1
33	51.5	40.4	3.2	2.9	36.8	-3.6	39.8	-3.0
34	43	33	2.9	2.4	31	-2	33.2	-2.2
35	47.6	39	2.5	2.6	35.3	-3.7	36.7	-1.4
36	49.3	38.4	4.2	3.4	35.2	-3.2	38.1	-2.9
37	56	42.7	3.5	2.4	42.7	0	43.2	-0.5
38	47.6	37.1	2.5	2.6	36.1	-1	36.7	-0.6
39	49.8	38.5	3.0	2.2	37.1	-1.4	38.4	-1.3
40	46.7	37	3.3	2.7	34.3	-2.7	36.1	-1.8
41	49.1	38.5	3.8	3.5	35.1	-3.4	37.9	-2.8
42	50.4	37.6	3.4	2.2	37.7	0.1	38.9	-1.2
43	49.8	38.4	4.8	3.9	36.7	-1.7	38.4	-1.7
44	47.2	36.9	2.8	2.4	35.2	-1.7	36.4	-1.2
45	49.3	39.3	4.7	3.5	35.9	-3.4	38.1	-2.2
46	50.4	37.8	3.0	2.4	38.1	0.3	38.9	-0.8
47	48.1	37	2.3	2.4	35.5	-1.5	37.1	-1.6
48	52	42.4	4.4	3.5	37	-5.4	40.1	-3.1
49	45.7	35.6	3.2	2.9	33.8	-1.8	35.3	-1.5
50	53.5	42.8	4.7	3.7	38.8	-4	41.3	-2.5

Appendix IX

Discrepancy in Maxillary anterior sum

Median (mm)	2.22
Average (mm)	2.27
Range Min (mm)	0.38
Range Max (mm)	4.42

Discrepancy in Mandibular anterior sum

Median (mm)	-1.75
Average (mm)	-1.81
Range Min (mm)	-3.14
Range Max (mm)	-0.53

Appendix X

Measuring accuracy of the thickness-adjusted ratios (centrals) on a patient sample

	Paiient Measurements				Simulation Measurements		Comparison with thickness-adjusted ratios (centrals)		
Patient	Anterior Mx Sum (mm)	Anterior Mn Sum (mm)	Thickness Centrals (mm)	Thickness Laterals (mm)	Ideal Anterior Mx Sum (mm)	Discrepancy in Sum	Thickness-adj. Ratio	New Mx Sum	Discrepancy in Sum
1	50.2	39.2	4.1	4.0	53.4	3.2	0.71	55.1	-1.7
2	50.7	39.9	3.6	2.8	53.6	2.9	0.73	54.7	-1.1
3	51.7	39.6	4.4	3.8	55.6	3.9	0.70	56.3	-0.7
4	51.1	41.8	4.3	2.6	56.8	5.7	0.71	59.1	-2.3
5	50.3	38.6	3.6	3.0	52.1	1.8	0.73	52.9	-0.8
6	49.5	38.6	4.1	3.5	54.4	4.9	0.71	54.2	0.2
7	47	35.6	3.9	3.4	50.3	3.3	0.72	49.4	0.9
8	50.2	37.8	4.1	3.1	51.4	1.2	0.71	53.1	-1.7
9	43.3	34.9	3.4	2.7	46.7	3.4	0.74	47.4	-0.7
10	51.7	40.5	3.8	3.1	55.2	3.5	0.72	55.9	-0.7
11	46.6	36.7	4.4	2.7	49.7	3.1	0.70	52.1	-2.4
12	45.9	35.9	3.1	2.7	48.8	2.9	0.75	48.1	0.7
13	48.6	36.6	1.9	1.9	47.8	-0.8	0.78	47.0	0.8
14	50.4	37.5	3.6	3.5	50.8	0.4	0.73	51.4	-0.6
15	50.8	39.2	3.0	2.9	55.2	4.4	0.75	52.4	2.8
16	50.5	39.2	3.1	2.8	53.1	2.6	0.75	52.5	0.6
17	50.7	39.4	4.3	2.4	53.6	2.9	0.71	55.7	-2.1
18	42.6	35.4	3.1	3.4	47.9	5.3	0.75	47.4	0.5
19	46.4	36.8	3.0	2.3	49	2.6	0.75	49.2	-0.2
20	49.9	37.8	3.2	2.5	51.6	1.7	0.74	50.9	0.7
21	49.2	40.2	4.3	3.2	53	3.8	0.71	56.9	-3.9
22	42.1	33.6	2.4	2.8	43.9	1.8	0.77	43.9	0.0
23	46.7	38.2	3.8	2.4	51.3	4.6	0.72	52.8	-1.5
24	49.8	38.9	4.1	3.1	51.8	2	0.71	54.6	-2.8
25	47.7	38.5	3.5	2.0	50.9	3.2	0.73	52.5	-1.6

Patient	Anterior Mx Sum (mm)	Anterior Mn Sum (mm)	Thickness Centrals (mm)	Thickness Laterals (mm)	Ideal Anterior Mn Sum (mm)	Discrepancy in Sum	Thickness-adj. Ratio	New Mn Sum	Discrepancy in Sum
26	49.4	39.3	4.1	3.7	35.8	-3.5	0.71	35.2	0.6
27	51.4	40.1	4.0	3.1	37.4	-2.7	0.72	36.9	0.5
28	48.7	39.2	3.2	2.9	36.8	-2.4	0.74	36.1	0.7
29	51	40.1	3.6	3.5	38.6	-1.5	0.73	37.2	1.4
30	52.4	40.6	3.3	3.0	38.7	-1.9	0.74	38.8	-0.1
31	47.7	31.9	4.3	3.3	35.2	3.3	0.71	33.7	1.5
32	47.7	38.1	3.9	3.0	33.7	-4.4	0.72	34.3	-0.6
33	51.5	40.4	3.2	2.9	36.8	-3.6	0.74	38.2	-1.4
34	43	33	2.9	2.4	31	-2	0.75	32.3	-1.3
35	47.6	39	2.5	2.6	35.3	-3.7	0.76	36.3	-1.0
36	49.3	38.4	4.2	3.4	35.2	-3.2	0.71	35.1	0.1
37	56	42.7	3.5	2.4	42.7	0	0.73	41.1	1.6
38	47.6	37.1	2.5	2.6	36.1	-1	0.76	36.3	-0.2
39	49.8	38.5	3.0	2.2	37.1	-1.4	0.75	37.3	-0.2
40	46.7	37	3.3	2.7	34.3	-2.7	0.74	34.6	-0.3
41	49.1	38.5	3.8	3.5	35.1	-3.4	0.72	35.5	-0.4
42	50.4	37.6	3.4	2.2	37.7	0.1	0.74	37.1	0.6
43	49.8	38.4	4.8	3.9	36.7	-1.7	0.69	34.5	2.2
44	47.2	36.9	2.8	2.4	35.2	-1.7	0.76	35.6	-0.4
45	49.3	39.3	4.7	3.5	35.9	-3.4	0.69	34.1	1.8
46	50.4	37.8	3.0	2.4	38.1	0.3	0.75	37.7	0.4
47	48.1	37	2.3	2.4	35.5	-1.5	0.77	37.0	-1.5
48	52	42.4	4.4	3.5	37	-5.4	0.70	36.6	0.4
49	45.7	35.6	3.2	2.9	33.8	-1.8	0.74	33.9	-0.1
50	53.5	42.8	4.7	3.7	38.8	-4	0.69	37.0	1.8

Appendix XI

Discrepancy in Maxillary sum

Median (mm)	-0.65
Average (mm)	-0.70
Range Min (mm)	-3.86
Range Max (mm)	2.79

Discrepancy in Mandibular sum

Median (mm)	0.15
Average (mm)	0.24
Range Min (mm)	-1.54
Range Max (mm)	2.24

Appendix XII

Measuring accuracy of the thickness-adjusted ratios (laterals) on a patient sample

	Paiient Measurements				Simulation Measurements		Comparison with thickness-adjusted ratios (laterals)		
Patient	Anterior Mx Sum (mm)	Anterior Mn Sum (mm)	Thickness Centrals (mm)	Thickness Laterals (mm)	Ideal Anterior Mx Sum (mm)	Discrepancy in Sum	Thickness-adj. Ratio	New Mx Sum	Discrepancy in Sum
1	50.2	39.2	4.1	4.0	53.4	3.2	0.72	54.1	-0.7
2	50.7	39.9	3.6	2.8	53.6	2.9	0.76	52.8	0.8
3	51.7	39.6	4.4	3.8	55.6	3.9	0.73	54.5	1.1
4	51.1	41.8	4.3	2.6	56.8	5.7	0.76	54.8	2.0
5	50.3	38.6	3.6	3.0	52.1	1.8	0.75	51.6	0.5
6	49.5	38.6	4.1	3.5	54.4	4.9	0.74	52.4	2.0
7	47	35.6	3.9	3.4	50.3	3.3	0.74	48.1	2.2
8	50.2	37.8	4.1	3.1	51.4	1.2	0.75	50.5	0.9
9	43.3	34.9	3.4	2.7	46.7	3.4	0.76	46.0	0.7
10	51.7	40.5	3.8	3.1	55.2	3.5	0.75	54.2	1.0
11	46.6	36.7	4.4	2.7	49.7	3.1	0.76	48.4	1.3
12	45.9	35.9	3.1	2.7	48.8	2.9	0.76	47.4	1.4
13	48.6	36.6	1.9	1.9	47.8	-0.8	0.77	47.3	0.5
14	50.4	37.5	3.6	3.5	50.8	0.4	0.74	50.9	-0.1
15	50.8	39.2	3.0	2.9	55.2	4.4	0.75	52.1	3.1
16	50.5	39.2	3.1	2.8	53.1	2.6	0.76	51.9	1.2
17	50.7	39.4	4.3	2.4	53.6	2.9	0.77	51.5	2.1
18	42.6	35.4	3.1	3.4	47.9	5.3	0.74	47.8	0.1
19	46.4	36.8	3.0	2.3	49	2.6	0.77	47.8	1.2
20	49.9	37.8	3.2	2.5	51.6	1.7	0.76	49.5	2.1
21	49.2	40.2	4.3	3.2	53	3.8	0.75	53.9	-0.9
22	42.1	33.6	2.4	2.8	43.9	1.8	0.76	44.5	-0.6
23	46.7	38.2	3.8	2.4	51.3	4.6	0.77	49.9	1.4
24	49.8	38.9	4.1	3.1	51.8	2	0.75	52.0	-0.2
25	47.7	38.5	3.5	2.0	50.9	3.2	0.77	49.8	1.1

Patient	Anterior Mx Sum (mm)	Anterior Mn Sum (mm)	Thickness Centrals (mm)	Thickness Laterals (mm)	Ideal Anterior Mn Sum (mm)	Discrepancy in Sum	Thickness-adj. Ratio	New Mn Sum	Discrepancy in Sum
26	49.4	39.3	4.1	3.7	35.8	-3.5	0.73	36.1	-0.3
27	51.4	40.1	4.0	3.1	37.4	-2.7	0.75	38.4	-1.0
28	48.7	39.2	3.2	2.9	36.8	-2.4	0.75	36.6	0.2
29	51	40.1	3.6	3.5	38.6	-1.5	0.74	37.6	1.0
30	52.4	40.6	3.3	3.0	38.7	-1.9	0.75	39.2	-0.5
31	47.7	31.9	4.3	3.3	35.2	3.3	0.74	35.4	-0.2
32	47.7	38.1	3.9	3.0	33.7	-4.4	0.75	35.7	-2.0
33	51.5	40.4	3.2	2.9	36.8	-3.6	0.75	38.5	-1.7
34	43	33	2.9	2.4	31	-2	0.77	32.9	-1.9
35	47.6	39	2.5	2.6	35.3	-3.7	0.76	36.1	-0.8
36	49.3	38.4	4.2	3.4	35.2	-3.2	0.74	36.5	-1.3
37	56	42.7	3.5	2.4	42.7	0	0.77	42.8	-0.1
38	47.6	37.1	2.5	2.6	36.1	-1	0.76	36.1	0.0
39	49.8	38.5	3.0	2.2	37.1	-1.4	0.77	38.3	-1.2
40	46.7	37	3.3	2.7	34.3	-2.7	0.76	35.4	-1.1
41	49.1	38.5	3.8	3.5	35.1	-3.4	0.74	36.2	-1.1
42	50.4	37.6	3.4	2.2	37.7	0.1	0.77	38.8	-1.1
43	49.8	38.4	4.8	3.9	36.7	-1.7	0.72	36.1	0.6
44	47.2	36.9	2.8	2.4	35.2	-1.7	0.77	36.1	-0.9
45	49.3	39.3	4.7	3.5	35.9	-3.4	0.74	36.3	-0.4
46	50.4	37.8	3.0	2.4	38.1	0.3	0.77	38.6	-0.5
47	48.1	37	2.3	2.4	35.5	-1.5	0.77	36.8	-1.3
48	52	42.4	4.4	3.5	37	-5.4	0.74	38.3	-1.3
49	45.7	35.6	3.2	2.9	33.8	-1.8	0.75	34.4	-0.6
50	53.5	42.8	4.7	3.7	38.8	-4	0.73	39.1	-0.3

Appendix XIII

Discrepancy in Maxillary sum

Median (mm)	1.09
Average (mm)	0.96
Range Min (mm)	-0.89
Range Max (mm)	3.07

Discrepancy in Mandibular sum

Median (mm)	-0.83
Average (mm)	-0.71
Range Min (mm)	-1.98
Range Max (mm)	1.01