ORIGINAL ARTICLE
AJO-DO

The influence of labiolingual and mesiodistal anterior tooth dimensions on interarch relationships: A modified anterior Bolton analysis

Yelena Akselrod Beygelman,[a] Roozbeh Khosravi,[a] Mohamed Masoud,[b] David Turpin,[a] and Anne-Marie Bollen[a]
Seattle, Wash, and Boston, Mass

Introduction: Tooth size and morphology of anterior teeth influence interarch relationships. The Bolton analysis uses tooth width to calculate a sum of mandibular to maxillary tooth width ratios 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 labioligual thickness as well as mesiodistal width of anterior teeth. **Methods:** The role of tooth thickness in interarch relationships was studied using simulations in a 3D modeling software (Suresmile). To develop a new chart of interarch 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 2 mm if the overall tooth width of the dentition increases and the interarch anterior ratio is maintained. The thickness-adjusted anterior mandibular to maxillary tooth ratio ranges from 0.70-0.79 depending on the tooth thickness. This thickness-adjusted ratio provides a superior prediction for the sum of anterior tooth width compared with the Bolton analysis. **Conclusion:** Tooth thickness affects interarch 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. (Am J Orthod Dentofacial Orthop 2019;156:727-34)

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 mesiodistal 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.[1] 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.

[a]Department of Orthodontics, School of Dentistry, University of Washington, Seattle, Wash.
[b]Department of Orthodontics, School of Dentistry Medicine, Harvard, Boston, Mass
The research was funded by the Department of Orthodontics and Orthodontic Alumni of the University of Washington.
Address correspondence to: Yelena Askelrod Beygelman, Department of Orthodontics, School of Dentistry, University of Washington, Seattle, WA 98195; e-mail, yakselro@uw.edu.
Submitted, July 2018; revised and accepted, November 2018.
0889-5406/$36.00

https://doi.org/10.1016/j.ajodo.2018.11.020

Bolton also noted that extreme anterior labiolingual thickness is rare and may require a larger maxillary anterior sum.[2] 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.[3-5] On the other hand, the mean anterior ratio was found to be significantly greater than Bolton's among Indian, Black, and Hispanic populations.[6,7] 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 intermaxillary relationships.[1,8,9]

White females with ideal occlusion comprised the sample population for Bolton's study. The models displayed a mean overjet of 0.74 mm, suggesting that these subjects were representative of thinner teeth in the labiolingual 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 labiolingual dimension than in the mesiodistal dimensions between populations.[10] Furthermore, marginal ridge thickness of anterior teeth was analyzed in a study of 120 pretreatment 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, nonwhites show higher frequency of thicker marginal ridges than whites, and there is a high correlation between marginal ridge thickness and the Bolton index.[11] 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[9] evaluated the influence of tooth thickness on the interarch 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 the maxillary and mandibular 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 mandibular to maxillary teeth that accounts for the labiolingual thickness. The proposed formula states that, if the average anterior tooth thickness is < 2.75 mm, then the predicted ideal interarch anterior ratio can be calculated by the following formula:

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

If anterior tooth thickness is ≥ 2.75 mm, 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 than Bolton's error of 1.29 ± 0.81.[9] 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.[12] These software technologies can be useful in comparing various treatment plans[13] 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 labiolingual thickness and mesiodistal 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.

MATERIAL AND METHODS

Overall, maxillary incisor thickness can be defined as the distance from the labial surface of the maxillary incisor to the lingual point of contact with the mandibular 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 (Fig 1).

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 (Viade Products, Camarillo, Calif). This model was first scanned into digital form using Ortho Insight 3D (MotionView, Hixson, Tenn), and then imported into Suresmile (OraMetrix, Richardson, Tex), 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 mesiodistal widths. Class I canine relationship was defined by mesial and distal contact on the maxillary canines. Overbite was adjusted to 2 mm for the central incisors and 1.5 mm for the lateral incisors, with an overjet of 2-3 mm. Light occlusal contact was present on each anterior tooth, as well as the interproximal contact.

The first set of simulations evaluated how changes in mesiodistal tooth width of the maxillary anterior teeth affect their buccolingual tooth thickness necessary to maintain ideal occlusion. The tooth widths of central incisors, lateral incisors, and canines were changed on the typodont model, and the ideal thickness associated with the maxillary central incisors and lateral incisors was measured. For each simulation, the mandibular incisor 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.[14-16] Based

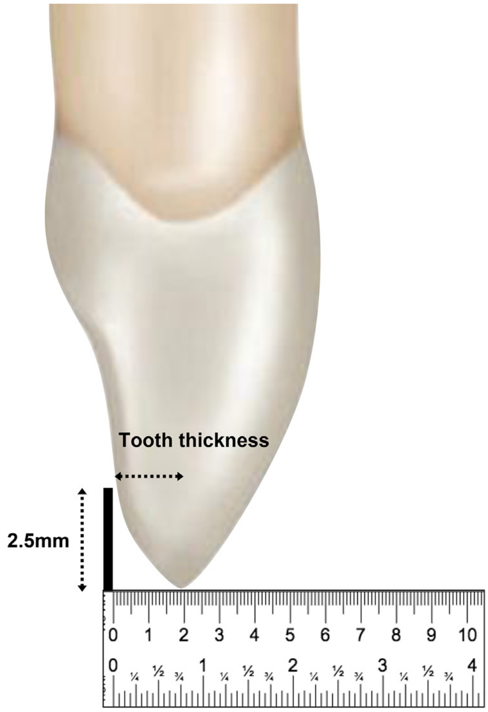

Fig 1. Custom ruler measuring tooth thickness.

on the findings, the tooth width of both maxillary and mandibular incisors was changed by an increment of 2% in each simulation. A total of 15 simulations were produced, ranging from 84%-118% of the average tooth width. At the 2-standard deviations boundaries, 84% and 118% sizes served as the 2 extremes.[14-16] 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 2 mm. For teeth with a thickness of <2 mm, the occlusion would be minimally affected.

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 with average tooth widths was used. 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) + (interproximal spaces produced by labial movement)

or

(Sum of anterior dental widths)−(interproximal 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 118% 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.

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 patients the width of the maxillary anterior teeth was adjusted, and in the next 25 patients 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 thicknesses and widths. Each cast was scanned into Suresmile and adjusted to proper occlusion. In the first 25 models, the mandibular anterior dentition was aligned ideally with interproximal contact. The maxillary teeth were aligned to the mandibular teeth, with canines in a Class

Table I. The effect of changing tooth width on tooth thickness

Simulation	Tooth width (%)	Width maxillary canines (mm)	Width maxillary lateral incisors (mm)	Width maxillary central incisors (mm)	Width mandibular canines (mm)	Width mandibular lateral incisors (mm)	Width mandibular central incisors (mm)
1	84	6.55	5.80	7.39	5.80	4.96	4.54
2	86	6.71	5.93	7.57	5.93	5.07	4.64
3	88	6.86	6.07	7.74	6.07	5.19	4.75
4	90	7.02	6.21	7.92	6.21	5.31	4.86
5	92	7.18	6.35	8.10	6.35	5.43	4.97
6	94	7.33	6.49	8.27	6.49	5.55	5.08
7	96	7.49	6.62	8.45	6.62	5.66	5.18
8	98	7.64	6.76	8.62	6.76	5.78	5.29
9	100	7.80	6.90	8.80	6.90	5.90	5.40
10	102	7.96	7.04	8.98	7.04	6.02	5.51
11	104	8.11	7.18	9.15	7.18	6.14	5.62
12	106	8.27	7.31	9.33	7.31	6.25	5.72
13	108	8.42	7.45	9.50	7.45	6.37	5.83
14	110	8.58	7.59	9.68	7.59	6.49	5.94
15	118*	9.20	8.14	10.38	8.14	6.96	6.37

*Tooth width 2 standard deviations above average.

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

RESULTS

Fifteen simulations were prepared with tooth widths ranging from 84%-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 I). It appears that if the interarch ratio remains the same, then increasing tooth widths does not have significant effect on tooth thickness.

Thirty-two simulations were prepared using the Hamaguchi typodont with average tooth widths. Tooth thickness ranged from 1.4-4.9 mm in increments of 0.1 mm. The resulting maxillary anterior sum ranged from 46.2-52.3 mm. As tooth thickness increased, the maxillary anterior arch length increased. The sum of the anterior maxillary arch increased by 1.96 mm for every millimeter of tooth thickness of the central incisors. The sum of the maxillary arch increased by 1.75 mm for every millimeter of tooth thickness of the lateral incisors (Fig 2, *A* and *B*). The resulting ratio of mandibular anterior arch length to maxillary anterior arch length ranged from 0.70-0.79 (Appendix IV).

Thirty-three simulations were repeated on a typodont with tooth widths greater than the average. The resulting maxillary anterior sum ranged from 50.8-57.7 mm. The anterior maxillary arch length increased by 2.2 mm for every millimeter of tooth thickness of the central incisors. The arch length increased by 1.9 mm for every millimeter of tooth thickness of the lateral incisors (Fig 3, *A* and *B*). The resulting ratio of mandibular anterior arch length to maxillary anterior arch length ranged from 0.70-0.79 (Appendix V).

Thirty-three simulations were repeated with tooth widths smaller than average. The resulting maxillary anterior sum ranged from 39.6-45 mm. The anterior maxillary arch length increased by 1.6 mm for every millimeter of tooth thickness of the central incisors. The arch length increased by 1.6 mm for every millimeter of tooth thickness of the lateral incisors (Fig 4, *A* and *B*). The resulting ratio of mandibular anterior arch length to maxillary anterior arch length ranged from 0.70-0.79 (Appendix VI).

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

Evaluating the Thickness-Adjusted Ratios on Patients

A sample of 50 pretreatment patient models was collected from a University Orthodontic department and

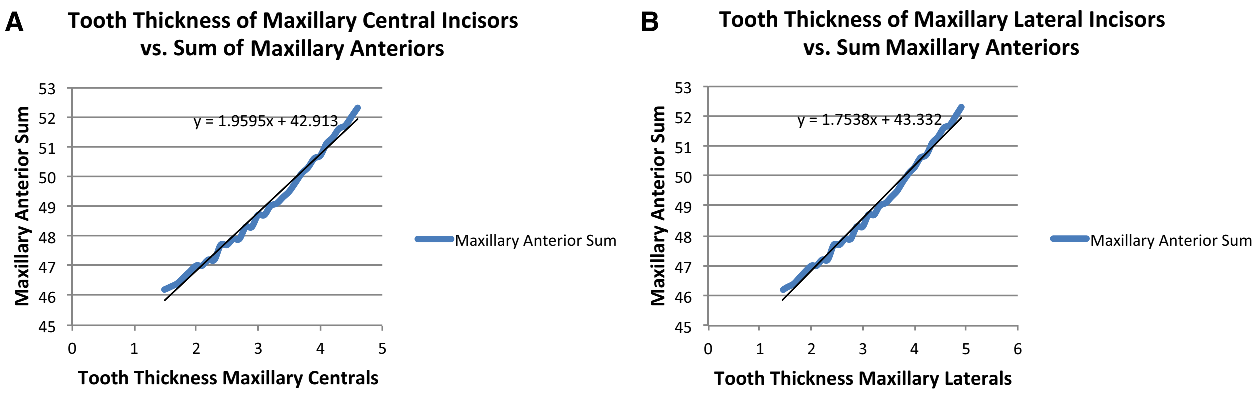

Fig 2. Relationship of (**A**) maxillary central incisor thickness and (**B**) maxillary lateral incisor thickness to maxillary anterior sum (average tooth width).

faculty private offices. Treatment simulations were made to an ideal occlusion. In the first 25 patients, the maxillary anterior sum was adjusted to accommodate occlusion. Thus, the ideal maxillary anterior sums were compared with that predicted by Bolton (Appendix VIII), the thickness-adjusted ratios referencing maxillary central incisors (Appendix X) and maxillary lateral incisors (Appendix XII). In the next 25 patients, the mandibular anterior sum was adjusted to accommodate the occlusion. Thus, the ideal mandibular anterior sums were compared with that predicted by Bolton and the thickness-adjusted ratios. The average discrepancy of the Bolton was 2.3 mm in the maxillary arch and 1.8 mm in mandibular arch (Appendix IX). The average discrepancy of the thickness-adjusted ratio based on maxillary central incisors was 0.7 mm in the maxillary arch and 0.2 mm in the mandibular arch (Appendix XI). The average discrepancy of the new ratio based on maxillary lateral incisors was 1.0 mm in the maxillary arch and 0.7 mm in the mandibular arch (Appendix XII, Tables III and IV).

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 2 mm. 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 0.7 mm, significantly smaller than the average today. His white female patient sample may have had narrower teeth. Overall, the findings suggest that tooth thickness >2 mm may affect the occlusion.

The next set of simulations evaluated the effect of changing tooth thickness beyond 2 mm. When maxillary incisor 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.

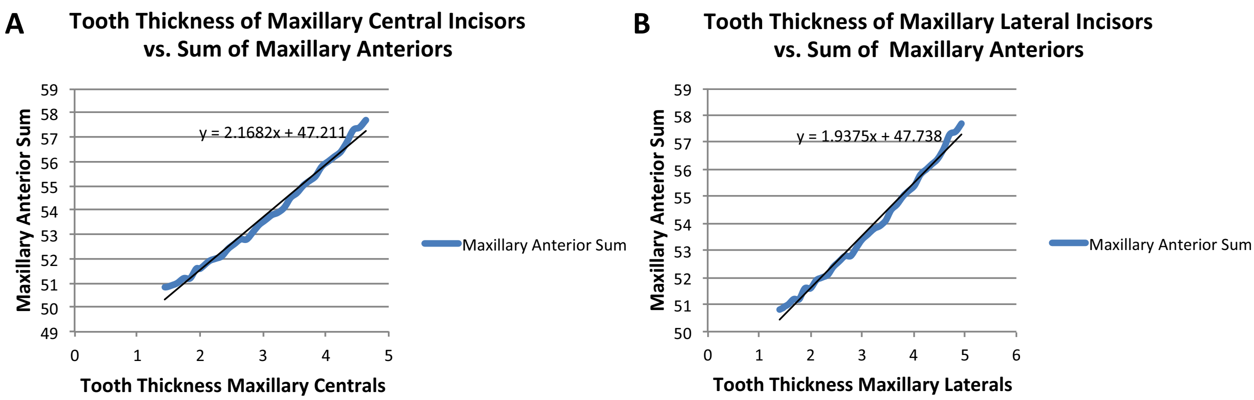

Fig 3. Relationship of (**A**) maxillary central incisor thickness and (**B**) maxillary lateral incisor thickness to maxillary anterior sum (wider tooth width).

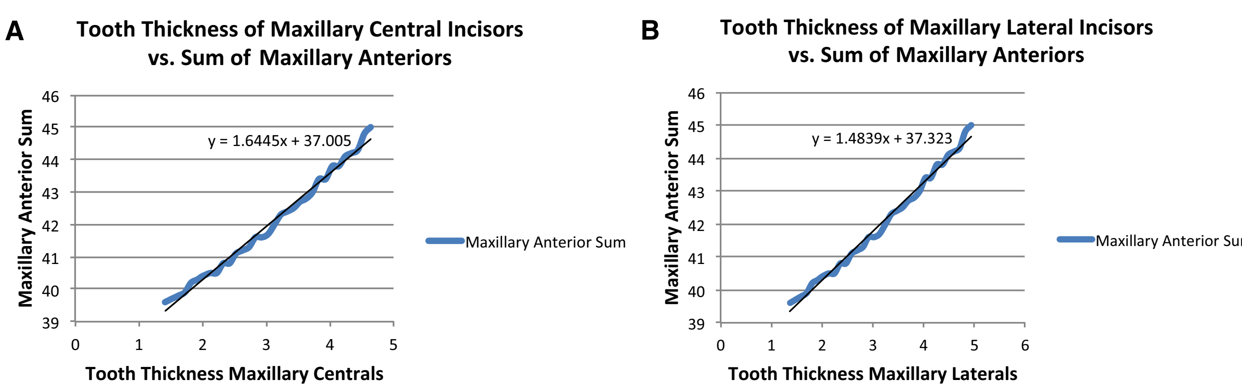

Fig 4. Relationship of (**A**) maxillary central incisor thickness and (**B**) maxillary lateral incisor thickness to maxillary anterior sum (narrower tooth width).

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 3 scenarios. It is therefore logical that, in wider teeth, increasing tooth thickness demands slightly greater amount of increase in tooth width compared with the change necessary in average teeth. Similarly, dentitions with average tooth width demand a slightly greater change in width compared with 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 central incisors 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 2.3 mm less than the sum necessary, whereas the thickness-adjusted ratio on average predicted a maxillary sum 0.7 mm 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 incisors 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 2.5 mm from the incisal edge (Fig 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 cone beam computed tomography. To address this issue, tooth inclination was adjusted based on lateral cephalographs

Table II. Thickness-adjusted anterior mandibular/maxillary ratios

Tooth thickness central incisors (mm)	*Mandibular/maxillary anterior sum (mm)*
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

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 central incisors and lateral incisors are uniform, whereas clinically there may be variation in morphology, such as the presence of barrel-shaped lateral incisors. 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.

In clinical practice, the thickness-adjusted ratio can be used in a similar fashion as the current use of the Bolton analysis. The addition of the incisor thickness to the calculation of the Bolton ratio provides a more accurate estimation of the relationship and potential discrepancy between the maxillary and mandibular anterior teeth. This is helpful in treatment planning as well an in preparation for potential adjustments of the anterior teeth during finishing.

Table III. Discrepancies in maxillary anterior width sum

Discrepancy	*Bolton ratio*	*Thickness-adj ratio (central incisors)*	*Thickness-adj ratio (lateral incisors)*
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 IV. Discrepancies in mandibular anterior width sum

Discrepancy	*Bolton ratio*	*Thickness-adj ratio (central incisors)*	*Thickness-adj ratio (lateral incisors)*
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

CONCLUSIONS

Findings of the 3D simulations suggest that maxillary incisor thickness does affect occlusion and interarch 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 0.70-0.79 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 with sums calculated by the Bolton ratio. Therefore, a thickness-adjusted ratio can be used in dentitions with variation in maxillary anterior tooth thickness.

ACKNOWLEDGMENTS

Thank you to the University of Washington Department of Orthodontics, and the University of Washington Orthodontic Alumni for their support.

SUPPLEMENTARY DATA

Supplementary data associated with this article can be found, in the online version, at https://doi.org/10.1016/j.ajodo.2018.11.020.

REFERENCES

1. Bolton WA. Disharmony in tooth size and its relation to the analysis and treatment of malocclusion. Angle Orthod 1958;28:113-30.
2. Bolton WA. The clinical application of a tooth-size analysis. Am J Orthod 1962;48:504-29.

3. Nourallah AW, Splieth CH, Schwahn C, Khurdaji M. Standardizing interarch tooth-size harmony in a Syrian population. Angle Orthod 2005;75:996-9.
4. Al-Tamimi T, Hashim HA. Bolton tooth-size ratio revisited. World J Orthod 2005;6:289-95.
5. Kachoei M, Ahangar-Atashi MH, Pourkhamneh S. Bolton's intermaxillary tooth size ratios among Iranian schoolchildren. Med Oral Patol Oral Cir Bucal 2011;16:e568-72.
6. Subbarao VV, Regalla RR, Santi V, Anita G, Kattimani VS. Interarch tooth size relationship of Indian population: does Bolton's Analysis apply? J Contemp Dent Pract 2014;15:103-7.
7. Smith SS, Buschang PH, Watanabe E. Interarch tooth size relationships of 3 populations: "Does Bolton's Analysis apply? Am J Orthod Dentofacial Orthop 2000;117:169-74.
8. Alamir G. Revisiting bolton analysis using American Board of Orthodontics cast models [thesis]. University of Illinois at Chicago 2013.
9. Rudolph DJ, Dominguez PD, Ahn K, Thinh T. The use of tooth thickness in predicting intermaxillary tooth-size discrepancies. Angle Orthod 1998;68:133-8: discussion 139.
10. Bishara SE, Jakobsen JR, Abdallah EM, Fernandez Garcia AF. Comparisons of mesiodistal and buccolingual crown dimensions of the permanent teeth in three populations from Egypt, Mexico, and the United States. Am J Orthod Dentofacial Orthop 1989;96:416-22.
11. Foster M. Marginal ridge thickness (MRT) of maxillary incisors. Available at: http://epublications.marquette.edu/cgi/viewcontent.cgi?article=1091&context=theses_open; 2011.
12. Favero L, Terrazzani C, Favero V, Stellini E, Cocilovo F. Virtual study models: a comparison of modular application systems. Prog Orthod 2009;10:16-25.
13. Hou D. The effect of digital diagnostic setups on orthodontic treatment planning. University of Washington Department of Orthodontics; 2017. [web].
14. Orozco-Varo A, Arroyo-Cruz G, Martínez-de-Fuentes R, Jiménez-Castellanos E. Biometric Analysis of the Clinical Crown and the Width/length Ratio in the Maxillary Anterior Region. J Prosthet Dent 2015;113:565-70.e2.
15. Parciak E. Comparison of maxillary anterior teeth width to facial dimensions among three races. Loma Linda University; 2015.
16. Troncoso-Pazos J, Courdurier C, Santi C, Aravena PC. Relationship between width and length ratios of upper anterior teeth in young Chilean population. J Oral Res 2017;6:205-8.