The use of tooth thickness in predicting intermaxillary tooth-size discrepancies

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Tooth-size discrepancies are thought to exist frequently in the human dentition.[1-4] If so, it would benefit the practitioner to be aware of their existence before beginning orthodontic treatment.[5] If a patient has a significant tooth-size discrepancy, orthodontic alignment of the teeth into ideal occlusion may not be possible. Anterior discrepancies are often due to a decrease in maxillary anterior arch length. If unattended, the discrepancy will usually lead to an end-to-end anterior relationship that prevents the anterior teeth from functioning in a mutually protected occlusion.[5] In a sample of 100 cases, Bolton[1,6] found that 29% presented anterior discrepancies of greater than one standard deviation (1.65, mean 77.2). Similar mean values have been found in other studies.[7,8]

Crosby[2] found no significant differences in the incidence of tooth-size discrepancies among malocclusion groups, and he found a relatively large

Abstract

Intermaxillary tooth-size discrepancies can be assessed using a diagnostic setup or predicted using a mathematical formula, such as the Bolton analysis. However, variations in tooth thickness may produce inaccuracies in the Bolton analysis ratio. To date, no method for incorporating tooth thickness into discrepancy prediction has been proposed. The purpose of this study was to design and test a new method of predicting anterior tooth-size discrepancy that takes into account tooth thickness and width. Forty-four positioner setup models were set to ideal overbite (2.5 mm) and occlusion (Class I canine relationship). Interproximal gaps between the maxillary or mandibular central incisors were allowed in order to optimize tip and torque. The mesiodistal width of all anterior teeth and the labiolingual thickness of the maxillary incisors were measured on these idealized setups to the nearest 0.1 mm. Actual intermaxillary anterior ratios were then calculated. A new method of prediction was developed by assuming a linear relationship between tooth thickness and ideal intermaxillary ratio. Errors in Bolton's method were compared with the new method. The results showed wide variations in mesiodistal tooth widths, tooth thicknesses, and intermaxillary anterior ratios in orthodontically treated patients. The correlation coefficient between the intermaxillary ratio and tooth thickness was $r = 0.68$ when tooth thickness was <2.75 mm, and $r = 0.28$ when tooth thickness was ≥2.75 mm. The mean absolute errors in predicting the actual intermaxillary ideal ratio was 1.29 ± 0.81 for Bolton's ratio and 0.84 ± 0.46 for the new prediction formula. These new formulas were better than Bolton's ratio in predicting tooth-size discrepancies ($p = 0.003$). Tooth thickness combined with mesiodistal width may be useful in predicting intermaxillary tooth-size discrepancies.

Commentary by Dennis M. Killiany

Key Words

Tooth-size discrepancy • Bolton analysis

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Table 1
Mesiodistal tooth widths

Tooth	Mean width (mm)	Range (mm)
Maxillary		
R. canine	8.10 ± 0.47	7.0 - 9.0
L. canine	8.02 ± 0.50	6.7 - 9.0
R. lateral	7.11 ± 0.47	6.3 - 8.0
L. lateral	7.16 ± 0.57	5.9 - 8.3
R. central	9.01 ± 0.63	7.8 -10.4
L. central	9.03 ± 0.60	8.0 -10.6
Mandibular		
R. canine	7.16 ± 0.46	6.5 - 8.9
L. canine	7.08 ± 0.49	5.9 - 8.4
R. lateral	6.25 ± 0.45	5.0 - 7.4
L. lateral	6.21 ± 0.50	5.0 - 7.4
R. central	5.68 ± 0.40	5.0 - 6.9
L. central	5.67 ± 0.37	5.0 - 6.9

Table 2
Labiolingual tooth thickness

Tooth	Mean thickness (mm)	Range (mm)
Maxillary		
R. lateral	2.56 ± 0.22	2.1 - 3.2
L. lateral	2.53 ± 0.22	2.1 - 3.2
R. central	2.77 ± 0.34	2.2 - 3.7
L. central	2.77 ± 0.39	2.3 - 3.8
Mandibular		
R. lateral	2.49 ± 0.29	2.1 - 3.4
L. lateral	2.46 ± 0.27	1.9 - 3.2
R. central	2.44 ± 0.33	1.8 - 3.5
L. central	2.41 ± 0.30	1.7 - 3.3

number of tooth-size discrepancies in all malocclusion groups (Class I, Class II, and Class III).

In order to obtain ideal occlusion, it is necessary to know if and where a significant tooth-size discrepancy exists. Prior to the discovery of mathematical formulas to evaluate tooth-size discrepancies, plaster setups were the only diagnostic tool available. Today, some clinicians still use diagnostic setups; however, many are using Bolton's tooth-size analysis as their primary guide for predicting discrepancies. The results of Bolton's analysis may describe the magnitude of the discrepancy in the majority of cases. However, when a large anterior tooth-size problem is suspected, a setup is likely indicated.[9] Other researchers have suggested that "occlusal simulation" with occlusograms is a more accurate method of evaluating tooth-size discrepancies.[10] Potential treatments include modification of tooth position, restoration of relatively small teeth, interproximal reduction of relatively large teeth, and extraction.

Limitations of Bolton's method

Although the convenience and relative usefulness of the Bolton analysis is widely known, its accuracy and dependability have been challenged.[8,9] Good occlusal relationships have been demonstrated in cases with significant Bolton discrepancies, and patients who have normal Bolton ratio measurements may have teeth that cannot be brought into proper occlusion.

Other authors have speculated or indicated that overbite,[1] overjet,[6] tip,[5] torque,[5,6] interincisal angles,[5,6] and tooth thickness[6] influence ideal tooth-size relationships. It has been demonstrated with diagnostic setups that increased or decreased arch length results from changes in incisal angulation (root torque) and tip (root tip).[5] When the maxillary incisors are in extreme labial inclination (with resultant decreased interincisal angle) or when a dentition has an extreme labiolingual thickness or pronounced marginal ridges, the intermaxillary size relationship may be disturbed.[6] However, no definite conclusions have been drawn as to the effect that overbite, overjet, interincisal angle, tip, and incisor thickness have on the accuracy of Bolton's analysis. In addition, no method of identifying tooth-size discrepancies that accounts for these factors has been proposed and tested.

The purpose of this study was to design and test a new formula for predicting tooth-size discrepancies that takes into account tooth thickness.

Materials and methods

Sample

Forty-four positioner setup models from the offices of three practitioners were selected on the basis of availability. These models were taken from patients who were treated with full orthodontic appliances, debanded, and issued positioners. All setups showed a full set of anterior teeth. Six setups were missing one or more posterior teeth due to extraction therapy.

Model preparation

Each of the positioner setup models was evaluated to ensure that it met the following criteria:

Table 3
Average width-to-thickness ratio for each type of incisor

Tooth	Average width-to-thickness ratio	Range
Maxillary		
R. lateral	2.34 ± 0.20	2.2 - 3.5
L. lateral	2.64 ± 0.20	2.4 - 3.5
R. central	2.62 ± 0.05	2.3 - 4.0
L. central	2.58 ± 0.09	2.4 - 4.0
Mandibular		
R. lateral	2.10 ± 0.36	1.8 - 3.2
L. lateral	2.23 ± 0.46	1.9 - 3.3
R. central	2.07 ± 0.58	1.6 - 3.0
L. central	2.07 ± 0.65	1.6 - 3.4

Table 4
Comparative success of Bolton's method and the new method in predicting tooth-size discrepancies greater than .05 mm

	Bolton's method	New method
True positives	15	17
False negatives	9	7
True negatives	10	14
False positives	10	6
Sensitivity	62.5%	70.8%
Specificity	50.0%	70.0%

Table 5
Tooth thicknesses and ideal anterior intermaxillary ratios for predicting tooth-size discrepencies

Tooth thickness (mm)	Ideal ratio
2.0	80.92
2.1	80.21
2.2	79.51
2.3	78.80
2.4	78.10
2.5	77.39
2.6	76.69
2.7	75.98
2.8	76.48
2.9	76.28
3.0	76.09
3.1	75.90
3.2	75.70
3.3	75.51
3.4	75.32
3.5	75.13
3.6	74.93
3.7	74.74
3.8	74.55
3.9	74.35
4.0	74.16

1. Class I canine relationship
2. Maxillary and mandibular anterior teeth in occlusion
3. Overbite of 2.5 mm
4. Optimized tip and torque

If any of these criteria were not met, minor adjustments were made. If necessary, interproximal gaps were allowed between maxillary or mandibular central incisors to achieve the above relationships.

Measurements

The greatest mesiodistal width of each anterior tooth was measured to the nearest 0.1 mm at the interproximal contact using a Boley gauge. If a gap existed, it was measured similarly. The greatest labiolingual thickness of the maxillary incisors was also measured to the nearest 0.1 mm using a crown gauge at the level of occlusal contact determined by articulating paper. Finally, overjet was identified to the nearest 0.1 mm by measuring the distance from the upper incisal tip to a pencil line made on the labial surface of the lower incisors corresponding to the amount of vertical overlap (overbite). Each measurement was repeated three times by one observer. If the values were not repeated within 0.1 mm at least twice, all three measurements were repeated. Measurements within 0.1 mm were then averaged to obtain the final value.

Prediction equation

For each model, the ideal intermaxillary ratio was determined from the recorded mesiodistal widths and gaps of the six anterior teeth. This ratio was calculated by dividing the sum of the mesiodistal widths plus gap (if any) of the mandibular teeth by the sum of the mesiodistal widths plus gap (if any) for the maxillary teeth. Furthermore, each case was categorized as having thin or thick teeth. The thin-tooth setups had an average maxillary incisor thickness <2.75 mm, while the thick-tooth setups had an average maxillary incisor thickness ≥2.75mm. Two prediction equations were developed by plotting a linear regression of thickness on intermaxillary ratio for

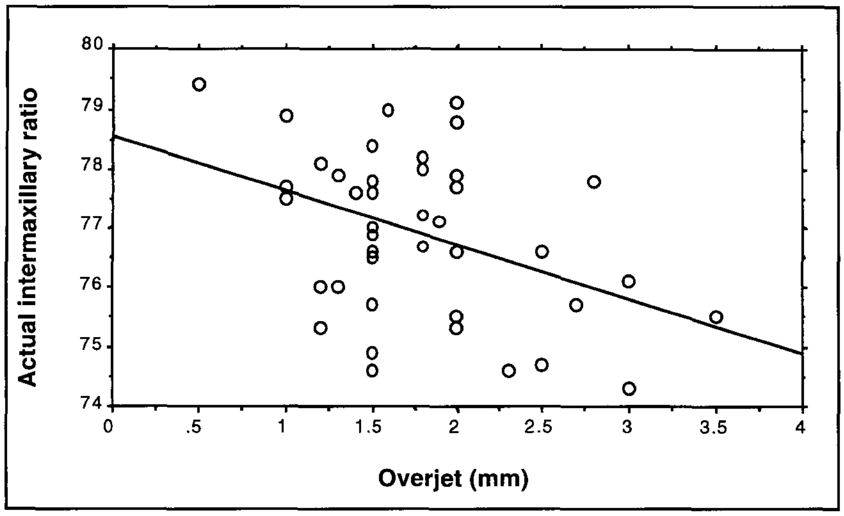

Figure 1
Correlation (r = .406) between overjet and actual intermaxillary ratio

each data set (one prediction equation for models with thin teeth and one for models with thick teeth). Sensitivity (ability to identify tooth-size discrepancies) and specificity (ability to identify normal cases) were calculated for both Bolton's equations and the new ones.

Finally, both prediction methods were applied to the models to test their accuracy in predicting the existence of tooth-size discrepancies. If a gap of 0.5 mm or more resulted in the setup, then it was determined that a tooth-size discrepancy did exist.

Results

Tooth dimensions

Table 1 shows wide variation in mesiodistal tooth widths. The maxillary central incisors were the widest teeth (9.0 mm) and the mandibular centrals were the narrowest (5.7 mm). Furthermore, the maxillary centrals had the greatest width variation of all teeth (SD 0.62 mm, range 7.8 to 10.6 mm) while the mandibular centrals had the least (SD 0.38 mm, range 5.0 to 6.9 mm). There were no significant differences among the variations of mesiodistal tooth widths between the right and left sides for any of the teeth (p >.05) using a paired t-test. Table 2 shows wide variations in buccolingual tooth thickness. The maxillary central incisors were the thickest teeth (2.8 mm) while the mandibular centrals were the thinnest (2.4 mm). In addition, the maxillary centrals showed the greatest variation in thickness (SD 0.39 mm, range 2.2 to 3.8 mm) and the lower laterals had the least variation (SD 0.28 mm, range 1.9 to 3.6 mm). There were no significant labiolingual tooth thickness differences between right and left sides for any of the teeth (p >.05) using a paired t-test.

Interestingly enough, there was also a large range of width-to-thickness ratios (Table 3). The maxillary centrals tended to have the greatest ratio and the least variation, while the mandibular centrals had the lowest ratio and the greatest variation. The correlation between tooth thickness and width was r = .34 for the maxillary teeth and r = .24 for the mandibular teeth. It must be kept in mind that these tooth relationships came from a group of patients, many of whom had significant tooth-size discrepancies.

Predicting intermaxillary ratio

There was a substantial variation in intermaxillary tooth-size ratios that produced ideal setups. The actual mean ideal intermaxillary ratio was 76.75 ± 1.29 (range 71.8 to 79.4). Figure 1 shows the correlation between overjet and intermaxillary ratio (r = 0.41). As overjet increased, the intermaxillary ratio decreased. Setups with overjet of 1.00 mm or less tended to have a large intermaxillary ratio (mean = 78.38 ± 0.78), while occlusions with overjet greater than 2.0 mm tended to have a lower intermaxillary ratio (mean = 75.66 ± 0.89). However, overjets between 1 mm and 2 mm had no correlation with intermaxillary ratio.

Tooth thickness proved to have a stronger correlation with intermaxillary ratio than with overjet (r = 0.57). The correlation was strongest in the case of thin teeth. When the tooth thickness was <2.75 mm, the correlation coefficient was r = 0.68 (Figure 2A); when tooth thickness was ≥2.75 mm, the correlation coefficient was r = 0.28 (Figure 2B). Furthermore, overjet correlated strongly with tooth thickness (r = 0.63) (Figure 3). Thus, some of the prediction capability of tooth thickness in predicting tooth-size discrepancies may be associated with the resultant change in overjet.

Using a linear regression model, the following formulas were developed to predict the ideal ratio, given a specific tooth thickness:

1. Predicted = -7.053 (tooth thickness) + 95.024 if tooth thickness <2.75mm
2. Predicted = -1.928 (tooth thickness) + 81.874 if tooth thickness ≥2.75mm

The mean absolute error for Bolton's ratio was significantly greater (1.29 ± 0.81) in predicting the ideal intermaxillary ratio than the new prediction formula (0.84 ± 0.46, p= 0.003). Table 4 shows that the sensitivity in identifying tooth-size discrepancies of 0.5 mm or more for the new method is greater than Bolton's (70.8 vs. 62.5). In cases that did not have a tooth-size discrepancy of greater than 0.5 mm, the new prediction formula had greater specificity than Bolton's method (70.0% vs. 50.0%).

Table 5 shows the ideal intermaxillary ratio for use in predicting tooth-size discrepencies when labiolingual tooth thickness varies from 2.0 mm to 4.0 mm. This table shows that the appropriate ratio can vary from 80.9 when maxillary incisor thickness is 2.0 mm to 74.2 when the thickness is 4.0 mm.

Discussion

This study showed that a wide variation in mesiodistal widths and tooth thicknesses occurred in these treated cases. This is consistent with the work of other investigators.[10] This study also showed a wide variation in tooth thickness, which is also consistent with others.[11] Interestingly, the correlation between width and thickness was low. This indicates that the shape of teeth from an occlusal view varies.

Peck and Peck[11] reported that tooth width-to-thickness ratios could serve three purposes: prediction of unerupted tooth size, assessment of tooth-size–arch-size compatibility within the same arch, and asessment of tooth-size compatibility between arches (tooth-size discrepancy).

Two major differences exist between this study and the Peck and Peck study. First of all, in this article the emphasis on tooth thickness was placed on the maxillary anterior dentition instead of the mandibular. In addition, tooth thickness was measured at the point of occlusal contact while Peck and Peck measured the maximum faciolingual thickness.

Bolton reported a mean anterior ratio of 77.2 ± 1.65, and White[9] reported 77.3 ± 4.0. In this study we found the mean ideal ratio to be 76.91 ± 1.12. The large range of ideal ratios demonstrates how difficult it is to predict tooth-size discrepancies.

Prediction of tooth-size discrepancies

This study showed that using tooth thickness and mesiodistal tooth width to predict the intermaxillary ratio to reach ideal intercuspation was more accurate than using the Bolton method (p =.003). When the Bolton method is used to predict anterior tooth-size discrepencies, a ratio of 77.2 of lower-to-upper mesiodistal width is used. The method presented in this study (equations 1 and 2) varies depending upon labiolingual tooth thickness. For example, if tooth thickness is 2.0 mm, then equation 1 shows that the ideal anterior intermaxillary ratio for predicting tooth-size discrepancies is 80.9. When tooth thickness is 4.0 mm, then equation 2 shows that the ideal ratio is 74.2. This is similar to the ideal range of 74.5 to 80.4 reported by Bolton.[6] The errors reported in prediction of the appropriate ratio were 50% greater when tooth thickness was not taken into account. Furthermore, this study showed that both sensitivity (ability to identify tooth-size discrepancy when it existed) and specificity (ability to identify an absence of tooth-size discrepancy) were greater with the new prediction method than with Bolton's method. However, even with the new method, predicting tooth-size discrepancies of 0.5 mm was not successful 30% of the time.

Although Bolton[6] was the first to point out that tooth thickness would affect the anterior ratio, an approach for actually predicting its effect is needed. By accounting for both the thickness (labiolingually) and width of teeth (mesiodistally), prediction of the ideal intermaxillary ratio is more accurate and therefore more useful in the prediction of true overall tooth-size discrepancies. By accounting for tooth thickness, the mean error in predicting the optimum intermaxillary ratio was reduced from 1.29 ± 0.81 to 0.84

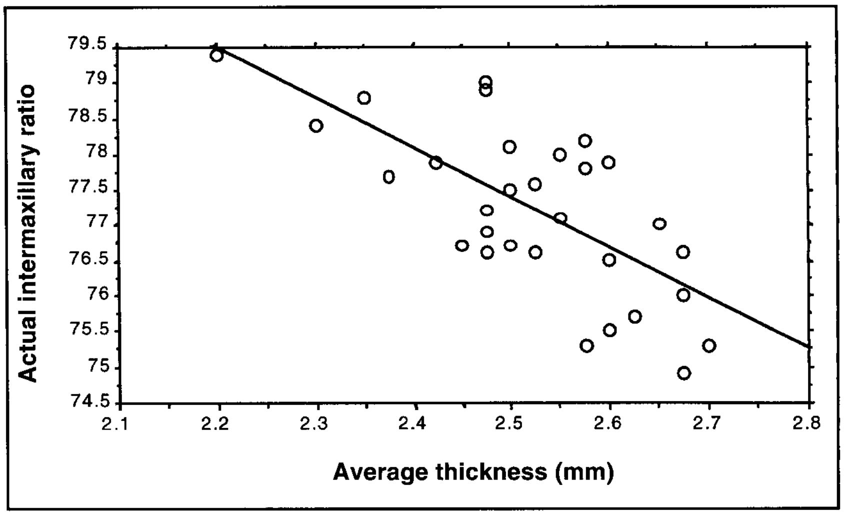

Figure 2A

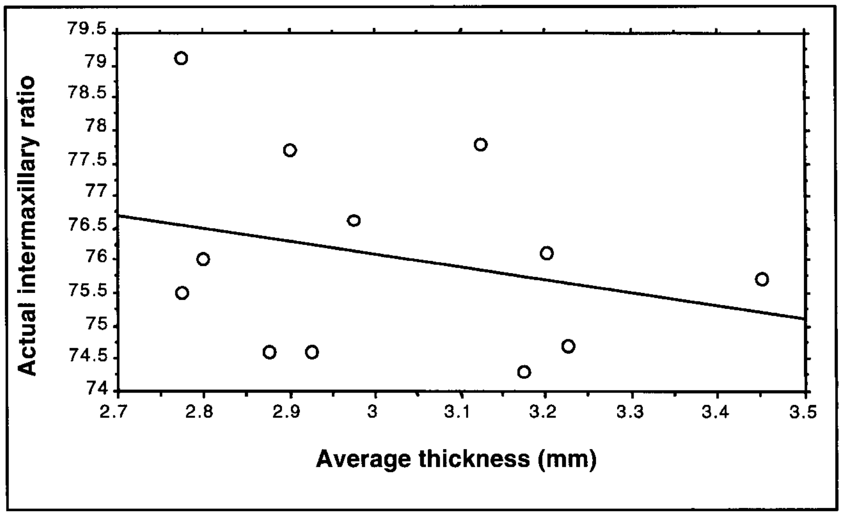

Figure 2B

Figure 2A
Correlation (r = .680) between average incisor thickness and actual intermaxillary ratio when average incisor thickness was less than 2.75 mm. The correlation coefficient between tooth thickness and intermaxillary ratio was much lower (r= 0.28) when tooth thickness was greater than 2.75 mm.

Figure 2B
Correlation (r = .280) between average incisor thickness and actual intermaxillary ratio when average incisor thickness was ≥2.75 mm.

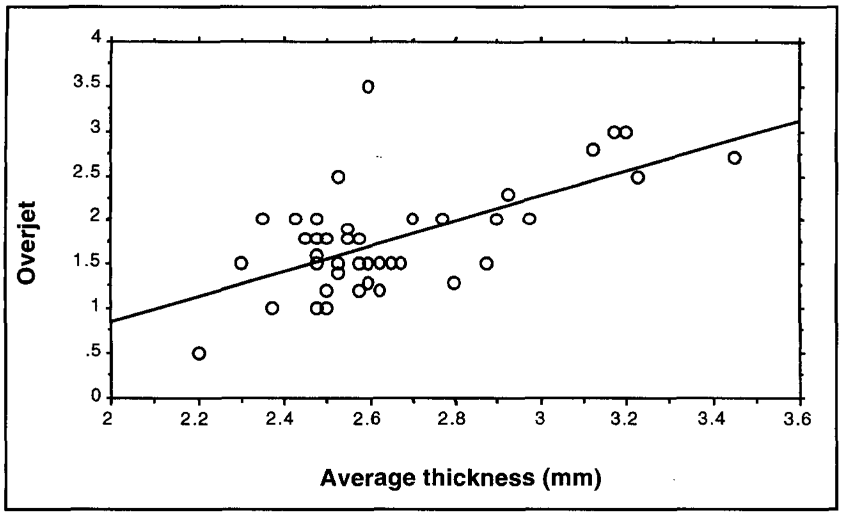

Figure 3
Correlation (r = .630) between overjet and average thickness of incisors.

± 0.46. The higher correlation coefficient for thin (<2.75 mm) teeth shows that we can more accurately predict tooth-size discrepancies in these cases. Thus, when dealing with cases of thin maxillary incisors, a clinician's confidence in prediction should be much greater. In the case of thick teeth (≥2.75 mm), more errors occur and diagnostic setups may be indicated.

This research used a linear regression model of tooth discrepancy prediction. However, many mathematical prediction equations are possible. A weighted polynomial equation that accounts for other factors besides tooth thickness may be even more accurate in predicting tooth-size discrepancies.

In this study, a correlation between tooth thickness and ideal intermaxillary ratio was found, such that as tooth thickness increased, the ideal ratio decreased. Therefore, in patients with thick teeth, one would expect a lower intermaxillary ratio. If a tooth-size discrepancy exists, several options are available for addressing the problem, including reproximation, restoration, extraction, or reducing labiolingual thickness.

Limitations of this study include a small sample size, all samples coming from orthodontically treated cases, and the sample used to develop the prediction equations was the same sample used to test it. Future studies must include testing this prediction equation on a new and larger sample. In addition, alternate prediction equations could be developed that account for more factors, including overjet, overbite, tooth angulation, and tooth tip.

Conclusions

1. A wide variation in mesiodistal and labiolingual tooth sizes exists in orthodontically treated cases.
2. A wide variation in width/thickness ratios exists in orthodontically treated cases.
3. The variation in intermaxillary ratios that can produce an ideal setup is wide.
4. As tooth thickness increases, the ideal intermaxillary ratio decreases.
5. The anterior intermaxillary ratio that produces an ideal setup is more accurately identified when both tooth width and tooth thickness are used.
6. Tooth-size discrepancies were more accurate when predicted with the new method presented than with Bolton's method.

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Commentary: The use of tooth thickness in predicting intermaxillary tooth-size discrepancies

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This paper introduces a diagnostic test to detect the existence of intermaxillary tooth-size discrepancies. The study was conducted in the hope of developing a tool that would be more accurate than the widely used Bolton analysis. Although the authors found only a weak relationship between labiolingual tooth thickness and mesiodistal tooth width, including tooth thickness in the prediction model was shown to improve the detection of an intermaxillary tooth-size discrepancy. However, the new analysis is still not as accurate as using a diagnostic setup—the gold standard for such predictors—and does not eliminate the need for the more labor-intensive procedure.

A calculation of the ability of a diagnostic test to detect the presence (sensitivity) or absence (specificity) of a disease is widely used in medicine to judge the worth of the test. The new test is compared with the standard test, which is often more complex and expensive to conduct. It is hoped that the new test will match the results of the standard test, although a sensitivity of at least 85% is often acceptable.

The Bolton analysis performed less favorably than the new test (19/44 cases categorized incorrectly) when compared with a diagnostic setup. The new method scored 20% higher for specificity and 8% better for sensitivity. Although improved, the new test was also often in error. As the authors clearly stated, the test will be in error one-third of the time.

I decided to put the new method to a test. Using the distribution of positives and negatives in Table 4, I calculated the positive and negative predictive values and the accuracy of both methods (Table 1). Similar to the calculation for sensitivity and specificity, the results favored the new method. Yet none of the values was greater than or equal to the 80% benchmark. (For a simple explanation of these concepts and the formulas used in their calculation, see the article in the *Canadian Dental Journal.*[2])

Table 1
Additional properties of examined diagnostic tests

	Bolton method	New method
Positive predictive value	60.0%	73.9%
Negative predictive value	52.6%	66.6%
Accuracy	56.8%	70.5%

Unlike the Bolton analysis, the new method fails to pinpoint the arch that is out of balance and it does not include a way to quantify the amount of imbalance. After doing the test, a practitioner cannot say with confidence that there is 2 mm of maxillary anterior excess of 3 mm of mandibular deficiency distributed through the entire arch. Rather, the new test allows the practitioner to state only that there is an indication of a tooth-size discrepancy.

One must not lose sight of the fact that the sample that was used to create the prediction equation was the same sample used to test the method. It has been my experience that when such tests are applied to a new group of subjects, the results are usually not as good. If this were to occur here, the accuracy of the new method might approach that of the Bolton analysis.

I am in agreement with the authors that, because more errors were found with thicker teeth, diagnostic setups are more likely to be indicated for individuals with thicker teeth. This study may inspire future work and lead one day to a mathematically based diagnostic test for intermaxillary tooth-size discrepancy that approaches the level of accuracy of the diagnostic setup.

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