

# Bolton analysis: An alternative proposal for simplification of its use

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## Abstract

**Introduction:** Mesiodistal size discrepancies of upper and lower teeth and their effect on occlusion have been related. Bolton's method for tooth size discrepancies is, undeniably, one of the most commonly-used methods in orthodontics because of its simplicity. However, the application of this method requires mathematical calculations and use of tables, which often prevents its clinical use. **Purpose:** Evaluate an alternative method for Bolton's analysis proposed by Wolford that does not require table information. **Material and Methods:** The sample was composed of 90 initial dental casts of adult patients, with different malocclusions. The ratio between the sum of widths of maxillary and mandibular teeth was calculated for each patient, resulting in the attainment of two indices: The overall ratio and the anterior ratio. Indices were calculated by Bolton's method and by an alternative method, using two different formulas (one simplified and a variation of the same formula) that were separately analyzed. **Results:** In comparison with Bolton's method, the Simplified Formulas demonstrated a slight trend towards an overestimation of the inferior dental discrepancies (overall and anterior). **Conclusion:** Both formulas employed for the alternative method may be used to substitute the traditional method, since each demonstrated, on average, differences of less than 0.58 mm when compared with Bolton's method and no clinical significance.

**Keywords:** Bolton's analysis. Tooth size discrepancy. Diagnosis. Orthodontic treatment planning.

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## INTRODUCTION

Normal occlusion exists when the 28 teeth are well arranged on the upper and lower arches and are in harmony with all the static and dynamic forces that act upon them, i.e. normal occlusion is stable, healthy and esthetically attractive.<sup>19</sup> However, many factors influence the correct interarch relationship, including tooth size proportionality.

The method created by Bolton<sup>4</sup> for the diagnosis of tooth size discrepancy is one of the most commonly used in orthodontics. Similar to previous studies,<sup>2,13</sup> Bolton proposed a tooth size analysis that indicates ideal proportions between the upper and lower teeth to achieve adequate occlusion. According to Bolton,<sup>5</sup> this proportionality is provided by the sum of the mesiodistal diameter of the lower teeth in relation to the upper ones. However, extrinsic factors such as sexual dimorphism,<sup>1,14</sup> racial and ethnic variations,<sup>3,10,18</sup> type of malocclusion,<sup>6,7,12,14,15</sup> inclination of anterior teeth,<sup>8,9</sup> incisor edge thickness,<sup>8,9</sup> and the smile arc<sup>8,9</sup> can affect this proportionality, usually requiring adjustments in the anterior ratio, as described by Bolton. In other words, a high or low Bolton ratio does not necessarily reflect the real discrepancy, and this ideal index does not guarantee an ideal occlusion.

Orthodontists should pay special attention to the presence of tooth size discrepancy because about 60% of orthodontic patients present an anterior Bolton discrepancy.<sup>6,11</sup> Failure to identify this disparity during diagnosis and treatment planning can invariably create difficulties for finishing such cases, especially in regard to the ideal relationship of molars and canines, while respecting the ideal overjet and overbite<sup>15</sup>.

It is, therefore, important that the evaluation of tooth size discrepancy be applied to all orthodontic cases. Although Bolton's analysis is well-known and relatively simple to apply, many professionals do not use this methodology

during clinical evaluation, since the method requires calculations and the use of tables that are not always available at the time of patient care. According to Sheridan,<sup>17</sup> only 47% of interviewed orthodontists often use this index.

Taken all together, the application of an alternative method is proposed for analysis of tooth size discrepancy without using tables.

## MATERIALS AND METHODS

This study included data from a retrospective study<sup>15</sup> that used the Bolton's method to determine the overall and the anterior tooth size discrepancy. Ninety initial dental casts of Brazilian adult patients (both sexes) with different malocclusions were obtained from the Center for Research and Treatment of Orofacial Deformities (CEDEFACE, Araraquara – Brazil) and private clinics.

In this study, the reference values for the mesiodistal width of twelve maxillary and mandibular teeth (first molar to first molar) were used to calculate the tooth size discrepancy using two different methods: The method originally proposed by Bolton<sup>4</sup> and an alternative method proposed by Wolford,<sup>20</sup> consisting of two formulas that were analyzed separately.

The ratio between the sum of upper and lower teeth was calculated for each patient, resulting in the identification of two indices: The overall ratio, which compares the sum of the mesiodistal width of the twelve lower teeth with the twelve upper teeth (from the right first permanent molar to the left first permanent molar); and the anterior ratio, which compares the sum of the mesiodistal width of the mandibular anterior teeth with the upper anterior teeth.

According to Bolton<sup>4</sup>, the overall ratio is calculated by the following formula:

$$\frac{\text{Sum of 12 lower teeth}}{\text{Sum of 12 upper teeth}} \times 100 = \text{Overall Ratio}$$

Meanwhile, the anterior ratio is calculated by:

$$\frac{\text{Sum of 6 lower teeth}}{\text{Sum of 6 upper teeth}} \times 100 = \text{Anterior Ratio}$$

To calculate the excess amount of dental material, Bolton proposed the use of a table that displays, for each sum of maxillary teeth (overall or anterior), a corresponding value for the mandibular arch. Based on these values, the excess amount existing in the upper or lower jaw could be calculated according to the overall ratio and the anterior ratio values.

After obtaining the discrepancy indices based on Bolton's original formula, we applied the alternative method for each sample case in order to evaluate which simplified formula (1 or 2) would achieve values that are closer to those obtained by the traditional method. The first formula, denominated "Simplified Formula 1", is a variation of the Bolton's original formula and maintains only one decimal place after the comma. This variation was obtained by applying the rule of three to the equation of the Bolton's total overall ratio, as indicated below:

$$\frac{\text{Sum of 12 inferior (Mand}_{12})}{\text{Sum of 12 superior (Max}_{12})} \times 100 = 91.3$$

$$\text{Max}_{12} = \frac{\text{Mand}_{12}}{91.3} \times 100 \Rightarrow \text{Max}_{12} = \text{Mand}_{12} \times 1.0953$$

That is to say:

$$\text{Overall Discrepancy} = \text{Max}_{12} - (\text{Mand}_{12} \times 1.1)$$

If there is a positive value, it is indicative of a maxillary dental excess, while negative values indicate mandibular dental excess.

Likewise, the equation for calculating the anterior dental discrepancy can be simplified

by applying the rule of three to the Bolton's anterior ratio:

$$\frac{\text{Sum of 6 inferior (Mand}_6)}{\text{Sum of 6 superior (Max}_6)} \times 100 = 77.2$$

$$\text{Sum of 6 superior (Max}_6)$$

$$\text{Max}_6 = \frac{\text{Mand}_6}{77.2} \times 100 \Rightarrow \text{Max}_6 = \text{Mand}_6 \times 1.2953$$

Therefore:

$$\text{Anterior Discrepancy} = \text{Max}_6 - (\text{Mand}_6 \times 1.3)$$

The other formula of the alternative method, called the "Simplified Formula 2", is similar to the Simplified Formula 1, but it uses two decimal places after the comma.

Therefore, the Simplified Formula 2 for the total ratio can be described as:

$$\text{Overall Discrepancy} = \text{Max}_{12} - (\text{Mand}_{12} \times 1.09)$$

As for the anterior ratio:

$$\text{Anterior Discrepancy} = \text{Max}_6 - (\text{Mand}_6 \times 1.29)$$

As indicated by Simplified Formula 1, positive values indicate maxillary dental excess, while negative values demonstrate mandibular dental excess.

Descriptive statistics were performed to calculate the mean, standard deviation, standard error, the minimum and maximum values and coefficient of variation of the anterior and overall ratio of all the patients, according to the Bolton and alternative methods (Formula 1 and Formula 2). Subsequently, a statistical test for linear regression was used to compare the values of the overall ratio and the two discussed methods.

## RESULTS

Statistical analyses showed a high significance ( $p < 0.001$ ) when comparing the two different

TABLE 1 - Estimation, standard errors for  $\beta_0$  and  $\beta_1$  coefficients;  $t_0$ ,  $f_0$ ,  $r^2$  and p values for the comparative linear regression model between total reason (12) of Bolton's Formula and Simplified Formulas 1 and 2.

Comparison	Rate	Standard error	$t_0$	p <	$F_0$	p <	$r^2$
Simplified F1 (12)	$\beta_0 = 0.456$	0.009	52.093 s	0.0001	114899.37 s	0.0001	0.999
	$\beta_1 = 0.935$	0.003	-21.666 s	0.0001			
Simplified F2 (12)	$\beta_0 = -0.363$	0.008	-45.371 s	0.0001	102985.54 s	0.0001	0.999
	$\beta_1 = 0.941$	0.003	-19.666 s	0.0001			

s = significant value; n = non-significant value.

TABLE 2 - Estimation, standard errors for  $\beta_0$  and  $\beta_1$  coefficients;  $t_0$ ,  $f_0$ ,  $r^2$  and p values for the comparative linear regression model between anterior reason (6) of Bolton's Formula and Simplified Formulas 1 and 2.

Comparison	Rate	standard error	$t_0$	p <	$F_0$	p <	$r^2$
Simplified F1 (6)	$\beta_0 = 0.250$	0.012	20.695 s	0.0001	15319.87 s	0.0001	0.994
	$\beta_1 = 0.833$	0.007	-23.857 s	0.0001			
Simplified F2 (6)	$\beta_0 = -0.059$	0.011	-5.5376 s	0.0001	15683.58 s	0.0001	0.994
	$\beta_1 = 0.834$	0.007	-23.714 s	0.0001			

s = significant value; n = not significant value.

TABLE 3 - Descriptive statistics of overall and anterior dental discrepancies of Simplified Formulas 1 and 2, Bolton's formula, and the differences between them.

	Descriptive Statistical Analysis			
	Mean	s.d.	Minimum	Maximum
Formula 1 (12)	-1.89	2.56	-9.28	4.77
Formula 2 (12)	-1.01	2.55	-8.36	5.60
Bolton's F (12)	-1.31	2.40	-8.07	5.16
Overall ratio (12)	0.927	0.025	0.864	1.001
Formula 1- Bolton's F (12)	-0.58	0.18	-1.20	-0.37
Formula 2 - Bolton's F (12)	0.30	0.17	-0.29	0.50
Formula 1 (6)	-1.08	1.44	-4.56	2.79
Formula 2 (6)	-0.71	1.44	-4.16	3.19
Bolton's F (6)	-0.65	1.20	-3.38	2.97
Anterior ratio (6)	0.787	0.024	0.730	0.844
Formula 1- Bolton's F (6)	-0.43	0.26	-1.18	-0.15
Formula 2- Bolton's F (6)	-0.06	0.25	-0.76	0.22

methods, as well as for the correlation coefficient for the overall ratio ( $r^2 = 0.999$ ) and anterior ratio ( $r^2 = 0.994$ ), as shown in Tables 1 and 2.

According to the descriptive statistical analysis (Table 3), the reason for the overall ratio difference between the mean of the total

Simplified Formula 1 and Bolton's Formula was  $-0.58 \pm 0.18$  mm (ranging from -1.20 mm to -0.37 mm). These values were even lower when the Simplified Formula 2 and the Bolton's Formula were compared. The average difference between the results of these two methods was  $0.30 \pm 0.17$  mm (ranging from -0.29 mm to 0.50 mm), indicating a greater equivalence between the two formulas.

Regarding to the anterior ratio, the results showed smaller differences ( $<0.5$  mm) than those obtained for the overall ratio when comparing the two methods. The following values were obtained for the difference between Formula 1 and Bolton's Formula: Average of  $-0.46 \pm 0.26$  mm (ranging from -1.18 mm to -0.15 mm). When comparing to the Simplified Formula 2, smaller differences for all comparisons were found (mean  $-0.06 \pm 0.25$  mm, ranging from -0.79 mm to 0,22 mm), demonstrating similarity between the values obtained by the two formulas (Formula 2 and Bolton's Formula).

Figures 1 and 2 show the sample distribution for the overall ratio, based on the differences

between the values of both methods. Figure 1 demonstrates the difference between Formula 1 and Bolton's Formula that always resulted in negative values, and in 95% of cases this difference was lower than 1.0 mm.

In Figure 2 (Formula 2 – Bolton's Formula), there is a more homogeneous distribution between positive and negative values for the difference, although there is a tendency towards values greater than zero.

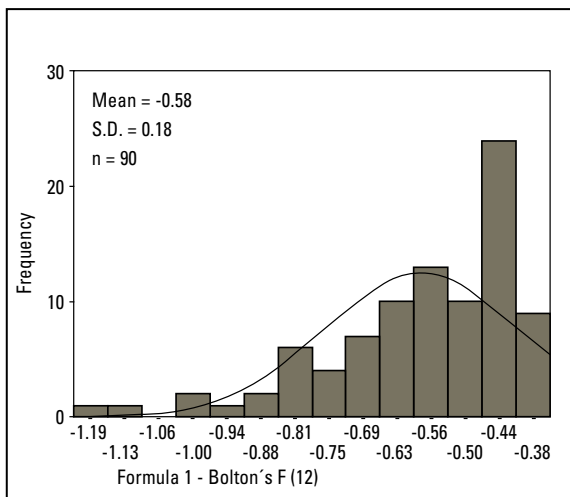


FIGURE 1 - Sample distribution, according to the mean overall ratio obtained from the difference between the Simplified Formula 1 and Bolton's Formula.

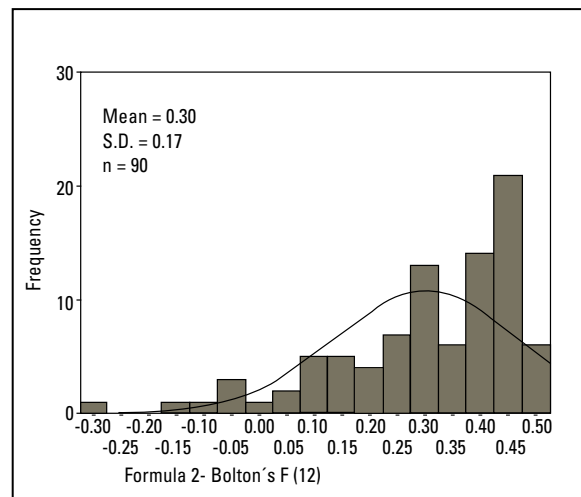


FIGURE 2 - Sample distribution, according to the mean overall ratio obtained from the difference between the Simplified Formula 2 and Bolton's Formula.

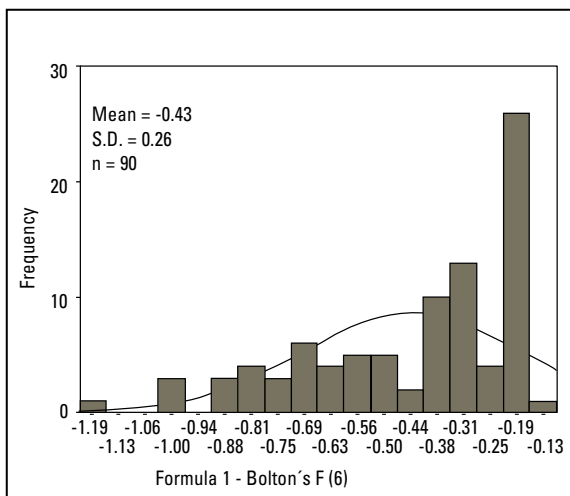


FIGURE 3 - Sample distribution, according to the mean anterior ratio obtained from the difference between the Simplified Formula 1 and Bolton's Formula.

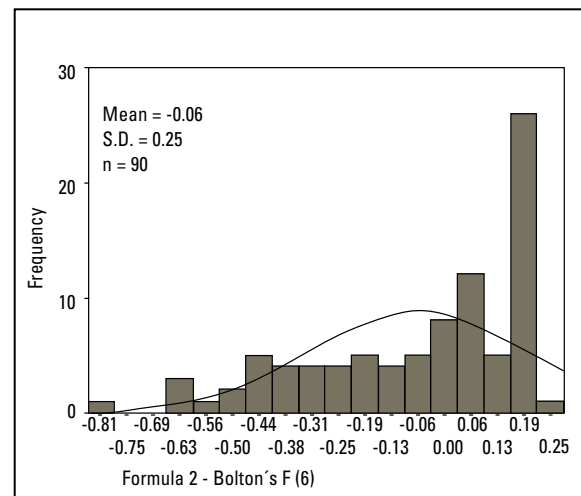


FIGURE 4 - Sample distribution, according to the mean anterior ratio obtained from the difference between the Simplified Formula 2 and Bolton's Formula.

Meanwhile, the anterior ratio shown in Figures 3 and 4 showed a better sampling distribution compared to the overall ratio, although in both graphs, there was a tendency towards negative values when comparing both methods.

For the overall ratio, Figures 5 and 6 showed a linear relationship between the Bolton's

method and the corresponding values for the alternative methods (Formula 1 and Formula 2, respectively).

Figures 7 and 8 showed the same linear relationship between values obtained for the Bolton's method and the alternative method for the anterior ratio.

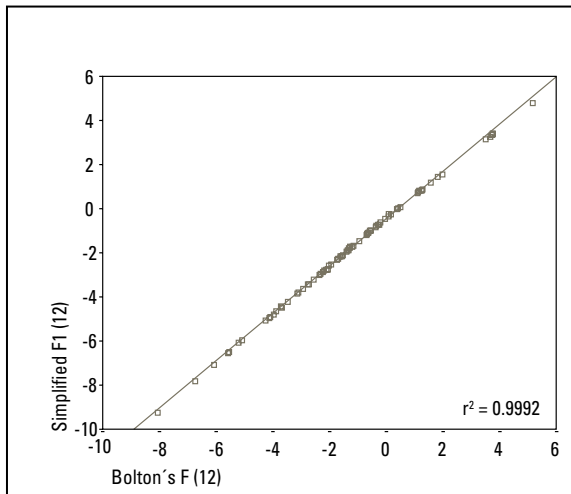


FIGURE 5 - Correlation between overall ratio obtained with Bolton's method and the Simplified Formula 1.

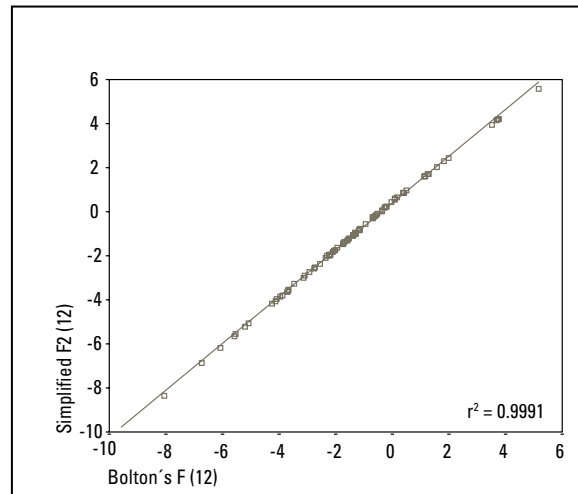


FIGURE 6 - Correlation between overall ratio obtained for Bolton's method and the Simplified Formula 2.

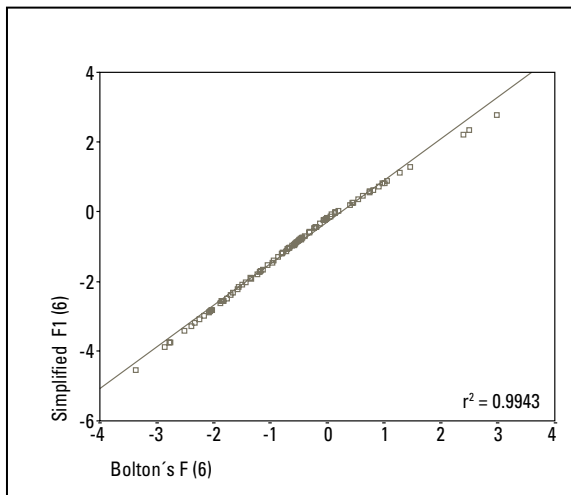


FIGURE 7 - Correlation between anterior ratio obtained for the Bolton's method and the Simplified Formula 1.

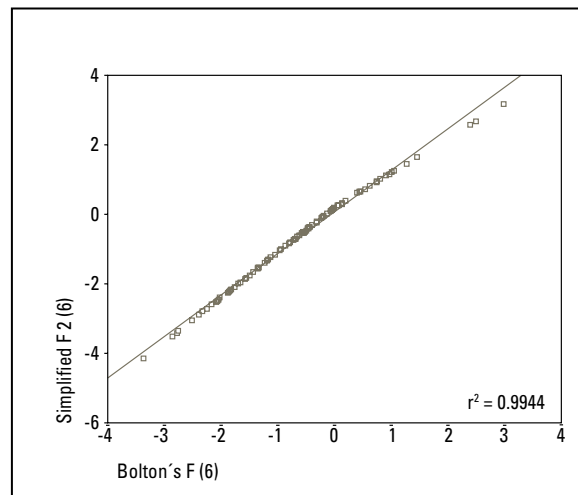


FIGURE 8 - Correlation between the anterior ratio obtained with Bolton's method and the Simplified Formula 2.

## DISCUSSION

An ideal functional occlusion, with adequate overbite and overjet, requires, among other factors, an adequate ratio between the upper and lower teeth. According to some authors,<sup>2,6,7,16,17</sup> about 5 to 60% of people have some degree of dental discrepancy. This incidence varies according to factors such as sex,<sup>1,14</sup> racial and ethnic characteristics,<sup>3,10,18</sup> kind of malocclusion,<sup>6,7,12,14,15</sup> amongst others.<sup>6,11</sup> Even with its limitations, including the need for calculations and use of tables, the Bolton's method<sup>5</sup> constitutes a valuable tool to achieve the correct occlusal relationship during treatment.

Prior to Bolton's analysis<sup>5</sup>, Neff<sup>13</sup> established a proportion coefficient for the anterior teeth of 1.2 (ranging from 1.17 to 1.41). This author stated that the sum of the mesiodistal width of the upper anterior teeth should be 20% higher than the lower ones to create appropriate vertical and horizontal relationships. Based on the studies of these two authors, our data support the efficacy to predict the dental interarch discrepancy by the two Simplified Formulas that were derived from the Bolton's analysis.

When comparing alternative methods to Bolton's method, there was a statistical significance ( $p < 0.001$ ) and a high correlation between them, with values of  $r^2 = 0.999$  for the overall ratio and  $r^2 = 0.994$  for the anterior ratio. When the overall ratio was evaluated, the Simplified Formula 1 (Figs 1 and 5) tended to underestimate the positive values of dental discrepancy. In other words, in cases of maxillary excess, Formula 1 showed smaller values than those obtained by the Bolton's method, although the maximum difference for this comparison was 0.39 mm. In contrast, when there were negative discrepancies, Formula 1 tended to overestimate negative values, compared to Bolton's analysis. Taken all together, in the present study, the first alternative method tested tended to potentiate the mandibular excess by 1.21 mm. The tendency

towards negative values in Formula 1 – Bolton's Formula relationship was reinforced by the value of -0.58 mm for the mean difference.

For the Simplified Formula 2 (Figures 2 and 6), for each negative Bolton value there was an even lower value for Formula 2. In this second comparison (Formula 2 – Bolton's Formula), there was a tendency to overestimate negative values, although this tendency was smaller than the one observed on the previous comparison (Formula 1 – Bolton's Formula). The difference between the two methods was even greater for the positive values of discrepancy, which also tended to overestimate the maxillary excess. Therefore, the Simplified Formula 2 overestimated both the mandibular (up to 0.29 mm) and the maxillary excess (maximum 0.50 mm), being the latter in a greater proportion.

When the two Simplified Formulas (1 and 2) were compared together, there was an average difference of 0.88 mm between the values of dental discrepancy. There was a tendency to potentiate negative discrepancies (mean -0.58 mm) in the first one (Formula 1), and a tendency to provide positive values in the second formula that were greater than the discrepancy found by the Bolton's method (mean 0.30 mm). According to the mean results, the Simplified Formula 2 was the one closest to the Bolton's method for the overall dental discrepancy, with differences always  $\leq 0.50$  mm.

Meanwhile, the Simplified Formula 1 also tended to overestimate the negative values of discrepancy for the anterior ratio (minimum -1.18 mm). For the values of discrepancy close to zero (positive or negative), the difference between Formula 1 and Bolton's Formula was smaller. In cases of maxillary excess, the results showed a tendency to underestimate the positive dental discrepancies (up to -0.15 mm), with a mean difference for this comparison of -0.43 mm, i.e. tended to negative values of dental discrepancies.

When comparing Formula 2 with Bolton's Formula for the anterior region, it was observed that the greater the discrepancy (positive or negative), the greater the difference between the values of both methods. However, there was a greater tendency to overestimate negative values (mandibular excess) than positive values (maxillary excess). This becomes evident for Bolton indices of less than 1 mm, where there was a maximum difference of 0.2 mm between the methods. Meanwhile, for larger negative discrepancies (up to -2,9 mm), this difference was 0.79 mm. When comparing both formulas, Formula 2 (in relation to the Bolton's method) tended to show smaller differences (-0.6 mm) than Formula 1 (-0.43 mm) for the anterior ratio. This may be partly explained by the multiplication factor (1.29) used in Formula 2, with two decimal places, that reduced the error of method, and achieved a value that was closer to the coefficient for anterior dental proportion established by Neff<sup>3</sup> (1.2).

Even with the greater accuracy of Formula 2, the applicability of each formula must be considered. It is clear that the implementation of the Simplified Formula 1 is considerably simple and avoided the use of a calculator. Moreover, although the Simplified Formula 2 provided values closer to those obtained by the Bolton's method, it is much more difficult to be applied due to the use of two decimal places.

Although the difference between methods were small, in general, we should pay attention to the clinical application of these findings. According to data obtained from Bolton's method<sup>5</sup>, the standard deviation from the average of the overall ratio and anterior ratio

was established as 1.91 mm and 1.65 mm, respectively. Therefore, it may be assumed that differences between the tested methods are within acceptable parameters. Likewise, Proffit<sup>16</sup> found that discrepancies of less than 1.5 mm are rarely significant.

Considering that the biggest difference was 1.18 mm when both methods were compared (always less than that described by Bolton<sup>5</sup> and Proffit<sup>16</sup>), it may be stated that differences between the methods were not clinically significant.

## CONCLUSION

According to the results, we conclude that:

- » Both alternative methods (Simplified Formula 1 and Simplified Formula 2) to calculate the tooth size discrepancy are reliable, require less time for their application and waive the use of traditional Bolton's tables.
- » The Simplified Formula 1 tends to overestimate the mandibular excess, both for the overall and the anterior ratios, while the Simplified Formula 2 tends to overestimate both the maxillary and mandibular excess, although in a smaller proportion.
- » The Simplified Formulas 1 and 2 provide a greater reliability for calculating the anterior discrepancy, compared to the overall dental discrepancy.
- » Both alternative methods may be used to replace the traditional method, since they demonstrated smaller mean differences ( $\leq 0.58$  mm) and no clinical significance when compared to the Bolton's method.



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