# Determination of Bolton tooth-size ratios by digitization, and comparison with the traditional method

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SUMMARY The Bolton Index is one of the most useful calculations for precise orthodontic diagnosis as it shows if there is a correct ratio between dental proportions. However, at times, this calculation is not applied because it is a long and time-consuming procedure compared with digital methods.

A new digital method for measuring tooth sizes and for calculating the Anterior (ABI) and the Overall (OBI) Bolton Index was tested on 100 sets of study dental casts of the permanent dentition in a Spanish sample and compared with the traditional method. The reproducibility of this digital method versus the traditional one was analysed to determine intra- and inter-examiner measurement errors by calculating the coefficients of variation.

The results demonstrated that the digital method provided results comparable with those of the traditional technique, since the regression parameters for each index showed that the correlation coefficients of the two methods were very high and similar to each other: r = 0.976 and r = 0.979 for the ABI and OBI, respectively. The results also showed more discrepancies in the ABI than in the OBI using both methods in this sample.

### Introduction

The result of any orthodontic malocclusion treatment should be comfortable contact between neighbouring teeth. This makes the correct ratio between tooth sizes absolutely necessary (Proffit, 2000).

There are often discrepancies between tooth sizes that affect the occlusion and that are not apparent until the final stages of orthodontic treatment (Crosby and Alexander, 1989; Freeman *et al.*, 1996). Consequently, many varied methods for measuring tooth-size discrepancies have been developed, even though they are not always used (Pont, 1909; Howes, 1947; Neff, 1949, 1957; Steadman, 1952; Rees, 1953; Stifter, 1958). Nonetheless, the Bolton analysis (1958, 1962) is still the most widely used for measuring such discrepancies and it is always suggested before initiating orthodontic treatment on a patient (Crosby and Alexander, 1989), especially in the anterior region where relative tooth sizes control the amount of overbite, overjet, crowding and spacing.

Bolton (1958, 1962) introduced two indices, the Anterior Bolton Index (ABI) which is the percentage obtained by adding the mesiodistal size of the six mandibular anterior teeth (from canine to canine) divided by the mesiodistal size of the six maxillary anterior teeth (from canine to canine); and the Overall Bolton Index (OBI) which is the percentage obtained by dividing the total mesiodistal size of the 12 mandibular teeth (from first molar to first molar) by the mesiodistal size of the 12 maxillary teeth (from first molar to first molar). The indices for a correct occlusion, extrapolated from Bolton's studies, are:

ABI = 77.2 per cent (74.5 - 80.4 per cent)OBI = 91.3 per cent (87.5 - 94.8 per cent)

Traditionally, the Bolton indices are measured manually. This is a laborious task, so the possibility of using a digital method, which was introduced and tested to measure mesiodistal tooth size, is an attractive alternative (Paredes *et al.*, 2003). With the digital method, the images of dental arches are digitized and, with the aid of a computer program, the Bolton indices are quickly, simply and automatically calculated.

Tomassetti *et al.* (2001) compared three digital measuring techniques with the traditional method for calculating the Bolton Index and concluded that the digital methods were quicker, but that they needed to be improved.

Therefore, the aims of this study were to determine the Bolton indices in a large number of patients using a digital method (Paredes, 2003; Fayos *et al.*, 2004; Paredes *et al.*, 2004) and the traditional method (using dental callipers), and to compare the results obtained with both procedures.

#### Materials and methods

One hundred dental casts of patients attending the Orthodontic Department of the University of Valencia, Spain, were selected.

In order to compare the two measuring procedures under the best conditions, the selection criteria of the casts were:

- 1. A permanent dentition from first molar to first molar;
- 2. Good quality casts;
- 3. No tooth agenesis or extractions;
- No large restorations that could change the mesiodistal diameters of the teeth;
- 5. No teeth with anomalous shapes.

The sample comprised 30 females and 70 males, with a mean decimal age of 14.8 years (range 11.2–22.7 years) which was similar in both genders.

The mesiodistal sizes of the upper and lower teeth of each cast, excluding the second and third molars when they were present, were measured by both methods as follows:

For the traditional method callipers were used (model P. 1078.15; Leone **®**) to measure the mesiodistal size of the cast. This is the maximum diameter between the mesial and distal points of contact of each tooth. The ABI and OBI of these mesiodistal sizes were calculated by totalling the sizes of the teeth and determining the corresponding index.

For the digital method the casts were scanned. Digitization was carried out by placing the stone dental casts on a scanner (Hewlett Pachard Scan Jet  $\mu c^*/T$ ), surrounded by a squared sheet of paper. This enabled calibration of the two axes and thus calculation of the ABI and OBI. As a result, when the casts were digitized, the upper and lower dental cast images appeared in the middle of the screen with the squared paper around them; the different measurement options of the software program (Department of Orthodontics, University of Valencia) were located on the right of the screen. The scanned image was then scaled so that two different vertical and horizontal marks on the squared paper were selected at a specific distance of 30 mm apart, to establish both the horizontal and the vertical transformation dimension factors.

These transformation dimension factors (the horizontal factor 'x' and the vertical factor 'y'), which must have

the same numerical value, serve as verification. If the transformation dimension factors obtained are the same for the 'x' and 'y' axes, the calibration has been correctly carried out and the image has not been distorted; the equivalence relationship of the original cast model has been maintained but has simply been made larger. If, on the other hand, the factors 'x' and 'y' do not have the same value, the calibration must be repeated because the measurement are inaccurate.

With the aid of a computer mouse as the user interface, the points on the mesial distal aspect of the tooth were placed for the mesiodistal size. The software determined dental sizes in millimeters from these data, through the formula:

 $D = ((posx_2 - posx_1)^2 \times factx^2 + ((posy_2 - posy_1)^2 \times facty^2))^{\frac{1}{2}}$ 

where  $posx_2$ ,  $posy_2$ ,  $posx_1$  and  $posy_1$  are respectively the co-ordinates of the points marked in pixels, and factx and facty are the magnification factors of the two axes.

Once all the points on the dental cast images had been marked, the software designed for this purpose automatically calculated the ABI and OBI. It can even show when the indices are not within what is considered to be normal intervals and where the discrepancy is located (Figure 1).

#### Statistical method

The data obtained with the digital and traditional methods were stored in the computer and presented as an Excel page.

A statistical package (SPSS, Chicago, Illinois, USA) was used to analyse the comparison of paired measurement means and the correlation between variables calculated by the analysis of linear regression and correlation coefficients.

The proportion comparison test was also used to validate statistically the ratio of correct predictions.

The reproducibility of the digital versus the traditional method was analysed by determining intra- and interexaminer measurement errors in turn, calculated by the



Figure 1 The results for mesiodistal tooth size using the digital method. Anterior Bolton Index: 79.81% 77.2% (74.5–80.4%); Overall Bolton Index: 90.99% 91.3% (87.5–94.8%).

coefficients of variation (CV). These CV (CV = SD  $\times$  100/ mean) were expressed as a percentage.

#### Results

Twenty dental casts from the present study were randomly selected in order to assess the reproducibility of both methods. The tooth-size measurements were again determined by the same (intra-examiner error) and different (inter-examiner error) operators in order to obtain the CV. All CV were very low (below 5.8 per cent) and similar between both methods and examiners, which indicates that the digital and traditional methods provide similar results (Table 1).

Concordance and discrepancies in the ABI and the OBI using both measuring methods are shown as percentages of patients in Figure 2.

For the ABI there was concordance in 90 cases. In 66 cases the ABI was normal using both methods, while in 24 cases discrepancies were found with both methods. In 10 cases, in which there was no concordance between the methods, seven presented ABI discrepancies using the traditional method and three using the digital method.

Regarding the OBI, concordance was found in 97 cases, of which 92 had normal OBI values and five showed discrepancies. In the three cases in which the determination was different using both methods, one was with the digital method and two with the traditional method.

The ABI and OBI for the cases in which discrepancies were found using only one of the measuring methods are shown in Table 2. The values in the white cells show the results that are considered to be within Bolton intervals while those in the grey cells are considered to be outside. This shows that the differences between the values obtained with both methods are very small and consequently only affect cases around the borderline of normality.

With a view to demonstrating the similarity between the results obtained by both measuring procedures, a regression analysis was performed. In view of the separation of the values involved in determining ABI and OBI, both indices and their corresponding settings are shown on the same graph (Figure 3). The regression parameters for each index (Figure 3) showed that the correlation coefficients between the two methods were very high and similar to each other: r = 0.976 and r = 0.979 for the ABI and OBI, respectively. For the OBI the confidence interval of 95 per

 Table 1
 Intra-examiner and inter-examiner tooth-size coefficients of variation.

	Coefficient of variation (%)							
	Intra-examiner error				Inter-examiner error			
	Traditional method		Digital method		Traditional method		Digital method	
	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.
Tooth size	0	2.82	0.05	2.88	0	5.79	0.16	5.70



**Figure 2** Percentages of concordance and discrepancy obtained with the digital and traditional methods for (a) the Anterior Bolton Index and (b) the Overall Bolton Index.

**Table 2** Anterior (ABI) and Overall (OBI) Bolton Index for thecases in which discrepancies were detected using only one of themeasuring methods (traditional or digital).

Case	ABI		OBI		
	Traditional	Digital	Traditional	Digital	
1			94.2	95.29	
2			94.9	94.59	
3	80.5	80.35			
4	80.6	80.35			
5	80.3	80.44			
6	80.3	80.85	94.7	95.39	
7	80.5	80.14			
8	80.6	80.06			
9	80.1	80.54			
10	80.6	80.33			
11	81.4	79.90			
12	74.4	75.05			

Grey cells show discrepancies outside Bolton intervals.



Figure 3 Linear regression of the Anterior Bolton Index and Overall Bolton Index values obtained with the digital and traditional methods.

**Table 3** Linear regression parameters of the Anterior (ABI) and Overall (OBI) Bolton Index values obtained by the digital method versus the traditional method, and 95 per cent confidence intervals.

	Linear regression parameters	Confidence interval
ABI		
Intercept	3.775	(0.444/7.107)
Slope OBI	0.953	(0.911/0.996)
Intercept	3.419	(-0.275/7.113)
Slope	0.964	(0.924/1.004)

cent of the intercept and of the slope of the linear regression line include 0 and 1, respectively. For the ABI, even though the 95 per cent intervals do not include those values, the differences were not significant (Table 3).

To determine differences in the values obtained for each patient using both of the measuring methods, the means comparison test for paired measurements was used. The results for the difference between the values obtained using the digital and traditional method are shown in Table 4. The average difference between both methods was 0.1 per cent, with a confidence interval that does not include zero. Consequently, the digital method can be deemed to provide slightly higher values for the Bolton Index, although the discrepancies were very small.

The differences between the ABI and OBI values determined by the two measuring methods are shown in Figure 4. Most of the patients had differences in ABI and OBI with both the digital and traditional methods; these differences are in the middle of the bar diagram, with values ranging from -0.50 to 0.50 per cent.

#### Discussion

Sheridan (2000), reported that the Bolton Index was the most widely used diagnostic tool in clinical practice. However, as determining this index with traditional measuring methods is laborious, it is not undertaken for more than half of the cases in clinical practice.

The digital method presented in this study makes it possible to determine measurements and calculations quickly and accurately, once the casts have been digitized.

The regression parameters found in the present study, r = 0.976 (ABI) and r = 0.979 (OBI), were very high compared with other similar digital methods: Quick-Ceph Image Pro®, r = 0.439 (ABI) and r = 0.432 (OBI); Hats®, r = 0.825(ABI) and r = 0.885(OBI); or OrthoCad®, r = 0.574 (ABI) and r = 0.715 (OBI) (Tomassetti *et al.*, 2001).

The ABI results were very good, the findings for 90 patients concurring with both methods (24 patients with and 66 patients without discrepancies for the ABI), but there was discordance in 10 patients who presented a discrepancy in the ABI which was detected by only one of the procedures.

The OBI results with both methods showed concordance for 97 patients (5 patients with and 92 without discrepancies

Table 4Mean, standard deviation (SD) and 95 per cent con-fidence intervals of the differences between the Anterior (ABI) andOverall (OBI) Bolton Index values obtained using both measuringmethods (traditional versus digital) for each case.

	Mean	Confidence interval	SD	Maximum differences
ABI	0.11	(0.001/0.219)	0.55	-1.50/1.39
OBI	0.11	(0.026/0.185)	0.40	-1.11/1.09



**Figure 4** Ratio differences (mm) between the values obtained with the digital and traditional methods for the (a) the Anterior Bolton Index and (b) the Overall Bolton Index.

in the OBI), and a discordance for three patients who presented a discrepancy in the OBI with only one of the procedures.

It must be emphasised that the discordances were not significant, as many of the results were very near the values that Bolton (1958, 1962) gave as being correct, and are within the upper and lower interval limit. Moreover, the maximum discrepancies obtained (1.5 per cent for the ABI and 1 per cent for the OBI) indicate that the normality values of these indices are 77.2 per cent and 91.3 per cent, respectively. These discrepancies are not clinically significant, as they are located near the limit values.

Smith *et al.* (2000) stated that the parameters considered as normal for the Bolton Index can only be applied to white females, basing this on comparative studies on populations of different races and genders, while other authors found that discrepancies in the Bolton Index are seen more frequently in patients with Class III malocclusions (Nie and Lin, 1999; Araujo and Souki, 2003).

Occasionally, a discrepancy in the Bolton Index coefficient does not necessarily mean a size discrepancy, nor does a coefficient within the limits considered as 'ideal' guarantee an ideal occlusion; there are a series of factors, such as the curvature of the dental arch or the thickness of the incisal edges, that can change this ratio (Halazonetis, 1996).

In view of this, as with any index, borderline cases, which are the most difficult to diagnose, have to be considered separately. However, determination of the Bolton indices using the digital method is highly applicable to clinical practice and provides the advantages of measuring with ease and speed.

Nevertheless, discrepancies in the ABI are more numerous than in the OBI, with both methods. These findings are in agreement with those of Fernández-Riveiro *et al.* (1995), Shellhart *et al.* (1995) and Santoro *et al.* (2000).

These results show that the majority of size discrepancies are in the anterior teeth. This is apparent by the presence of

crowding and diastemas. A form of compensation in the buccal segment relieves the clinical consequences of these anterior discrepancies.

#### Conclusions

The proposed digital method is as sensitive and accurate as the traditional method for calculating the Bolton indices. It is faster and easier to carry out and it offers all the advantages associated with computer methods, such as the storage of images and data for subsequent use.

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