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A comparison between dental measurements taken from CBCT models and those taken from a Digital Method

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SUMMARY The aims of the study were to assess speed, reliability, accuracy, and reproducibility in measuring mesiodistal tooth sizes, bicanine widths, bimolar widths, and arch lengths (ALs) using cone beam computed tomography (CBCT) and to compare them with the same measurements obtained using a two-dimensional (2D) Digital Method. Plaster study models were made for 27 patients and then digitalized and measured using a 2D Digital Method. CBCTs were undertaken on the same 27 patients using the Dental Picasso Master 3D® and the images obtained were then analysed using the InVivoDental program. The correlation study of the two measuring methods, which were compared by determining the regression parameters and the values of one method as opposed to the other, show how both methods are comparable, although the mean and standard deviation of all the measurements analysed present statistically significant differences for the first upper right premolar, first upper left molar, first lower left premolar, and second lower right premolar, as well for the lower intercanine distance and lower AL. The differences, however, are less than 1 per cent. CBCT digital models are as accurate and reliable as the digital models obtained from plaster casts. The differences existing between both methods are clinically acceptable.

Introduction

The introduction of cone beam computed tomography (CBCT) at the end of the 1990s represented a huge advance in orthodontic diagnosis by means of imaging. The CBCT, specifically developed for the maxillofacial region, provides numerous clinical applications, from the positioning of dental implants to the study of the respiratory system. Furthermore, it provides greater spatial resolution of high quality images, through shorter scans and with less radiation than conventional computed tomography.

In the field of orthodontics, CBCT allows us to undertake a more precise diagnosis, by providing information on the three-dimensions of the orofacial structures and to replace two-dimensional (2D) radiographs. Moreover, we can obtain three-dimensional images of teeth that can then be measured; measurements that traditionally were done by hand on plaster study models.

The reliability of craniofacial parameters measured with CBCT has been extensively dealt with in the literature. Many authors have found differences between them and measurements taken on conventional radiographs but these were not considered as clinically significant (Hilgers *et al.*, 2005; Moshiri *et al.*, 2007; Kumar *et al.*, 2008; Hassan *et al.*, 2009; Berco *et al.*, 2009). However, Periago *et al.* (2008) found that most differences in measurements between CBCT and 2D radiographs could be clinically considered as sufficiently accurate, given that they were less than 2 mm in 90 per cent of cases. All but the Kumar *et al.* (2008) study (*in vivo*) were performed on skull material. As regards studies carried out on prototype measurements, Lagravere *et al.* (2008) and Ballrick *et al.* (2008) found differences of less than 1 mm and 0.1 mm, respectively.

In studies undertaken on human craniums, Damstra *et al.* (2010) did not find differences between CBCT measurements undertaken on craniums and measurements on real craniums, whereas Baumgaertel *et al.* (2009) observed a slight underestimation. Similar results are provided by Liu *et al.* (2010), who, on analysing the accuracy of the CBCT volumetric analysis, stated that the CBCT deviated from the physical volumes from minus 4 to 7 per cent. Other studies have compared tooth length and radicular measurements on the CBCT and on periapical radiographs, finding differences between them, although CBCT scans were at least as accurate and reliable as periapical radiographs (Sherrard *et al.*, 2010).

There is only one study undertaken on patients that compared the CBCTs of 30 patients using the InVivoDental program and the digital models obtained by OrthoCad; no statistically significant differences between them being found for tooth measurements (Kau *et al.*, 2010). The InVivoDental program requires segmentations from CBCT images. There is a difference between undertaking dental measurements on volumetric CBCT images and undertaking them on segmentations from CBCT images. Segmentations are undertaken by an operator and so are subjective to error.

The aims of this study were, therefore, to asses the speed, reliability, accuracy, and reproducibility in measuring mesiodistal tooth sizes, bicanine widths, bimolar widths, and arch lengths (ALs) on the CBCT and to compare them with the same measurements obtained using a 2D Digital Method on digitalized plaster models. We used the Digital Method as a gold standard since the reliability, accuracy, and reproducibility of the 2D Digital Method had previously been tested by other authors (Leifert *et al.*, 2009; Bootvong *et al.*, 2010).

Materials and methods

Twenty-seven patients who had attended the Orthodontics Department of the Faculty of Medicine and Odontology at the University of Valencia, Spain, were randomly selected. Most of them were going to undergo orthognathic surgery or had a CBCT in their medical record for other reasons. Plaster study models and a CBCT image were made for all of them.

The inclusion criteria were as follows:

1. Permanent dentition from the first permanent molar of one side to the other.
2. Absence of anomalies in the number, size, and dental shape.
3. Good quality of study models.
4. Absence of large occlusal restorations or the presence of prostheses.

A Digital Method was employed, designed by a work group of the University of Valencia, Spain, the reliability and reproducibility of which had previously been tested (Paredes *et al.*, 2003; Paulino *et al.*, 2008) for measuring plaster study models. The method consists of carrying out a scan, using a conventional scanner, of the patients' plaster models obtained from alginate prints that enable us to obtain an image of each dental arch in 2D. Having undertaken the scan of each model, the 2D images were stored in a computer and analysed using measurement software (Figure 1). With the aid of the mouse as a user interface, we marked the points of the mesiodistal size (MS) of each tooth on the image of the casts. The software designed for this purpose automatically determines dental sizes in millimetres from these data.

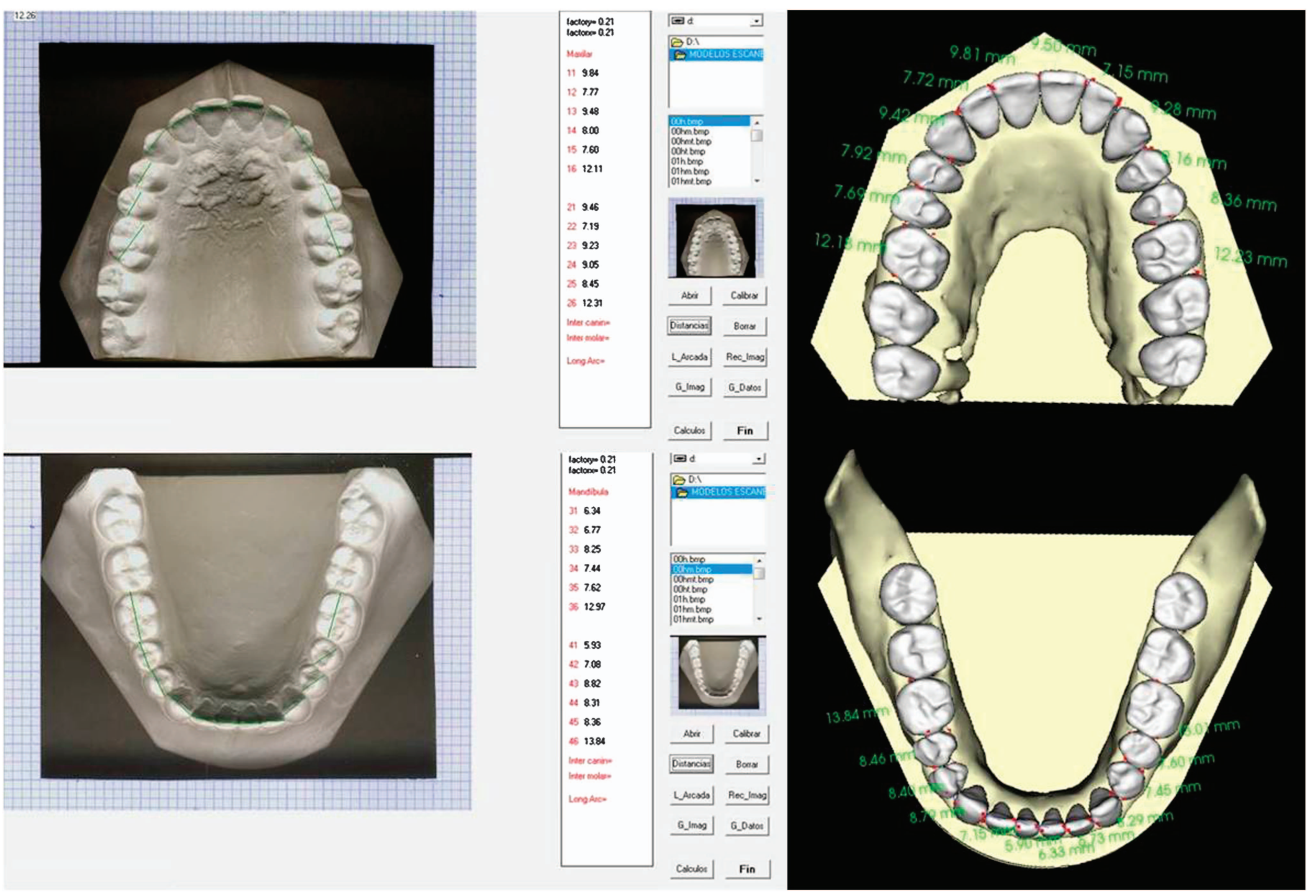

Figure 1 Measurement of mesiodistal tooth sizes using the Digital Method and the cone beam computed tomography (CBCT)

The CBCT employed in this study was the Dental Picasso Master 3D® (EWOO technology, Republic of Korea, 2005) belonging to the Faculty of Medicine and Odontology at the University of Valencia. The patients were scanned in full occlusion rather than with a wax bite as this is important for the segmentation process due to the shape of the device. This CBCT has two field of view (FOV) modes: standard and full. The scanning dimensions for the full head of these two modes are 200 × 150 mm (12 bits) or 200 × 19 0mm (14 bits). Scanning time varies from 15 to 24 seconds depending on whether the mode employed is normal or high quality. Slice thickness is 0.1 mm; the scanning angle covers 360º and it generates a number of slice images that also depend on the mode chosen: 592 for the full FOV of 200 × 190 mm and 496 for the standard FOV 200 × 150 mm. Voxel size is 0.4 mm. It has a tube voltage range of 40–90 kV and an intensity range of 2–10 mA. The computer program used for analysing the CBCT images was the InVivoDental (Anatomage, San Jose, California, USA) program. CBCT images were safely sent in DICOM format to the Web of the InVivoDental company to be segmented and to obtain the three-dimensional images of the models (Figure 1).

Having obtained the sample, we proceeded to undertake the tooth measurements from each of the models using the two described measuring methods: the Digital and the CBCT. The measurements that were taken were

1. MS. This size corresponds to the maximum width and distance between the mesial and distal anatomical contact points. The second and third, both upper and lower, were excluded. In badly positioned teeth, the hypothetical contact points are measured on their proximal, mesial, and distal faces.
2. Intercanine distance (ICD). This is the linear distance between the cusp tips of both canines or in the centre of their wear facets should they be present, both in the upper and in the lower arch.
3. Intermolar distance (IMD). This is the maximum distance between the vestibular surfaces of the first permanent molars on one and the other side of the arch, both upper and lower.
4. AL. This is the ideal line that passes through the ideal points of contact of each of the teeth and is obtained, therefore, by joining the most mesial and distal points of each tooth selected, from the mesial of the first molar to the mesial of the upper and lower first molar. This measurement is based on a subjectively assessed ideal arch.

Statistical analysis

All the measurements were introduced into an Excel spreadsheet and analysed using the statistics program SPSS v.15.0 for Windows. All the data from the sample and for the two methods were checked using the Kolmogorov–Smirnov test to see whether they followed a normal distribution, the significance for each variable analysed being obtained. The data obtained showed that all the variables followed a normal distribution with significance values from 0.100 to 0.989.

To compare means, the paired Student's *t*-test was used. The correlation between variables of both methods was determined using Pearson's correlation coefficient and the estimation of the slope and ordinate at origin and their respective confidence intervals of 95 per cent. In order to consider that both measuring methods are comparable, the correlation coefficients must be high and the confidence intervals of the slope and ordinate at origin must contain 1 and 0, respectively. This ensures that there are no systematic differences in the measurements (something that would occur if the confidence level of the ordinate were not to contain 0) and that an increase in the size of the object measured would represent the same increase in the two measuring methods (something that would not occur if the confidence level of the slope did not contain 1).

The discrepancy between methods was calculated as the differences between the mean value of each item determined by each method compared to the mean value of the item measured by the Digital Method and expressed as a percentage.

To discover the intraobserver error of the measurements taken by CBCT, 7 of the 27 patients were chosen and all measurements were repeated three times by the same observer (90 measurements). The variation coefficient was 1.8 per cent for tooth sizes and 1.1 per cent for the intercanine, intermolar, and AL jointly (IC: 1.6 per cent, IM: 1.1 per cent, and LAI 0.7 per cent). These values were analysed together as the differences were relatively small. The reproducibility of the Digital Method had previously been tested (Paredes *et al.*, 2003; Paulino *et al.*, 2008), being 2.1 per cent for tooth sizes and 1.7 per cent for the intercanine, intermolar, and AL; the latter being analysed jointly as the jointly differences were relatively small. The two methods have similar coefficients of variance. No interexaminer error has been calculated for CBCT measurements.

Results

Table 1 shows the mean mesiodistal sizes of each of the teeth, for both arches and their standard deviations for both methods: the CBCT and the Digital Method, whereas Table 2 shows the mean and standard deviation of the ICD, the IMD, and AL.

Only small differences were found, but statistical significance ($P < 0.05$; paired Student's *t*-test) was reached between the two measuring methods for mesiodistal sizes of the following teeth: first upper right premolar (14), first upper left molar (26), first lower left premolar (34), and second lower right premolar (45), as well as for the lower ICD and the lower AL (Table 3). It may be observed that how in all these cases the discrepancy between both methods is lower than 1 per cent.

Table 1 Mesiodistal tooth size mean and standard deviation (SD) for the Digital Method and cone beam computed tomography (CBCT).

Teeth		Digital Method		CBCT	
		Right, mean ± SD	Left, mean ± SD	Right, mean ± SD	Left, mean ± SD
Upper arch	CI	8.39 ± 0.85	8.36 ± 0.74	8.41 ± 0.82	8.4 ± 0.75
	LI	6.74 ± 0.82	6.62 ± 0.78	6.73 ± 0.75	6.65 ± 0.82
	Canine	7.56 ± 0.6	7.62 ± 0.69	7.57 ± 0.6	7.6 ± 0.67
	First PM	6.89 ± 0.67	6.93 ± 0.75	6.82 ± 0.63	6.91 ± 0.68
	Second PM	6.78 ± 0.65	6.82 ± 0.7	6.73 ± 0.6	6.8 ± 0.69
	1 M	10.13 ± 0.89	10.28 ± 1.01	10.18 ± 0.87	10.19 ± 0.9
Lower arch	CI	5.33 ± 0.38	5.47 ± 0.38	5.36 ± 0.35	5.42 ± 0.35
	LI	5.33 ± 0.44	5.93 ± 0.44	5.36 ± 0.43	5.87 ± 0.43
	Canine	6.69 ± 0.79	6.68 ± 0.79	6.71 ± 0.79	6.7 ± 0.79
	First PM	7.1 ± 0.48	6.98 ± 0.75	7.06 ± 0.48	6.9 ± 0.68
	Second PM	7.44 ± 0.76	7.51 ± 0.7	7.38 ± 0.74	7.41 ± 0.69
	1 M	10.92 ± 1.15	10.84 ± 1.01	10.92 ± 1.09	10.78 ± 0.9

Table 2 Intercanine distance (ICD), intermolar distance (IMD), and arch length (AL) mean and standard deviation (SD) for the Digital Method and cone beam computed tomography (CBCT).

Method	ICD		IMD		AL	
	Upper (U), mean ± SD	Lower (L), mean ± SD	Upper (U), mean ± SD	Lower (L), mean ± SD	Upper (U), mean ± SD	Lower (L), mean ± SD
Digital	32.9 ± 6.1	26.2 ± 3.5	54.5 ± 4.8	52.3 ± 4.9	76.2 ± 6.7	64.2 ± 7.4
CBCT	33.0 ± 5.7	26.5 ± 3.2	54.1 ± 4.3	52.6 ± 4.7	76.2 ± 6.5	63.9 ± 7.4

Table 3 Mean and standard deviation (SD) of the statistically significant differences and discrepancy (per cent) in the determination of these values between the Digital Method and CBCT.

Variable	Mean ± SD	% Discrepancy	*P*-value
Tooth 14	+0.07 ± 0.19	1.0	0.047
Tooth 26	+0.09 ± 0.24	0.9	0.037
Tooth 34	+0.07 ± 0.17	1.0	0.020
Tooth 45	+0.06 ± 0.15	0.8	0.026
ICD lower	−0.23 ± 0.63	0.9	0.017
AL lower	+0.29 ± 0.66	1.0	0.041

Upper right first premolar (14), upper left first molar (26), lower left first premolar (34) and lower right second premolar (45), lower intercanine distance (ICD lower), and lower arch length (AL lower).

To compare both measuring methods (CBCT and Digital Method), a dispersion diagram was made representing, in ordinates, the data obtained with the Digital Method, whereas the data obtained using the CBCT was located in abscissae. We have represented the mesiodistal teeth sizes, the ICD and IMD, and the ALs in a single graphic, as can be seen in Figure 2. The proximity of the points that represent each of the measurements taken at the bisection indicates that both methods, Digital and CBCT, are comparable and that there is a good correlation between the measurements taken with them. To specify the aspects indicated, a linear regression analysis was applied to each of these data groups,

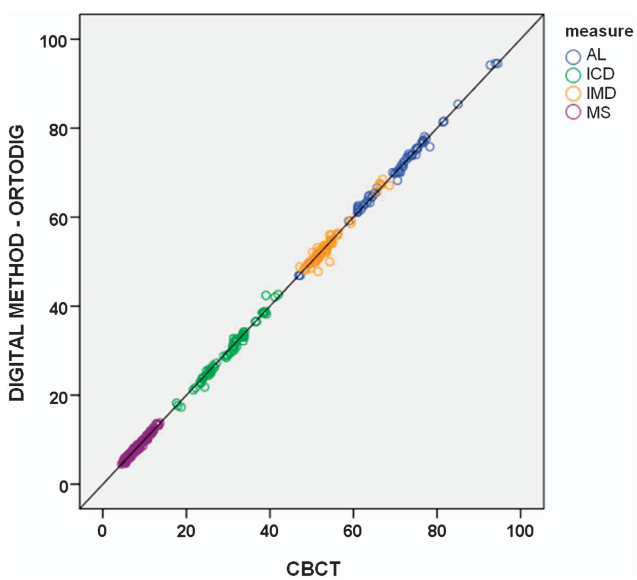

Figure 2 Dispersion diagram of all the data; ordinates (Digital Method) versus abscissae [cone beam computed tomography(CBCT)]. AL, arch length; ICD, intercanine distance; IMD, intermolar distance; MS, mesiodistal size.

Table 4 Slope and ordinate at origin, 95 per cent confidence intervals (95% CIs), and correlation coefficients for the regression analysis for each group: the Digital Method and CBCT. ICD, intercanine distance; IMD, intermolar distance; AL, arch length.

	Slope [95% CI]	Ordinate at origin [95% CI]	Correlation coefficient (*r* Pearson)
Upper mesiodistal tooth sizes	0.999 [0.986–1.013]	0.017 [−0.089 to 0.122]	0.999
Lower mesiodistal tooth sizes	1.003 [0.993–1.013]	0.010 [−0.063 to 0.083]	0.991
Upper ICD, IMD, and AL	1.006 [0.997–1.014]	−0.342 [−0.828 to 0.145]	0.999
Lower ICD, IMD, and AL	1.012 [1.000–1.022]	−0.622 [−1.145 to 0.099]	0.999
All measures	1.000 [0.999–1.001]	0.005 [−0.029 to 0.038]	0.9998

so determining the slope, ordinate at origin, and the correlation coefficient (Table 4).

Table 4 shows that the correlation coefficients (Pearson's *r*) obtained are very high both for upper (0.999) and lower mesiodistal sizes (0.991), ICD and IMD, and the AL of both arches (0.999) and that the 95 per cent confidence levels of the regression line slopes include one in all cases and ordinates at origin include 0. A joint regression analysis of all the measurements taken, mesiodistal tooth sizes, ICD and IMD, and ALs, had a correlation coefficient of 0.9998, a slope of 1.000, 95 per cent CI [0.999–1.001] and an ordinate at origin of 0.005, 95 per cent [−0.029 to 0.038].

Another interesting aspect is to evaluate the speed of the method when measuring the mesiodistal sizes and distances on the digital models extracted from the CBCT compared to the Digital Method. To do so, the mean time that it took using the two methods from the moment the image in the computer appeared to when all the values were obtained on the screen were calculated for each dental arch. With the digital models of the CBCT, the mean time was 1 minute and 34 seconds for each arch, whereas with the Digital Method, the mean time was 1 minute and 58 seconds. The execution times are, therefore, practically identical for both methods.

Discussion

Both plaster and digital study models have for a long time been an important diagnostic tool for drawing up a suitable treatment plan. The measurements that we normally carry out on them, the mesiodistal sizes, the ICD and IMD, and AL, have been used in our study to check whether the measurements undertaken on the digital models taken from the CBCT are as reliable as those taken from conventionally digitalized study models.

The reliability and reproducibility of the dental measurements in the CBCT have been tested on prototypes, minimal errors having been found, even though the CBCT undervalues the measurements. Our results show that there are no differences between both measuring methods, given that even in the cases where we found a statistically significant difference, these differences did not reach 1 per cent and, therefore, are without interest in terms of their clinical application. Our results coincide with the study of Lagravere *et al.* (2008) who found errors lower than 1 mm in some measurements, with the study of Ballrick *et al.* (2008) who found even lower errors, of less than 0.1 mm, with the studies of Baumgaertel *et al.* (2009) and Liu *et al.* (2010).

In our study, we have checked the reliability and reproducibility of the dental measurements in humans. The adjustment lines show us how all the measurements analysed are found close to the bisection, so we may state that both methods are comparable. All these data indicate that the measurements taken on the CBCT models are accurate and reproducible. These results coincide with those of Kau *et al.* (2010) who examined 30 CBCTs and their corresponding 30 digital models. The software used was OrthoCAD® and the CBCTs were segmented using the InVivoDental® software. The measurements analysed were the Little Index, overjet, and overbite.

The measurements of mesiodistal sizes, ICD and IMD, and AL on digital models taken with CBCT are as quick as those taken with Digital Method, so presenting an advantage for the CBCT. The results of this work suggest the possibility of eliminating one of the traditional recording methods of orthodontics, that of plaster study models, so providing a saving in physical storage space, an important problem in Orthodontic offices. Another advantage of using CBCT measurements is the ability to remove teeth to better measure the image in cases of crowding, besides providing dynamic images as opposed to the static images of digital models in 2D.

However, the benefits of CBCT should be balanced against the additional cost. The segmentation of the models increases the cost further (segmentation by InVivo costs around $70 per patient). In addition, the use of CBCT scanning exposes the patient to ionizing radiation. Image quality may also be impaired in subjects wearing braces, implants, or metal prostheses as segmentation is less accurate. Finally, CBCT scans are not justified for all orthodontic cases.

Conclusions

The conclusions of this study are that

- CBCT allows us to determine mesiodistal sizes, ICD and IMD, and ALs quickly, reliably, accurately, and

reproducibly compared with measurements obtained using the Digital Method on digitalized plaster models.
- There are no clinical differences between measurements using the CBCT method and those using the Digital Method.

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