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Mesiodistal tooth dimensions and anterior and overall Bolton ratios evaluated by cone beam computed tomography

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Aim: The mesiodistal widths of the maxillary and mandibular teeth and anterior and overall tooth size ratios were measured by CBCT and conventional orthodontic plaster methods, compared, and correlation coefficients for both methods determined.
Material and methods: The records of 26 patients (14 males and 12 females) between the ages of 18 and 28 years were randomly selected from the archives of the Oral Diagnosis, Radiology and Orthodontic Departments at the Karadeniz Technical University. The mesiodistal diameters of the maxillary and mandibular permanent teeth from first molar to first molar were measured on the patient's plaster models and also on CBCT arch renditions. Anterior and overall Bolton ratios were calculated for each method. Comparisons were performed using Pearson's correlation coefficient (PCC).
Results: The measurements of the mesiodistal widths of most maxillary and mandibular teeth were similar and consistent between the conventional and CBCT methods. PCC values ranged from 0.637 (mandibular right second premolar) to 0.916 (maxillary right canine). PCC values for anterior and overall ratios were 0.756 and 0.781, respectively, indicating that correlations between conventional and CBCT methods were acceptable.
Conclusion: Dental measurements and anterior and overall Bolton ratios calculated on CBCT showed acceptable PCC values indicating that CBCT measurements could be used instead of those obtained from conventional plaster models.
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Introduction

Successful orthodontic treatment is based on comprehensive diagnosis and treatment planning.[1] The fundamental requirements assisting in diagnosis are orthodontic models, photographs, radiographs, and a thorough clinical examination.[2]

An orthodontic model is a precise three-dimensional replica of a patient's dentition on which measurements may be performed more easily and accurately than in the patient's mouth.[3] In addition to the facilitation of diagnosis and treatment planning, model analysis allows an evaluation of treatment progress and results may be used for case presentation and record keeping.[2,4,5] However, the process of model generation is time-consuming and physical storage space is required, both of which add financial and logistic burdens.[1]

The use of computer technology in dentistry has become an integral part of practice management. The electronic capture of patient information eliminates the problems of physical storage, retrieval, maintenance and improves office management.[2,6,7] A contemporary focus has been on the generation of digital models, either by intra-oral laser scanning,[8] laser scanning of the orthodontic model,[9] non-destructive scanning of the model or impressions with micro-computed tomography or destructive imaging of the model with incremental image captures.[10]

Several reports have compared the reliability and accuracy of dental casts with digital scans of corresponding impressions. The reliability of measurements conducted on digital models produced from impressions has been proven to be as good, if not better, than measurements obtained from plaster casts.[11] El-Zanaty et al.[2] confirmed excellent agreement between dental measurements including mesiodistal widths of the teeth, arch widths, arch lengths, arch perimeters and palatal depths determined by conventional and computerised tomographic (CT) methods. Although the use of digital models is increasing, their generation still involves the taking of impressions and their subsequent scanning which requires time to complete.[12] According to Kau et al.,[13] current imaging techniques involving cone beam computed tomography (CBCT) could potentially eliminate the time-consuming and often uncomfortable process of obtaining impressions. It was determined that CBCT digital models were as accurate as OrthoCAD digital models in providing linear measurements for overjet, overbite, and crowding values.[13] To date, however, no study has compared the anterior and overall Bolton ratios and tooth widths generated from CBCT and conventional orthodontic plaster model methods. Therefore, the aim of the present study was to determine correlation coefficients by the measurement of the mesiodistal widths of the maxillary and mandibular teeth and to calculate anterior and overall tooth size ratios via CBCT and conventional study cast methods.

Material and methods

The present sample size was based on a significance level of 0.05 and a power of 85% to detect a clinically meaningful difference of 0.15 mm (± 0.17 mm) for the mesiodistal width of a tooth. The power analysis indicated that 24 patients were required. In order to increase the power of the study, the records of 26 patients (14 males and 12 females) were enrolled. The patients were aged between 18 and 28 years and were randomly selected from the archives of the Oral Diagnosis, Radiology and Orthodontics departments at the Karadeniz Technical University.

The selection criteria included the presence of erupted mandibular and maxillary permanent dentitions from the first molar to first molar, the presence of a reproducible, stable occlusion and the existence of plaster orthodontic models (taken with alginate) and a CBCT scan (Kodak 9500 Cone Beam 3D System, Kodak Dental Systems, Carestream Health, Rochester, NY, USA) of the dentofacial region. All patients had skeletal and dental Class I relationships without tooth agenesis. Minimal crowding of less than 3 mm in both arches was a required criterion. Approval for the study was previously granted by the Ethics Committee of the Karadeniz Technical University.[14] The patients were not subjected to any additional radiation for this retrospective study and so, no further ethics approval was required.

CBCT scans were performed according to the following settings: a field of view (FOV) of 18.4 x 20.6 cm, a voxel size of 0.3 mm, a scan time of 10.8 seconds at 90 kV and 10 mA. Each person was positioned through adjustment of the chin support until the Frankfurt plane coincided with a horizontal laser reference. Following the scan, 3D virtual models were reconstructed and tooth widths were measured by Invivo5 imaging software (Anatomage, San Jose, CA, USA) (Figures 1 and 2). Mesiodistal diameters of the permanent teeth from the first molar to first molar in the maxillary and mandibular arches were measured on conventional plaster casts and by CBCT methods by the same examiner using a method previously described by Hunter and Priest.[15] Cast measurements were obtained using a digital caliper accurate to 0.01 mm (Mitutoyo, Tokyo, Japan).

Anterior and overall Bolton ratios were calculated from the tooth width measurements and based on the following formulae:

Anterior ratio = Sum of the mandibular 6 anterior teeth/Sum of the maxillary 6 anterior teeth

Overall ratio = Sum of the mandibular 12 teeth/Sum of the maxillary 12 teeth

Statistical analysis

A Kolmogorov-Smirnov test showed normal distribution and so parametric tests were applied for data analysis. Mean and standard deviations of the mesiodistal width of each tooth were determined using both measurement methods. Pearson's correlation coefficients (PCC) were calculated to assess the inter-method variation. In order to determine measurement error, plaster and CBCT models of 15 patients were

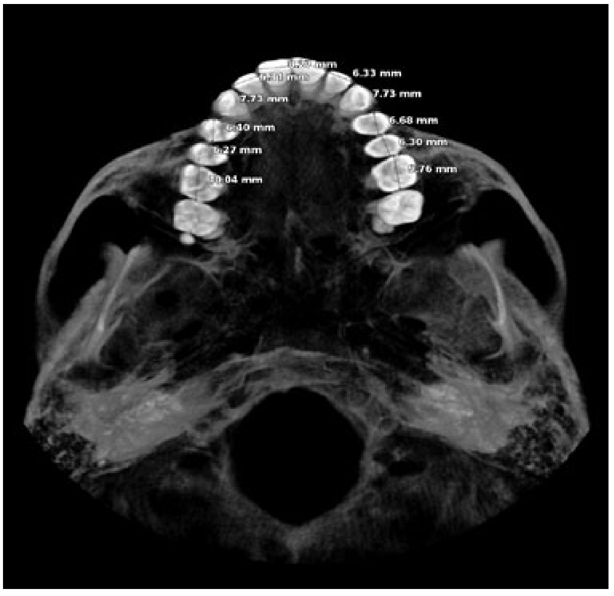

Figure 1. An example of a 3D virtual model of the maxillary arch used in the present study.

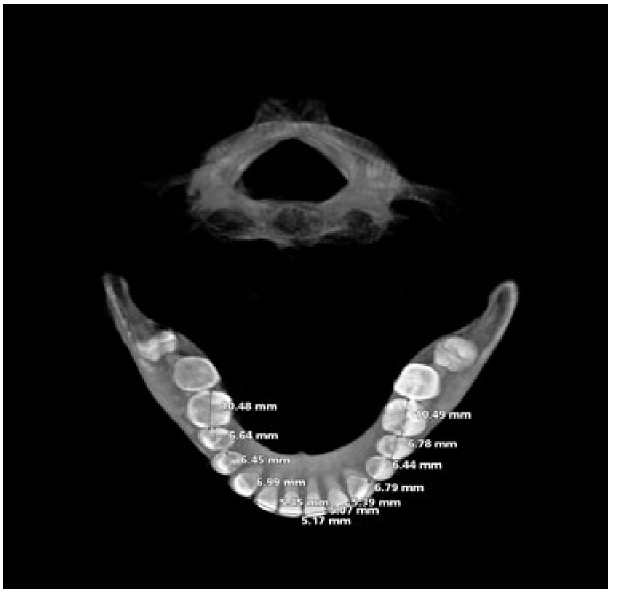

Figure 2. An example of a 3D virtual model of the mandibular arch used in the present study.

randomly selected and re-measured by the same examiner, one month after the first measurements. Intra-class correlation coefficients were performed to assess the reliability of the measurements as described by Houston.[16] All statistical analyses were performed using the SPSS software package program (SPSS for Windows 98, version 10.0, SPSS Inc, Chicago, IL, USA). A p value of < 0.05 was considered statistically significant.

Results

The coefficients of reliability (Houston method) for all measurements ranged from 0.92 to 0.97 for the conventional method and from 0.94 to 0.99 for CBCT method, confirming the reliability of the measurements by either method. The mean and standard deviation of the mesiodistal widths of the teeth and the difference in values between the methods are shown in Table I. The mean difference of mesiodistal tooth width measurements between the methods (CBCT-conventional) ranged from -0.34 mm (mandibular left first premolar) to 0.24 mm (maxillary right first molar). The total mean differences between the methods in the maxillary and mandibular arches were -0.01 mm and -0.03 mm, respectively. Measurements of the mesiodistal widths of most maxillary and mandibular teeth showed strong correlations between the conventional and CBCT methods. PCC values ranged from 0.637 (mandibular right second premolar) to 0.916 (maxillary right canine).

The mean and standard deviation values of the anterior and overall Bolton ratios calculated by means of conventional and CBCT methods are shown in Table II. PCC values for anterior and overall ratios were 0.756 and 0.781, respectively, which indicated that conventional and CBCT methods showed high correlations. The results of the paired t-test revealed that the difference between the methods was insignificant in regard to the overall ratio (a difference of 0.58%, $p = 0.184$), while it was statistically significant for the anterior ratio (a difference of 1.11%, $p = 0.018$).

Discussion

The digitisation of orthodontic records and the use of computer technology is becoming commonplace and welcome in orthodontic diagnosis and treatment planning.[17] According to Proffit and Ackerman,[18] an advantage of digitising tooth dimensions for space analysis was the provision of a quick patient assessment. In agreement, Tomasetti et al.[17] compared three computerised Bolton tooth size analyses (QuickCeph, OrthoCad, and Hamilton Arch Tooth System (HATS)) with a conventional manual measurement method and found that QuickCeph was the fastest (1.85 minutes) in the time required to complete a Bolton analysis, followed by HATS

Table I. Correlation of the mesiodistal tooth widths measured conventionally and digitally.

Mesiodistal tooth width (mm)	Conventional		CBCT		Difference		PCC
	Mean	SD	Mean	SD	Mean	SD	
Maxillary right							
Central incisor	8.87	0.61	9.04	0.65	0.17	0.37	0.834
Lateral incisor	6.96	0.69	6.83	0.61	-0.16	0.31	0.891
Canine	7.77	0.47	7.92	0.51	0.15	0.20	0.916
First premolar	7.08	0.46	6.77	0.50	-0.31	0.28	0.838
Second premolar	6.77	0.49	6.56	0.40	-0.21	0.32	0.767
First molar	10.31	0.63	10.55	0.80	0.24	0.46	0.811
Maxillary left							
Central incisor	8.95	0.59	9.01	0.57	0.06	0.38	0.789
Lateral incisor	6.83	0.69	6.78	0.62	-0.05	0.31	0.893
Canine	7.68	0.45	7.90	0.55	0.22	0.23	0.911
First premolar	7.05	0.40	6.77	0.51	-0.28	0.32	0.773
Second premolar	6.70	0.48	6.59	0.47	-0.11	0.26	0.850
First molar	10.39	0.61	10.56	0.78	0.17	0.48	0.791
Mandibular right							
Central incisor	5.63	0.40	5.66	0.37	0.03	0.24	0.792
Lateral incisor	6.05	0.36	5.89	0.42	-0.16	0.17	0.814
Canine	6.79	0.38	6.84	0.44	0.05	0.29	0.757
First premolar	7.10	0.49	6.80	0.59	-0.30	0.38	0.774
Second premolar	6.99	0.42	7.03	0.65	0.04	0.50	0.637
First molar	10.81	0.74	11.13	0.78	0.32	0.48	0.804
Mandibular left							
Central incisor	5.61	0.36	5.54	0.33	-0.07	0.25	0.885
Lateral incisor	6.01	0.39	5.93	0.41	-0.08	0.26	0.782
Canine	6.81	0.38	6.84	0.44	0.03	0.24	0.833
First premolar	7.09	0.50	6.75	0.59	-0.34	0.33	0.832
Second premolar	7.10	0.47	6.96	0.59	-0.14	0.33	0.829
First molar	10.76	0.73	10.95	0.80	0.19	0.49	0.798

PCC > 0.750 shows acceptable correlation

Table II. Anterior and overall tooth size ratios measured conventionally and digitally.

Tooth size ratios	Conventional	CBCT	PCC	Paired *t*-test
	Mean and SD	Mean and SD		
Anterior ratio	78.69 ± 3.34	77.58 ± 2.71	0.756	0.018
Overall ratio	91.27 ± 3.10	90.69 ± 2.21	0.781	0.184

PCC > 0.750 shows acceptable correlation

(3.40 minutes), OrthoCad (5.37 minutes), and the conventional method (Vernier caliper) (8.06 minutes). Although QuickCeph was the fastest to produce a result, it offered the lowest correlation with manual measurement (PCC value for anterior and overall discrepancies were 0.439 and 0.432, respectively) and was therefore considered the most inaccurate.

The beneficial use of CBCT in dentistry is increasingly being documented.[19,20] Although several reports[3,13,14,21,22] have substantiated the reliability and accuracy of angular and linear measurements, few have focused on dental measurements.[3,13,22] Nguyen et al.[22] tested the accuracy and reproducibility of CBCT in predicting the mesiodistal diameter of unerupted teeth and found that CBCT could be used with confidence as an accurate measurement tool. Kau et al.[13] indicated that CBCT digital models were as accurate as OrthoCad digital models in performing measurements of overjet, overbite, and Little's irregularity index. The present study was based on the knowledge that no previous investigation had compared tooth widths and calculated Bolton ratios using CBCT and conventional manual plaster cast methods.

The present study revealed that PCC values for anterior and overall Bolton ratios generated by CBCT and conventional methods were 0.756 and 0.751, respectively. Because few studies have investigated a Bolton analysis performed and produced by CBCT, comparison was difficult. However, Bolton's ratios have been assessed in different populations and malocclusion groups.[23-26] Tomasseti et al.[17] compared the computerised Bolton analyses performed using conventional and CT methods and found that the PCC values were the highest when the HATS method was used (anterior: 0.825; overall: 0.885) and the least for QuickCeph (anterior: 0.439; overall: 0.432). The CBCT method showed a high correlation (anterior: 0.756; overall: 0.751) as did the HATS method. Tarazona et al.[27] evaluated the reliability and reproducibility of calculating the Bolton index using CBCT and a two-dimensional digital method and showed that the Bolton ratio calculated from 3D models obtained from the CBCT was as accurate and reproducible as the ratio calculated on digital models obtained from plaster casts.

The high correlation coefficients for the Bolton ratios found in the present study were also compared with CBCT and conventional methods by means of a paired t-test. The statistical results indicated that the difference in the overall ratio was insignificant (p = 0.184), but was found to be significant for the anterior ratio (p = 0.018). However, as the difference in the anterior ratio between the groups was only 1.1%, it was unlikely to be of clinical significance.[28]

An additional significant finding of the present study was the high correlation in the measured mesiodistal diameter of respective teeth, except for the mandibular right second premolar. While few studies have compared tooth widths measured on CBCT and plaster models, El-Zanaty et al.[2] assessed the accuracy of dental measurements performed on CT and plaster models. It was considered that a three-dimensional dental measurement method was a viable alternative to caliper measurements on a conventional plaster model, as fair agreement (PCC < 0.75) was established for several teeth (maxillary right and left second premolar, right first molar, left central incisor, and the mandibular left and right central incisors, right canine and left first premolar). The present study found high intra-class correlation coefficients using the Houston method,[16] which confirmed the reliability of the measurements determined by both methods (0.92 - 0.97 for the conventional method and 0.94 - 0.99 for CBCT method). El-Zanaty et al.[2] also found higher intra-class correlation coefficients, using 3D virtual models generated from CT scans (0.954- 0.999 for the CT method and 0.913 - 0.999 for the conventional plaster model).

The operator's familiarity and skill in sensitively using a computer mouse are possible contributing factors affecting the accuracy of all computer-based measurements of digital casts.[2] In the present study, all measurements were conducted by an experienced radiologist and PCC scores were found to be high. Measurement results may be additionally affected by a systematic error associated with the CBCT method.[3] However, CBCT has been used to measure the diameter of unerupted teeth in orthodontic patients more accurately than other methods to date.[22] Although the correlation coefficient for the widths of almost all teeth was high, it was low and unexplained for several measurements including the width of the mandibular right second premolar (0.637).

It has been suggested that the conventional plaster cast recording method could be eliminated by CBCT measurements and therefore provide a saving in physical storage space. Although CBCT has an obvious advantage over conventional radiography as it provides three-dimensional scans,[14,29] the higher dose of radiation is a significant consideration.[30] In addition, the advantages of the CBCT come at an additional cost compared with traditional radiographs.[27]

Conclusion

According to the results of the present study, dental measurements, anterior and overall Bolton ratios calculated on CBCT showed acceptable PCC values, indicating that CBCT could be used for dental measurement and analysis in place of conventional plaster models.

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