Reliability and Validity of Dental Measurements Made on Digital and Stone Orthodontic Models

Original Article

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Received: Mar 14, 2012
Accepted: Apr 22, 2012

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Abstract

Introduction: A study model is a precise three dimensional replica of patient's dentition and plays an important role in treatment planning. Many digital multi-media applications have become available to the clinician and his or her staff to facilitate standard procedures in practice and management. The aim of this study is to evaluate reliability and validity of dental measurement made on digital and stone orthodontic models.

Materials and Methods: The study sample consisted of 22 pairs of randomly selected initial study models from patients that referred to the orthodontic clinic, school of dentistry, Guilan university of medical sciences for treatment. Three dimensional reconstructions of the stone model were generated by dental cone-beam computed tomograghy (CBCT). Mesiodistal widths, Little's irregularity index, Bolton analysis, arch widths, available and required arch length were measured directly on the casts with a digital caliper and , also on the digital model in ALMA software. Reliability and validity were assessed by using intra-class correlation and paired t-test.

Results: Intra and inter-observer reliability for both methods was generally high and acceptable. Comparisons between the measurements on stone cast and digital model showed no statistically significant difference for available arch length, Little's irregularity index and for mesiodistal tooth width, Bolton analysis and arch widths measurement. However, difference between required arch length and space analysis on digital and stone models were not clinically significant.

Conclusion: The results of this study support the use of CBCT technology in dental measurements in routine orthodontic analysis except for space analysis.

Key words: •Cone-Beam Computed Tomography •Orthodontics • Cast, Surgical

Introduction

Digital technology is slowly influencing and improving different fields of sciences. In orthodontics, some diagnostic tools such as digital photography and cephalometric analysis software in comparison with others are effective in improvement of this science.(1)

Orthodontic study models are an important part of treatment planning. A study model is a precise three dimensional (3D) replica of a patient's dentition, routinely used in orthodontics. With the increasing use of computers in orthodontic offices, many digital multi-media applications have become available to the clinician and his or her staff to facilitate standard procedures in practice and management.(2)

Stone models require physical space for storage, add financial and logistic burdens. Virtual models are stored electronically. Model retrieval is greatly facilitated and communication with other dental specialties is improved by virtual model. Traditional duplicating of stone casts, handling, and shipping becomes obsolete.(1) Many studies evaluated different methods to measure tooth size and some(1-9) found no statistical significant differences in the measurements obtained from stone and digital models. They suggested the need for further research to determine accuracy, reliability and reproducibility of digital models using new software versions.

In orthodontics, cone-beam computed tomograghy (CBCT) images have predominantly been used to gather qualitative information. To maximize the amount of diagnostic information that can be obtained from a volumetric scan, it is necessary to also generate quantitative information.(2)

According to increasing trend to digital model application, in this study we compared common measurements in orthodontics on three dimensional digital images derived from CBCT images of a dental cast and direct measurements on the same cast. Danger of radiation is no more a matter of concern, as a major advantage of this study.

Materials and Methods

The study sample included consisted of 22 pairs of randomly selected initial model casts, upper and lower jaws, from patients that referred to the orthodontic clinic, school of dentistry, Guilan university of medical sciences for orthodontic treatment. The following selection criteria were used:

- Permanent dentition erupted from right first molar to left first molar
- No missing tooth from right first molar to left first molar
- No large restorations or interproximal cavities on teeth
- No void or bulb in the stone models
- No fractures on the crown of teeth on the stone models

Alginate impressions (Zhermack, Badia Polesine, Italy) were taken by one person. Then, the stone models were poured in a laboratory with orthodontic stone (Orthotechnology, Tampa Florida, USA).

They were mounted in a box and scanned with dental CBCT New Tom VG (QR SRL,Verona, Italy) device in zoom mode (4-inch field of view), and three-dimensional reconstructions of the dentitions were generated. Seven measurements including mesiodistal widths, Bolton analysis, Little's irregularity index, arch widths, arch length available, and arch length required were made directly on the dental portion of the cast with 0.01 mm precision digital caliper (S.D.M, China) and on the digital three-dimensional reconstruction models that in ALMA software (3D DK 2010) with the same accuracy of digital caliper. Digital images for all models were prepared with the following radiographic characteristics: field of view of 50×120, resolution of 60×250 pixels, magnification of 1.20. Then calibration rulers in the bottom of image were used to convert pixel information to the length unit of millimeter.

Mesiodistal widths were measured using the point to point measurement tool, so we were able to calculate the greatest mesiodistal diameter from the mesial anatomic contact point to the distal anatomic contact point of each tooth, parallel to the occlusal plane. Arch length available was measured by the segmented arch approach(3) in which a dental arch is subdivided into four segments (Figure 1).

The segments were summed with 0.01 mm precision to obtain the arch length for both arches. This indicates the space available for alignment of all teeth. Arch length required is the summation of the maxillary and mandibular mesiodistal tooth widths from right to left second premolars. These measurements were made directly on the teeth and on the computer-based models. Space analysis is provided via the subtraction of space available from the space required.

Bolton analysis is a ratio to compare the size of teeth in upper and lower arch. Anterior ratio is the proportion of mesiodistal width of the six anterior mandibular teeth to the six anterior maxillary teeth. The normal range for this ratio is 91.3. Accordingly, the overall ratio is the proportion of the mesodistal width of the twelve mandibular teeth to the twelve maxillary teeth. The normal range for this ratio is 77.2.

Arch width was measured in maxilla and mandible as the distance between the mesiolingual cusp tips of the maxillary first permanent molars and between the central grooves of the mandibular first molars.

Irregularity of the anterior teeth was another variable that was measured as the distance between the adjacent contact points from canine to canine in both arches. Sum of these numbers has been called “The Little’s index” which shows the amount of contact point displacement of the anterior teeth compared to the ideal contact position meaning anterior crowding (Figure 2).

All measurements were done by two researchers (one senior dental student and one orthodontist). First, the inter-examiner reliability was calculated in a pilot study on ten pairs of models, using Paired t-test and Pearson correlation coefficient. The SPSS software version 16 was employed to analyze the data. Data revealed a perfect reliability (difference of less than 0.14 millimeter) and Pearson correlation coefficient of 0.97 ($p< 0.001$).

Repeated measurements were carried out after 10 days from the first one by the same researchers.

Reliability and validity of all measurements were assessed using intra-class correlation coefficient (ICC), Pearson correlation coefficient (PCC), Paired t-tests and independent t-test. A level of ≤0.05 was established as a significant level. Normality was assessed by one-sample Kolmogorove-Smirnov test. Whereas, Wilcoxon non-parametric tests (Mann Whitney U-test and Spearman correlation coefficient) were applied to non-normal parameters.

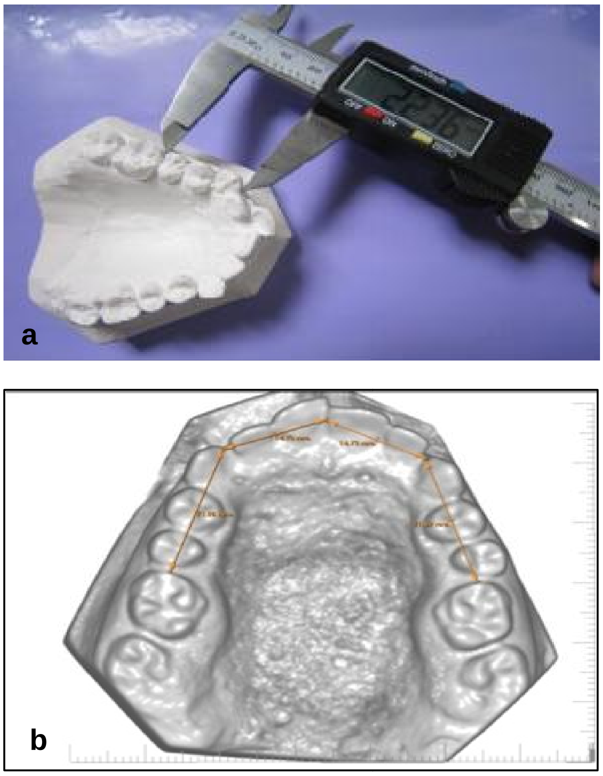

Figure1.The method employed in the measurement of available arch length on stone (a) and digital models (b).

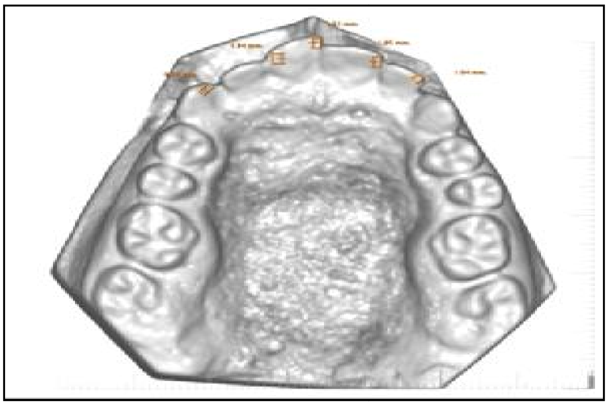

Figure 2. The method employed to measure little’s irregularity index on CBCT image

Results

Data analysis using ICC test shows that mesiodistal width measurements in two methods were highly reliable (Table-1).Validity was evaluated by the difference between the mean of measurements in two methods using Paired t-test. This analysis showed statistically significant difference ($P<0.01$).However it was about 0.2 - 0.7 mm that was not noticeable (Table1and 2).

Bolton analyses of tooth size discrepancy in anterior and overall segments were reliable in both methods (Table 3). Difference of mean values between two methods was 0.037 for anterior ratio and 0.022 for overall ratio that was not statistically significant (P<0.01). It was not high, however.

ICC was in acceptable range for space available, space required and space analysis in both arches (Table 4). The means difference between two methods was statistically significant for space required (P<0.01) in a 2.5-4.5mm range and space analysis in maxilla and mandible (P<0.01) with the range of 4.1-5.1mm, but not significant for space available or arch length in maxilla (P=0.32) and mandible (P=0.17) in range of a 0.14-0.6 mm (Table 4).

Little's irregularity index in two methods was highly reliable. Means difference (0.6-0.8mm) between two methods was not significant in maxilla (P=0.57) and mandible (P=0.33) (Table 5).

Arch width evaluation in two methods showed a high reliability and a statistical difference (P<0.01) in validity with the range of 0.19-0.21 mm (Table 6).

Pearson correlation coefficient was calculated for all parameters in this study which was within the range of 0.52-0.99 (Table1-6).

Table 1. Reliability and validity of mesiodistal tooth width in maxilla

Tooth	Reliability				Validity			
	PCC† of 2 methods	ICC¥ manual	ICC digital	ICC of 2 methods	mean manual	mean digital	mean diff. of methods	P- value*
Left first molar	0.87	0.99	0.99	0.88	9.54	9.29	0.24±0.27	0.000
Left second premolar	0.79	0.98	0.99	0.62	6.21	5.75	0.46±0.24	0.000
Left first premolar	0.84	0.97	0.99	0.79	6.40	6.07	0.33±0.27	0.000
Left canine	0.54	0.97	0.58	0.63	6.88	6.54	0.34±0.53	0.000
Left lateral	0.86	0.98	0.99	0.83	6.40	5.94	0.46±0.37	0.000
Left central	0.55	0.99	0.99	0.59	8.20	7.82	0.38±0.70	0.000
Right first molar	0.78	0.98	0.99	0.82	9.60	9.32	0.28±0.36	0.000
Right second premolar	0.86	0.97	0.99	0.79	6.29	5.90	0.38±0.26	0.000
Right first premolar	0.75	0.98	0.98	0.70	6.43	6.01	0.42±0.33	0.000
Right canine	0.78	0.98	0.99	0.78	7.03	6.67	0.36±0.36	0.000
Right lateral	0.93	0.99	0.99	0.83	6.25	5.76	0.49±0.24	0.000
Right central	0.75	0.98	0.99	0.73	8.30	7.85	0.44±0.41	0.000

†: Pearson correlation coefficient ¥: Inter examiner correlation coefficient *: Paired sample t-test

Table 2. Reliability and validity of mesiodistal tooth width in mandible

Tooth	Reliability				Validity			
	PCC† of 2 methods	ICC¥ manual	ICC digital	ICC of 2 methods	mean manual	mean digital	mean diff. of methods	P- value*
Left first molar	0.76	0.99	0.99	0.74	9.92	9.28	0.63±0.58	0.000
Left second premolar	0.91	0.98	0.97	0.84	6.46	6.11	0.34±0.21	0.000
Left first molar	0.70	0.99	0.98	0.63	6.51	6.07	0.44±0.40	0.000
Left canine	0.63	0.98	0.99	0.66	6.07	5.63	0.43±0.07	0.000
Left lateral	0.57	0.98	0.99	0.41	5.7	4.94	0.77±0.44	0.000
Left central	0.52	0.99	0.99	0.41	5.37	6.63	0.74±0.61	0.000
Right first molar	0.65	0.99	0.99	0.75	9.91	9.59	0.33±0.44	0.000
Right second premolar	0.65	0.97	0.99	0.68	6.44	6.02	0.41±0.47	0.000
Right first molar	0.79	0.97	0.94	0.75	6.70	6.06	0.41±0.33	0.000
Right canine	0.73	0.97	0.99	0.77	5.97	5.64	0.33±0.44	0.000
Right lateral	0.74	0.98	0.99	0.62	5.55	6.94	0.60±0.39	0.000
Right central	0.70	0.98	0.99	0.50	5.25	4.64	0.60±0.32	0.000

†: Pearson correlation coefficient ¥: Inter examiner correlation coefficient ∗: Paired sample t-test

Table 3. Reliability and validity of Bolton analysis

Bolton ratio	Reliability				Validity			
	PCC† of 2 methods	ICC¥ manual	ICC digital	ICC of 2 methods	mean manual	mean digital	mean diff. of methods	P- value*
Anterior	0.64	0.98	0.98	0.65	0.78	0.75	0.03±0.039	0.000
Overall	0.64	0.99	0.98	0.68	0.90	0.88	0.02±0.026	0.000

†: Pearson correlation coefficient ¥: Inter examiner correlation coefficient ∗: Paired sample t- test

Table 4. Reliability and validity of space analysis in maxilla and mandible

Space analysis	Reliability				Validity			
	PCC† of 2 methods	ICC¥ manual	ICC digital	ICC of 2 methods	mean manual	mean digital	mean of diff. methods	P-value*
Space required in maxilla	0.88	0.99	0.99	0.73	68.45	64.34	4.11±2.06	0.000
Space available in maxilla	0.57	0. 82	0.46	0.71	74.01	73.41	0.60±4.01	0.32**
Space required in mandible	0.83	0.99	0.99	0.63	59.84	54.72	5.11±2.39	0.000
Space available in mandible	0.97	0.98	0.99	0.98	64.32	64.17	0.14±0.70	0.17**
Space analysis in maxilla	0.64	0.87	0.69	0.68	5.55	9.06	-3.51±4.5	0.000
Space analysis in mandible	0.70	0.97	0.99	0.50	4.47	9.45	-4.97±2.59	0.000

†: Pearson correlation coefficient ¥: Inter examiner correlation coefficient
∗: Paired sample t-test **: Not significant statistical difference

Table 5. Reliability and validity of Irregularity index

Irregularity index	Reliability				Validity			
	PCC† of 2 methods	ICC¥ manual	ICC digital	ICC of 2 methods	mean manual	mean digital	mean diff. of methods	P- value*
Maxilla	0.91	0.99	0.93	0.95	7.68	7.56	0.12±1.4	0.57**
Mandible	0.96	0.99	0.99	0.98	6.17	6.04	0.12±0.89	0.33**

†: Pearson correlation coefficient ¥: Inter examiner correlation coefficient
*: Paired sample t-test **: Not significant statistical difference

Table 6. Reliability and validity of arch width

Arch width	Reliability				Validity			
	PCC† of 2 methods	ICC¥ manual	ICC digital	ICC of 2 methods	mean manual	mean digital	mean diff. of methods	P- value*
Maxilla	0.99	0.99	0.99	0.99	47.96	47.75	0.21±0.288	0.000
Mandible	0.99	1	0.99	0.99	45.26	45.07	0.19±0.288	0.000

†: Pearson correlation coefficient ¥: Interexaminer correlation coefficient *: Paired Sample t-test

Discussion

Our goal in this study was to assess the reliability and validity of dental measurements made on 3D CBCT images. The same measurements were made on the teeth of stone model with high-precision digital calipers, used as the gold standard for comparison.(1)

In this study, we measured mesiodistal width, arch width, arch length, and also calculated Bolton analysis, space analysis, and Little’s irregularity index. To evaluate the reliability of the methods, we used intra-class and inter-class correlation coefficient (ICC). According to Robots and Richmond(10) reliability is low if ICC is lower than 0.4, acceptable if it is between 0.4 and 0.75 and excellent if it is more than 0.75. In this study, ICC for all teeth were acceptable and excellent that shows high reliability of CBCT derived digital models. This result was similar to Watanabe et al(1) findings. In mesiodistal tooth width measurement, we found the highest reliability for mesiodistal width of first molar and the lowest for anterior teeth that can be related to irregularities in this area which makes contact points hard to be clearly defined.

For Bolton analysis, arch width and little’s irregularity index, reliability of digital method was excellent.

Our findings are in agreement with Kav et al(4) who found no significant difference between CBCT and OrthoCAD models. Besides, Mayers et al(5) study revealed a high reliability of Little’s index between CBCT and OrthoCAD digital models.

Baumgaertel et al(2) compared arch width measurements in CBCT models with caliper measurement and found no significant difference.

Acceptable reliability was found concerning space analysis, space required and space available. Lower arch length (space available) showed a higher reliability than upper arch that can be attributed to the more variations of upper incisor position related to lower incisors.

Validity was taken into consideration as the extent to which the CBCT digital model measurements were compatible with those on the stone models. Difference of measurements between the two methods; less than 1 millimeter, is supposed to be insignificant in clinical practice.(1)

Stone and CBCT digital models presented differences in mesiodistal tooth width measurements (0.2-0.7 mm), Bolton analysis (0.03-0.02 mm), and arch widths (0.19-0.21 mm). Most of the obtained values were statistically different, but clinically insignificant. By contrast, arch length required (2.5-4.5 mm) and space analysis (4.1-5.1 mm) were clinically significant.

Comparisons between the stone model and CBCT digital models also showed no significant difference concerning arch length available and little's irregularity index. Garino et al[6] found that the measurements made from digital models were clinically acceptable, with a reasonable reliability and adequate clinical information for diagnosis and treatment planning; consequently, eliminating the need for plaster models. Also, these findings are similar to Santoro et al[7] Stevens et al[8] and Mullen et al[9] who didn't find clinical significant difference in Bolton analysis between stone and electronic models.

It should be mentioned that similar findings could not be employed due to the lack of previously carried out researches with the same areas of interest.

In the present study, all measurements in digital model were lower than conventional model. It is similar to all other studies which compared conventional models with digital ones.[1-9] This difference can be attributed mostly to the physical limitations for caliper placement manually on the contact points. The real tooth size tends to overestimated employing caliper.

Furthermore, had the practitioner been expert in digital manipulation, mouse clicking and working on image on monitors, the results gained could be more satisfying.

According to kau et al[4], in CBCT derived models, edge contour of contact points are hard to be detected clearly.

Baumgaertel et al[2] found a systematic error for measurements on digital models. Measuring a distance in a digital CBCT model is defined as the distance between mid-points of the terminal voxels. In other words, if the contact point locates over midpoint, the distance would be underestimated. Whereas, it could be overestimated if contact points locate before mid point.

The other explanation for smaller measures in CBCT models is the partial volume effect which is a common artifact in CT. A voxel can only show a single density. IN case of being located in a voxel, border of the two objects appears with the average value of density (hybrid voxel). It can reduce tooth width when the border of tooth and air merges in a voxel.

Space required is the summation of mesiodistal tooth width from right first molar to the left first molar in each arch. In our study, we evaluated space analysis that is the subtraction of space required from space available. Space analysis and space required were the only measurements by which we found clinical significance between CBCT models and stone casts. We suggest that insignificant difference of mesiodistal tooth width becomes significant when we sum the teeth size in an arch. In Bolton analysis, no significant clinical difference was found; since, the summation of lower teeth measurements was divided by summation of upper teeth measurements.

Conclusion

These results support the use of CBCT technology to analyze the dentition except space analysis. These measurements proved to be reliable and accurate. A slight underestimation of the measured values using CBCT was found in comparison with the direct measurement and became significant when several measurements were combined and added together.

Acknowledgements

We are grateful to Dr Reza Zoroofi for providing ALMA software to facilitate 3D measurements.

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