Comparison of Measurements made on Plaster and CBCT-Scanned Models

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Abstract

Background: Digital models derived from CBCT scans have the potential to be as acceptable to patients and practitioners as other forms of digital dental models. The purpose of this study is to compare measurements made on traditional plaster models with measurements made from digital renderings of CBCT scans of the same plaster models.

Materials and Methods: Ten mandibular plaster models were obtained and 3-dimensional digital models were created from CBCT scans of the models. The casts that were used for direct measurement were the same casts that were scanned using CBCT. Three observers conducted 33 measurements on each plaster model and each digital model. Intra and inter-examiner measurements were compared statistically using the Intraclass Correlation Coefficient and a paired *t*-test.

Results: Statistically significant though not clinically relevant differences were detected. Standard deviations for most measurements were less than 1.0 mm, with 20 of the 33 measurements at 0.05 mm. or less.

Conclusions: The benefits of a digital model rendered from a CBCT scan of a plaster cast include good soft-tissue reproduction, no radiation exposure for the patient, no scatter on the image from metal dental restorations, no need to purchase another scanning method for facilities that have already obtained CBCT machines, and the ability to digitally archive any already existing plaster dental model. Clinical accuracy ensures that 3-dimensional digital models rendered from CBCT scans of plaster casts are an appropriate alternative to traditional plaster models.

Key Words: CBCT, Digital models, Comparison, Plaster models

Introduction

Maxillary and mandibular dental arch space analysis is essential in comprehensive clinical orthodontic evaluation. The analysis includes tooth dimensions, intra-arch widths and adequate alveolar volume corresponding to the present or planned tooth volume [1]. Not only should measurement values be recorded before and after treatment, but it is often desirable to have a 3-dimensional likeness of a dentition for comparison and evaluation [2]. Plaster models of the dentition have been used traditionally for orthodontic evaluation [3] and are considered the "gold-standard" for arch space analysis [4].

Some of the advantages of plaster dental models include accuracy, a high level of physical permanence over time and a relatively low production cost. However, plaster models have disadvantages, including breakage, storage costs and weight. These disadvantages are significant. Photocopies [5], microscopes [6], and holographs [7] have been suggested as substitutes for plaster models of the dentition, however none of these modalities has been well accepted.

However, support for the concept of computer-rendered digital impressions is promising [8]. Several studies have established that commercial optically-scanned computer-rendered digital models, such as Orthocad and Emodel, as clinically acceptable [9-11]. Others have stated that models should be taken directly from Cone Beam Computerized Tomography (CBCT) scans, citing ease, accuracy and patient comfort [12]. However, radiation exposure should not be discounted and should be kept as low as possible, especially for the adolescent patients that often make up a significant portion of the individuals undergoing active orthodontic treatment [13-15]. With several competing modalities currently available to the orthodontic practitioner, some authors have suggested that the profession should determine the best alternative to traditional plaster models and have dramatically called for a showdown [16]. Before drawing any conclusions about the best method to replace plaster models, computer-rendered digital models made from CBCT scans of traditional plaster orthodontic model should be considered. Digital models derived from CBCT scans have the potential to be as acceptable to patients and practitioners as other forms of digital dental models. The purpose of this study is to statistically compare observer measurements of plaster models with measurements from digital renderings of CBCT scans of the plaster models.

Materials and Methods

Ten mandibular plaster models were selected from the archives of orthodontic models from the Department of Orthodontics at the Columbia University College of Dental Medicine. The models were selected based on the following criteria

- Type-III stone orthodontic models, soaped and polished
- A complete dentition of 14 teeth from 2nd molar to 2nd molar
- No blebs or voids on the digital or plaster models
- No fractures on the teeth of the plaster models

Three licensed dentists were selected as observers for the study. A brief set of instructions was given to each and they were allowed as much time as they desired to familiarize themselves with the models and equipment before recording values for the measurements.

Digital calipers (Neiko 6" Digital LCD Vernier Caliper/ Micrometer, Zhejiang Kangle Group, Wenzhou City, Zhejiang,

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China. (*Figure 1*) were used to make measurements. On each cast to the nearest 0.01 millimeter. The observers measured the largest mesio-distal dimension (*Figure 2*), the largest bucco-lingual dimension of each tooth and the distances from mesio-buccal cusp tip to contralateral cusp tip of the 2nd and 1st molars, the buccal cusp tip to contralateral cusp tip of the2nd and 1st premolars, and the cusp tip to contralateral cusp tip of the canines. A total of 33 distinct measurements were recorded.

Each observer then made the same measurements on computer-rendered digital models of the same casts. The digital models were created by using i-CAT Classic CBCT digital scanner (Imaging Sciences International, Hatlefield, PA) at 60kVP, with a scan time of 29.6 seconds and a 0.20mm slice thickness. The Dicom file was viewed and 3-dimensional model rendered using Anatomage Invivo5(Anatomage, San Jose, CA) on a Dell XPS 720 with an NVIDIA GeForce8800 graphics card with a 19"monitor with 1280x1024 pixels (Dell, Dallas, TX). The data was recorded on Microsoft Excel 2004 (Microsoft Corporation, Redmond, WA) and then statistical analysis was performed with SPSS Version 11.5(SPSS, Chicago, IL).

The casts that were used for direct measurement were the same casts that were scanned using CBCT. Distortion and variation among alginate impressions was eliminated. Variance of measurements between the plaster and digital renderings is therefore attributable to either operator error or an inherent distortion of the CBCT-rendered images. The use of the same models for direct measurement and for creation of the test images is a major advantage in this project design.

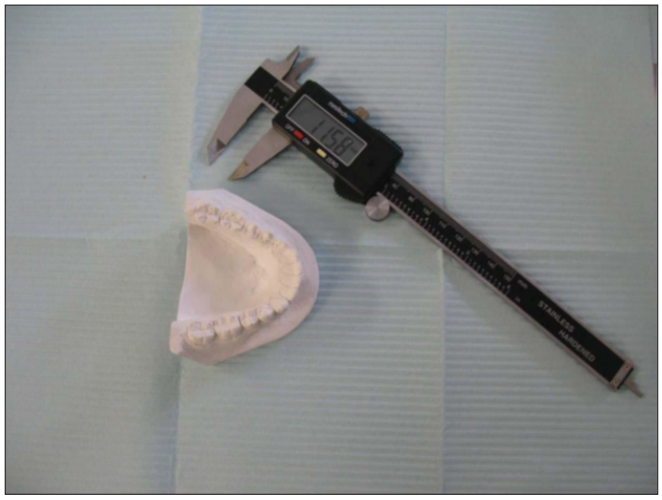

***Figure 1**. Plaster cast measured with Digital calipers (Neiko 6" Digital LCD Vernier Caliper/ Micrometer, Zhejiang Kangle Group, Wenzhou City, Zhejiang, China).*

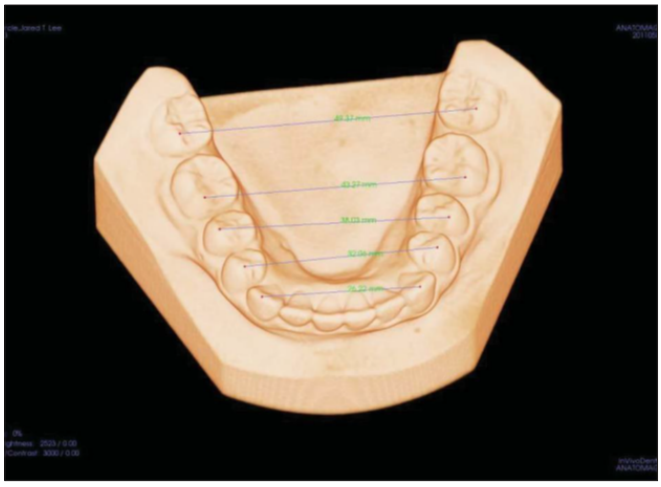

***Figure 2.** CBCT scan rendering of model.*

Statistical Analysis

The data set was evaluated first for descriptive statistics (*Tables 1-3*), then for Normality using the Shapiro-Wilks Test (*Tables 4-6*). Homogeneity of Variance was evaluated using the Levene Test (*Tables 7-9*).The Intraclass Correlation Coefficient was employed to test the agreement between the three examiners in the study (*Tables10-11*) [17]. Finally, a paired *t*-test was used to compare the measurements form the digital renderings to the "gold standard" of the plaster models (*Tables 12-14*).

Results

Standard deviations for most variables tested were less than 1mm.with 20 of the 33 deviations 0.5 mm or less. Mesio-distal and bucco-lingual measurement standard deviations ranged from 0.90 mm (bucco-lingual of right central incisor) to 0.29 mm (mesio-distal of mandibular right first premolar). Average measurement comparison varied most for the series of cusp to cusp measurements, with a standard deviation range of 1.3 to 3.13 mm.

The Intraclass Correlation Coefficient results show that intra-examiner CBCT measurement correlation was 0.681 (bucco-lingual of left 1st premolar) to 0.991 (mesio-buccal cusp of right 1st molar to mesio-buccal cusp of left 1st molar). The intra-examiner correlation for plaster cast measurements varied from 0.679 (mesio-distal of left canine) to 0.993 (mesio-buccal cusp tip of right 1st molar to mesio-buccal cusp tip of left 1st molar). However, the correlation of the mesio-distal left 1st premolar was 0.227.

Inter-examiner CBCT correlation ranged from 0.386

***Table 1**. Descriptive Statistics: Cusp to Cusp in millimeters.*

	N	Minimum	Maximum	Mean	Std. Deviation
2nd Molars	60	48.26	57.42	53.06	3.14
1st Molars	60	42.62	51.08	47.31	2.46
2nd Pre molars	60	36.53	45.60	41.52	2.09
1st Pre molars	60	31.78	39.16	35.43	1.61
Canines	60	25.17	31.14	27.51	1.31

***Table 2**. Descriptive Statistics: Facial to Lingual in millimeters.*

	N	Minimum	Maximum	Mean	Std. Deviation
Left 2nd molar	60	7.49	11.82	10.58	0.70
Left 1st molar	60	9.95	12.39	11.39	0.56
Left 2nd premolar	60	6.53	8.36	7040	0.37
Left 1st premolar	60	5.83	8.15	7.35	0.43
Left canine	60	6.10	7.94	7.19	0.40
Left lateral incisor	60	4.92	7.12	6.03	0.44
Left central incisor	60	4.83	6.26	5.54	0.31
Right central incisor	60	4.95	6.82	5.50	0.33
Right lateral incisor	60	4.65	7.54	6.13	0.46
Right canine	60	6.22	7.99	7.14	0.37
Right 1st premolar	60	6.34	8.53	7.30	0.50
Right 2nd premolar	60	6.98	8.32	7.55	0.30
Right 1st molar	60	10.29	12.65	11.33	0.53
Right 2nd molar	60	9.58	11.97	10.68	0.67

Table 3. *Descriptive Statistics: Mesial to Distal in millimeters.*

	N	Minimum	Maximum	Mean	Std. Deviation
Left 2nd molar	60	7.49	11.82	10.58	0.70
Left 1st molar	60	9.95	12.39	11.39	0.56
Left 2nd premolar	60	6.53	8.36	7.40	0.37
Left 1st premolar	60	5.83	8.15	7.35	0.43
Left canine	60	6.10	7.94	7.19	0.40
Left lateral incisor	60	4.92	7.12	6.03	0.44
Left central incisor	60	4.83	6.26	5.54	0.31
Right central incisor	60	4.95	6.82	5.50	0.33
Right lateral incisor	60	4.65	7.54	6.13	0.46
Right canine	60	6.22	7.99	7.14	0.37
Right 1st premolar	60	6.34	8.53	7.30	0.50
Right 2nd premolar	60	6.98	8.32	7.55	0.30
Right 1st molar	60	10.29	12.65	11.33	0.53
Right 2nd molar	60	9.58	11.97	10.68	0.67

Table 4. *Shapiro-Wilk Tests of Normality: Cusp to Cusp.*

	Modality	Statistic	df	Sig.
2nd Molars	*In vivo*	0.854	30	0.001
	Plaster	0.865	30	0.001
1st Molars	*In vivo*	0.917	30	0.022
	Plaster	0.924	30	0.034
2nd Premolars	*In vivo*	0.967	30	0.460
	Plaster	0.965	30	0.408
1st Premolars	*In vivo*	0.993	30	0.999
	Plaster	0.952	30	0.196
Canines	*In vivo*	0.965	30	0.404
	Plaster	0.907	30	0.013

Table 5. *Shapiro-Wilk Tests of Normality: Facial to Lingual.*

	Modality	Statistic	df	Sig
Left 2nd molar	*In vivo*	0.933	30	0.058
	Plaster	0.914	30	0.019
Left 1st molar	*In vivo*	0.947	30	0.137
	Plaster	0.939	30	0.084
Left 2nd premolar	*In vivo*	0.883	30	0.003
	Plaster	0.892	30	0.005
Left 1st premolar	*In vivo*	0.946	30	0.132
	Plaster	0.972	30	0.595
Left canine	*In vivo*	0.980	30	0.834
	Plaster	0.883	30	0.003
Left lateral incisor	*In vivo*	0.863	30	0.001
	Plaster	0.948	30	0.152
Left central incisor	*In vivo*	0.925	30	0.035
	Plaster	0.884	30	0.004
Right central incisor	*In vivo*	0.938	30	0.079
	Plaster	0.974	30	0.648
Right lateral incisor	*In vivo*	0.961	30	0.321
	Plaster	0.971	30	0.565
Right canine	*In vivo*	0.949	30	0.155
	Plaster	0.931	30	0.051
Right 1st premolar	*In vivo*	0.967	30	0.471
	Plaster	0.972	30	0.603
Right 2nd premolar	*In vivo*	0.985	30	0.929
	Plaster	0.954	30	0.216
Right 1st molar	*In vivo*	0.898	30	0.008
	Plaster	0.949	30	0.158
Right 2nd molar	*In vivo*	0.954	30	0.218
	Plaster	0.985	30	0.945

(bucco-lingual of left central incisor) to 0.970 (mesio-buccal cusp tip of right 1st molar to mesio-buccalcusp tip of left 1st molar). The inter-examiner correlation for the plaster models

Table 6. *Shapiro-Wilk Tests of Normality: Mesial to Distal.*

	Modality	Statistic	df	Sig
Left 2nd molar	*In vivo*	0.968	30	0.476
	Plaster	0.772	30	0.000
Left 1st molar	*In vivo*	0.970	30	0.553
	Plaster	0.933	30	0.060
Left 2nd premolar	*In vivo*	0.981	30	0.861
	Plaster	0.944	30	0.113
Left 1st premolar	*In vivo*	0.908	30	0.014
	Plaster	0.887	30	0.004
Left canine	*In vivo*	0.950	30	0.164
	Plaster	0.976	30	0.704
Left lateral incisor	*In vivo*	0.982	30	0.885
	Plaster	0.962	30	0.342
Left central incisor	*In vivo*	0.985	30	0.937
	Plaster	0.960	30	0.309
Right central incisor	*In vivo*	0.911	30	0.016
	Plaster	0.957	30	0.253
Right lateral incisor	*In vivo*	0.944	30	0.119
	Plaster	0.961	30	0.333
Right canine	*In vivo*	0.974	30	0.649
	Plaster	0.977	30	0.744
Right 1st premolar	*In vivo*	0.973	30	0.618
	Plaster	0.973	30	0.631
Right 2nd premolar	*In vivo*	0.952	30	0.187
	Plaster	0.960	30	0.302
Right 1st molar	*In vivo*	0.982	30	0.866
	Plaster	0.983	30	0.896
Right 2nd molar	*In vivo*	0.931	30	0.053
	Plaster	0.978	30	0.760

Table 7. *Levene's Test (Equal Variance Assumed): Cusp to Cusp.*

	F	Sig
Left 2nd molar	1.236	0.281
Left 1st molar	0.611	0.445
Left 2nd premolar	0.018	0.895
Left 1st premolar	1.066	0.316
Left canine	0.425	0.523
Left lateral incisor	15.040	0.001
Left central incisor	3.420	0.081
Right central incisor	1.528	0.232
Right lateral incisor	3.776	0.068
Right canine	0.321	0.578
Right 1st pre molar	0.931	0.347
Right 2nd pre molar	0.556	0.466
Right 1st molar	0.903	0.354
Right 2nd molar	1.330	0.264

Table 8. *Levene's Test (Equal Variance Assumed): Facial to Lingual.*

	F	Sig
2nd Molars	0.006	0.937
1st Molars	0.104	0.751
2nd Pre molars	0.036	0.851
1st Pre molars	0.213	0.650
Canines	0.187	0.671

was0.409 (mesio-distal of left canine) to 0.972 (buccal cusp tip of right 2nd premolar to buccal cusp tip of left 2nd premolar). Another outlier, the mesio-distal dimension of the left 1st premolar had a correlation value of 0.181.

Table 9. *Levene'sTest (EqualVarianceAssumed):Mesial toDistal.*

	F	Sig
Left2nd molar	0.951	0.342
Left 1st molar	2.458	0.134
Left 2nd pre molar	0.976	0.336
Left 1st pre molar	1.349	0.261
Left canine	1.874	0.188
Left lateral incisor	0.156	0.697
Left central incisor	0.751	0.398
Right central incisor	0.875	0.362
Right lateral incisor	1.201	0.288
Right canine	2.111	0.163
Right 1st pre molar	1.287	0.272
Right 2nd pre molar	0.014	0.909
Right 1st molar	0.150	0.703
Right 2nd molar	0.183	0.674

Table 10. *Intra-examiner Correlation.*

	In vivo			Plaster		
		Range			Range	
	CC	Lower	Upper	CC	Lower	Upper
Cusp to Cusp						
2nd Molars	0.987	0.963	0.997	0.993	0.980	0.998
1st Molars	0.990	0.970	0.997	0.993	0.981	0.998
2nd Premolars	0.978	0.937	0.994	0.990	0.971	0.997
1st Premolars	0.973	0.921	0.993	0.979	0.939	0.994
Canines	0.947	0.844	0.986	0.949	0.851	0.986
Mesial to Distal						
Left 2nd molar	0.957	0.873	0.988	0.866	0.608	0.964
Left1st molar	0.954	0.867	0.988	0.951	0.856	0.987
Left2nd premolar	0.754	0.279	0.933	0.830	0.501	0.954
Left1st premolar	0.973	0.920	0.993	0.227	-1.265	0.791
Left canine	0.938	0.818	0.983	0.679	0.059	0.913
Left lateral incisor	0.865	0.604	0.964	0.942	0.830	0.984
Leftcentralincisor	0.893	0.687	0.971	0.899	0.704	0.973
Right central incisor	0.784	0.367	0.942	0.942	0.830	0.984
Right lateral incisor	0.901	0.711	0.973	0.957	0.874	0.988
Rightcanine	0.845	0.546	0.958	0.762	0.304	0.936
Right 1st premolar	0.968	0.905	0.991	0.972	0.918	0.992
Right2nd premolar	0.844	0.544	0.958	0.841	0.533	0.957
Right 1st molar	0.929	0.544	0.981	0.977	0.934	0.994
Right2nd molar	0.973	0.920	0.993	0.964	0.893	0.990
Facial to Lingual						
Left2nd molar	0.893	0.686	0.971	0.772	0.333	0.939
Left1st molar	0.946	0.842	0.985	0.966	0.899	0.991
Left 2nd premolar	0.952	0.859	0.987	0.954	0.864	0.987
Left 1st premolar	0.681	0.065	0.914	0.922	0.770	0.979
Left canine	0.756	0.284	0.934	0.932	0.802	0.982
Left lateral incisor	0.683	0.072	0.914	0.910	0.736	0.976
Left central incisor	0.692	0.099	0.917	0.809	0.442	0.948
Right central incisor	0.741	0.242	0.930	0.962	0.890	0.990
Right lateral incisor	0.661	0.006	0.908	0.952	0.858	0.987
Right canine	0.905	0.723	0.974	0.909	0.735	0.976
Right 1st premolar	0.903	0.715	0.974	0.821	0.474	0.952
Right 2nd premolar	0.640	0.056	0.903	0.966	0.899	0.991
Right 1st molar	0.892	0.685	0.971	0.930	0.794	0.981
Right 2nd molar	0.891	0.680	0.971	0.791	0.388	0.944

It is important to determine the appropriate significance level when reporting paired *t*-test results. After a multiple comparison adjustment was performed, it was determined that for this study a p-value should be found significant when p<0.0015 (0.0533), since the *t*-test performed 33 tests simultaneously. Using this criteria, 3 of the 33 paired measurements were found to have a significant p value; inter-cusp distance between mesio-buccal cusps of 2nd molars on digital models, inter-cusp distance between mesio-buccal cusps of 1st molars on digital models, and the bucco-lingual measurement of the left canine on digital models.

Table 11. *Inter-examiner Correlation.*

	In vivo			Plaster		
		Range			Range	
	CC	Lower	Upper	CC	Lower	Upper
Cusp to Cusp						
2nd Molars	0.963	0.948	0.986	0.983	0.975	0.994
1st Molars	0.970	0.958	0.990	0.981	0.979	0.982
2nd Premolars	0.954	0.941	0.965	0.973	0.969	0.978
1st Premolars	0.946	0.920	0.973	0.951	0.945	0.959
Canines	0.876	0.845	0.911	0.865	0.802	0.952
Mesial to Distal						
Left 2nd molar	0.886	0.845	0.914	0.845	0.737	0.911
Left1st molar	0.905	0.873	0.955	0.878	0.873	0.887
Left2nd premolar	0.523	0.408	0.738	0.636	0.524	0.735
Left1st premolar	0.928	0.891	0.983	0.181	-0.134	0.699
Left canine	0.865	0.834	0.893	0.409	0.169	0.611
Left lateral incisor	0.683	0.625	0.796	0.856	0.762	0.912
Left central incisor	0.737	0.656	0.814	0.749	0.663	0.821
Right central incisor	0.598	0.460	0.738	0.844	0.776	0.906
Right lateral incisor	0.834	0.750	0.961	0.892	0.863	0.931
Right canine	0.789	0.731	0.847	0.547	0.491	0.576
Right 1st premolar	0.911	0.887	0.928	0.924	0.900	0.944
Right 2nd premolar	0.667	0.507	0.752	0.651	0.577	0.700
Right 1st molar	0.833	0.757	0.873	0.954	0.926	0.980
Right 2nd molar	0.926	0.896	0.977	0.905	0.854	0.968
Facial to Lingual						
Left2nd molar	0.737	0.669	0.805	0.637	0.474	0.861
Left1st molar	0.865	0.777	0.922	0.911	0.880	0.939
Left2nd premolar	0.868	0.842	0.887	0.878	0.848	0.903
Left1st premolar	0.441	0.131	0.808	0.808	0.680	0.896
Left canine	0.517	0.277	0.685	0.823	0.704	0.96
Left lateral incisor	0.438	0.145	0.748	0.771	0.616	0.899
Left central incisor	0.386	0.017	0.787	0.661	0.399	0.846
Right central incisor	0.485	0.269	0.811	0.930	0.884	0.955
Right lateral incisor	0.388	0.266	0.614	0.872	0.797	0.969
Right canine	0.772	0.689	0.842	0.781	0.711	0.908
Right 1st premolar	0.762	0.612	0.946	0.600	0.397	0.926
Right2nd premolar	0.402	0.092	0.572	0.903	0.876	0.919
Right 1st molar	0.741	0.690	0.784	0.840	0.777	0.927
Right 2nd molar	0.788	0.731	0.851	0.618	0.569	0.646

Discussion

Regarding the Interclass Correlation Coefficient (ICC), it is essential to remember that the values fall within a range. A perfect positive correlation value is 1.000, and no correlation is 0.000. For this study we determined that values above 0.750 have excellent correlation, values above 0.400 can be considered to correlate well, and values below 0.400 do not show good correlation [18]. The Intraclass Correlation Coefficient results show that intra-examiner CBCT measurement correlation was good to excellent at 0.681, (bucco-lingual of left 1st premolar) to 0.991 (mesio-buccal cusp of right 1st molar to mesio-buccal cusp of left 1st molar). The intra-examiner correlation for plaster cast measurements varied from 0.679 (mesiodistal of left canine) to 0.993

Table 12. *t-Test: Paired Differences of Plaster Models and CBCT Scans Cusp to Cusp.*

	Mean	Std.Deviation	Std.Error Mean	95% Confidence Interval of the Difference		t	df	Sig.(2-tailed)
				Lower	Upper			
2nd Molars	0.8673	0.87038	0.15891	0.54233	1.19234	5.458	29	0.000
1st Molars	0.6953	0.81376	0.14857	0.39147	0.99919	4.680	29	0.000
2nd Premolars	0.1380	0.78076	0.14255	-0.15354	0.42954	0.968	29	0.341
1st Premolars	0.2380	0.78037	0.14248	-0.05339	0.52939	1.670	29	0.106
Canines	0.2750	0.64110	0.11705	0.03561	0.51439	2.349	29	0.026

Table 13. *t-Test: Paired Differences of Plaster Models and CBCT Scans Facial to Lingual.*

	Mean	Std.Deviation	Std.Error Mean	95% Confidence Interval of the Difference		t	df	Sig.(2- tailed)
				Lower	Upper			
Left 2nd molar	-0.1363	0.44736	0.08168	-0.30338	0.03071	-1.669	29	0.106
Left 1st molar	0.0320	0.28634	0.05228	-0.07492	0.13892	0.612	29	0.545
Left 2nd pre molar	0.0413	0.30044	0.05485	-0.07085	0.15352	0.754	29	0.457
Left 1st pre molar	0.0197	0.44145	0.08060	-0.14517	0.18451	0.244	29	0.809
Left canine	0.2990	0.40818	0.07452	-0.45142	-0.14658	-4.12	29	0.000
Left lateral incisor	0.3070	0.81793	0.14933	0.00158	0.61242	2.056	29	0.049
Left central incisor	0.3370	0.90880	0.16592	-0.00235	0.67635	2.031	29	0.052
Right central incisor	0.4177	0.82229	0.15013	0.11062	0.72471	2.782	29	0.009
Right lateral incisor	0.2827	0.71059	0.12974	0.01733	0.54801	2.179	29	0.038
Right canine	-0.0737	0.62240	0.11363	-0.30607	0.15874	-0.648	29	0.522
Right 1st pre molar	0.0697	0.26187	0.04781	-0.02812	0.16745	1.457	29	0.156
Right 2nd pre molar	0.1953	0.36759	0.06711	0.05807	0.33259	2.911	29	0.007
Right 1st molar	0.0683	0.32182	0.05876	-0.05184	0.18850	1.163	29	0.254
Right 2nd molar	-0.1047	0.28208	0.05150	-0.21000	0.00066	-2.032	29	0.051

Table 14. *t-Test: Paired Differences of Plaster Models and CBCT Scans Mesial to Distal.*

	Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference		t	df	Sig. (2-tailed)
				Lower	Upper			
Left 2nd molar	-0.0143	0.61529	0.11234	-0.24409	0.21542	-0.128	29	0.899
Left 1st molar	0.0070	0.33772	0.06166	-0.11911	0.13311	0.114	29	0.910
Left 2nd pre molar	0.1077	0.43150	0.07878	-0.26879	0.05346	-1.367	29	0.182
Left 1st pre molar	0.1037	0.46506	0.08491	-0.06999	0.27732	1.221	29	0.232
Left canine	0.1343	0.35099	0.06408	0.00327	0.26539	2.096	29	0.045
Left lateral incisor	-0.0497	0.35818	0.06539	-0.18341	0.08408	-0.759	29	0.454
Left central incisor	-0.05573	0.281361	0.051369	-0.160795	0.049329	-1.085	29	0.287
Right central incisor	0.0433	0.33011	0.06027	-0.07993	0.16660	0.719	29	0.478
Right lateral incisor	0.1103	0.37135	0.06780	-0.02833	0.24900	1.627	29	0.114
Right canine	0.0537	0.41852	0.07641	-0.10261	0.20994	0.702	29	0.488
Right 1st pre molar	0.0057	0.22408	0.04091	-0.07801	0.08934	0.139	29	0.891
Right 2nd pre molar	0.0520	0.30029	0.05483	-0.06013	0.16413	0.948	29	0.351
Right 1st molar	0.0633	0.33405	0.06099	-0.06140	0.18807	1.038	29	0.308
Right 2nd molar	-0.0733	0.39182	0.07154	-0.21964	0.07298	-1.025	29	0.314

(mesio-buccal cusp tip of right 1st molar to mesiobuccal cusp tip of left 1st molar) and were essentially equally as strong. However, the correlation of the intra-examiner measurements for mesio-distal left 1st premolar was 0.227. This should be considered poor correlation.

Inter-examiner CBCT correlation ranged from 0.386 (labio-lingual of left central incisor) to 0.970 (mesio-buccal cusp tip of right 1st molar to mesio-buccal cusp tip of left 1st molar). The inter-examiner correlation for the plaster models was 0.409 (mesio-distal of left canine) to 0.972 (buccal cusp tip of right 2nd premolar to buccal cusp tip of left 2nd premolar). The low value of 0.386 for the inter-examiner digital model measurements is technically poor correlation, and the value of 0.409 for plaster model measurement is technically good

correlation. But, it should be kept in mind that the values fall along a range from 1.000 to 0.00. A value of 0.386 is not so far from our determined cut-off of 0.400 for good correlation and should not be summarily dismissed. Similarly, 0.406 is very close to the bottom and should be regarded as very weak correlation.

The extreme outlier is the mesio-distal dimension of the left1st premolar with an inter-examiner correlation value of 0.181. It is worthwhile to examine potential causes for both the intra- and inter- examiner correlation to be so low for the measurements of the left 1st premolar. We have controlled for blebs and fractures. Is abnormal anatomy to blame? Perhaps the 1st premolars in the sample are anomalous. Checking the correlations of the right first premolar shows the intra examiner correlation value at 0.972 and the inter-correlation value at 0.924. These values display excellent correlation and are among the best in the study.

Another source of the poor correlation is measurement error. Before concluding that sloppy measurement is to blame, some perspective in the measurement values is helpful. The average linear measurement value discrepancy for all evaluations of the left 1st premolar is 0.10mm. The measurement of the plaster casts with calipers by all observers and the measurement of distance in virtual models by the same observers only varies on average one-tenth of one millimeter. The tolerances for correlation and no correlation are so stringent that the average discrepancy of a tenth of a millimeter results in a correlation value that by strict statistical analysis should be rejected. However a deviation this small has been excused by other researchers as being apparently not clinically relevant [19].

The paired *t*-test conducted on the data set is an inter-examiner comparison of the measurements of the digital models to the "gold standard" of measurements of the plaster models. The plaster models were directly CBCT scanned and the same models were directly measured by the observers in the study. The variance of measurements between the plaster and digital model renderings is attributable to either operator error or an inherent distortion in the computer-rendered images. The paired *t*-test seeks to answer the question: Are differences between paired measurement means statistically significant?

At a significance level of $p < 0.0015$ three inter-examiner measurements were statistically significant. They were inter-cusp distance between mesio buccal cusps of 2nd molars on digital models, inter-cusp distance between mesio buccal cusps of 1st molars on digital models, and the bucco-lingual measurement of the left canine on digital models. The mean measurement discrepancy for these measurements was 0.80 mm, 0.7 mm and 0.3 mm, respectively.

For comparison, the average absolute difference for all variables in this study was 0.16 mm. It is likely that human measurement error is to blame for the statistical red flags. Clinically speaking, our observers were only discrepant in the worst case by an average of 0.8 millimeter when measuring a distance of over 50 millimeters from digital cusp to digital cusp.

Statistically, the discrepancy is noteworthy. Practically, it is not clinically significant. Several similar studies have noted measurement error as a source of variation of observation [9,10,20].

In the future, there will not be one single dominant modality for deriving digital dental models, since there are advantages to each alternative.

The benefits of digital models rendered from a CBCT scan of plaster casts include excellent soft-tissue reproduction, no radiation exposure for the patient, no scatter on the image from metal dental restorations, no need to purchase another scanning method for offices that have already obtained CBCT machines, and the ability to digitally archive any already existing plaster dental model. These advantages coupled with clinical accuracy ensure that 3-dimensional digital models rendered from CBCT scans of plaster casts are an appropriate alternative to traditional plaster models.

Conclusion

1. Standard deviations for most variables tested were less than 1.0 mm. with 20 of the 33 measurements at 0.5 mm or less.
2. Inter-examiner correlation was acceptable except for the labial-lingual width of the left central incisor.
3. Intra-examiner correlation was acceptable except for the mesio-distal length of left central incisor.
4. Digital images from CBCT scans of plaster models are an acceptable alternative to plaster models.

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