Are there differences between comparison methods used to evaluate the accuracy and reliability of digital models?

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Objectives: The accuracy and reliability of plaster models and digital models acquired with two different surface laser scanners were tested by means of three methods: measurement with calipers, digital measurement with proper software and superimposition of the digital models.

Methods: Thirty plaster models with permanent dentition that met the inclusion criteria were selected and scanned with two laser scanners (R700 and Xcad). Three examiners measured distances on plaster models with a digital caliper and on digital models using Ortho Analyzer software. The digital models were also compared by means of superimposition of the models using the Geomagic Qualify software. The intra and inter-examiner reliability of the measurements were evaluated using the ICC. Paired *t* test was used to test the accuracy of the measurements on digital and plaster models.

Results: The measurements on plaster and digital models acquired by two different scanners showed high values for the ICC. Although statistically significant differences between the measurements on plaster and digital models have been found, these discrepancies were not considered clinically relevant. The superimposition method with Geomagic Qualify software showed that the two digital models were not significantly different.

Conclusions: Digital models created from scanned plaster models using the R700 or Xcad scanners were clinically accurate according to the two methods of comparison used.

Keywords: Orthodontics. Dimensional measurement accuracy. Reproducibility of results.

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INTRODUCTION

Plaster models have been an essential part of patient records for orthodontic treatment. They are a valuable tool for diagnosis and treatment, and can also provide a dynamic copy of the actual treatment progress of orthodontic cases. It is widely used but often associated with some problems such as storage, breakage and loss.[1,2] The procedure of scanning the plaster models to create digital models, or directly scanning the teeth, gingiva and palate, is becoming a routine in clinical orthodontics. In 2014, 35% of graduate programs in Orthodontics in the United States and Canada used digital study models for most of the treated cases.[3] The manufacturing of dental models to be used for CAD/CAM systems in Prosthetic Dentistry has been used for some decades.[4]

Digital models can be fabricated with the indirect method of laser scanning of plaster models[1,5-18] and by scanning alginate and PVS impressions with laser scanners or with CT scanners.[2] The direct method of intraoral scanning has been successfully introduced.[12,19] Finally, the dentition can be evaluated and measured on the patient's cone beam computed tomography (CBCT) image.[2,5,14]

Several studies evaluated the accuracy and reliability of measurements of digital models made by plaster models scan. Many of these studies found statistically significant differences between the plaster model and digital model, but these differences were considered to be clinically not relevant.[1,5-17] Some studies found statistically significant differences and concluded that the measurements on the digital models were significantly larger,[6,7,9,10,12] while others found significant lower values for the measurements on digital models.[1,8,11] According to this literature survey, it may be concluded that there is no agreement on the accuracy of digital model dimensions made in plaster models scans.

Digital models present several advantages compared to plaster models, such as ease of data storage and data transmission. A major advantage of digital models is the

Table 1 - Parameters definitions.

Parameter	Abbreviation	Definition
Mesiodistal diameter	MDD	Upper and lower mesiodistal diameter of each tooth from first molar to first molar (largest mesiodistal diameter of the mesial contact point to the distal contact point, parallel to the occlusal plane)
Sum of upper 6 teeth	Sum upper 6	Diameter sum of 6 anterior upper teeth
Sum of upper 12 teeth	Sum upper 12	Diameter sum of 12 anterior upper teeth
Sum of lower 6 teeth	Sum lower 6	Diameter sum of 6 anterior lower teeth
Sum of lower 12 teeth	Sum lower 12	Diameter sum of 12 anterior lower teeth
Crown Height	CH	Upper and lower crown height from first molar to first molar (from incisal edge or cusp tip to the lower gingival margin from the vestibular axis of each clinical crown - Andrews)
Upper intercanine distance	Upper ICD	Distance between the cusp tip of the upper left canine to cusp tip of the upper right canine
Upper intermolar distance	Upper IMD	Distance between the tip of the mesiobuccal cusp of the upper left first molar to the tip of the mesiobuccal cusp of the upper right first molar
Lower intercanine distance	Lower ICD	Distance between the cusp tip of the lower left mandibular canine to cusp tip of the lower right canine
Lower intermolar distance	Lower IMD	Distance between the tip of the mesiobuccal cusp of the lower left first molar to the tip of the mesiobuccal cusp of the lower right first molar
Overjet	Overjet	Distance from the middle of the incisal edge closest to the buccal surface of the upper right maxillary central incisor to the buccal surface of the lower incisor antagonist, parallel to the occlusal plane
Overbite	Overbite	Vertical distance between the marking where the incisal edge of the upper right central incisor overlaps the buccal surface of the lower incisor antagonist until its respective incisal edge
Interarch right sagittal relationship 1	Right Sag Rel 1	Distance from the cusp tip of the upper right canine to the marking where the mesiobuccal cusp of the upper right first molar occludes to the lower arch
Interarch left sagittal relationship 1	Left Sag Rel 1	Distance from the cusp tip of the upper left canine to the marking where the mesiobuccal cusp of the upper left first molar occludes to the lower arch
Interarch right sagittal relationship 2	Right Sag Rel 2	Distance from the cusp tip of the upper right canine to the meeting point between the gingival margin and the extension of the mesiobuccal groove of the lower right first molar
Interarch left sagittal relationship 2	Left Sag Rel 2	Distance from the cusp tip of the upper left canine to the meeting point between the gingival margin and the extension of the mesiobuccal groove of the lower left first molar

ability to superimpose digital models for comparison, which cannot be done with plaster models, because of their physical nature.[20]

As there are several types of plaster model scanners available, studies that evaluate the accuracy and reliability of digital models produced by a specific scanner are required. There are two different methods to compare the accuracy of digital models: measurements of distances between teeth; and superimposition of the digital model on stable structures of the models. The aim of our study is to evaluate if these two methods of comparison present similar results and can be used to test the accuracy of digital models in a complementary way.

MATERIALS AND METHODS

A pilot study with plaster models of 15 individuals was used to determine the sample size for this study. The formula described by Pandis,[21] assuming a 80% power test and $\alpha = 0.05$ was used to detect a difference of 0.7 mm between the models whit a standard deviation of 1.0 mm. This sample size calculation revealed the need for a sample of at least 29 plaster models. Ethical approval for the study was received before the start of the study (reference number: 221.664, 01/02/2013).

Impressions from a sample of students at the Orthodontic Department of *Universidade Federal Fluminense* were made. Inclusion criteria for the selected patients were: fully erupted permanent dentition (including all upper and lower first permanent molars). Dentitions showing dental anomalies in size and shape, presence of severe gingival recessions, dental crown abrasions, attritions and erosions or with fixed orthodontic retention, were excluded. The final sample consisted of impressions of 30 volunteers. The age of the volunteers at the time of impression taking was between 21 and 39 years, with an mean of 27 years and 9 months.

Alginate impressions of the upper and lower arches were made (Hydrogum, Zhermack®, Badia Polesine, Rovigo, Italy), following the manufacturer's guidelines. The bite registration was made with a #7 dental wax (Clássico®, São Paulo, Brazil). This bite registration was used for trimming the base of the plaster models. The impression of the teeth and the alveolar ridge were poured with type IV plaster (Vigodent®, Rio de Janeiro, Brazil) and the base of the plaster model was poured with white plaster (Mossoró®, Rio de Janeiro, Brazil). The plaster models were scanned with two different types of surface laser scanners: R700 (3Shape®, Copenhagen, Denmark) and Xcad (XCADCAM Tecnologia®, São Paulo, Brazil), according to the instructions of the manufactures. The digital models were used for measurements of dimensions and distances, using the Ortho Analyzer software (3Shape®, Copenhagen, Denmark), and for superimposition with Geomagic Qualify software (3D Systems®, Rock Hill, South Carolina, USA). Before the start of the measurements, sagittal, transverse and vertical adjustments on digital models were made when needed, with the mentioned software.

Sixty two parameters with clinical relevance for orthodontics were defined (Table 1). Three trained and calibrated examiners performed the measurements on the dental models. For measurements on plaster

Figure 1 - Measurement of the height of the dental crown in the plaster model, with a digital caliper.
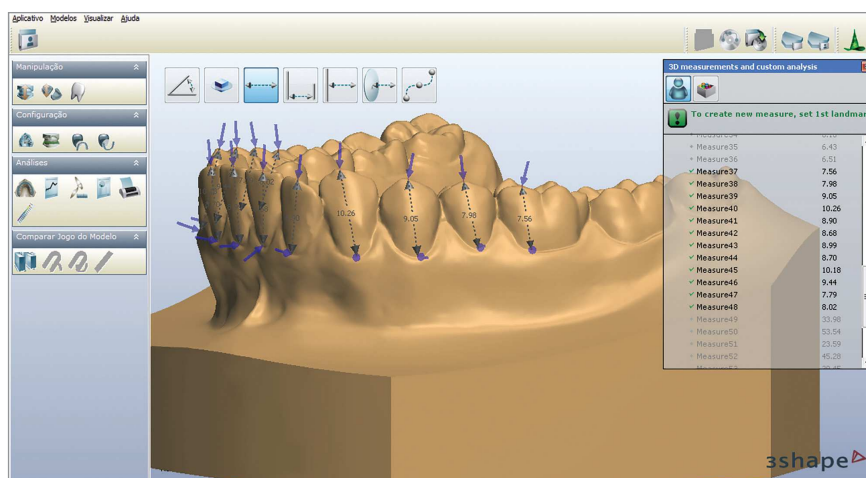
Figure 2 - Measurement of the height of the dental crown in the digital model, using the Ortho Analyzer software.

models, it was used a caliper with accuracy of 0.01 millimeter (Starrett®, Itu, São Paulo, Brazil) (Fig 1). The measurements on digital models were made with the Ortho Analyzer software (Fig 2). In order to evaluate the accuracy and reliability of the measurements performed by the three examiners, they measured all the parameters on five pairs of models randomly selected from the sample and measured this subsample again after 15 days. After this calibration process, the examiners started measuring all the models.

The digital models of both scanners were also compared using the superimposition method on Geomagic Qualify software. The dentition of the two models was aligned using the best-fit surface alignment tool of the software. After alignment, the model edges were trimmed with digital cutting tool, to create coincident borders between the models. Geomagic Qualify software then calculated the maximum and mean distances (positive and negative differences) as well as the standard deviation between the "capturing points" of the two digital models. These values are visually displayed with a "color map" which shows the distances between the models in different colors. The distance limit used for preparation of this color map was 0.25 mm (Fig 3).
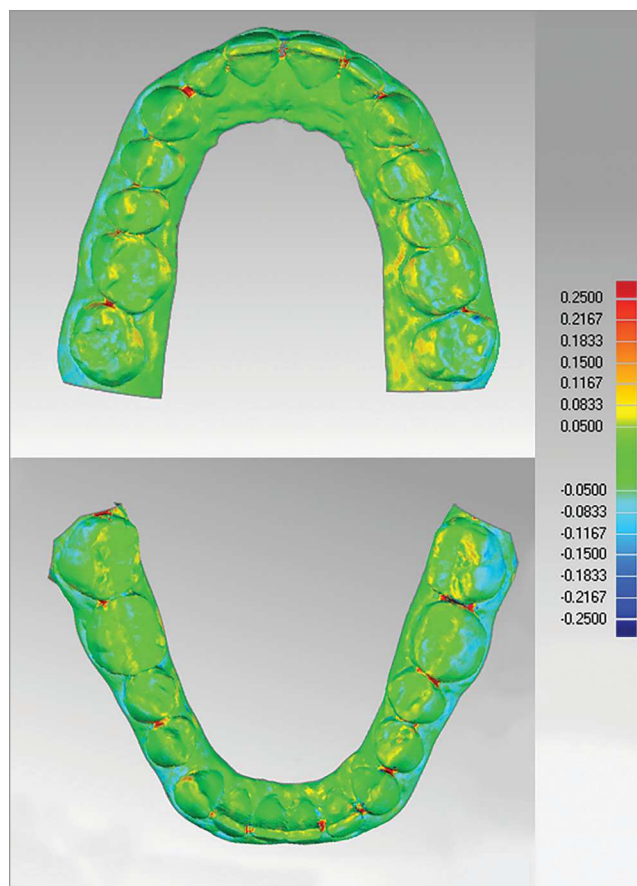

Figure 3 - Superimposition of 3Shape and Xcad models.

Table 2 - Correlation between examiners on plaster models vs. digital models.

PARAMETER	Plaster model n = 30		3Shape model n = 30		Xcad model n = 30	
	Intraclass Correlation Coefficient	95% Confidence Interval	Intraclass Correlation Coefficient	95% Confidence Interval	Intraclass Correlation Coefficient	95% Confidence Interval
Upper MDD (Mean)	0.891	0.814 - 0.942	0.844	0.737 - 0.915	0.851	0.749 - 0.920
Sum upper 6	0.967	0.940 - 0.983	0.904	0.833 - 0.950	0.955	0.920 - 0.977
Sum upper 12	0.964	0.936 - 0.982	0.941	0.895 - 0.969	0.970	0.946 - 0.985
Lower MDD (Mean)	0.881	0.797 - 0.937	0.813	0.697 - 0.896	0.827	0.713 - 0.906
Sum lower 6	0.953	0.917 - 0.976	0.930	0.876 - 0.963	0.932	0.880 - 0.965
Sum lower 12	0.967	0.941 - 0.983	0.960	0.928 - 0.979	0.966	0.940 - 0.983
Upper CH (Mean)	0.955	0.921 - 0.977	0.950	0.911 - 0.974	0.955	0.920 - 0.977
Lower CH (Mean)	0.929	0.876 - 0.963	0.941	0.895 - 0.969	0.947	0.906 - 0.972
Upper ICD	0.967	0.940 - 0.983	0.962	0.932 - 0.980	0.957	0.923 - 0.978
Lower ICD	0.947	0.906 - 0.973	0.950	0.910 - 0.974	0.954	0.917 - 0.976
Upper IMD	0.987	0.977 - 0.993	0.988	0.979 - 0.994	0.991	0.983 - 0.995
Lower IMD	0.965	0.937 - 0.982	0.977	0.959 - 0.988	0.986	0.974 - 0.993
Overjet	0.930	0.877 - 0.964	0.948	0.908 - 0.973	0.858	0.759 - 0.924
Overbite	0.965	0.936 - 0.982	0.991	0.984 - 0.996	0.946	0.904 - 0.972
Sag Rel (Mean)	0.885	0.802 - 0.939	0.933	0.882 - 0.965	0.925	0.867 - 0.961

STATISTICAL ANALYSIS

Statistical analysis of the measurements was performed using the SPSS program, version 20.0 (IBM®, Armonk, NY, USA). The intraclass correlation coefficient (ICC) was used to evaluate the intra and inter-examiner reliability of measurements for each model type. Paired *t* test was used to evaluate the intra-examiners accuracy and to compare the difference in distances measured on plaster models and digital models. Descriptive statistical analysis was used to show the results of the superimposition of the digital models. *P*-values < 0.05 were considered to be significant.

RESULTS

The intra-examiners accuracy showed non-significant differences between the two sets of measurements. For plaster models, examiners one and three presented mean differences (for all parameters) of 0.013 mm, and examiner two, a mean difference of 0.012 mm. For digital models scanned with the R700 scanner (3Shape models), mean difference of 0.035 mm in measurement error for all parameters was found for examiner one, 0.184 mm for examiner two and 0.057 mm for examiner three. The mean

Table 3 - Paired *t* tests mean differences between examiners on plaster models vs. digital 3Shape models (mm).

Parameter	Plaster model vs. 3Shape model					
	Examiner 1		Examiner 2		Examiner 3	
	Mean	SD	Mean	SD	Mean	SD
Upper MDD (Mean)	-0.064	0.238	0.123	0.326	0.014	0.296
Sum upper 6	-0.570	1.001	1.077	0.769	0.393	1.253
Sum upper 12	-0.851	1.313	1.487	1.505	0.169	2.176
Lower MDD (Mean)	-0.149	0.222	0.094	0.321	-0.051	0.255
Sum lower 6	-0.488	0.675	0.888	0.939	-0.144	0.821
Sum lower 12	-1.789	1.054	1.129	1.364	-0.622	1.608
Upper CH (Mean)	0.005	0.299	-0.041	0.257	-0.133	0.274
Lower CH (Mean)	0.063	0.285	-0.047	0.325	-0.029	0.281
Upper ICD	0.275	0.488	0.088	0.577	0.285	0.458
Upper IMD	-0.361	0.365	-0.026	0.845	-0.246	0.528
Lower ICD	-0.085	0.513	0.337	0.534	-0.107	0.456
Lower IMD	-0.469	0.540	0.510	0.833	0.171	0.607
Overjet	-0.164	0.412	0.091	0.394	-0.259	0.274
Overbite	0.338	0.287	0.569	0.250	0.287	0.292
Sag Rel (Mean)	-0.027	0.637	-0.427	0.783	-0.142	0.658

Table 4 - Paired *t* tests mean differences between examiners on plaster models vs. digital Xcad models (mm).

Parameter	Plaster model vs. Xcad model					
	Examiner 1		Examiner 2		Examiner 3	
	Mean	SD	Mean	SD	Mean	SD
Upper MDD (Mean)	-0.143	0.229	0.081	0.360	-0.064	0.233
Sum upper 6	-1.043	0.563	0.726	0.990	-0.055	0.655
Sum upper 12	-1.719	0.893	0.974	1.656	-0.777	0.973
Lower MDD (Mean)	-0.232	0.232	-0.015	0.362	-0.155	0.233
Sum lower 6	-1.431	0.814	0.137	0.879	-0.821	0.658
Sum lower 12	-2.791	0.953	-0.188	1.588	-1.871	0.845
Upper CH (Mean)	-0.102	0.261	-0.141	0.304	-0.286	0.273
Lower CH (Mean)	-0.050	0.298	-0.093	0.300	-0.129	0.264
Upper ICD	0.444	0.464	0.369	0.599	0.448	0.586
Upper IMD	-0.288	0.599	0.182	0.788	-0.141	0.475
Lower ICD	0.212	0.306	0.625	0.614	-0.076	0.470
Lower IMD	-0.286	0.506	0.778	0.638	0.379	0.458
Overjet	0.056	0.459	0.529	0.496	-0.013	0.302
Overbite	0.199	0.435	0.528	0.522	0.217	0.621
Sag Rel (Mean)	0.218	0.654	-0.238	0.770	-0.139	0.601

difference in measurement error for all measurement parameters on digital models scanned by Xcad scanner (Xcad models) was 0.083 mm for examiner one, 0.099 mm for examiner two, and 0.063 mm for examiner three. According to the ICC, all examiners presented excellent intra-examiners reliability: examiner one showed an mean ICC for all parameters of 0.961 for plaster models, 0.929 for 3Shape models and 0.951 for Xcad models; for examiner two, mean ICC of 0.959 for plaster models, 0.931 for 3Shape models and 0.939 for Xcad models was found; while for examiner three, mean ICC of 0.959 for plaster models, 0.966 for 3Shape models and 0.974 for Xcad models was found.

The analysis of the reliability of the measurements performed by the three examiners revealed a high ICC for the measurements on the plaster model, as well as on the digital models. The lowest ICC among examiners in plaster models was 0.775. For 3Shape models, the lowest ICC was 0.521, and for Xcad models the lowest ICC was 0.726. Of the 62 measurements on plaster models, the ICC of 55 measurements was larger than 0.850, while the ICC for 50 of the 62 measurements in 3Shape models and the ICC of 48 of the measurements on the Xcad models, was larger than 0.850 (Table 2).

Paired t test was used to compare the measurements performed by each examiner on plaster model and on the two types of digital models. Clinically relevant differences

Table 5 - Paired t tests mean differences between examiners on 3Shape models vs. Xcad models (mm).

Parameter	3Shape model vs. Xcad model					
	Examiner 1		Examiner 2		Examiner 3	
	Mean	SD	Mean	SD	Mean	SD
Upper MDD (Mean)	-0.079	0.259	-0.042	0.368	-0.078	0.338
Sum upper 6	-0.472	0.894	-0.351	1.134	-0.449	1.465
Sum upper 12	-0.868	0.927	-0.513	1.514	-0.946	2.482
Lower MDD (Mean)	-0.083	0.257	-0.109	0.344	-0.104	0.268
Sum lower 6	-0.943	0.651	-0.751	0.863	-0.677	1.081
Sum lower 12	-1.002	1.021	-1.317	1.337	-1.248	1.689
Upper CH (Mean)	-0.107	0.265	-0.099	0.237	-0.153	0.227
Lower CH (Mean)	-0.114	0.299	-0.046	0.275	-0.099	0.201
Upper ICD	0.168	0.432	0.281	0.550	0.162	0.587
Upper IMD	0.072	0.500	0.209	0.554	0.105	0.474
Lower ICD	0.297	0.469	0.288	0.533	0.031	0.416
Lower IMD	0.183	0.328	0.268	0.597	0.208	0.382
Overjet	0.220	0.421	0.438	0.487	0.246	0.254
Overbite	-0.139	0.261	-0.041	0.426	-0.070	0.472
Sag Rel (Mean)	0.245	0.571	0.189	0.644	0.002	0.627

Table 6 - Descriptive analysis of the comparison on 3Shape models vs. Xcad models by superimposition using Geomagic Qualify software (mm).

Parameter	Minimum	Maximum	Mean	SD
Upper arch				
Mean deviation	-0.068	0.057	0.013	0.022
Mean positive differences	0.036	0.196	0.077	0.036
Mean negative differences	-0.215	-0.026	-0.073	0.050
Standard Deviation	0.044	0.233	0.102	0.048
Lower arch				
Mean deviation	0.001	0.082	0.026	0.016
Mean positive differences	0.026	0.253	0.067	0.040
Mean negative differences	-0.408	-0.029	-0.059	0.070
Standard Deviation	0.047	0.695	0.124	0.122

between the plaster and digital models were found in some of the measurements (Tables 3 and 4). Paired *t* test showed less clinically relevant differences on the measured values between the two digital models (Table 5).

The superimposition of the digital models was used to evaluate the mean distances and the standard deviations between the models. The outcome of the descriptive statistical analysis of the differences between the superimposition of the two digital models is shown in Table 6.

DISCUSSION

This study evaluated the accuracy and reliability of measurements on two digital models made with two different plaster model scanners, compared to measurements on plaster models. The differences between digital models created by the two different scanners were also evaluated by models superimposition. It can be concluded that measurements on plaster models or digital models are associated with some degree of inaccuracy. Accuracy is presented as the difference in measurements of an object (a "gold standard") with known dimensions, but it should be noticed that since these plaster models are a copy of the real dentition, they could present some inaccuracy. The reliability of the scanned plaster model depends on the repeatability and reproducibility of the measurements used.[15,22] As reported in other studies,[1,7,8] the location of the selected reference points for measurements may vary among the examiners, regardless of the method used. This problem of measurement point identification directly affects the reliability of the measurements. To compare the reliability of the measurements among the examiners, the ICC was used. In this study, the reliability of the measurements was considered excellent for plaster models (mean r = 0.919), for 3Shape models (mean r = 0.900) and for Xcad models (mean r = 0.906) (Table 2). These results show that, due to the training and calibration of examiners before the start of this research, specified distances could be accurately measured with both calipers and digital measuring software, on respectively plaster models and digital models.

For the orthodontic measurements used in this study, statistically significant differences are not very important; only clinically relevant differences in measurements do really matter. In this study, it was decided to use the same values for clinically relevant differences (cut-offs) as reported in the literature.[12,13,23] Mean differences in measurements for the overjet, overbite, tooth size and tooth height greater than 0.3 mm, and for transverse and sagittal distances greater than 0.4 mm were considered to be clinically relevant. Although according to the paired *t* test results, the difference between several measurements was statistically significant, the difference between most of the parameters was not considered clinically relevant (Tables 3, 4 and 5).

The differences on measurements of 8 of the 62 measures were considered clinically relevant for the 3Shape models. For the Xcad models, 19 of the 62 measures were considered clinically relevant. This outcome suggests that the digital models made with the 3Shape scanner could be more accurate. The highest mean difference in measurements was 0.92 mm on the 3Shape models and 0.77 mm on the Xcad models, excluding the sum of dental diameters parameters. These data demonstrate a relatively high accuracy and reliability of the dimensions for both digital models. These findings are in concordance with other studies.[6-12,16-18]

Examiners one and three found in general, higher values for measurements on digital models, compared to the same measurements on plaster models (Tables 3 and 4), which is in accordance with the results of some studies.[9,12] On the other hand, examiner two found lower values in the measurements on digital models, compared to measurements on plaster models (Tables 3 and 4). This outcome is in concordance with the measurement differences published by Watanabe-Kanno et al.[11]

When measurements on 3Shape models and Xcad models were compared, the differences between these models were lower than the differences between the measurements on plaster model and digital models (Table 5). Differences on only 3 out of 62 distances measured were considered clinically relevant. The highest difference in the mean distance was 0.48 mm for the right sagittal relationship parameter measured with Ortho Analyzer software for examiner one. A possible explanation for this result is that the same method was used to compare the digital models (Ortho Analyzer software), which suggests that different measuring methods can affect the measurement accuracy.
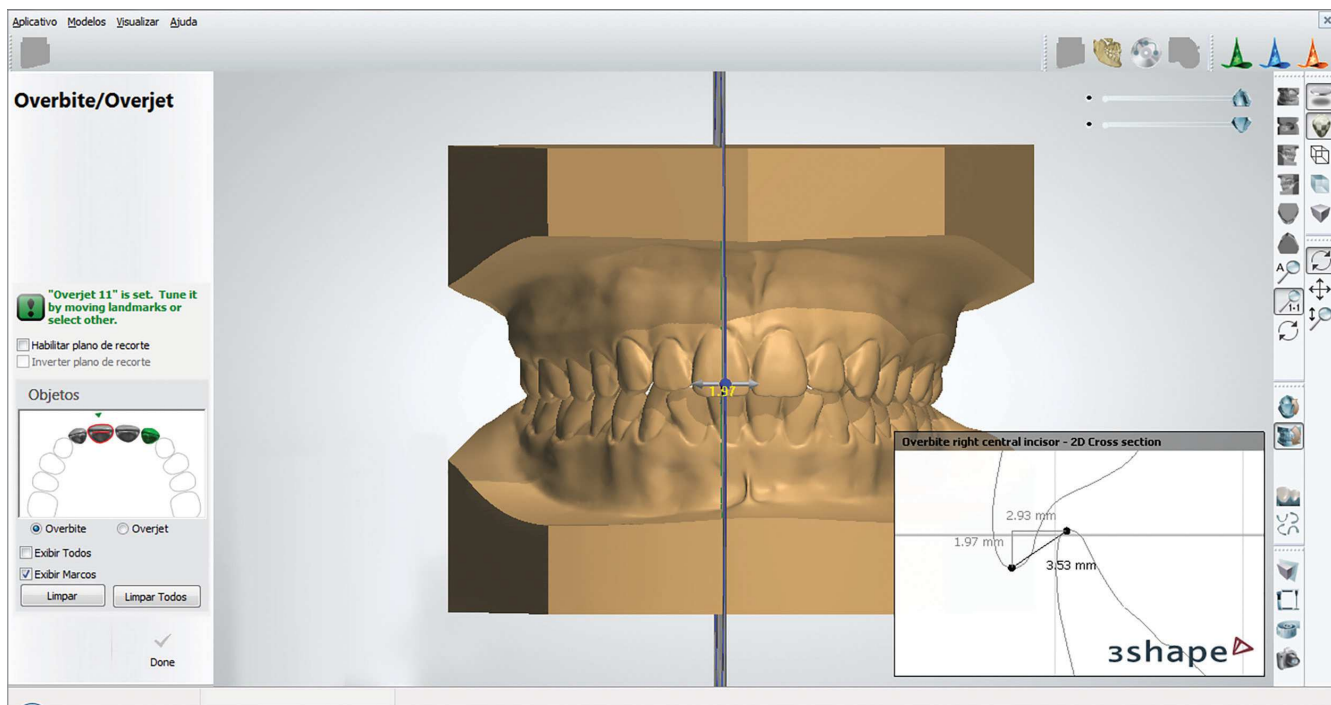
Figure 4 - Overbite measurement in the digital model using the Ortho Analyzer software.

For the measurements of overbite on plaster models and digital models, relatively large differences were found. Mean differences for the overbite measurement on the 3Shape models presented clinically relevant differences for two examiners. For one examiner the overbite measurements presented clinically relevant different on the Xcad models (0.52 mm). The largest difference in overbite measurements found in this study was 0.56 mm (Tables 3 and 4). These findings are similar to the results published by Santoro et al[18] and Bootvong et al.[16] These results could show that the overbite measurement between the models is actually different, but it can also be possible that a difference in measurement method leads to different values of the overbite. On the other hand, the differences in overbite measurements between the two digital models were not clinically relevant (Table 5). For calipers both the angle and the thickness of the tip of the calipers may have contributed to some inaccuracies in the overbite measurement on plaster models.[18] For digital models, it is possible to magnify and section the image (clipping of the model).

This feature combined with the small reference cursor used for measurement on digital models, facilitates accuracy in measurement point identification compared to the measurement procedure with calipers on plaster models (Fig 4). Regarding the sagittal interarch relationship, two measurements for 3Shape models and two measurements for Xcad models showed clinically relevant differences, as compared to the measurements on plaster models. The largest difference in sagittal relationship was found in the 3Shape models measured by examiner two (Tables 3 and 4). The differences in the sagittal interarch relationship measurements between the 3Shape model and Xcad model were small (Table 5). These results indicate that for the studied digital models, a clinically acceptable interarch accuracy and reliability can be expected, compared to the sagittal relationship found for the plaster models.

The measuring method using calipers on plaster models and software on digital models was also validated. However, it is important to mention that mistakes can happen during this measuring technique due to the

subjective interpretation in locating the reference points. It is important to differentiate between statistically different measurements and clinically relevant differences, is order to evaluate if differences in the measurements found on plaster or digital models can really affect the orthodontic diagnosis and treatment planning. It also indicates if the appliances created with computer-aided design/computer-aided manufacturing (CAD/CAM) over the digital dental models will be sufficiently accurate to be used for orthodontic treatment.

The alternative comparison method of models superimposition can be effectively used for digital models[20,24] and this method can also be used to visualize and quantify tooth movement during orthodontic treatment.[25] There are several software which can be used for this superimposition method. In this study, it was used the Geomagic Qualify software. This superimposition method showed that the differences between the surfaces of the two digital models were insignificant (Table 6). Blue and red surfaces on the color maps indicate areas with difference bigger than 0.25 mm between the superimposed models. Differences over 0.25 mm were mainly localized on less relevant locations, such as interdental spaces, surface areas that were not smoothed with the software in Xcad models and on the base of the model.

Compared to the distance measurement technique, the superimposition technique as used in this study, is an accurate and reliable method. This super-

imposition method is easy and fast and misinterpretations caused by measurements of different examiners can be avoided as the superimposition method and analysis are made by computer software. Continued research to test the accuracy and reliability of digital models made by indirect methods such as scanning dental models, impressions and direct methods using intraoral scanners and 3D radiographs, is needed as the use of these digital models for diagnosis, treatment planning, restoration and custom appliance fabrication in Dentistry will increase.

CONCLUSIONS

Digital models from scanned plaster models using the R700 or Xcad scanners were considered clinically accurate according to the two methods of comparison used. Both measurement and superimposition methods to compare the digital models can be efficiently used to evaluate the accuracy and reliability of digital dental models.

Acknowledgments

REFERENCES

1. Abizadeh N, Moles DR, O'Neill J, Noar JH. Digital versus plaster study models: how accurate and reproducible are they? J Orthod. 2012 Sept;39(3):151-9.

2. de Waard O, Rangel FA, Fudalej PS, Bronkhorst EM, Kuijpers-Jagtman AM, Breuning KH. Reproducibility and accuracy of linear measurements on dental models derived from cone-beam computed tomography compared with digital dental casts. Am J Orthod Dentofacial Orthop. 2014 Sept;146(3):328-36.

3. Shastry S, Park JH. Evaluation of the use of digital study models in postgraduate orthodontic programs in the United States and Canada. Angle Orthod. 2014 Jan;84(1):62-7.

4. Touchstone A, Nieting T, Ulmer N. Digital transition: the collaboration between dentists and laboratory technicians on CAD/CAM restorations. J Am Dent Assoc. 2010 June;141 Suppl 2:15S-9S.

5. Grünheid T, Patel N, De Felippe NL, Wey A, Gaillard PR, Larson BE. Accuracy, reproducibility, and time efficiency of dental measurements using different technologies. Am J Orthod Dentofacial Orthop. 2014 Feb;145(2):157-64.

6. Asquith J, Gillgrass T, Mossey P. Three-dimensional imaging of orthodontic models: a pilot study. Eur J Orthod. 2007 Oct;29(5):517-22.

7. Stevens DR, Flores-Mir C, Nebbe B, Raboud DW, Heo G, Major PW. Validity, reliability, and reproducibility of plaster vs digital study models: comparison of peer assessment rating and Bolton analysis and their constituent measurements. Am J Orthod Dentofacial Orthop. 2006 June;129(6):794-803.

8. Mullen SR, Martin CA, Ngan P, Gladwin M. Accuracy of space analysis with emodels and plaster models. Am J Orthod Dentofacial Orthop. 2007 Sept;132(3):346-52.

9. Goonewardene RW, Goonewardene MS, Razza JM, Murray K. Accuracy and validity of space analysis and irregularity index measurements using digital models. Aust Orthod J. 2008 Nov;24(2):83-90.

10. Sousa MV, Vasconcelos EC, Janson G, Garib D, Pinzan A. Accuracy and reproducibility of 3-dimensional digital model measurements. Am J Orthod Dentofacial Orthop. 2012 Aug;142(2):269-73.

11. Watanabe-Kanno GA, Abrão J, Miasiro Junior H, Sánchez-Ayala A, Lagravère MO. Reproducibility, reliability and validity of measurements obtained from Cecile3 digital models. Braz Oral Res. 2009 July-Sept;23(3):288-95.

12. Naidu D, Freer TJ. Validity, reliability, and reproducibility of the iOC intraoral scanner: a comparison of tooth widths and Bolton ratios. Am J Orthod Dentofacial Orthop. 2013 Aug;144(2):304-10.

13. Keating AP, Knox J, Bibb R, Zhurov AI. A comparison of plaster, digital and reconstructed study model accuracy. J Orthod. 2008 Sept;35(3):191-201; discussion 175.

14. Kim J, Heo G, Lagravère MO. Accuracy of laser-scanned models compared to plaster models and cone-beam computed tomography. Angle Orthod. 2014 May;84(3):443-50.

15. Veenema AC, Katsaros C, Boxum SC, Bronkhorst EM, Kuijpers-Jagtman AM. Index of Complexity, Outcome and Need scored on plaster and digital models. Eur J Orthod. 2009 June;31(3):281-6.

16. Bootvong K, Liu Z, McGrath C, Hagg U, Wong RW, Bendeus M, et al. Virtual model analysis as an alternative approach to plaster model analysis: reliability and validity. Eur J Orthod. 2010 Oct;32(5):589-95.

17. Tomassetti JJ, Taloumis LJ, Denny JM, Fischer JR Jr. A comparison of 3 computerized Bolton tooth-size analyses with a commonly used method. Angle Orthod. 2001 Oct;71(5):351-7.

18. Santoro M, Galkin S, Teredesai M, Nicolay OF, Cangialosi TJ. Comparison of measurements made on digital and plaster models. Am J Orthod Dentofacial Orthop. 2003 July;124(1):101-5.

19. Cuperus AM, Harms MC, Rangel FA, Bronkhorst EM, Schols JG, Breuning KH. Dental models made with an intraoral scanner: a validation study. Am J Orthod Dentofacial Orthop. 2012 Sept;142(3):308-13.

20. Flugge TV, Schlager S, Nelson K, Nahles S, Metzger MC. Precision of intraoral digital dental impressions with iTero and extraoral digitization with the iTero and a model scanner. Am J Orthod Dentofacial Orthop. 2013 Sept;144(3):471-8.

21. Pandis N. Sample calculations for comparison of 2 means. Am J Orthod Dentofacial Orthop. 2012 Apr;141(4):519-21.

22. Dowling AH, Burns A, Macauley D, Garvey TM, Fleming GJ. Can the intra-examiner variability of Little's Irregularity Index be improved using 3D digital models of study casts? J Dent. 2013 Dec;41(12):1271-80.

23. Fleming PS, Marinho V, Johal A. Orthodontic measurements on digital study models compared with plaster models: a systematic review. Orthod Craniofac Res. 2011 Feb;14(1):1-16.

24. Grunheid T, McCarthy SD, Larson BE. Clinical use of a direct chairside oral scanner: an assessment of accuracy, time, and patient acceptance. Am J Orthod Dentofacial Orthop. 2014 Nov;146(5):673-82.

25. Cha BK, Lee JY, Jost-Brinkmann PG, Yoshida N. Analysis of tooth movement in extraction cases using three-dimensional reverse engineering technology. Eur J Orthod. 2007 Aug;29(4):325-31.