SCIENTIFIC SECTION

From alginate impressions to digital virtual models: accuracy and reproducibility

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Objective: To compare the accuracy and reproducibility of measurements performed on digital virtual models with those taken on plaster casts from models poured immediately after the impression was taken, the 'gold standard', and from plaster models poured following a 3–5 day shipping procedure of the alginate impression.

Design: Direct comparison of two measuring techniques.

Setting: The study was conducted at the Department of Orthodontics, School of Dentistry, University of Aarhus, Denmark in 2006/2007.

Participants: Twelve randomly selected orthodontic graduate students with informed consent.

Methods: Three sets of alginate impressions were taken from the participants within 1 hour. Plaster models were poured immediately from two of the sets, while the third set was kept in transit in the mail for 3–5 days. Upon return a plaster model was poured as well. Finally digital models were made from the plaster models. A number of measurements were performed on the plaster casts with a digital calliper and on the corresponding digital models using the virtual measuring tool of the accompanying software. Afterwards these measurements were compared statistically.

Results: No statistical differences were found between the three sets of plaster models. The intraand inter-observer variability are smaller for the measurements performed on the digital models.

Conclusions: Sending alginate impressions by mail does not affect the quality and accuracy of plaster casts poured from them afterwards. Virtual measurements performed on digital models display less variability than the corresponding measurements performed with a calliper on the actual models.

Key words: Orthodontics, plaster models, digital models, alginate impressions, virtual models

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Introduction

Traditional plaster casts are among the last clinical record in the orthodontic office to be converted into digital media, but virtual dental models are gradually becoming more prevalent.[1–4] This change, although meeting opposition from conservative orthodontists who want to 'feel' the plaster models in their hands, has considerable advantages, particularly in obviating the need for extensive storage facilities, reducing the risk of physical damage and/or the disappearance of the casts stored in the wrong location. In addition, there is the possibility of sharing the models with colleagues, other specialists involved in the treatment, and even with the patient.

The questions asked by the 'less computer-enthusiastic' orthodontists are; can a virtual dental model actually replace the plaster cast as a basis for treatment planning? And whether measurements carried out on virtual models can replace those performed on the study casts?

OrthoCAD™ (Cadent, Carlstadt, NJ, USA) introduced virtual models in 1999, followed by E-models™ (Geodigm Corp., Chanhassen, MN, USA) in 2001. Both these products have been evaluated and found to be useful in the treatment planning process. Measurements carried out in relation to the Bolton analysis were not significantly different from those carried out on the 'gold standard' whether this was the original plaster model from which the virtual model was developed[5] or a dentoform model.[6] Although linear measurements with a digital calliper on a physical model have been reported to be more accurate than their virtual counterparts,[7] the accuracy of the digital measurements was considered to be clinically acceptable. Another consideration will be the ease of measuring using the different dedicated software programs.

Virtual models can be produced by several methods. The most direct method is by using an intra-oral laser-scanner (Orametrix Inc., Richardson, TX, USA). This

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method makes the impression superfluous, but the clinical chair time may be increased. Digital virtual models can also be produced by a negative surface model technique generated by laser-scanning the inside of an impression; however this method might encounter difficulties in relation to undercuts and the limited space inside the impression. The most frequently applied method seems to be to pour a plaster model as a half-way step. This plaster model is either non-destructively digitized using stereophotogrammetry,[8–10] a surface laser-scanner[11,12] or industrial computer tomography or by using a destructive sequential slicing technique.

For most current brands of digital virtual models, the technology to create the models is outsourced from the orthodontic practice by sending alginate impressions or plaster models to a company specializing in creating digital models (OrthoCAD™, Cadent, Carlstadt, NJ, USA; E-models™, Geodigm Corp., Chanhassen, MN, USA; DigiModel™, OrthoProof, Nieuwegein, The Netherlands; O3DM™, OrtoLab, Częstochowa, Poland). After a number of days, the models can be downloaded from the company's web-site. This approach has the advantage that individual practices do not have to invest in the technology and know-how to produce virtual models; however a potential error may be introduced by the fact that the alginate impressions are sent by mail. OrthoCAD™ initially required silicon impressions to counter this problem, but is now accepting alginate ones. This is not a trivial issue, because alginate as a dental impression material has been reported to be subject to volume changes during storage.[13] The influence of shipping has so far not been investigated and the 'gold standard' in the above mentioned trial has always been the model from which the virtual model was generated.

The overall aim of the study was to examine the stability of alginate impressions over a period of time. The specific objectives were:

- to detect any significant differences in the measurements taken from models poured immediately and models poured after 3–5 days;
- to assess the variability in the measurements performed on plaster and digital models;
- to measure inter-observer variability;
- to determine the reproducibility of performing measurements directly on plaster models compared with those obtained from digital models.

Materials and methods

Three sets of alginate (Aroma Fine™ DF III, GC Corp., Tokyo, Japan) impressions were taken from twelve randomly selected orthodontic graduate students using plastic impression (ASA Dental™, Bozzano, Italy). The students provided verbal consent for their discarded practice impressions to be used in this study, as in Denmark, ethics approval is not required for this type of study. The three sets of impressions from each student were taken within one hour. Plaster models were poured immediately from two sets of impressions, while the third set was wrapped in a moist gauze, put in a sealed bag and mailed from Aarhus, Denmark to an address in Copenhagen, Denmark and back, thus being 3 to 5 days in transit in total. Upon return to the School of Dentistry in Aarhus, the plaster models were poured.

The following measurements were obtained from the three sets of plaster models using a digital calliper (Digimatic Calliper: 700-113 MyCal Lite, Mitutoyo America Corp., Plymouth, MI, USA) with an accuracy of 0.01 mm:

- mesio-distal dimension of teeth 11 and 16 (maximal crown width);
- maxillary inter-canine width measured from cusp to cusp;
- maxillary arch width measured as the maximal distance between the buccal surfaces of the first molars;
- maxillary arch length measured as the distance from the contact point of the central incisors to a frontal plane through the most posterior aspect of the first molars;
- overbite measured as the largest overlap perpendicular to the occlusal plane;
- overjet measured as the largest overlap parallel to the occlusal plane.

The plaster models were carefully packed and shipped to Częstochowa, Poland for the production of the digital virtual models (O3DM™, OrtoLab, Częstochowa, Poland), using a laser surface scanning technique. Once the digital models became available on-line, they were downloaded and the same measurements were performed using the O3DM™ software (Figures 1 and 2).

In order to establish both the intra- and inter-observer variation one set of plaster models and the corresponding digital models were measured twice by an inexperienced and an experienced person.

The measurements were practised by performing the measurements on a single plaster model and the corresponding digital virtual model ten times by the inexperienced observer.

Statistical methods

Comparison of possible changes in the plaster models obtained from the three sets of alginate impressions was

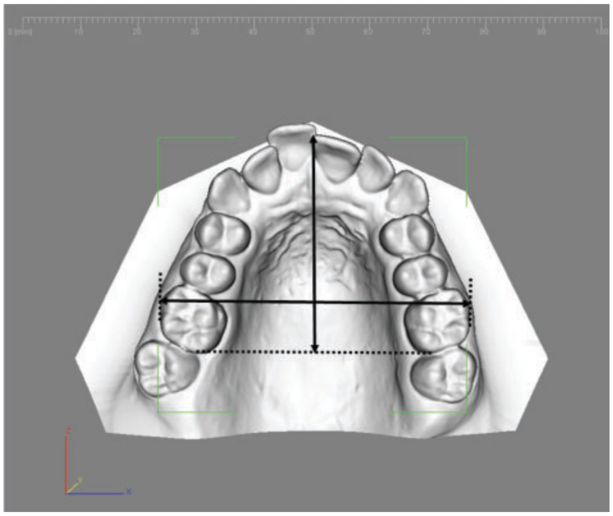

Figure 1 Example of a digital model showing the measurement of the maxillary arch width (horizontal arrow) and maxillary arch length (vertical arrow)

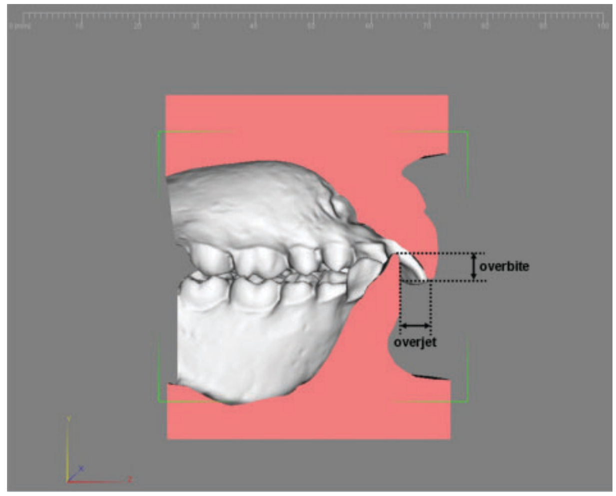

Figure 2 Example of a digital model cut in a sagital plane to facilitate the measurement of the overbite and overjet

undertaken using a one-way ANOVA with a significance level of $P=0.05$. Intra- and inter-observer variability as well as inter-model variability was determined by calculating the error of the method from double measurements using Dahlberg's formula.[14] The validity of the measurements performed on the virtual models was assessed by comparing results obtained by the measurements of the 'gold standard' and the results obtained from the digital models. The differences between the 10 repeated measurements on the plaster and digital model were assessed by an independent sample *t*-test.

Results

A delay of 3 to 5 days in pouring a plaster model from an alginate impression was found not to affect the accuracy of the model as no statistically significant differences were observed between the measurements performed on the plaster models obtained from the three sets of alginate impressions (Table 1).

Table 1 Comparison of the measurements (mean and standard deviation; all in mm) of the plaster models obtained from the three sets of alginate impressions. Set III had been in transit in the mail for 3 to 5 days. No significant differences were found between the sets (ANOVA)

	Set I ($n=12$)	Set II ($n=12$)	Set III ($n=12$)
Crown width 11	8.71 (0.52)	8.73 (0.53)	8.70 (0.49)
Crown width 16	10.14 (0.57)	10.09 (0.54)	10.08 (0.56)
Inter-canine width	39.34 (2.35)	39.37 (2.38)	39.45 (2.34)
Maxillary arch width	61.37 (3.22)	61.35 (3.16)	61.05 (3.35)
Maxillary arch length	47.73 (2.83)	47.71 (2.78)	47.19 (2.75)

The error of the method, the intra-observer variation, was dependent on the parameter measured. For both observers the error of the method was smallest for the maxillary arch width on both plaster and digital models (0.05–0.11 mm). The error of the method for other parameters varied between 0.09 and 0.38 mm for the plaster models and between 0.05 and 0.28 mm for the digital virtual models (Table 2). The inter-observer variation depended on the type of model and measurement, and was least for the maxillary arch length measurement on plaster models (within 0.70 mm). Apart from the inter-canine distance and the overjet, the inter-observer variation was smaller when measuring on the digital virtual models (Table 3). The inter-model agreement for comparing the respective measurements on the plaster and digital models also varied with Observer II (the experienced observer) scoring better in general (Table 3). Yet, Observer I managed to achieve the best overall agreement between the measurements on the plaster and digital models when measuring the arch width (within 0.05 mm), although at the same time they scored worst when measuring the arch length (within 0.85 mm).

The reproducibility of the measurements, based on the 10 repeated measurements on a single plaster model and the corresponding digital model proved to be better for the digital models, where the standard deviation of the measurements never exceeded 0.10 mm, whereas for the plaster models the standard deviation was almost 0.40 mm for the arch length measurements (Table 4). The arch length and the overjet were significantly larger when measured on the plaster model than when measured on the digital model. This could be explained by the fact that the measurements with the calliper were performed to the most procumbent contour of the incisors rather than to the incisal edge as done by the O3DM™ software. The significant differences of the other measurements were not clinically relevant.

Discussion

This study assessed the influence of three to five days mailing of alginate impressions on the measurements obtained from plaster casts and compared the parameters obtained from digital models with those obtained from measurement of an immediately poured cast. The time in transit in the mail did not have a significant influence on the alginate. Although some of the longer measurements (maxillary arch width and length) appeared to be slightly shorter in the set which had been in the mail, possibly due to some shrinkage of the alginate. These changes were not statistically significant (Table 1). The impressions were sent by mail during the Autumn season. Although the exact weather conditions were not recorded during transit, it is highly unlikely that the impressions had been exposed to extreme heat or frost.

The intra-observer variation was generally lower for the measurements on the digital models than on the plaster models, although there was a considerable variation in the error related to the different parameters. The error of the method was 0.09 to 0.38 mm for the measurements on the plaster models, while 0.05 to 0.28 mm for the measurements taken on the digital models (Table 2). This corroborated the findings of Bell *et al.* in a similar study.[10] The difference in the intra-observer variation indicated the existence of a learning curve, both in relation to measuring on plaster and virtual models.

In spite of providing clear definitions for the individual parameters, some disagreement in the measurements between the observers occurred. Apart from

Table 4 Comparison of the reproducibility (mean and standard deviation; both in mm) for 10 repeated measurements on a single plaster and corresponding digital virtual model

	Plaster (n=10)	Digital (n=10)	P value
Crown width 11	8.05 (0.12)	8.67 (0.09)	<0.001
Crown width 16	9.62 (0.28)	10.29 (0.04)	<0.001
Inter-canine width	33.40 (0.13)	33.52 (0.03)	0.016
Maxillary arch width	55.74 (0.06)	55.81 (0.01)	0.001
Maxillary arch length	36.32 (0.38)	35.12 (0.06)	<0.001
Overjet	2.43 (0.24)	1.19 (0.03)	<0.001
Overbite	4.36 (0.24)	4.28 (0.02)	0.329

Table 2 Comparison of the intra-observer variability (error of the method; in mm) according to observer and type of model based on double measurements

	Observer I		Observer II	
	Plaster (n=12)	Digital (n=12)	Plaster (n=12)	Digital (n=12)
Crown width 11	0.16	0.12	0.09	0.12
Crown width 16	0.31	0.11	0.22	0.11
Inter-canine width	0.38	0.28	0.24	0.14
Maxillary arch width	0.05	0.05	0.09	0.11
Maxillary arch length	0.28	0.11	0.28	0.11
Overjet	0.29	0.10	0.30	0.11
Overbite	0.23	0.05	0.16	0.18

Table 3 Comparison of the inter-observer and inter-model variation (in mm) in measuring

	Inter-observer variation		Inter-model variation	
	Plaster (n=12)	Digital (n=12)	Observer I (n=12)	Observer II (n=12)
Crown width 11	0.31	0.12	0.29	0.12
Crown width 16	0.49	0.25	0.52	0.26
Inter-canine width	0.32	0.34	0.21	0.21
Maxillary arch width	0.26	0.23	0.05	0.15
Maxillary arch length	0.70	0.11	0.85	0.44
Overjet	0.30	0.42	0.50	0.23
Overbite	0.21	0.13	0.67	0.54

the overjet measurement, the agreement between the observers when measuring on the digital virtual models was better (Table 3), thus supporting the findings of Costalos *et al.*[15] This variation can be ascribed to a more precise definition and execution of the measuring protocol when using the measuring tools in the dedicated software.

Inter-observer agreement for measurements performed on the plaster and digital models was worse than the intra-observer agreement for the plaster models. This may be a somewhat surprising result as the same observer should have the same set of definitions for the measuring protocol in mind when executing them.

Santoro *et al.* found smaller values when measuring tooth widths on digital models.[16] A similar consistent 'width' bias was not found in the present results. The variation in all measurements was clearly larger for the plaster models than for the digital models, in particular for the point-to-plane measurements (arch length, overjet and overbite) the plaster models displayed variations 6 to 10 times larger than the ones in the digital models (Table 4).

Overall, a better accuracy and reproducibility was found for measurements taken from the digital virtual models. Quimby *et al.* and Zilberman *et al.* concluded that measurements obtained with a calliper were slightly superior to those obtained using the virtual measurement tools;[5,7] however the present study could not corroborate this. It should be noted here that a different brand of digital models and its associated visualization and analysis software had been employed and it could be that the new software measuring tools are easier to handle.

Based on the evaluation performed O3DM™ digital models can fully replace the traditional plaster models as no clinically relevant difference could be established between the measurements obtained from the virtual model and the 'gold standard' and the reproducibility was better in the case of the virtual models. The typical size of O3DM™ digital models is around 4 MB, which is more than OrthoCAD™ files (~3 MB) and considerably more than E-models™ files (~0.8 MB). The reason for this difference was partly the method, but also the resolution. Since digital storage is not a problem, 120 models can be stored on a CD and 1500 models can be stored on a DVD. The legal aspects related to replacing plaster models by digital models seem to have been solved with European law accepting the validity of virtual models provided the producer delivers a digital signature ensuring that the original data files have not and cannot be tampered with.

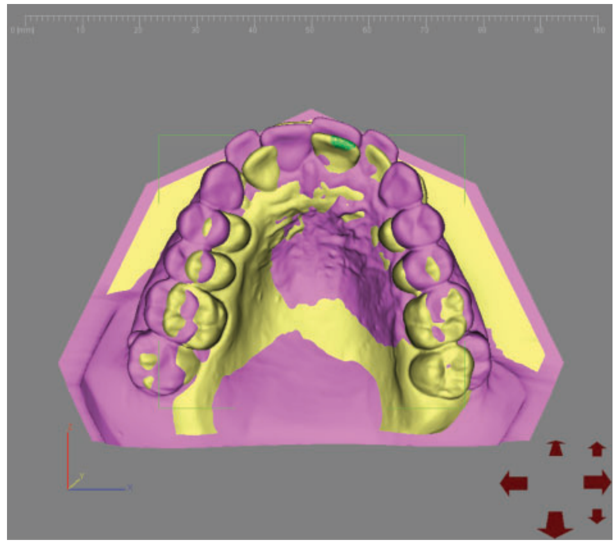

Figure 3 Example of a superimposition of a post- and pre-treatment digital model to visualize the tooth movements that have occurred during treatment

Copies of digital model files can easily be shared with colleagues for consultation and/or with patients as an extra stimulus for their motivation to comply with their treatment. The result of this study supports the replacement of plaster casts for diagnosis and planning within all fields of dentistry. In addition to replacing the plaster casts the digital models offer a long list of additional tools including: the possibility for cutting the model (Figure 2) in any plane of space to allow for assessment of the third order alignment of the individual teeth and superimposition on stable structures (Figure 3) making it possible to evaluate the changes generated during treatment. Finally the old storage spaces will surely find a better use in the future….

Conclusions

- There was no statistically significant difference in the measurements taken from the alginate impressions that were cast immediately and those that had been in transit for several days.
- Measuring distances on plaster models gives rise to more intra- and inter-observer variability than measuring the same distances on digital models using virtual measuring tools.

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