

Accuracy and reproducibility of 3-dimensional digital model measurements

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Introduction: The purpose of this study was to evaluate the reliability of measurements made on 3-dimensional digital models obtained with a surface laser scanner (D-250; 3Shape, Copenhagen, Denmark). **Methods:** Twenty orthodontic dental casts of permanent dentitions were selected. Three-dimensional images were obtained on this scanner and analyzed by using the Geomagic Studio 5 software (Raindrop Geomagic, Inc, Morrisville, NC). Measurements were made with a digital caliper directly on the dental casts and also digitally on the digital models. Fifteen anatomic dental points were identified, and a total of 11 linear measurements were taken from each cast, including arch length and width. Dependent *t* tests were used to evaluate intraexaminer reproducibility and measurement accuracy on the digital models. **Results:** No statistically significant differences were found between the measurements made directly on the dental casts and on the digital models. **Conclusions:** Linear measurements on digital models are accurate and reproducible. Digital models obtained with the surface laser scanner are reliable for measurements of arch width and length. (Am J Orthod Dentofacial Orthop 2012;142:269-73)

The fast and continuous advances in computer sciences have resulted in increased usage of new technologies in all levels of modern society. Orthodontics has also been influenced by this phenomenon. Computer-based records are routine in many orthodontic offices. Digital models are increasingly available and provide qualified diagnostic images at a reasonable cost.¹ Digital record storage has several advantages: easy access, need for less physical space, and ability to share information via the Internet with other professionals.² With new advances in 3-dimensional dental and orthodontic softwares, orthodontists can examine intra-arch and interarch relationships digitally. Transverse relationships between maxillary and mandibular arches can be better evaluated when 3-dimensional models are viewed in occlusion in different perspectives

in the screen. Digital casts also have the advantage of allowing a “virtual treatment” and a “virtual setup.”³

Several studies in the literature have verified the accuracy of angular and linear measurements on 3-dimensional digital models with different softwares and found divergent results.^{1,4-12} Recently, Leifert et al⁴ evaluated the accuracy of digital models using OrthoCad software. They measured mesiodistal tooth widths and arch lengths, and found slight but statistically significant differences in some measurements. They concluded that, despite these differences, digital models are clinically acceptable and reproducible when compared with traditional model analyses. Similar results were found by other authors using the same software,^{1,5-7} Pointstream software,⁸ and Emodel software.⁹⁻¹¹

Bell et al¹³ observed no statistically significant differences between linear measurements made on digital models using the C3D-builder software and conventional models, validating the virtual evaluation. On the other hand, Redlich et al¹² measured 3-dimensional scanned orthodontic models with cross-section planes reconstructed by Teledent software. They observed differences of 1.19 to 3 mm between measurements of space taken from digital and conventional models, showing significantly less crowding when using the linear measurements from the digital models. They concluded that the accuracy of linear measurements on

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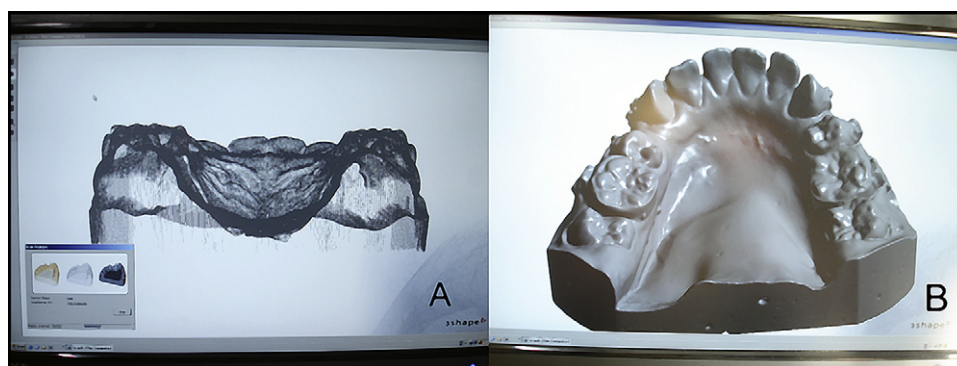


Fig 1. A, Early formation of the virtual image of dental casts; **B,** digital image completely finished.

digital models is sometimes questionable, especially in severely crowded dentitions.

No previous study has validated digital models obtained from the 3Shape scanner (D-250; 3Shape, Copenhagen, Denmark) for linear orthodontic measurements. Considering the controversies aforementioned and that digital models are increasingly available for both dental practice and research in orthodontics, the purpose of this study was to determine the accuracy and reproducibility of arch widths and lengths obtained with the surface laser scanner 3Shape.

MATERIAL AND METHODS

Twenty orthodontic dental models from patients under treatment, in the permanent dentition, were selected. The sample size was calculated before the study; it was estimated that a sample size of 10 to 13 dental models was needed to obtain a statistical power of 95%.¹⁰ These dental casts belonged to a prospective study for which the first premolars had been extracted according to the orthodontic treatment plans. The dental casts were digitized by using the 3Shape D-250 3-dimensional scanner. This scanner operates with a main laser beam, with 2 cameras to capture the image. The images are automatically processed by the 3Shape Sewer Scan software, which generated files with the STL (stereolithography) extension for each dental model (Fig 1).

Two examiners (M.V.S.S. and E.C.V.) were trained sufficiently in using both methods: measuring with a digital caliper, and manipulation and measuring of the virtual images with the software.

The measurements were obtained from conventional dental casts with a digital caliper with 0.01-mm accuracy (Mitutoyo Co, Kanagawa, Japan). Three-dimensional images were analyzed by using Geomagic Studio 5 software (Raindrop Geomagic, Inc, Morrisville, NC).

The digital images of the dental models were enlarged on screen to facilitate measurements. All the direct and virtual measurements were made by the 2 examiners.

Fifteen anatomic dental points were identified on each pair of casts (plaster and digital models) by using the modified Euclidean distance matrix analysis¹⁴ (Fig 2). Arch widths and lengths were measured as shown in Figure 3. A total of 11 measurements were made on each dental model.

The dental cast and digital model measurements were repeated for 5 randomly selected patients after 15 days by both examiners. The random errors were evaluated with Dahlberg's formula,¹⁵ and the systematic errors were investigated with dependent *t* tests. The results were considered significant at $P < 0.05$. Because there were no significant intraexaminer differences, the average between the 2 operators was used for both methods.

Statistical analysis

Dependent *t* tests were used for intergroup comparisons. The results were considered significant at $P < 0.05$.

RESULTS

The individual intraexaminer random errors ranged from 0.054 (distance 3-4) to 0.955 (distance 14-15) for the physical measurements, and from 0.064 (distance 1-5) to 0.943 (distance 12-13) for the digital measurements. There were no significant systematic errors for either examiner (Tables I and II).

No statistically significant differences were found between the physical and digital measurements of the dental models for arch width and length (Table III).



Fig 2. The measurements between selected points: 1-2 distance, tip to tip of the cusps of the canines; 3-4 distance, tip to tip of the buccal cusps of the second premolars; 5-6 distance, tip to tip of the mesiobuccal cusps of the first molars; 1-5 distance, the cusp tip of the right canine to the mesiobuccal cusp tip of the right first molar; 2-6 distance, the cusp tip of the left canine to the mesiobuccal cusp tip of the left first molar; 7-8 distance, the cervical and middle points of the lingual surface of the right second premolar to the cervical and middle points of the lingual surface of the left second premolar; 9-10 distance, the cervical and middle points of the lingual surface of the right first molar to the cervical and middle points of the lingual surface of the left first molar; 11-12 distance, the midpoint of the mesial marginal ridge of the right first molar to the uppermost distal point of the incisal edge of the right lateral incisor; 12-13 distance, the uppermost distal point of the incisal edge of the right lateral incisor to the uppermost mesial point of the incisal edge of the right central incisor; 13-14 distance, the uppermost mesial point of the incisal edge of the right central incisor to the uppermost distal point of the incisal edge of the left lateral incisor; 14-15 distance, the uppermost distal point of the incisal edge of the left lateral incisor to the midpoint of the mesial marginal ridge of the left first molar.

DISCUSSION

Geomagic Studio 5 was used instead of the software that comes with the 3Shape scanner because no authors have investigated its accuracy in the dental literature.

The 20 pairs of dental models selected for this study were derived from orthodontic patients with Class I and Class II malocclusions, with severe dental crowding, treated with premolar extractions.¹⁶ Patients with severe tooth crowding were selected for this study because the difficulty in performing linear measurements on dental casts increases with malocclusion complexity.^{4,5,8,10,12} Sample size seemed to be adequate because it was

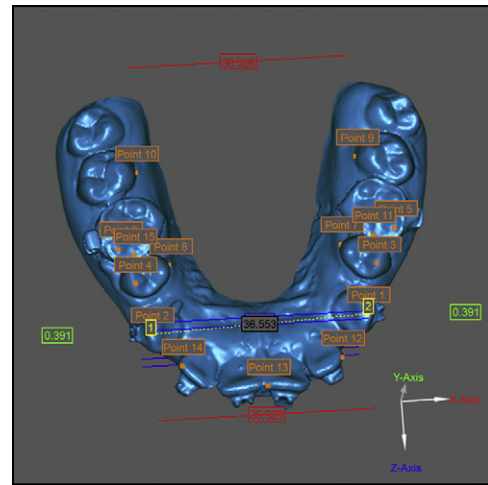


Fig 3. Example a measurement obtained with the digital method (distance 1-2: cusp tip to cusp tip of the canines).

above the calculated minimum and also because previous studies with digital models used similar sample sizes.^{5,6,8}

The reproducibility of the linear measurements made directly on the dental casts and on the digital models was high in this study (Tables I and II). These results agree with previous findings.^{1,10,13,17}

Landmarks can be difficult to identify, and the examiner's opinion concerning the exact location of a point can vary at random. This study showed that errors can be reduced by precise definitions of points if the examiners are previously trained.

The linear measurements on the digital models showed no significant differences when compared with measurements with the digital caliper on the physical dental casts (Table III). Points on the digital models were easy to identify with the Geomagic Studio 5 software. A simple click on 2 points is enough for the program to generate a linear measurement automatically. Additionally, this software allows moving the images around the 3 axes of rotation and magnifying the images. Magnification of the virtual image is an excellent advantage compared with the plaster models, because anatomic details can be more accurately viewed. Bell et al¹³ comparatively assessed direct measurements on 22 dental casts and measurements from computer-generated 3-dimensional images using a photostereometric technique. They found no statistically significant difference between either type of measurement. Their results agree with ours.

On the other hand, some authors have found different and smaller values for some linear distances taken from virtual models compared with the physical

Table I. Casual and systematic errors of examiner 1 (Dahlberg and dependent *t* tests)

Measurement	Measurement 1 (mm)		Measurement 2 (mm)		Dahlberg	P
	Mean	SD	Mean	SD		
Caliper						
1-2	28.894	4.480	29.044	4.563	0.233	0.299
3-4	36.88	3.701	36.918	3.939	0.054	0.895
5-6	43.528	4.046	43.564	3.977	0.482	0.802
1-5	19.268	2.312	18.734	2.793	0.232	0.344
2-6	18.454	2.293	17.654	2.744	0.694	0.119
7-8	27.328	2.629	27.162	2.606	0.482	0.220
9-10	37.208	2.530	37.462	2.290	0.833	0.565
11-12	18.722	2.348	18.618	2.422	0.694	0.621
12-13	12.206	1.273	12.304	1.263	0.913	0.463
13-14	12.134	1.721	12.358	1.647	0.833	0.275
14-15	19.18	1.834	19.342	1.985	0.955	0.557
3-dimensional image						
1-2	28.706	4.062	28.856	4.518	0.389	0.611
3-4	36.778	3.857	36.662	4.233	0.152	0.761
5-6	43.288	3.858	43.446	4.502	0.624	0.768
1-5	19.174	2.504	19.258	2.473	0.389	0.277
2-6	17.626	2.839	17.930	2.581	0.790	0.689
7-8	26.976	2.421	27.370	2.339	0.624	0.144
9-10	37.224	2.691	37.196	2.500	0.889	0.799
11-12	18.604	1.830	18.916	1.685	0.790	0.605
12-13	11.640	1.404	11.822	1.382	0.943	0.356
13-14	12.318	1.226	12.866	1.843	0.889	0.223
14-15	18.288	2.146	18.492	1.977	0.971	0.743

measurements for both tooth sizes and arch dimensions.^{9,10,12} A possible cause for these differences is that the software provides a 3-dimensional view of interproximal contacts on an enlarged image, and also because digital measurements can be made on selected sections of the image.^{9,10} The user can rotate the cast on the screen to accurately assess the points chosen as the greatest diameter, but this process is still difficult. The resolution of the software is high, but it is difficult to choose the exact contact point between 2 teeth. When estimating the contact areas, the operator will tend to underestimate the measurements.

This problem, combined with the difficulty of measuring teeth in a crowded dentition, can lead to wrong decisions. For example, a severely crowded dentition underestimated as moderately crowded would impact the extraction decision.¹²

According to Santoro et al⁶ and Quimby et al,¹ depending on the orthodontist's training, abilities, and preferences, measuring on a computer screen can be more or less accurate than the traditional gauge-on-cast method. Moreover, Kusnoto and Evans¹¹ found that digital models produced more accurate measurements in height and width, but less accurate

Table II. Casual and systematic errors of examiner 2 (Dahlberg and dependent *t* tests)

Measurement	Measurement 1 (mm)		Measurement 2 (mm)		Dahlberg	P
	Mean	SD	Mean	SD		
Caliper						
1-2	28.860	4.523	28.440	4.277	0.409	0.290
3-4	37.084	3.959	36.918	4.196	0.298	0.298
5-6	43.774	4.313	43.228	4.295	0.544	0.253
1-5	19.278	2.263	18.990	2.344	0.250	0.057
2-6	18.300	2.313	18.082	2.442	0.224	0.206
7-8	26.994	2.773	26.996	2.705	0.061	0.973
9-10	37.142	2.345	37.094	2.377	0.093	0.676
11-12	18.674	1.828	18.714	2.072	0.240	0.854
12-13	11.996	1.404	12.142	1.297	0.181	0.270
13-14	12.348	1.693	12.342	1.540	0.258	0.978
14-15	18.196	1.809	18.272	2.048	0.203	0.697
3-dimensional image						
1-2	29.102	4.516	29.044	4.563	0.106	0.562
3-4	36.946	3.833	37.024	4.035	0.208	0.623
5-6	43.634	4.251	43.526	4.251	0.135	0.504
1-5	19.012	2.627	18.950	2.636	0.064	0.659
2-6	17.980	2.562	18.092	2.575	0.077	0.297
7-8	27.410	2.804	27.172	2.453	0.447	0.469
9-10	37.128	2.527	37.228	2.542	0.128	0.359
11-12	19.376	1.965	19.472	1.990	0.191	0.501
12-13	12.128	1.656	12.012	1.690	0.118	0.382
13-14	12.610	1.730	12.582	1.616	0.068	0.726
14-15	19.180	1.834	19.442	1.811	0.249	0.235

measurements in depth compared with conventional dental casts. For intermolar width, digital measurements tended to produce smaller values than did manual measurements. Conversely, digital measurements produced larger values when measuring palatal depth.

A possible explanation for the high accuracy in our study is that the examiners were previously calibrated. In addition, the latest version of the 3Shape scanner has the laser beam emitted from bottom to top, eliminating the discrepancies of the first generation of 3-dimensional scanners.¹¹ Our findings suggest that linear measurements of arch width and length on digital models with the 3Shape scanner are highly accurate and reproducible. More studies should be carried out with the same modality of scanner to evaluate depth measurements, tooth sizes, and arch size discrepancies.

CONCLUSIONS

1. The reproducibility of digital measurements of arch width and length on digital models was similar to direct measurements on the dental casts with a caliper.

Table III. Accuracy of the measurements on the digital dental casts (dependent *t* tests)

Measurement	Digital caliper (mm)		Geomagic software (mm)		Difference between methods (mm)	P
	Mean	SD	Mean	SD		
1-2	30.619	5.410	31.507	6.227	-0.888	0.388
3-4	38.384	5.868	38.479	5.937	-0.095	0.403
5-6	44.923	5.054	44.775	5.131	0.148	0.184
1-5	18.459	2.379	18.546	2.446	-0.087	0.704
2-6	18.637	2.472	18.517	2.667	0.120	0.655
7-8	27.222	2.820	27.446	2.832	-0.224	0.054
9-10	37.561	2.036	37.677	1.985	-0.116	0.123
11-12	18.559	2.387	18.858	2.485	-0.299	0.124
12-13	12.513	2.092	12.435	2.095	0.078	0.606
13-14	13.339	2.431	13.656	2.513	-0.317	0.061
14-15	19.235	2.652	19.345	2.702	-0.110	0.194

- Measurements of arch width and length on digitized models showed high accuracy.
- Digital models can be used for storing cast models and for research with satisfactory degrees of accuracy and reproducibility of linear measurements of arch width and length.

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