EGYPTIAN
DENTAL JOURNAL

Vol. 64, 91:99, January, 2018

I.S.S.N 0070-9484

Orthodontics, Pediatric and Preventive Dentistry

www.eda-egypt.org • Codex : 223/1801

EVALUATION OF THE ACCURACY OF DIGITAL SCANNING OF A LOW-END LABORATORY LASER SCANNER

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ABSTRACT

Background: Digital scanning of orthodontic models is the first step towards a completely digital patient file in the digital orthodontic practice. The wide array of available laboratory scanners that are used for digitization of orthodontic models is challenging. The choice among the available scanners should be prioritized according to the accuracy of transforming the plaster stone model into a digital replica. The aim of this study was to evaluate the accuracy of digital Scanning of a low-end laboratory laser scanner of an affordable cost to the gold standard plaster model.

Materials and Methods: Twenty-six plaster models were used in this study. They were digitized using 3Shape R500 laboratory laser scanner. Sixteen measurements were measured on the plaster models and on their digitized replica. Intra- and interobserver reliability errors were evaluated.

Results: The results showed that the 3Shape R500 laboratory laser scanner is accurate for digitization of plaster models. There were no statistically significant difference between the measurements taken on the plaster models and those taken on the digitized models. The intra- and inter-observer reliability results showed non-statistically significant difference within the same observer or between the different observers.

Conclusion: The low-end laboratory laser scanner is reliable for digitization of dental orthodontic models. The upgrade of laboratory scanner should be considered for purposes other than the accuracy.

INTRODUCTION

The popularity and availability of virtual technology in orthodontics for the replacement of hard-copy records with electronic records is growing rapidly, with a move towards a 'digital patient' for diagnosis, treatment planning, monitoring of treatment progress and outcomes.[1-6]

The introduction and use of digital models is inevitable in the otherwise digitized everyday life of dentistry. Easy and effective storage, access, durability, transferability, and diagnostic versatility have been presented as advantages.[2]

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There is little information within the literature regarding the current status of hardware and software for the production of three-dimensional (3D) digital model. This is probably due to rapid progress in this dynamic area of the supply industry. Consideration should be given to the type of scanner and its application for use if the scanner is to be used effectively. (1,3,7-15,17-20)

3Shape (http://www.3shape.com) have produced a series of model and impression scanners for both the dental and orthodontic market. Their R500™ series scanner is their 'entry level' most economic model and uses laser scanning technology and two 1.3 megapixel cameras to capture both plaster models and impressions to create indirect digital study models. (1)

In view of ongoing technological advances and the availability of several different brands of 3D scanners in the market, studies that evaluate the accuracy and reliability of digital models produced by a specific scanner are required (3,8-15,23-28)

Therefore, the aim of this study was to evaluate the accuracy of measurements made on three-dimensional digital models obtained with the low-end desktop laser scanner 3Shape R500 in comparison to the gold standard plaster model.

MATERIAL AND METHODS

In this study, orthodontic study models were used to evaluate the accuracy of digital scanning of the 3Shape red laser beam laboratory scanner R500.* The inclusion criteria for the orthodontic models to be enrolled in the study were:

a. Dentulous dental models including bilateral central incisors, canines and the first molar erupted.

b. Properly poured stone models with no air bubbles on the occlusal, incisal or buccal surfaces of the teeth that will affect the measurements.

c. No stone overhangs that might affect the image capturing of the scanner laser beam.

In order to determine the sample size of the current study, paired Student's t-test was used, to identify a clinically significant difference of 0.2 mm. Standard deviation of the difference is 0.35 mm. The power of the test is set to 80% and 4%bilateral alpha level. The sample size calculation resulted in a sample of 26 cast models.

The scanner was first calibrated using the calibration phantom object. This ensures the image capturing of the scanner is set to the optimum level. The included models were fixed to the scanning platform on the scanner one at a time. Using ScanIt Manager**, full scanning of the models was done.

The scanned models were exported to the Ortho-Analyzer***, where measurements will be made. The measurements were taken on the physical model (Fig.1) using a digital caliper with accuracy up to 0.01mm. The same measurements were repeated on the digital models (Fig. 2a&b) with computer measurement accuracy up to 0.01mm

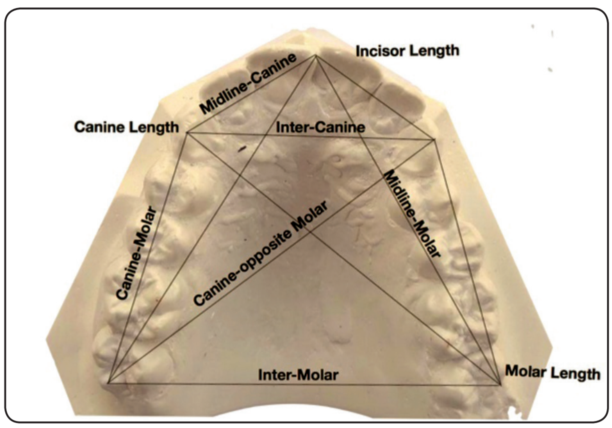

Fig. (1) Showing the measurements taken on the physical models

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*** Software, OrthoAnalyzer, 3Shape, Copenhagen, Denmark

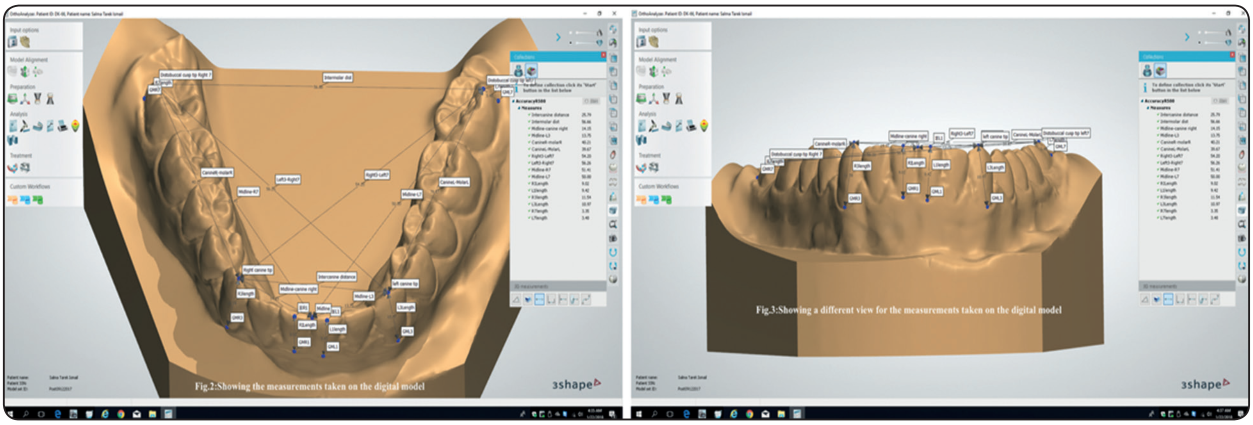

Fig 2a&b: Showing the measurements taken on the digital models

The measurements showed in Table 1 were done on each cast:

TABLE (1) Shows the measurements taken to compare the digital to the physical model

Serial	Measurement	Description
1	IC	Intercanine distance
2	IM	Intermolar distance
3	MCR	Midline-canine right
4	MCL	Midline-canine left
5	CMR	Canine right-molar right
6	CML	Canine left-molar Left
7	CROM	Canine right-opposite molar
8	CLOM	Canine left -opposite molar
9	MMR	Midline-molar right
10	MML	Midline-molar Left
11	RIL	Right central incisor length
12	LIL	Left central incisor length
13	RCL	Right canine length
14	LCL	Left canine length
15	RML	Right molar length
16	LML	Left molar length

In order to determine the error of the method, intra-observer reliability was tested by re-measuring eight models (physical and digital) by the same principle observer. While the inter-observer reliability tests were performed on eight models (physical and digital) that were measured by the second observer and compared with those measured by the principal observer.

STATISTICAL ANALYSIS

Statistical analysis was performed using SPPS/ SPSS® v. 15 (IBM corporation, Armonk, NY). The Dahlberg error and Intraclass Correlation coefficient tests with 95% confidence intervals were used to evaluate the intraobserver and interobserver rliability tests. The Dahlberg error and Intraclass Correlation coefficient tests with 95% confidence intervals and the Bland and Altman's limits of agreement were used to evaluate the agreement between the manual and digital measurements.

RESULTS

The results showed excellent agreement between the intraobserver (Table 2) and the interobserver (Table 3) measurements. Relative Dahlberg error was less than 5% for all variables. All Intra Class Correlation coefficients were almost 1 indicating perfect agreement, and excellent intraobserver reliability.

TABLE (2) Showing the Dahlberg error and Intraclass Correlation coefficient to assess the intraobserver reliability tests

							Intraclass Correlation Coefficient		
			Mean	**SD**	**DE**	**RDE**	**ICC**	**95% confidence limits Lower**	**95% confidence limits Upper**
IC	**Intercanine distance**	**Manual**	31.29	4.05	0.12	0.4%	1.000	0.998	1.000
		Digital	31.29	4.01					
IM	**Intermolar distance**	**Manual**	58.43	4.81	0.12	0.2%	1.000	0.999	1.000
		Digital	58.37	4.74					
MCR	**Midline-canine right**	**Manual**	17.43	3.05	0.19	1.1%	0.998	0.991	1.000
		Digital	17.47	3.13					
MCL	**Midline-canine left**	**Manual**	17.76	2.64	0.23	1.3%	0.996	0.982	0.999
		Digital	17.69	2.67					
CMR	**Canine-molar right**	**Manual**	37.24	3.08	0.14	0.4%	0.999	0.996	1.000
		Digital	37.32	3.24					
CML	**Canine-molar Left**	**Manual**	36.93	2.74	0.38	1.0%	0.991	0.953	0.998
		Digital	36.87	2.87					
CROM	**Canine right-opposite molar**	**Manual**	56.98	2.74	0.12	0.2%	0.999	0.995	1.000
		Digital	56.97	2.72					
CLOM	**Canine left -opposite molar**	**Manual**	56.38	2.99	0.12	0.2%	0.999	0.996	1.000
		Digital	56.38	2.98					
MMR	**Midline-molar right**	**Manual**	51.33	2.86	0.24	0.5%	0.997	0.985	0.999
		Digital	51.40	3.13					
MML	**Midline-molar Left**	**Manual**	51.45	3.02	0.19	0.4%	0.998	0.991	1.000
		Digital	51.52	3.04					
RIL	**Right central incisor length**	**Manual**	10.12	1.92	0.17	1.7%	0.996	0.981	0.999
		Digital	10.04	1.91					
LIL	**Left central incisor length**	**Manual**	10.19	1.40	0.16	1.5%	0.993	0.968	0.999
		Digital	10.23	1.33					
RCL	**Right canine length**	**Manual**	10.67	1.90	0.10	0.9%	0.999	0.993	1.000
		Digital	10.67	1.81					
LCL	**Left canine length**	**Manual**	10.53	1.72	0.15	1.5%	0.996	0.981	0.999
		Digital	10.60	1.64					
RML	**Right molar length**	**Manual**	5.39	0.75	0.15	2.7%	0.977	0.884	0.995
		Digital	5.40	0.62					
LML	**Left molar length**	**Manual**	5.84	1.08	0.18	3.0%	0.986	0.932	0.997
		Digital	5.97	1.08					

DE: Dahlberg Error ***RDE: Relative Dahlberg Error***

TABLE (3) Showing the Dahlberg error and Intraclass Correlation coefficient to assess the interobserver reliability tests

							Intraclass Correlation Coefficient		
			Mean	**SD**	**DE**	**RDE**	**ICC**	**95% confidence limits Lower**	**95% confidence limits Upper**
IC	**Intercanine distance**	**Manual**	30.30	4.09	0.27	0.9%	0.998	0.990	1.000
		Digital	30.46	4.03					
IM	**Intermolar distance**	**Manual**	55.52	4.71	0.19	0.3%	0.999	0.996	1.000
		Digital	55.51	4.79					
MCR	**Midline-canine right**	**Manual**	16.84	2.49	0.24	1.4%	0.995	0.977	0.999
		Digital	16.82	2.60					
MCL	**Midline-canine left**	**Manual**	16.46	2.18	0.20	1.2%	0.996	0.980	0.999
		Digital	16.38	2.21					
CMR	**Canine-molar right**	**Manual**	35.80	4.16	0.28	0.8%	0.998	0.990	1.000
		Digital	35.88	4.39					
CML	**Canine-molar Left**	**Manual**	35.65	3.10	0.24	0.7%	0.997	0.986	0.999
		Digital	35.61	3.19					
CROM	**Canine right-opposite molar**	**Manual**	54.29	4.14	0.50	0.9%	0.993	0.969	0.999
		Digital	54.61	4.44					
CLOM	**Canine left -opposite molar**	**Manual**	54.79	4.32	0.41	0.8%	0.996	0.978	0.999
		Digital	54.75	4.44					
MMR	**Midline-molar right**	**Manual**	48.69	3.91	0.21	0.4%	0.999	0.993	1.000
		Digital	48.68	3.96					
MML	**Midline-molar Left**	**Manual**	48.48	3.39	0.18	0.4%	0.999	0.993	1.000
		Digital	48.57	3.36					
RIL	**Right central incisor length**	**Manual**	8.98	2.27	0.15	1.6%	0.998	0.989	1.000
		Digital	8.98	2.19					
LIL	**Left central incisor length**	**Manual**	9.26	1.69	0.28	3.1%	0.985	0.930	0.997
		Digital	9.07	1.61					
RCL	**Right canine length**	**Manual**	9.64	2.11	0.21	2.2%	0.995	0.977	0.999
		Digital	9.66	2.19					
LCL	**Left canine length**	**Manual**	9.28	2.17	0.22	2.4%	0.995	0.974	0.999
		Digital	9.28	2.20					
RML	**Right molar length**	**Manual**	4.82	1.05	0.13	2.8%	0.992	0.964	0.998
		Digital	4.77	1.09					
LML	**Left molar length**	**Manual**	5.07	1.41	0.19	3.8%	0.991	0.956	0.998
		Digital	5.00	1.41					

DE: Dahlberg Error ***RDE: Relative Dahlberg Error***

TABLE (4) Showing the Bland and Altman limits of agreement and the Intraclass Correlation Coefficient with 95% confidence limits between the manual and digial measuremens

									Bland & Altman Limits of Agreement (LOA)		Intraclass Correlation Coefficient		
			Mean	SD	Dahlberg error DE	RDE	MOD (Digital - Manual)	SD of the Difference	95%confidence limits			95%confidence limits	
									Lower	Upper	ICC	Lower	Upper
IC	Intercanine distance	Manual	30.40	4.60	0.31	1.0%	0.05	0.44	-0.82	0.92	0.998	0.995	0.999
		Digital	30.45	4.49									
IM	Intermolar distance	Manual	57.17	4.35	0.27	0.5%	0.14	0.36	-0.57	0.84	0.998	0.995	0.999
		Digital	57.31	4.24									
MCR	Midline-canine right	Manual	17.24	3.41	0.29	1.7%	0.12	0.40	-0.66	0.89	0.996	0.992	0.998
		Digital	17.36	3.30									
MCL	Midline-canine left	Manual	16.91	2.83	0.33	2.0%	-0.10	0.47	-1.01	0.81	0.993	0.986	0.997
		Digital	16.81	2.96									
CMR	Canine-molar right	Manual	37.58	2.54	0.25	0.7%	0.07	0.35	-0.62	0.76	0.995	0.990	0.998
		Digital	37.65	2.66									
CML	Canine-molar Left	Manual	36.96	4.14	0.31	0.8%	0.10	0.44	-0.76	0.95	0.997	0.994	0.999
		Digital	37.06	4.22									
CROM	Canine right-opposite molar	Manual	56.53	3.97	0.26	0.5%	0.07	0.36	-0.64	0.78	0.998	0.995	0.999
		Digital	56.59	3.76									
CLOM	Canine left -opposite molar	Manual	55.82	3.78	0.23	0.4%	0.13	0.31	-0.49	0.74	0.998	0.995	0.999
		Digital	55.94	3.76									
MMR	Midline-molar right	Manual	51.26	4.12	0.26	0.5%	0.07	0.36	-0.64	0.77	0.998	0.996	0.999
		Digital	51.33	4.20									
MML	Midline-molar Left	Manual	51.43	4.09	0.36	0.7%	-0.14	0.50	-1.12	0.85	0.996	0.991	0.998
		Digital	51.29	4.15									
RIL	Right central incisor length	Manual	8.61	1.58	0.26	3.0%	0.04	0.37	-0.69	0.77	0.986	0.970	0.994
		Digital	8.65	1.60									
LIL	Left central incisor length	Manual	8.70	1.62	0.26	3.0%	0.07	0.36	-0.64	0.79	0.987	0.972	0.994
		Digital	8.77	1.61									
RCL	Right canine length	Manual	8.91	1.67	0.26	2.9%	0.00	0.37	-0.73	0.74	0.987	0.972	0.994
		Digital	8.92	1.62									
LCL	Left canine length	Manual	9.01	1.88	0.33	3.7%	-0.01	0.48	-0.94	0.92	0.983	0.963	0.993
		Digital	9.00	1.77									
RML	Right molar length	Manual	4.61	1.06	0.30	6.5%	0.05	0.43	-0.79	0.89	0.959	0.908	0.981
		Digital	4.65	1.06									
LML	Left molar length	Manual	4.65	1.00	0.25	5.3%	0.05	0.35	-0.64	0.74	0.969	0.930	0.986
		Digital	4.70	1.01									

DE: Dahlberg Error, RDE: Relative Dahlberg Error

MOD:Mean of Difference

Assessment of the error between the manual and the digital measurements showed Dahlberg error less than 0.4 mm for any variable (Table 4). Relative Dahlberg error is less than 5% for all variables except for the right molar length and left molar length it reaches a maximum of 6.5%. Mean of the difference is mostly positive indicating that digital measurements have positive bias (tend to be larger than manual). All Intra Class Correlation coefficients are almost 1 indicating perfect agreement.

DISCUSSION

Study models are central to orthodontic diagnosis, treatment planning, and evaluation. Commercially available digital cast models can be produced by either direct or indirect techniques. Direct methods use interior scanners, and indirect methods use either laser scanning or computed tomography imaging of the impressions or plaster models.[2]

Many papers have reported clinically valuable precision and trueness of current IOS (intra oral scanners), both in vitro and in vivo [4, 5-8]. However, in vivo full-arch impression is reported to be associated with a phenomenon of distortion, in particular for triangulation, confocal, or AWS technologies.[8-10] Handling is particularly difficult during the change of axis, such as the passage from posterior to anterior tooth or in case of malposition. The capture of areas with a steep downward slope, such as the anterior mandibular area, is often associated with difficulties in the treatment of the image [11].

In the current study, we chose the 3Shape R500, a low-end 'entry-level' desktop scanner as an economic digitizing tool that can be conveniently integrated within the orthodontic clinic work flow. The R500 series use red light laser technology with two 1.3-megapixel digital cameras which ensure 20 microns accuracy [12]. The advertised R500 series scanning time is 50 seconds for a plaster model. The Standard Tessellation Language (STL) open file format created by the R series scanners can be imported into 3Shape's Ortho Analyzer™ Orthodontic software for analysis, tooth movement simulation or superimposition of study models. [13]

Basic indicators of quality of 3D digitization are accuracy and precision. Accuracy represents the degree of closeness of measurements of a quantity to that quantity's true value [14, 15]. In previously published studies, linear distance measurements were used to investigate the trueness of dental models [14, 15]

In a comparable study, Lemos et al evaluated the accuracy of the lab scanner 3Shape R750 using similar measurements.[16] However, in the current study, measurements were extended to the second molar rather than the first molar, to investigate whether the arch depth has any effect upon the scan capturing. Besides, measurements were taken with a wider variety of small measurements representing the occluo-cervical height of the second molars, upto the large measurements midline-second molar arch depth. This large variation of measurements will investigate the effect of minor scanning errors on the small and lareg measurements.

Unlike the measurements used in the aforementioned study where they measured interarch relation in the form of overjet and overbite, in the current study these measurements were not considered. The reason is that the aim of the current study is focused upon the scanning precision of the scanner. On the other hand the process of scanning a full case in occlusion involves three steps. The first and second steps represent the scanning of the upper and lower models separately. In the third step, the upper and lower models are put together into proper interdigitation and scanned together. The outcome of this step is coupled with registration of the separately scanned upper then lower models on the scanned models in occlusion. This registration procedure is totally pertinent to the superimposition algorithm encoded into the softwares. Thus, the process of evaluating the interarch relation is actually a process of evaluating the accuracy of registration algorithm of the softwares rather than the actual scanning accuracy of the scanner hardware.

In consensus to other studies [16], the results of the current study investigating the accuracy of the laboratory scanners. The tests showed excellent intraobsever and interobserver reliability measurements, which denotes the accuracy of landmarks identification of the models either on the physical plaster models or on the digital models, which is reflected on accurate agreement of measurements between the two methods.

In the current study, The Dahlberg's formula proposed in 1940 provides a method of quantifying measurement error in cephalometric studies. Dahlberg error is the square-root of the averaged squared difference may be considered as the amount of measurement error. The relative Dahlberg error (RDE) is the Dahlberg error divided by the mean of reference measurement. Relative Dahlberg error is less than 5% for all variables except for the right molar length and left molar length it reaches a maximum of 6.5%. Mean of the difference is mostly positive indicating that digital measurements have positive bias (tend to be larger than manual) with no clinical significance since the maximum difference was no more than 0.15mm. All Intra Class Correlation coefficients are almost 1 indicating perfect agreement. ICC is a measure of agreement between two measurements on continuous scales. In the current results, comparable to the previous studies[16,20-22,24,26-28] the ICC values were almost +1 which denotes perfect agreement between the physical model measurements and the digital models.

CONCLUSION

In view of the foregoing discussion, the 3Shape R500 desktop scanner can be considered as a reliable scanner that produces digital replica of the dental model comparable to the physical model. Hence, there is no extra benefit of upgrading such scanner for a high-end-scanner except for the reduced scanning time. Advancement of the scanners should focus primarily on reducing time and cost.

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