RESEARCH ARTICLE

Reliability of measurements made on scanned cast models using the 3Shape R700 scanner

¹L S Lemos, ²I M C R Rebello, ¹C J Vogel and ¹M C Barbosa

¹Department of Orthodontics, Federal University of Bahia, Salvador, Bahia, Brazil; ²Department of Integrated Clinic and Propaedeutics, Federal University of Bahia, Salvador, Bahia, Brazil

Objectives: In dentistry, the latest technological advancements have been incorporated primarily into diagnostic tools such as virtual dental models. The aim of this study was to evaluate the reliability of measurements made on digital cast models scanned in the 3Shape R700 scanner (3Shape, Copenhagen, Denmark) that uses a non-destructive laser beam to reproduce model surfaces so that the plaster model is not destroyed.

Methods: The sample consisted of 26 cast models, and 6 linear measurements were made on the cast models and compared with the same measurements on digital models. The measurements assessed were: (1) distance between mandibular canines; (2) distance between mandibular molars; (3) distance between canine and maxillary molar; (4) buccal–lingual diameter of maxillary central incisor; (5) distance between two points of the incisive papillae of maxillary and mandibular central incisors; and (6) distance between the buccal surface of the maxillary central incisor and the buccal surface of the mandibular antagonist (overjet). The Student's *t*-test or Wilcoxon test was used at 5% and the Lin's concordance test at 95% confidence interval.

Results: The overjet measurement was the only one that showed a statistically significant difference ($p < 0.05$). A high level of concordance was found for all measurements.

Conclusions: The digital models obtained from the 3Shape R700 scanner are reliable and can be considered an alternative to cast models for performing measurements and analyses in orthodontic practice.

Dentomaxillofacial Radiology (2015) **44**, 20140337. doi: [10.1259/dmfr.20140337](https://doi.org/10.1259/dmfr.20140337)

Cite this article as: Lemos LS, Rebello IMCR, Vogel CJ, Barbosa MC. Reliability of measurements made on scanned cast models using the 3Shape R700 scanner. *Dentomaxillofac Radiol* 2015; **44**: 20140337.

Keywords: dental models; three-dimensional imaging; orthodontics

Introduction

The analysis of models allows a three-dimensional assessment of the maxillary and mandibular dental arches and their occlusal relation. This diagnostic tool has acceptable reliability, and it can be viewed at different angles, which would not be clinically possible without causing patient discomfort.¹ It also enables the assessment of symmetry of the arches, the analysis of the

discrepancy of models and Bolton analysis, and the analysis of the dental arch shape and intensity of the Spee and Wilson curves.²

The disadvantage of cast models is that they require an appropriate location for storage owing to the risk of breaking, which can cause permanent loss of patient record.³ Other disadvantages include the difficulty of long-distance information exchange with other professionals⁴ and possible accumulation of bacteria and fungi on the models during long-term storage.⁵

In recent decades, the use of digital dental models was announced by the orthodontic industry as being a new

Correspondence to: Larissa Santos Lemos. E-mail: larilemos@hotmail.com

This work was supported by authors LSL, IMCRR, CJV and MCB.
Received 29 September 2014; revised 17 December 2014; accepted 3 February 2015

totally digital form of documentation.⁶ Digital models are analysed by specific software, and the results are instantly displayed on the computer screen.⁷

Considering what has been explained, it can be stated that the digital dental models can eliminate the limitations of the dental cast models. The advantages of the digital models are diagnostic accuracy and speed of data output, easy storage of information and the ability to share data *via* the internet.⁸

There are several methods for the production of three-dimensional digital models but three can be cited as the main ones: (1) laser scanning of plaster models and alginate impressions; (2) CBCT scans and CBCT scanning of alginate impressions or plaster models; and (3) direct intraoral scanning of the dentition.^{9–11} Although plaster models have a few drawbacks, their accuracy for dental measurements is still regarded as the gold standard for orthodontic diagnosis and research.¹⁰

In general, the construction of digital dental models by laser scanning of plaster models can be summarised in “laser destructive scanning” and “laser non-destructive scanning”.¹²

In laser destructive scanning, the plaster model is surrounded by a transparent resin matrix, and thin slices of the model are then removed by a computerized cutter. After removal of each increment, a digital image of the exposed area is captured. The scanned layers are electronically combined to recreate the original geometry model. In this case, the plaster model is destroyed. In laser non-destructive scanning, the light emitted by the laser scanner is reflected from the surface of the plaster model. The resulting dispersion pattern is captured by an optical sensor, and the original geometry is reconstructed using mathematical algorithms. In this case, the plaster model is not destroyed.¹²

Virtual models have some disadvantages such as the impossibility of being assembled and articulated in relation to the temporomandibular joint and are not able to be manipulated manually as well as the need for technical support for the software and the possibility of loss of information in case of damage to electronic data storage. However, these drawbacks are considered negligible compared with the benefits that digital technology can offer.^{13,14} If desired, a real “copy” of the virtual models can be obtained by a process called prototyping.¹³

Alcan *et al*¹⁵ investigated the effects of different storage periods of alginate impressions in comparison with the accuracy of digital models obtained from the 3Shape D250 scanner (3Shape A/S, Copenhagen, Denmark). These authors concluded that the digital models are as reliable as traditional cast models.

Similarly, Sousa *et al*¹⁶ conducted a study to assess the reliability of measurements made on digital models obtained from the 3Shape D250 scanner and found no statistically significant difference between the measurements made directly on the cast models and digital models. They concluded that the digital models can be used with a satisfactory degree of accuracy and reproducibility.

With the advent of new equipment for obtaining digital models and the software used for analysis, the aim of this study was to evaluate the reliability of measurements made on digital cast models scanned in the 3Shape R700 scanner (3Shape A/S, Copenhagen, Denmark) and analysed by the 3Shape OrthoAnalyzer™ (3Shape A/S) program.

Methods and Materials

For this research, dental cast models were used that met the following inclusion criteria: the presence of mandibular first permanent molars, mandibular permanent canines, maxillary canine and first molar on the left side, maxillary central incisors on the right side and mandibular incisors (at least one of the mandibular incisor was required to measure overjet). The models were duplicated to prevent damage to the original models. Six linear measurements were performed on the vertical, transversal and antero-posterior directions of the cast models, and these measurements were compared with those of the digital dental models.

The sample size was determined using the paired Student's *t*-test to identify a difference of 0.2 mm, which was considered clinically significant,¹⁷ standard deviation of the difference of 0.35 mm, test power of 80% and the bilateral alpha level of 4%. The test resulted in a sample of 26 cast models.

Perforations were made on the cast models using a low-speed tungsten carbide bur number ½ (JET Carbide Burs; Beavers Dental, São Paulo, Brazil) to determine the exact location of where the rods of the measuring instrument should be placed in the techniques to be compared, except for overjet described below, for which no drilling was performed. These markings were made with the purpose of reducing error when placing the instrument to record measurements. The measurements were taken by a single examiner.

The measurements assessed were as follows:

- (1) intercanine distance (33–43): space between the tips of cusps of the mandibular permanent canines
- (2) intermolar distance (36–46): space between the tips of mesiobuccal cusps of the mandibular first permanent molars
- (3) distance between canine and maxillary first molar (23–26): space between the tips of cusps of the left mandibular permanent canine and mesiobuccal cusp of the left maxillary first permanent molar
- (4) buccolingual diameter of right maxillary permanent central incisor (VL-11): distance between the buccal and lingual surface of Tooth 11, measurement on the gingival margin limit
- (5) distance between the point of the incisive papilla of the maxillary permanent central incisors and incisive papilla of the mandibular permanent central incisors (papillae)

Figure 1 The measuring instruments used for manual measuring.

- (6) overjet: measured from the buccal surface, in the mesial third, of the right maxillary central incisor to the buccal surface of the mandibular antagonist (overjet).

Manual measurements were obtained with the aid of a digital caliper Cen-Tech 4" (Harbor Freight Tools, Calabasas, CA) with a precision of 0.01 mm, noting the previously mentioned references, with the exception of the overjet measurement, which was measured with a steel millimetre ruler (Figure 1) owing to the difficulty of measuring with the caliper. The manual measurements are shown in Figure 2.

The R700 equipment was used to scan the models, it uses the non-destructive scanning method. The appliance uses a laser beam to scan the surface by means of a mobile system with two cameras and three axes of rotation required for greater precision for acquiring a geometric object (Figure 3).

Scanning occurred in three stages to obtain a pair of digital models: first the upper and lower models were scanned individually, followed by the occluded models. Scanning was performed using the ScanIt Ortho Impression™ program (3Shape A/S). The image was formed by capturing points on the model surface to be processed to allow virtual assembly. The image formation occurred through the organization of the points in a triangular shape, forming a cloud of points (Figure 4). The virtual image was saved as a digital imaging and communications in medicine file.

The scanned models were analysed by the Ortho-Analyzer software. Initially, we created our analysis for this research with the marking points referring to the measurements to be analysed. The points were marked in accordance with the sequence provided by software and transformed into a two-dimensional image (Figure 5).

To evaluate the reliability of the measurements, repetition of all the measures at three different times (t_1 , t_2 and t_3) was performed with an interval of 10 days between them. All measurements were obtained by the same examiner.

Statistical analysis

Statistical analysis was performed using SPSS/SPSS® v. 15 (IBM corporation, Armonk, NY) and MedCalc 9 (Ostend, Belgium) software, followed by descriptive analysis (mean and standard deviation). To compare manual measurements with the digital ones, the parametric paired Student's t -test or the Wilcoxon exact non-parametric test was used, depending on the normality of data distribution at a 5% significance level. Lin's concordance test was used to calculate the degree of reproducibility of the measurements at a 95% confidence interval.

Figure 2 The measuring instruments in place for manual measuring. (a) 33–43; (b) 36–46; (c) 23–26; (d) VL-11; (e) papila; (f) overjet.

Figure 3 Mobile system of the 3Shape R700 scanner (3Shape A/S, Copenhagen, Denmark) with two cameras and three axes of rotation.

Results

The reproducibility of the measurements was assessed using the kappa agreement test with a significance level of 95%, and was not found to show statistical differences between t_1 , t_2 and t_3 with $k = 0.9$.

Of the six measurements evaluated in this study, three showed normal distribution of the data (33–43, 36–46 and VL-11) and they were statistically analysed by the paired Student's t -test. The other three showed abnormal distribution (23–26; papilla; overjet), and they were analysed by the Wilcoxon exact test.

No statistically significant difference ($p > 0.05$) was found when the manual and digital measurements were compared for the measurements 33–43 ($p = 0.069$); 36–46 ($p = 0.188$); VL-11 ($p = 0.211$); 23–26 ($p = 0.315$); and papilla ($p = 0.052$), with the exception of the overjet measurement ($p = 0.010$). The mean, standard deviation and p -value for each measurement using the manual and digital methods are shown in Table 1.

The degree of reproducibility of the measurements, analysed by Lin's concordance test by Lin,¹⁸ showed an almost perfect degree of concordance (ρ_c) for all parameters, (ρ_c) > 0.99 , according to the scale suggested by McBride.¹⁹ The concordance coefficient, its respective confidence interval and the degree of concordance suggested by McBride are shown in Table 2.

The graphical representation of the Lin's degree of concordance for all measurements is shown in Figure 6.

Discussion

To obtain a pair of digital models from the 3Shape R700 scanner, the scanning process occurs in three stages, in which each model is individually scanned (maxillary and mandibular), followed by the scanning of the models in occlusion to record the biting of the patient. Because each stage is independent, similar to the method used by Watanabe-Kanno *et al*,²⁰ the present study assessed each scanning stage by measuring the mandibular, maxillary dental arches and the occluded models.

In a review, Houston²¹ pointed out that the major source of random error in this type of study is the difficulty in identifying a position to use as a reference point for the measuring instruments, which leads to a problem in reproducibility when using computer analysis. For this reason, the purpose of the perforations in the cast models was to increase the reproducibility of measurements, since the examiner had to place the measuring instruments on the same reference points when measuring both the cast and digital models. This type of artificial reference point was used by Alcan *et al*¹⁵ to investigate the effects of different storage periods of alginate impressions by means of precision of digital models. Similarly, Grehs²² identified reference points using a number 3 pencil marking to facilitate the position of the measuring instruments.

The results of this study disagree with those of the study by Garino and Garino,²³ who found statistically significant differences between the measurements obtained from the cast and digital models. However, the authors mentioned advantages of the digital program, such as the ability to zoom in and rotate three-dimensional images without changing their dimensions, as well as the good resolution obtained with this type of program. The resolution of the digital instrument used by these authors was 0.1 mm, and for the manual caliper, it was 0.5 mm, which shows the limitation of manual measuring and the rationale for the statistical difference found by these authors. In addition, the inclination, rotation and dental crowding may have influenced the measurement and, in these cases, resulted in differences, particularly owing to the difficulty in measuring the mesiodistal points.

Similarly, Blos *et al*²⁴ concluded that there are significant differences between the manual and digital analysis of models. In the study discussed, the manual

Figure 4 Image obtained after organization of triangular-shaped points, forming a cloud of points (a). Close-up view (b).

Figure 5 Overjet measurement in the OrthoAnalyzer software (3Shape A/S, Copenhagen, Denmark) transformed into a two-dimensional image.

measurements were obtained by using a dry-point compass, but the measurements were transferred to cardboard paper before being measured with a millimeter ruler. This manual measurement process (dry-point compass, cardboard paper and millimeter ruler) may have increased the chance of error during measurement. Also, differences could have occurred owing to the variation in the angle of the instrument or even in the position of its shanks.

All the measurements in this study comparing manual and digital measurements showed an excellent degree of concordance, corroborating previous studies that used correlation coefficients.^{15,25,26} However, when the tests for paired samples were used, a statistically significant difference was only found for one of the parameters evaluated, the overjet measurement ($p < 0.05$).

A statistically significant difference found for the overjet parameter can be justified by the fact that

a millimeter ruler was used for the overjet measurement, that is, a less accurate measuring instrument than the precision of the measurements performed by the software through the digital method. Furthermore, no perforations were used as reference points to analyse this measurement.

The different possibilities for handling models are also considered as a factor that might interfere with the results in this type of study. While the cast models can be handled and evaluated from any plane, the digital ones, although they can be observed at any position of the three planes of space, need to be in a static position at the time of marking the desired points to enable the measurement.³

The results of this study corroborate previous findings^{5,16,20,26–30} regarding the fact that no statistically significant difference was found between the computer (obtained from scanned models) and manual

Table 1 Mean, standard deviation and p -value of each measurement for the manual and digital methods

Measurements	Manual method		Digital method		p-value
	Mean (mm)	Standard deviation (mm)	Mean (mm)	Standard deviation (mm)	
33–43	26.28	2.23	26.23	2.24	0.069
36–46	43.93	3.48	43.96	3.48	0.188
VL-11	6.46	0.69	6.43	0.71	0.211
23–26	21.62	2.52	21.60	2.44	0.315
Papilla	15.14	2.73	15.20	2.73	0.052
Overjet	3.97	2.38	4.09	2.31	0.010

Table 2 Concordance coefficient, 95% confidence interval (CI) and level of agreement for the reproducibility parameters analysed

Measurements	Concordance coefficient	95% CI	Degree of concordance
33–43	0.9977	0.9950–0.9990	Almost perfect
36–46	0.9994	0.9987–0.9997	Almost perfect
VL-11	0.9897	0.9776–0.9953	Almost perfect
23–26	0.9987	0.9977–0.9993	Almost perfect
Papilla	0.9987	0.9971–0.9994	Almost perfect
Overjet	0.9940	0.9873–0.9972	Almost perfect

Figure 6 Graphical representation of the Lin's concordance coefficient for measurements: (a) 33–43; (b) 36–46; (c) 23–26; (d) VL-11; (e) papila; (f) overjet.

measurements or because the differences were clinically insignificant.

Recent research^{15,16} using the previous version of the 3Shape D250 scanner, which has similar features as the scanner used in this study, concluded that orthodontic digital models can be used with satisfaction to a degree

of accuracy and reproducibility and will probably become the gold standard of clinical orthodontic practice over the current gold standard that is the measurement of plaster models.

Correia et al³¹ used the same scanner model as this research and compared the tooth-size discrepancy in

plaster models and digital models and concluded that there was no statistically significant difference. They carried out interproximal tooth measures and measures covering the curvature of models to obtain tooth-size discrepancy, so we concluded that the scan performed by R700 3Shape scanner is faithful also in interproximal and curvature areas.

References

- Matsui RH, Ortolani CLF, Castilho JCM, Costa C. Analysis for orthodontics models through digitalized methods. [In Portuguese.] *Rev Inst Ciênc Health* 2007; **25**: 285–90.
- Hou HM, Wong RWK, Hägg EUO. The uses of orthodontic study models in diagnosis and treatment planning. *Hong Kong Dent J* 2006; **3**: 107–15.
- Oliveira DD, Ruellas ACO, Drummond MEL, Pantuzo MCG, Lanna AMQ. Reliability of three-dimensional digital casts as a diagnostic tool for orthodontic treatment planning: a pilot study. [In Portuguese.] *Rev Dent Press Ortodon Ortop Facial* 2007; **12**: 84–93.
- de Almeida AM, Lauris RCMC, Peixoto AP, Gribel BF, Janson G, Garib DG. Digital models in orthodontics. [In Portuguese.] *Pro-dental Orto* 2011; **4**: 55–80.
- Gallão S. From gypsum models to tridimensional images. [In Portuguese.] Araraquara: Universidade Estadual Paulista; 2010.
- Motohashi N, Kuroda T. A 3D computer-aided design system applied to diagnosis and treatment planning in orthodontics and orthognathic surgery. *Eur J Orthod* 1999; **21**: 263–74.
- Paredes V, Gandia JL, Cibrián R. Digital diagnosis records in orthodontics. An overview. [In Spanish.] *Med Oral Patol Oral Cir Bucal* 2006; **11**: 88–93.
- Marcel TJ. Three-dimensional on-screen virtual models. *Am J Orthod Dentofacial Orthop* 2001; **119**: 666–8.
- Kau CH, Littlefield J, Rainy N, Nguyen JT, Creed B. Evaluation of CBCT digital models and traditional models using the Little's index. *Angle Orthod* 2010; **80**: 435–9. doi: [10.2319/083109-491.1](https://doi.org/10.2319/083109-491.1)
- Fleming PS, Marinho V, Johal A. Orthodontic measurements on digital study models compared with plaster models: a systematic review. *Orthod Craniofac Res* 2011; **14**: 1–16. doi: [10.1111/j.1601-6343.2010.01503.x](https://doi.org/10.1111/j.1601-6343.2010.01503.x)
- Lighthart KG, English JD, Kau CH, Akyalcin S, Bussa HI Jr, McGrory KR, et al. Surface analysis of study models generated from OrthoCAD and cone-beam computed tomography imaging. *Am J Orthod Dentofacial Orthop* 2012; **141**: 686–93. doi: [10.1016/j.jajodo.2011.12.019](https://doi.org/10.1016/j.jajodo.2011.12.019)
- Kuo E, Miller RJ. Automated custom-manufacturing technology in orthodontics. *Am J Orthod Dentofacial Orthop* 2003; **123**: 578–81.
- Joffe L. Current products and practices OrthoCAD™: digital models for a digital era. *J Orthod* 2004; **31**: 344–7.
- Mayers M, Firestone AR, Rashid R, Vig KW. Comparison of peer assessment rating (PAR) index scores of plaster and computer-based digital models. *Am J Orthod Dentofacial Orthop* 2005; **128**: 431–4.
- Alcan T, Ceylanoglu C, Baysal B. The relationship between digital model accuracy and time-dependent deformation of alginate impressions. *Angle Orthod* 2009; **79**: 30–6. doi: [10.2319/100307-475.1](https://doi.org/10.2319/100307-475.1)
- 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; **142**: 269–73. doi: [10.1016/j.jajodo.2011.12.028](https://doi.org/10.1016/j.jajodo.2011.12.028)
- Wiranto MG, Engelbrecht WP, Tutein Nolthenius HE, van der Meer WJ, Ren Y. Validity, reliability, and reproducibility of linear measurements on digital models obtained from intraoral and cone-beam computed tomography scans of alginate impressions. *Am J Orthod Dentofacial Orthop* 2013; **143**: 140–7. doi: [10.1016/j.jajodo.2012.06.018](https://doi.org/10.1016/j.jajodo.2012.06.018)
- Lin LI. A concordance correlation coefficient to evaluate reproducibility. *Biometrics* 1989; **45**: 255–68.
- McBride GB. *A proposal for strength of agreement criteria for Lin's concordance correlation coefficient*. Hamilton, New Zealand: NIWA Client Report; 2005.
- Watanabe-Kanno GA, Abrão J, Miasiro Junior H, Sánchez-Ayala A, Lagravère MO. Reproducibility, reliability and validity of measurements obtained from Cécile3 digital models. *Braz Oral Res* 2009; **23**: 288–95.
- Houston WJ. The analysis of errors in orthodontic measurements. *Am J Orthod* 1983; **83**: 382–90.
- Grehs B. Analyses and comparison of linear measurements performed on plaster models and three-dimensional images. [In Portuguese.] Araraquara: Universidade Estadual Paulista; 2009.
- Garino F, Garino GB. Comparison of dental arch measurements between stone and digital casts. *World J Orthod* 2002; **3**: 250–4.
- Blos JML, Vargas IA, Closs LQ. Evaluation of computer-aided space analysis compared to conventional method. [In Portuguese.] *Stomata* 2005; **11**: 13–19.
- Zilberman O, Huggare JA, Parikakis KA. Evaluation of the validity of tooth size and arch width measurements using conventional and three-dimensional virtual orthodontic models. *Angle Orthod* 2003; **73**: 301–6.
- Bootvong K, Liu Z, McGrath C, Hägg 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; **32**: 589–95. doi: [10.1093/ejo/cjp159](https://doi.org/10.1093/ejo/cjp159)
- 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; **71**: 351–7.
- Quimby ML, Vig KW, Rashid RG, Firestone AR. The accuracy and reliability of measurements made on computer-based digital models. *Angle Orthod* 2004; **74**: 298–303.
- Rheude B, Sadowsky PL, Ferriera A, Jacobson A. An evaluation of the use of digital study models in orthodontic diagnosis and treatment planning. *Angle Orthod* 2005; **75**: 300–4.
- Mullen SR, Martin CA, Ngan P, Gladwin M. Accuracy of space analysis with emodels and plaster models. *Am J Orthod Dentofacial Orthop* 2007; **132**: 346–52.
- Correia GD, Habib FA, Vogel CJ. Tooth-size discrepancy: a comparison between manual and digital methods. *Dental Press J Orthod* 2014; **19**: 107–13.

Conclusion

In view of the foregoing discussion, it may be concluded that the digital models obtained from the 3Shape R700 scanner are reliable and can be considered an alternative to cast models for performing measurements and analyses in orthodontic practice.