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A Comparison of Three Types of Orthodontic Study Models

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ABSTRACT

Plaster study models have been the gold standard for many years but have many disadvantages. Intra-oral scanners and three-dimensional printers have provided alternatives in the form of digital and printed study models. Their accuracy for clinical use requires further validation.

The aim of this research was to compare the accuracy of digital and printed study models with plaster study models. The objectives were to compare the accuracy of measurements obtained from digital and printed study models with those of plaster study models, to establish which type of study model yielded the most accurate measurements in comparison to plaster study models and to identify disadvantages associated with the use of these types of study models.

A study sample of 50 patients attending a private orthodontic practice for treatment participated. Patients' participation was voluntary and informed consent was obtained from all patients.

Dental impressions were taken from each patient and cast into plaster study models. Digital impressions using the 3Shape TRIOS® intra-oral scanner were taken for each patient and digital study models were generated and used to print study models using the Next Dent 5100 for Ceramill® 3D printer. Measurements were taken from each study model and respectively compared for accuracy.

Only four of the 28 sets of observations were statistically significantly different, namely: mesio-distal widths of teeth 15 and 26, the inter-canine widths in the maxillary arches and the inter-molar widths in the maxillary arches.

The researchers concluded that the measurements taken from digital and printed study models are as accurate as those taken from plaster study models and are accurate enough to be used in a clinical environment.

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Key words

Digital study models, plaster study models, printed study models, intra-oral scanner, three-dimensional (3D) printer, accuracy, measurements, orthodontics

Introduction and Literature Review

An orthodontic diagnosis and treatment plan are formulated once a thorough assessment of the patient and the patient's presenting problems have been addressed[1]. Clinical examinations of patients consist of extra-oral and intra-oral examinations. Diagnostic tools that are vital to formulate a diagnosis include: a study model assessment, extra and intra-oral photographs, radiographs and cephalometric analysis. [1]

Study models are an imperative part of orthodontic diagnosis and treatment planning[1]. They are used to measure overjets and overbites, tooth size, arch lengths [2], Bolton analysis[3] and can be used to predict the sizes of unerupted permanent teeth.[4] Study models are also needed to evaluate space analyses, arch form, symmetry, and curves of Wilson and Spee.[5]

Plaster study models have been accepted to be the 'gold standard' for study model analysis[6]. Measurements taken using a digital or analogue calliper have been considered reliable.[7] Plaster study models are considered an accurate representation of patients' occlusion, and this claim is further validated by the well-fitting orthodontic appliances that are made using these study models.[8] The advantages include that they are easy and cheap to produce.[9] The method of conventional impression taking is well tolerated and accepted and therefore still favoured by many practitioners.[10] Plaster study models are subject to breakage and damage,[7] can be misplaced[6] and are also time-consuming to measure.[11] For legal purposes, study models are required to be stored for a certain number of years and the storage of plaster study models is problematic due to their weight and size.[7]

The introduction of intra-oral scanners, digital models and three-dimensional (3D) printers has presented practitioners with a more modern and user-friendly approach to orthodontic treatment planning.[12] According to Reuschl *et al.* (2016), digital study models may replace the need for their plaster equivalents.[13] Digital study models may also be used to print physical study models using a three-dimensional (3D) printer.[14] The ability to print study models from digital impressions allows practitioners to make use of intra-oral scanners and still have physical models to analyse.[15]

Cadent was the first dental equipment manufacturing company that introduced an intra-oral scanner called iTero™ in 2008[16]. A digital intra-oral scanner is made up of three main parts: a wireless workstation, a handheld wand that

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has a built-in camera or sensor, and a computer monitor[16]. Intra-oral scanning is a direct method of obtaining digital study models by scanning patients' mouths using an intra-oral scanner.[17] Digital impressions eliminate many of the disadvantages associated with conventional impression taking.[18] These impressions are converted to digital study models.[18] Using software packages, practitioners can take linear measurements, conduct a space analysis and assess arch form, length and crowding.[14]

Advantages of using an intra-scanner include: the elimination of the many disadvantages associated with conventional impression taking and plaster study models.[14] Digital study models can be visualised three-dimensionally before scanning has been finalised[19]. Re-scans can be done immediately if the image captured is unsatisfactory and can be undertaken without repeating the entire impression taking process.[19] Improved patient experiences at the dentist or orthodontist are an advantage of this technology, as conventional impression taking can be an unpleasant experience for many patients[14]. Disadvantages include scanning difficulties in the posterior mandibular molar area due to the movements of the tongue and the limited area the intra-oral scanner head can access.[20] The price of training, software updates and subscriptions can make the purchase of an intra-oral scanner very expensive.[21]

Plaster study models have been accepted to be the 'gold standard' for study model analysis.[22] Measurements taken using a digital or analogue calliper have been considered reliable.[23] Plaster study models are considered an accurate representation of patients' occlusion, and this claim is further validated by the well-fitting orthodontic appliances that are made using these study models.[18] The advantages include that they are easy and cheap to produce.[19] The method of conventional impression taking is well tolerated and accepted and therefore still favoured by many practitioners.[20] Plaster study models are subject to breakage and damage,[7] can be misplaced[6] and are also time-consuming to measure.[11] For legal purposes, study models are required to be stored for a certain number of years and the storage of plaster study models is problematic due to their weight and size.[7]

The formation of digital study models depends on the technology used for each brand of intra-oral or desktop scanner and its associated software. Computer aided design/computer aided manufacture (CAD/CAM) technology made it possible for the dental arch to be scanned three-dimensionally.[14] CAD/CAM technology can scan plaster study models to convert them to digital study models or is available as a computer software programme that can manipulate digital study models.[4] Digital study models are created and stored as Standard Tessellation Language (STL) open format files.[14] Digital study models have numerous advantages. Digital files are stored electronically and do not require physical storage space.[22,23] The digital files can be sent worldwide instantly for laboratory work, consultation, referral or educational purposes,[7] eliminating the need for transport.[24] They are not subject to physical damage or loss as plaster study models are.[23] The software that is part of the intra-oral scanners allows practitioners to analyse, measure and manipulate digital study models and design orthodontic appliances and virtual set ups.[25,26,8,5] One of the most significant disadvantages of digital study models is the fact that practitioners cannot physically hold, view or feel the study model.[27] The accuracy of measurements can be affected by difficulty in distinguishing landmarks on the digital study models.[2] Practitioners need to orientate themselves and practise locating certain planes and landmarks on digital study models.[6] Storing digital study models requires maintenance, as digital files need to be backed up regularly and files must be password protected to ensure patients' records are kept confidential.[6] Several studies found the accuracy of measurements between plaster and digital study models similar and concluded that digital study models are accurate enough to replace the need for plaster study models; any differences found were not statistically significant.[4,5,28]

Digital study models are the blueprints for printing 3D study models using a 3D printer.[29] The additive method of 3D printing is also known as rapid prototyping,[29] and study models are produced using this method[15]. The digital study model is created by CAD software and translated to an STL file[30]. This file is processed by slicing the model[30] and the model is built in incremental layers, followed by post curing[15]. Advantages of 3D printed study models include the fact that the study model is a physical one[15], and this option caters to practitioners who want to physically hold and manipulate a study model[31]. Physical study models are also needed to construct orthodontic appliances[15]. A significant disadvantage of printed study models is that materials shrink during the building process, or study models shrink after the post curing process[15]. Keating *et al.* (2008) also reported that the researchers of their study claimed difficulty in measuring printed study models, as the translucency of the clear epoxy-based resin made it challenging to identify certain landmarks. The lack of detail in cervical margins of teeth in study models was also problematic.[11] 3D printing technology is also very expensive and not many practitioners can afford this type of equipment.[32] The complexity of the technology and equipment will require expert help.[33] Several studies that compared measurements taken from printed study models were as accurate as those taken from plaster, acrylic and digital study models. [15,33,28]

AIM AND OBJECTIVES

The aim of this research was to compare the accuracy of measurements taken from digital study models obtained from an intra-oral scanner, and printed study models, printed from digital study model files by a 3D printer, with measurements taken from plaster study models.

The objectives were:

- To compare the accuracy of measurements obtained from digital and printed study models with those taken from plaster study models.
- To establish which type of study model yielded the most accurate measurements in comparison to plaster study models.
- To identify possible disadvantages and errors that can be made using any of the three types of study models.

METHODOLOGY

The design of study was a comparative descriptive study with a study population consisting of 50 patients that attended the private practice of an orthodontist specialist for treatment. The study population consisted of 37 female patients and 8 male patients.

Inclusion criteria were as follows: impressions were only taken from patients who required it as part of their treatment and patients who had permanent teeth 1- 6 were used as the

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mesio-distal widths of these teeth needed to be measured and compared.

Exclusion criteria included: patients who did not require impressions or study models, who had missing permanent canines and first permanent molars, those with mixed dentition and fixed orthodontic appliances.

Ethics approval was granted from the University of the Western Cape Senate Biomedical Research Ethics Committee (BM 18/3/20). Patients' participation was voluntary and informed consent from all participating patients was obtained before participation commenced. In the case of minor patients, informed consent from a parent or legal guardian was obtained.

Conventional dental impressions using Kromogel® Advance alginate were taken for all participating patients and plaster study models were cast from these impressions. Digital impressions of patients' mouths were taken using the TRIOS® 3 3Shape intra-oral scanner and its software generated digital study models. The Next Dent 5100 for Ceramill® 3D printer, a digital light processing 3D printer, printed study models from the digital study model files. The following measurements were taken from both arches for each type of study model: the mesio-distal tooth widths of permanent teeth 1-6, the inter-canine widths and the inter-molar widths. An electronic digital calliper was used to measure the plaster and printed study models. Ortho Analyzer™, the software that is part of the TRIOS® 3 3Shape intra-oral scanner, was used measure the digital study models. Each study model was numbered for reference and confidentiality purposes and all data was recorded on Microsoft Excel spreadsheets.

Parametric techniques were employed to compare the accuracy of measurements taken from the plaster, digital and printed study models. Descriptive analyses and Tests Within-Subjects Effects, pairwise comparisons and interclass correlation techniques were conducted.

RESULTS

The descriptive data for the three sets of study models are presented in Table 1.

Tests Within-Subjects Effects

Tests of within-subjects effects evaluation was done to determine whether any significant differences in measurements taken from all three models exist. The

Table I: Descriptive analyses for plaster, digital and printed study models.

	Min	Max	Mean	Std deviation		Min	Max	Mean	Std deviation
Tooth 11					**Tooth 21**				
Plaster	8,04	10,3	8,8432	0,53635	Plaster	7,91	10,6	8,796	0,58888
Digital	8,06	10,36	8,8284	0,53236	Digital	7,79	10,65	8,7828	0,6106
Printed	8,11	10,2	8,823	0,51241	Printed	7,88	10,4	8,8222	0,56025
Tooth 12					**Tooth 22**				
Plaster	0	8,04	6,6858	1,11203	Plaster	5,31	7,92	6,8458	0,56001
Digital	0	7,92	6,667	1,1102	Digital	5,36	8,04	6,8676	0,56639
Printed	0	7,94	6,72	1,1078	Printed	5,55	7,93	6,8374	0,54643
Tooth 13					**Tooth 23**				
Plaster	5,36	8,72	7,7526	0,52373	Plaster	5,04	8,41	7,646	0,56753
Digital	5,58	8,61	7,7708	0,55042	Digital	5,1	8,55	7,6368	0,60315
Printed	5,31	8,52	7,7322	0,54313	Printed	5	8,56	7,6108	0,58542
Tooth 14					**Tooth 24**				
Plaster	5,8	8,41	7,1702	0,52058	Plaster	6,2	8,36	7,2146	0,52455
Digital	5,76	8,59	7,2028	0,55259	Digital	6,11	8,34	7,2066	0,50777
Printed	5,93	8,31	7,1474	0,55738	Printed	6,31	8,31	7,1844	0,53207
Tooth 15					**Tooth 25**				
Plaster	0	7,55	5,8126	2,21732	Plaster	0	7,64	6,3144	1,68402
Digital	0	7,65	5,876	2,24907	Digital	0	7,81	6,3456	1,69978
Printed	0	7,51	5,7626	2,20355	Printed	0	7,67	6,2986	1,6795
Tooth 16					**Tooth 26**				
Plaster	8,46	11,57	10,1678	0,66645	Plaster	9,04	11,94	10,2006	0,64745
Digital	8,57	11,58	10,2013	0,62009	Digital	9,04	11,69	10,241	0,63078
Printed	8,31	11,57	10,1366	0,67484	Printed	9,07	11,56	10,1208	0,63905
Tooth 41					**Tooth 31**				
Plaster	4,58	6,2	5,3034	0,37656	Plaster	4,72	6,16	5,3852	0,36212
Digital	4,32	6,16	5,2513	0,38446	Digital	4,5	6,37	5,3534	0,40656
Printed	4,67	6,24	5,2813	0,36626	Printed	4,67	6,11	5,3942	0,35292

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Tooth 42					**Tooth 32**				
Plaster	5,05	6,7	5,9074	0,39044	Plaster	5,16	6,72	5,9706	0,3801
Digital	5,21	7	5,9536	0,41511	Digital	5,16	6,9	6,0064	0,41034
Printed	5,8	6,85	5,9372	0,39626	Printed	5,21	6,73	5,9938	0,36033
Tooth 43					**Tooth 33**				
Plaster	2,6	7,89	6,808	0,74369	Plaster	6,02	8,53	6,8962	0,551
Digital	3	8,08	6,8108	0,72847	Digital	5,81	8,5	6,8954	0,52706
Printed	2,99	7,97	6,8517	0,69999	Printed	6,1	8,55	6,9286	0,54456
Tooth 44					**Tooth 34**				
Plaster	6,14	8,45	7,2288	0,55231	Plaster	6,33	8,51	7,2666	0,53929
Digital	6,26	8,43	7,2184	0,51859	Digital	6,29	8,47	7,2584	0,56018
Printed	6,21	8,47	7,2276	0,52867	Printed	6,45	8,64	7,2736	0,5069
Tooth 45					**Tooth 35**				
Plaster	0	8,06	6,8462	1,49907	Plaster	0	8,23	7,0352	1,8748
Digital	0	8,24	6,884	1,49471	Digital	0	8,35	7,0478	1,8164
Printed	0	8,33	6,8244	1,50101	Printed	0	8,8	6,9954	1,12612
Tooth 46					**Tooth 36**				
Plaster	9,14	12,26	10,9822	0,6646	Plaster	9,69	12,46	10,9948	0,65135
Digital	9,18	12,4	10,9817	0,67049	Digital	9,89	12,5	10,9974	0,65073
Printed	9,28	12,31	10,982	0,68685	Printed	9,7	12,58	10,9998	0,64605
ICW MX					**ICW MND**				
Plaster	30,89	42,52	34,6868	2,50635	Plaster	21,63	30,95	26,7506	2,52553
Digital	30,94	42,49	34,6948	2,52393	Digital	21,62	31,1	26,7188	2,49033
Printed	31,46	42,56	34,8476	2,5597	Printed	21,29	31,8	26,784	2,54398
IMW MX					**IMW MND**				
Plaster	30,11	56,98	51,111	3,95632	Plaster	39,49	59,11	45,443	3,43002
Digital	30,23	56,96	51,1384	3,94939	Digital	39,4	59,33	45,4092	3,4493
Printed	30,35	56,88	51,222	3,91223	Printed	39,38	58,95	45,4168	3,3776

significant value for sphericity assumed is set at $p=0.05$. If the significant value found between all three measurements for each type of model is $p \leq 0.05$, a statistically significant difference between the measurements exist. According to the data analyses; only four sets of measurements were found to be statistically significantly different in each type of model; namely mesio-distal widths of teeth 15 and 26, that had significant values of 0.001 and 0.000 respectively, the inter-canine widths in the maxillary arches that had a significant value of 0.001 and the inter-molar widths for the maxillary arches that had a significant value of 0.025.

Pairwise comparisons

The significant values of sphericity assumed of the tests within-subjects effects were $p \leq 0.05$ for the mesio-distal widths of teeth 15 and 26, the inter-canine widths in the maxillary arches and the inter-molar distances in the maxillary arches. These values indicate that statistically significant differences between these measurements taken from the 3 types of study models exist. In this instance, pairwise comparisons determine where the significant differences exist. This test directly compares the study models against each other. In the case of the mesio-distal widths of tooth 15, both digital and printed study model measurements are statistically significantly different from the plaster study model measurement with significant values of 0.033 and 0.033 respectively. In the case of the mesio-distal width of tooth 26, the printed study model measurement is statistically significantly different from the plaster study model measurement with a significant value of 0.011. The digital study model significant value was 0.064, which makes it not statistically different from the plaster study model measurements. The significant value for the inter-canine widths in the maxillary arches taken from printed study models was 0.002, making it statistically significantly different from the plaster study model measurements. The digital study model significant value was not statistically significantly different from the plaster study model inter-canine widths in the maxillary arches. The significant values for the inter-molar widths of both digital and printed study models were 0.126 and 0.016; making the measurements from the printed study models statistically significantly different from the plaster study model measurements. Out of the 4 sets of observations discussed above, it must be noted that the printed study models were the models that were statistically significantly different from their plaster counterparts, with the exception of the measurements taken for the mesio-distal width of tooth 15, where both digital and printed study model measurements differed significantly from the plaster study model observations.

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Inter-rater reliability

Fifteen study models of each study model type were randomly selected, and these were measured by a second operator (KJ). Comparing the results of the second operator to those of the researcher is necessary to establish the reliability and reproducibility of these results obtained from the study models.

An interclass correlation technique is used to measure inter-rater reliability of quantitative data. The total measurements of each model were analysed for inter-rater reliability. The interclass correlation values of the study models are tabulated below in Table 2.

Table II: Inter-rater reliability of study models

Study model	Interclass correlation value
Plaster	0.825
Digital	0.861
Printed	0.880

Based on the 95% confidence interval of the interclass correlation estimate, these values fall within the 'good' category of reliability. Results between the values of 0.75-0.9, are classified as having a 'good' reliability. Those that are greater than 0.9 are classified as being of excellent reliability[37].

DISCUSSION

Plaster study models have been well established as the 'golden standard' of study models[8,6,13, 9, 24, 22]. Measuring study models using electronic digital callipers have also been considered the most validated method of measuring study models.[7, 22, 34, 24, 13, 6, 8] There are many disadvantages associated with plaster study models and conventional impression taking, and the rise of digital technology and 3D printing in dentistry has given dental practitioners alternate techniques to obtain dental impressions and study models.[35] Plaster study models require storage and are susceptible to loss and physical damage[24]. The use of digital study models eliminates these disadvantages and numerous studies have shown that they are a reliable and clinically acceptable alternative to its plaster counterparts.[6, 28, 24, 22, 7] A major disadvantage is that a digital study model is not a physical object and cannot be physically manipulated or held.[27] Printing study models using 3D printers allows practitioners to obtain a physical representation of digital study models. Several studies have concluded that although the difference between measurements taken from plaster and printed models is statistically significant; the results are acceptable within in a clinical environment [15,21,28].

The manner study models are routinely measured impact the resultant measurements. The operator measuring the study models is required to position the tips of an electronic digital calliper on very specific landmarks to render a result; and the result is displayed on the screen of the electronic digital calliper and recorded.[36] When computer software is used to measure digital study models, the practitioner must click on specific landmarks and the software calculates the resultant measurement.[36] Intra- or inter-operator reliability needs to be accounted for both methods of measuring as a certain degree of variability will occur.[36] In this study, the study models' interclass correlation values based on a 95% confidence index was classified as 'good' reliability, as the values fall between the range of 0.75-0.9. Although these results do not reflect an 'excellent' reliability; these results could be due to difficulties in identifying certain landmarks and inexperience of the researcher in using OrthoAnalyzer™. While this is relevant statistically, clinically it is acceptable. Reuschl *et al.* (2015) concluded that although landmark identification will differ between practitioners; the differences are not clinically relevant and that measuring digital models using computer software is accurate enough to be used instead of measuring plaster study models with callipers.[13]

The results of this research are similar to previous studies that researched the accuracy of digital and printed study models for orthodontic practice. Hazeveld *et al* (2014) compared plaster study models and three types of study models printed by three different rapid prototyping techniques, namely: 3D printing, jetted photopolymer and DLP. They measured the clinical crown heights and mesio-distal widths of teeth of all permanent teeth, 1-6, in each arch and found a statistically significant difference in one measurement only, the clinical crown heights of the teeth from the 3D printed models[15]. However, these studies compared digital study models that were obtained by an extra-oral scanner.[6,7,13,35] This research used an intra-oral scanner to obtain the digital study models that were used for comparison.

Abizadeh *et al* (2012) compared measurements from plaster and digital study models and found that significant differences between the two types of study models existed but these differences were clinically irrelevant. They also found that the repeatability of digital study models when compared to their plaster equivalents to be acceptable to use in a clinical environment[6]. Saleh *et al* (2015) also concluded that the reproducibility of digital and printed study models to be favourable in comparison to plaster study models[28].

CONCLUSION

The researchers of this study have concluded that measurements taken from digital and printed study models are as accurate as those taken from plaster study models and are therefore accurate enough to be used in a clinical environment.

DISCLOSURE

The authors declare no conflict of interest.
The authors of this study did not receive any financial benefits and have no financial interests in the companies whose equipment and materials are included in this research.

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