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RESEARCH ARTICLE

An evaluation of concordance between linear measurements obtained from conventional, digital and reconstructed three-dimensional printed orthodontic models: An in vitro study

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Objective: To evaluate the potential use of digital and reconstructed three-dimensional printed models as an alternative to conventional plaster models by assessing the accuracy of their linear measurements. **Methodology**: Pre-treatment plaster models of 45 patients were selected from the archives of the Department of Orthodontics. Each physical plaster model was scanned and digitized using a three-dimensional (3D) laser surface scanning system (inEOS X5, Dentsply Sirona, Bensheim, Germany). The scanned STL files were later used to reconstruct models by 3D printing using Figure4® standalone 3D printer (3D systems, Rock Hill, South Carolina). Measurements of teeth 11 and 16, the transverse width of the upper jaw between the first molars (MM - intermolar width) and canines (CC - intercanine width) were done manually using a digital vernier caliper (Mitutoyo, Kawasaki, Japan), and the CAD Assistant software (Open cascade, Guyancourt, France). Intra examiner data, Intraobserver variability, and measurement accuracy were evaluated using Intraclass Correlation Coefficient (ICC) analysis was done using SPSS 20.0. **Results**: The intraclass correlation coefficients were >0.8 indicating high reproducibility and reliability. Significant differences were found between the physical and the digital models but to a small proportion which were deemed not clinically relevant. **Conclusion**: Both the digital models and reconstructed three-dimensional printed models using Figure4® technology were clinically permissible in terms of accuracy and reproducibility. The digital storage, transmission, and treatment planning in an environmentally friendly manner should promote digital over conventional records.

Keywords: dental models, digital technology, three-dimensional printing

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Introduction

Digitization is paving the way revolutionizing diagnostics and treatment planning in orthodontics [1,2]. Going green with digitization has its advantages. The digital storage of patient demographics, photographs, and X-rays is both cost-effective, search friendly and time-saving [3]. The use of digital models is one area where progress is still being made. If digital models are proven to be as accurate as conventional plaster models, they add to the list of advantages.

Comprehensive diagnosis and treatment planning are prerequisites for achieving quality aesthetic and functional end results. The knowledge of discrepancies in arch dimensions and tooth material on dental models is critical in deciding the orthodontic treatment option. Clinicians have traditionally measured these linear dimensions with calipers on the plaster models [4]. Also, these physical plaster models have disadvantages like increased storage requirements, added laboratory work, damage, and loss of models [5].

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Orthodontic offices are becoming digitized with technological advancement, and the use of digital models are rising [6,7]. The accuracy, reliability and reproducibility of the digital models must thus be first evaluated before the orthodontist utilizes these digital models in determining orthodontic treatment options. In recent years, various companies are offering three-dimensional (3D) scanner services, allowing an orthodontist to send an impression to a service provider, who scans and constructs a digital model, which is then sent back to the orthodontist in a digital format. The orthodontist can then evaluate, measure and manipulate the models using the software. There is usually a time lag between taking the impression and receiving the digital, which may be a disadvantage to the orthodontist [8]. Intra-oral scanners and desktop scanners allow transfer of the digital impression or model scanning process into practice or an in-clinic laboratory for this purpose [6,9].

Despite their numerous advantages, digital models have at least one significant disadvantage. Treatment planning for complex cases can be difficult without a physical model, and a physical model is still needed for orthodontic appliance fabrication. A plausible solution would be to reconstruct a physical replica of a digital model with the help of rapid prototyping. In orthodontics, the most common technique is the use of 3D printing, which involves building physical objects from digital data by incremental layering [10,11].

As a component of contemporary trends toward incorporating digital technologies into everyday practice [12], orthodontists are increasingly using digital models and reconstructed 3D printed orthodontic models [13-15]. Nevertheless, clinical technology has to be verified before being incorporated into clinical practice. The accuracy and reproducibility of a laboratory-based desktop scanner based on optical scanning technology, the use of third-party software to access these digital models and accuracy and reproducibility of non-contact membrane Figure4® technology reconstructed models is yet to be tested as per our knowledge through a literature search. Hence the aim our present study was to assess the accuracy of linear measurements obtained from digital models scanned from a laboratory-based optical scanner and their reconstructed three-dimensional printed models versus conventional plaster models.

Materials and Methods

Prior to the study, institutional ethical clearance was obtained - (protocol ref no - 20068). Pre-treatment plaster model sets of 45 patients were randomly selected (using random number table generated in Excel®) from the archives of Department of Orthodontics and Dentofacial Orthopaedics. All casts having permanent dentition from the first molar to the first contralateral molar, with absence of severe crowding (more than 6 mm) were included in the study. A pilot study was performed in 10 models and the regression coefficient obtained was 0.709 between digital and plaster model measurements. Using the r value of 0.709 (obtained from the pilot study), with an alpha error of 1% and a power of 99.9%, (the Z values of the given alpha and beta values are 2.57 and 3.09), required sample size arrived was 41.

Construction of the digital model

Each physical plaster model was digitalized after anonymization using a three-dimensional (3D) optical scanning system (inEOS X5, Dentsply Sirona, Bensheim, Germany). According to the manufacturer, the accuracy of this scanner was given as 2.1 μm. The output format used for calculating the model was an open standard Standard Triangle Language (STL) file. The collected data was saved as STL files and imported to Cad Assistant software (Open cascade, Guyancourt, France) for further editing and performing the measurements.

Reconstruction of three-dimensional printed models

The STL files were later prepared and 3D printed using Figure4® Standalone 3D printer (3D systems, Rock Hill, South Carolina) based on non-contact membrane Figure4® technology set to their most accurate printing settings. (Figure 1)

Performing the linear measurements

A standardized workflow was followed for the manual and digital measurements to assure that the quality and time courses will be identical for the two types of measurement. A single observer measured the widths of teeth 11 and 16. The contact locations were the crests of curvature between neighbouring teeth or the maximum mesiodistal diameter. Upper jaw transversal width was measured at two locations - intermolar width was measured between the palatal cusps of first molars(M-M) and intercanine width, between cusp tips of canine (C-C). Manual measurements were performed with a digital vernier caliper (Mitutoyo, Kawasaki, Japan) to an accuracy of one-tenth (1/10) of an mm (Figure 2). Digital measurements were performed with the CAD Assistant software (Open cascade, Guyancourt, France) (Figure 3). The measurements were done

Fig. 1. Reconstructed three dimensionally printed models using Figure 4 Standalone 3D printer based on non-contact membrane Figure4® technology set to their most accurate printing settings.

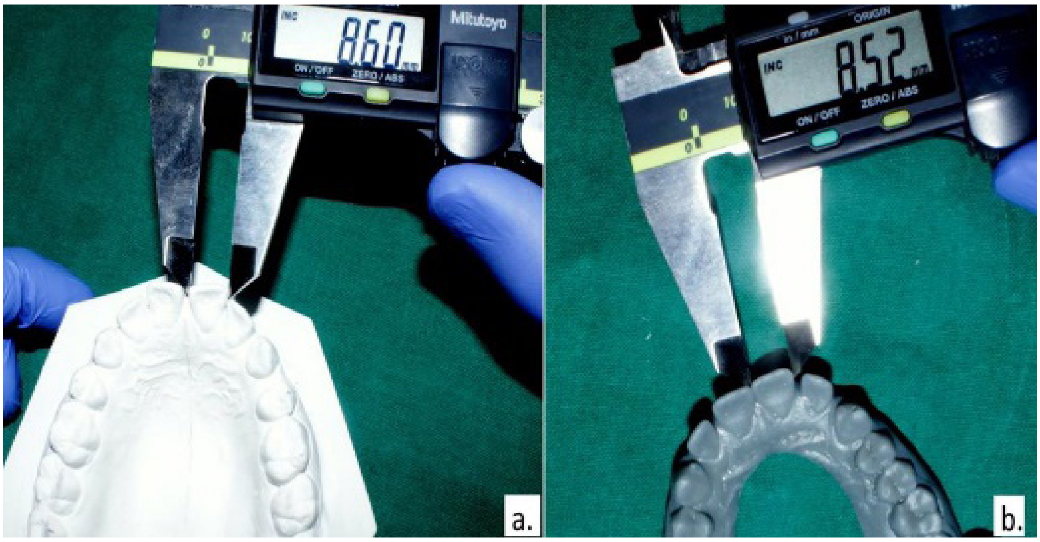

Fig. 2. Manual measurements performed with a digital vernier caliper on - a. Conventional plaster model and b. Reconstructed three-dimensional printed model.

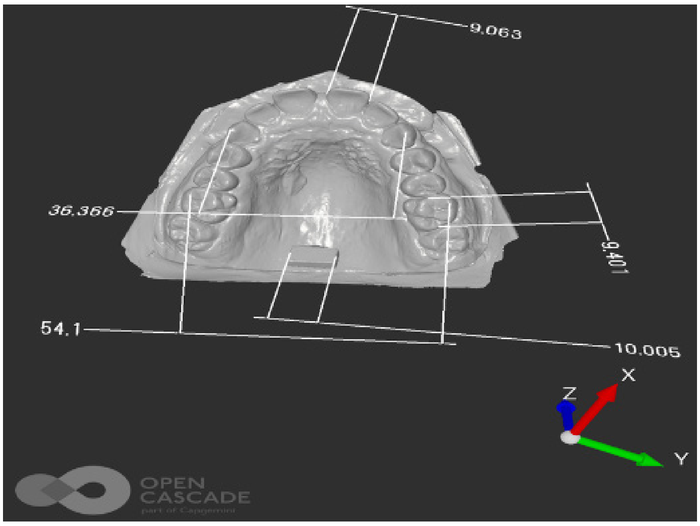

Fig. 3. Digital measurements performed with the Cad Assistant software (Open cascade, Guyancourt, France).

two times with a 2-week interval between measurements. Distances were measured in millimeters (mm).

Statistical analysis

Documented data were recorded in a Microsoft Excel™ 2019 spreadsheet and evaluated for reliability using SPSS 20.0 (IBM Chicago). Descriptive statistics of mean, standard deviation were compared between any two measurement techniques using paired t test. Intraclass Correlation Coefficient (ICC) analysis evaluated the intraobserver reliability of the repeated measurements and measurement accuracy between two methods of measurements.

Results

The intraobserver Intraclass correlation coefficient showed excellent agreement in all orthodontic models for the mesio distal widths of 11, 16, intermolar and intercanine measurements. The interclass correlation coefficient >0.9 (0.905 to 0.995), with p-value of <0.001 indicating efficient reproduction of measurements in digital and 3D printed formats. (Table I)

Dimensional comparison of individual teeth mesio distal width showed lower dimensions of digital and higher values of reconstructed models compared to the conventional measurements. The digital measurements were significantly lower by 0.09±0.11 mm, however the reconstructed models were not significantly different (difference of -0.04±0.2, p value 0.166). Comparison of the intercanine and inter molar widths showed varied results. Both reconstructed and digital measurements were lesser than the conventional methods in intercanine widths of which, the digital measurements were significantly lower by 0.14±0.27 mm (p = 0.001). However, Intermolar widths were lower in the digital but greater than the conventional methods in the reconstructed models, all of which were statistically significant (Table II)

Discussion

With the improvements in digitization processes and the need for digitally transmitting 3D information over cloud sharing, it is necessary to review digitized records' accuracy, reliability, and consistency. Hunter et al. [16] and Rossouw

Table I. Interclass correlation coefficient for agreement

Single Measures	Intraclass Correlation	95% Confidence Interval		F Test with True Value 0			
		Lower Bound	Upper Bound	Value	df1	df2	P value
Mesiodistal dimensions for teeth 11	0.950	0.920	0.971	58.432	44	88	<0.001
Mesiodistal dimensions for teeth 16	0.952	0.923	0.972	60.751	44	88	<0.001
Intercanine width	0.905	0.850	0.943	29.447	44	88	<0.001
Intermolar width	0.995	0.992	0.997	593.043	44	88	<0.001

Table II. Paired T test to compare the measurements in the three groups -Conventional, Digital and Reconstructed models

	Conventional	Digital	Reconstructed 3D model	Conventional - Digital difference (P value)	Conventional - Reconstructed 3 D model difference (P value)	Digital - reconstructed 3D model difference (P value)
11	8.76±0.57	8.67±0.6	8.8±0.63	0.09±0.11 (<0.001)	-0.04±0.2 (0.166)	-0.13±0.24 (0.001)
16	10.11±0.62	10.1±0.59	10.2±0.57	0.02±0.17 (0.521)	-0.09±0.16 (0.001)	-0.1±0.21 (0.003)
CC	35.25±2.74	35.11±2.72	35.12±3.13	0.14±0.27 (0.001)	0.14±1.53 (0.549)	0±1.51 (0.998)
MM	51.65±2.95	51.56±2.94	51.84±2.95	0.09±0.23 (0.013)	-0.19±0.32 (<0.001)	-0.28±0.32 (<0.001)

et al. [17] had described the method of measuring the study models with the help of calipers. Zilberman et al. [18] evaluated inaccuracies in measurements done using digital calipers and digital measurement systems. Their findings showed that measurement with calipers on plaster models had the better accuracy and reproducibility. A digital caliper measurement requires positioning of the caliper tips on predefined landmarks which may vary with observer. This may affect the measured distances indicating dimensions of teeth and transverse arch widths [19]. The difficulty in identifying these landmarks is one of the most common sources of random error [20]. We documented a detailed description of the reference points to reduce random error in our study with a repeated training of the observer. One observer took all measurements, so only intraobserver variation was relevant. The ICC of >0.9 indicated an excellent intrarater reproducibility.

The agreement between the conventional, digital and reconstructed models was high for all the four measurements carried out in this study. ICC ranged from 0.905-0.995 (excellent agreement), indicating that all models have high reproducibility. Though overall, there was a higher mean value for the reconstructed 3D model than conventional and digital models, both reconstructed and digital models were clinically acceptable in terms of accuracy and reproducibility. The higher mean values of the reconstructed 3D model might be attributed to the underlying factors governing the 3D printing technique [21-23]. The process of adding layer by layer during 3D printing will impact a product reconstructed. In addition, because of model shrinkage during reconstruction and post-curing, these techniques can result in differences in the final model reconstructed [24]. All of these factors could have influenced the 3D printed models' linear dimensions. There are limited studies that have defined the clinically acceptable measurement difference between reconstructed and conventional plaster models. Studies comparing the plaster models to digital models found that a difference of less than 0.30 mm on measurement is clinically acceptable because the reliability determined for manual measurements is nearly identical [25-27]. Because the highest mean systematic difference was 0.28 mm, the results of our study can be considered clinically acceptable.

Although reconstructed models are expected to contribute significantly to efficiency, their use in orthodontic practices is still limited due to the high costs of standard 3D printers. A centralized 3D printer laboratory catering to multiple canter's could be useful for academic and clinical institutions and clinic chains. However, as the number of applications increases, it is expected that prices will fall to a level comparable to traditional plaster study models.

This study compared conventional plaster models with replicas made with non-contact membrane Figure4® technology for clinical use in orthodontic offices. Suggestion for future research in this field is to include more observers and compare the measurements in all three-dimension using digital superimposition methods. As an outcome, more patient models and measurements could be planned, allowing both interobserver and intraobserver reliabilities to be studied.

Conclusion

Digital models are expected to replace plaster models in the medium term due to the advantages and development of quick and precise laboratory scanners. As a result, using a scanner, software, and 3D printer to perform digital measurements and reconstruct a patient model from digital information will become more significant, with results that should be at least as trustworthy and valid as those obtained through plaster model analysis. As a result of evaluating the accuracy of linear measurements in this study, it was observed that digital and reconstructed three-dimensional printed models could be utilized as a substitute for conventional plaster models.

Authors' contribution

SS - Conceptualization, Data curation, Formal Analysis, Investigation, Methodology, Validation, Visualization, Writing – original draft, Writing – review & editing.
SN - Methodology, Formal Analysis, Resources, Software, Writing – original draft, Writing – review & editing.
SN - Project administration, Resources, Supervision,

Writing – review & editing.
PS - Conceptualization, Validation, Writing – review & editing
KC - Data curation, Resources, Writing – review & editing.
MS – Methodology, Resource, Writing – re-view & editing.

Conflict of interest

None to declare.

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