

Comparison of Space Analysis from Computer-based Digital Model and Plaster Model

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Abstract

This study intended to determine the differences of space analysis in four groups each with a different level of crowding severity using digital models of impressions and compared with the plaster models. One hundred and twenty upper and lower plaster models were divided into four groups according to the crowding severity: group 1, no crowding; group 2, lack of space less than 2 mm; group 3, lack of space 2–4 mm; and group 4, more than 4 mm. These models were converted to digital models by impression scanning using the 3Shape R700™ scanner. Tooth size and segmental arch length measurement were performed on the plaster models using a digital caliper with a scale precision of 0.01 mm and digital models using the 3Shape OrthoAnalyzer™ software. Space discrepancy of each study model was calculated. Independent t-test and Wilcoxon rank-sum test were used to compare sum of tooth size, segmental arch length, and space discrepancy. No statistically significant differences were found between the plaster and digital models for sum of tooth size, segmental arch length or space discrepancy measurement in any group of crowding. The use of digital models obtained from the 3Shape R700™ scanner appears to be acceptable in tooth size, segmental arch length, and space discrepancy measurements.

Keywords: Digital model, Impression scanning, Orthodontics, Space analysis

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Introduction

Digital equipment and analyzing programs have been introduced in orthodontics. For proper orthodontic treatment plans, digital study models combined with different programs have become widely accepted.

Digital study models can be derived from direct scanning of a plaster model, impression scanning, intraoral scanning, and cone-beam computerized tomography (CBCT).¹⁻³ These digital models and analyzing programs can provide

all of the data which can be achieved from a plaster study cast. Moreover, model analysis such as Bolton's analysis or space analysis can also be easily obtained from these new technologies.

Digital models were introduced in 1999 by OrthoCAD™^{4,5} (Cadent, Carlstadt, NJ, USA) and in 2001 by emodels®^{6,7} (GeoDigm, Chanhassen, MN, USA) which generated the digital model by destructive scanning and laser-based scanning, respectively. Moreover, CBCT and 3D model desktop scanner were also developed and they are commonly used to create digital models.³ Due to the advanced development of the three-dimensional scanner and analyzing software, many studies tried to prove whether the measurements directly from a study model or manual method were different from the digital method. Previous studies and systematic reviews reported accuracy and reliability of the digital models made by the systems acquired from plaster models or impressions. Most of the research gave the idea that digital measurement can be used effectively in orthodontics.^{1,5,8-11}

Space analysis is one of the significant procedures in orthodontic treatment planning, especially in crowding problems. This analysis consists of measurements of segmental arch length and sum of tooth width. An accurate space analysis enhances proper treatment planning on whether extraction or arch expansion can be performed. Specifically, in moderate crowding cases, the precise evaluation of space discrepancy is essential since these are borderline cases for a decision of extraction or non-extraction.

Even though there are reports regarding many aspects of digital models, few studies have shown the differences of space analysis between digital and manual methods. Leifert studied space analysis measurements made on digital models from plaster dental casts.¹² A statistically significant difference in the space analysis on the maxillary models was found in that study. However, it was concluded that digital models could be used for space analysis compared with manual method. Redlich evaluated the accuracy of space analysis on digital

models obtained from plaster casts compared with plaster models divided into groups according to the level of crowding severity.¹³ The results showed that the measurements from digital models did not differ from the manual measurements on plaster models except in cases of severe crowding.¹³ However, no study has evaluated the space analysis based on severity of crowding carried out on plaster models compared with digital models produced from impression scanning with the 3Shape R700™ scanner (3-Shape™, Copenhagen, Denmark). The advantage of impression scanning is the avoidance of pouring stone to create a plaster cast. This advantage can save cost and time. Therefore, the purpose of this study was to evaluate the differences of space analysis in four groups with different crowding severity between two methods of measurement: digital models obtained by impression scanning and plaster models.

Materials and Methods

The research protocol was approved by the Research Ethics Committee, Faculty of Dentistry, Prince of Songkla University (EC5904-13-P-LR).

Study design, samples, and sampling methods

This study was a cross-sectional experimental study using the purposive sampling method. The sample consisted of 120 maxillary and mandibular pre-treatment plaster models derived from orthodontic patients. The sample size was calculated from a previous study.¹³ A sample size of 11 pairs of study models was required per group to obtain a statistical power of 95 %. The inclusion criteria of the sample were study models with fully erupted permanent dentition from first molar to first molar, no missing teeth, no supernumerary teeth, no abnormal tooth morphology, no attrition or large restoration that may affect the tooth mesio-distal width, no voids or beads, and no fractures or cracking of plaster models. All samples were divided equally into four groups according to crowding severity determined by one specialized orthodontist. Group 1 was no crowding (with or without spacing). Group 2 was mild crowding

(estimated space discrepancy <2 mm). Group 3 was moderate crowding (estimated space discrepancy 2–4 mm). Group 4 was severe crowding (estimated space discrepancy >4 mm).

Digital model production

The 120 plaster models were converted into digital models using impression scanning by the 3Shape R700™ scanner. Alginate impressions were taken from each plaster model and impressions were made. Only one brand of alginate (Alginoplast; Heraeus-Kulzer, Hanau, Germany) was used in this study and it was mixed strictly following the instructions of the manufacturer. Then, all impressions were immediately scanned into digital models with ScanItOrthoImpression™ software.

Measurements

The measurements were performed on plaster models with a digital caliper (573-721 Absolute, Mitutoyo Corporation, Tokyo, Japan) with a scale precision of 0.01 mm. Tooth size was measured from the mesial contact point to distal contact point parallel to the occlusal plane which is the greatest mesio-distal width

of each tooth. Arch length was measured as segmental arch length which was divided into four segments. Right and left posterior segments were measured from the mesial contact point of the first molar to the mesial contact point of the canine, and the right and left anterior segments were measured from the mesial contact point of the canine to the midline (Fig. 1). Digital models were analyzed using the 3Shape OrthoAnalyzer™ software to the nearest 0.01 mm for the tooth size and segmental arch length measurement, which was similar to the measurement made on plaster models. Tooth size measurement from the digital model was carried out by plotting the greatest mesio-distal width of each tooth starting from the right second premolar to the left second premolar, and arch length was measured as the segmental arch length (Fig. 2). Space analysis for each study model was calculated as the discrepancy between the space required (sum of tooth width from right second premolar to left second premolar) and the space available (sum of the four arch length segments).

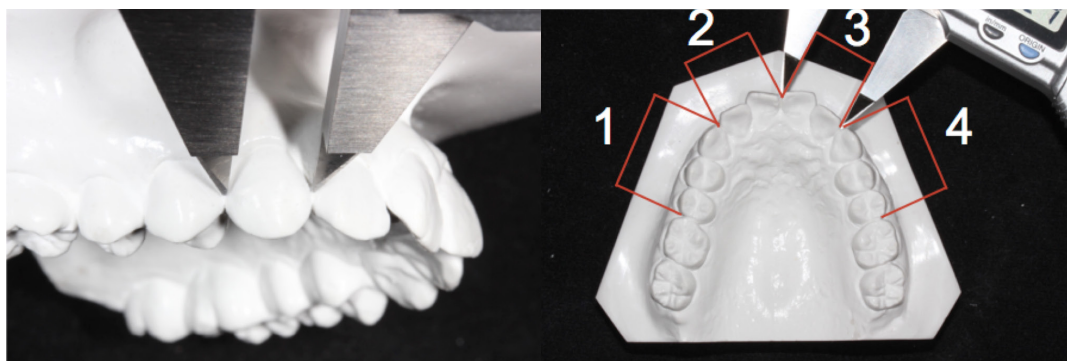


Figure 1 Measurements of tooth size and segmental arch length made on a plaster model using digital calipers.

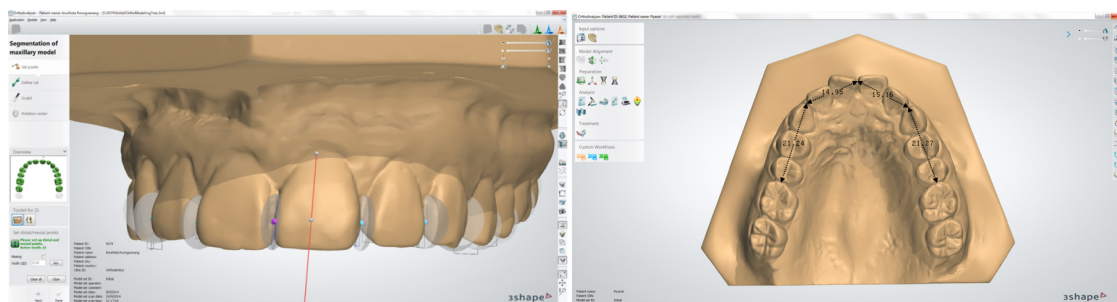


Figure 2 Measurements of tooth size and segmental arch length made on digital model OrthoAnalyzer™ software.

Error of the method

All measurements on the digital and plaster models were carried out by a single examiner trained and standardized by a specialized orthodontist in the use of both measuring methods. Internal reliability was performed on 10 randomly selected digital models and 10 randomly selected plaster models on which measurements were made separately 2 times with an interval of 2 weeks. An intraclass correlation coefficient (ICC) was calculated to evaluate the intra-observer reliability of measurement on the plaster and digital models and the measurement errors were evaluated using Dahlberg's formula.¹⁴

Statistical Analysis

IBM SPSS Statistics version 21 (SPSS Inc., Chicago, Illinois, USA) was used for the statistical analyses. The Shapiro–Wilk test was used to test for normality. Means and standard deviations of sum of tooth size, segmental arch length, and space discrepancy for plaster and digital models were calculated separately. Independent *t*-test or Wilcoxon rank-sum test was applied to determine whether the measurements on plaster and digital models had equal means for sum of tooth size, segmental arch

length, and space discrepancy measurements. The level of statistical significance was set at $p < 0.05$.

Results

The intra-examiner reliability of tooth size and segmental arch length measurements from repeated measurements were analyzed. The data showed that all measurements carried out using the two methods were highly correlated with ICC values more than 0.90 and measurement errors less than 0.50 mm.

Most of the data measurements by these two methods were normally distributed, except space discrepancy in mandibular moderate crowding. All measurements from the digital models were larger than the measurements from the manual method. However, a comparison of the means of the measurements from the plaster and digital models using the independent *t*-test and Wilcoxon rank-sum test showed no statistically significant differences in the measurements for the sum of tooth size and segmental arch length in any group ($p > 0.05$) (Tables 1 and 2). According to the space analysis, it also showed that the space discrepancies were not statistically significantly different between the plaster and digital model measurements (Table 3).

Table 1 Comparison of tooth size measurements between manual measurement from plaster model and digital measurement from impression scanning.

Degree of crowding	Maxillary arch				Mandibular arch			
	Manual measurement (mean±SD)	Digital measurement (mean±SD)	Mean Difference (mm)	<i>p</i> value	Manual measurement (mean±SD)	Digital measurement (mean±SD)	Mean Difference (mm)	<i>p</i> value
None	75.00±3.47	75.30±3.53	-0.30	0.814	64.19±3.51	65.03±3.61	-0.84	0.525
Mild	75.86±2.64	76.08±2.64	-0.22	0.824	65.88±2.32	66.74±2.76	-0.85	0.369
Moderate	78.48±4.63	78.84±4.26	-0.36	0.828	66.74±2.68	66.80±3.01	-0.06	0.952
Severe	80.67±3.55	80.60±3.78	0.07	0.957	69.25±3.06	69.09±3.04	0.16	0.890

*Significance at α level $p \leq 0.05$; NS, Not significant, $p > 0.05$

Table 2 Comparison of segmental arch length measurement between manual measurement from plaster model and digital measurement from impression scanning.

Degree of crowding	Maxillary arch				Mandibular arch			
	Manual measurement (mean±SD)	Digital measurement (mean±SD)	Mean Difference (mm)	p value	Manual measurement (mean±SD)	Digital measurement (mean±SD)	Mean Difference (mm)	p value
None	76.86±4.12	77.36±3.93	-0.50	0.734	66.61±3.28	67.51±3.34	-0.89	0.466
Mild	74.95±2.65	75.38±2.46	-0.44	0.644	64.69±2.19	65.63±2.40	-0.94	0.272
Moderate	75.22±4.43	75.71±4.28	-0.49	0.761	63.84±3.01	64.40±3.19	-0.55	0.629
Severe	73.58±3.24	73.71±2.89	-0.13	0.907	62.47±4.14	63.17±4.06	-0.70	0.645

*Significance at α level $p \leq 0.05$; NS, Not significant, $p > 0.05$

Table 3 Comparison of space discrepancy between manual measurement from plaster model and digital measurement from impression scanning.

Degree of crowding	Maxillary arch				Mandibular arch			
	Manual measurement (mean±SD)	Digital measurement (mean±SD)	Mean Difference (mm)	p value	Manual measurement (mean±SD)	Digital measurement (mean±SD)	Mean Difference (mm)	p value
None	1.86±2.02	2.06±2.22	-0.20	0.798	2.42±2.17	2.48±2.79	-0.06	0.820
Mild	-0.91±0.54	-0.70±1.22	-0.22	0.529	-1.19±0.62	-1.10±0.76	-0.09	0.729
Moderate	-3.26±0.56	-3.13±0.65	-0.13	0.553	-2.90±0.77	-2.41±0.67	-0.50	0.074
Severe	-7.10±2.78	-6.89±3.03	-0.20	0.848	-6.78±1.91	-5.93±2.04	-0.85	0.247

*Significance at α level $p \leq 0.05$; NS, Not significant, $p > 0.05$

Discussion

With the significant advances in technology, computer technology is being increasingly applied in dentistry. Nevertheless, when new equipment of digital models are released for orthodontic diagnosis, treatment planning or research purposes, an assessment of the accuracy and reliability of measurement needs to be determined.⁸ The objective of this study was to identify whether space analysis from impression scanning can replace the analysis from the traditional method. The outcome of the study can be applied in a clinical setting by scanning the impression taken from a patient's mouth.

Error in the measurements in both plaster and digital models may occur from many factors including different points of identification, differences in the measurement tools, and the examiner's experience. To

reduce measurement errors in this study, the measurements were carried out by a single examiner to avoid interobserver error. The examiner was trained and standardized by a professional orthodontist to minimize the random error. From intra-examiner reliability testing, tooth size and segmental arch length measurements showed high reliability and low measurement error with ICC values more than 0.9 and measurement errors less than 0.5 mm. This study created digital models by impression scanning with a three-dimensional scanner. Errors and problems of digital model production may occur in many processes, such as (1) the risk of dimensional deformation caused by moisture absorption or moisture loss from the impression material, (2) permanent deformation of the impression material can occur when there are deep

undercuts, (3) the time between taking the impression and the time of scanning to a digital model, and (4) impression material may not completely imprint all proximal contact areas, especially in crowding areas.^{2,15} All of these factors may affect the dimensions of the digital model and the precision of point identification. However, this study was designed to minimize the error by scanning the impression immediately after it was set. All procedures were done by one investigator who strictly followed the instructions of the manufacturers. The results showed no statistically significant differences of sum tooth size, segmental arch length or space discrepancy measurement between the measurements performed on digital models and plaster models.

Lemos *et al.*¹⁶ evaluated the reliability of linear measurements performed on plaster models compared with three-dimensional digital models obtained with a R700 scanner, which was the same scanner model used in the current study. No statistically significant differences between any linear measurements obtained directly on the plaster models versus the digital models were found in this study. The authors 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 analysis in orthodontic practice. This study also found no statistically significant differences in the space analysis on either the maxillary or mandibular models, which were in accord with the study conducted by Lemos *et al.*¹⁶ The results of this study were similar to those of Wiranto who compared the measurements on plaster models with digital models obtained from CBCT scanning, alginate impression, and intraoral scanning.²

However, the results of this study were in contrast to those reported by Leifert.¹² He found a statistically significant difference in the space analysis on the maxillary models. The factor that possibly affected the results was the different arch length measurement technique. This present study used the segmental arch technique to measure the arch length instead of the

circumferential technique. A large deviation from the circumferential technique can happen due to individual determination and low reproducibility.¹⁷

One of the factors that can influence identification of landmarks and affect the accuracy and reliability of the measurements is a significant amount of crowding. Measurements on models with moderate to severe crowding have limitations because it is difficult to identify the actual contact point of the teeth, especially in rotated or impacted teeth and also some teeth may have a large contact area which produces large variations in the measurements. Therefore, the access of manual instruments can be restricted by malalignment of teeth and tooth contact areas. However, the results of this study showed that the space discrepancy measurement of both plaster and digital models differed in the range of 0.06–0.85 mm which was not different in any of the groups based on severity of crowding. This result disagreed with a study by Redlich *et al.*¹³ who found statistically significant differences between the measurements obtained from the plaster and digital models and that the differences of space discrepancy were large (1.19–3.00 mm) in severely crowded teeth. The results from Redlich showed significantly less crowding using the measurements from the digital models which consequently influenced the treatment plan. However, the differences in space discrepancy measured in severe crowding of teeth in the present study were small (0.41–1.15 mm). Differences between the 3D scanner system and the analyzing software functions may influence the measurements. The use of 3Shape OrthoAnalyzer™ software in this study has advantages such as the ability to magnify and rotate the digital model to identify the landmarks of measurement without changing their dimensions, as well as excellent resolution obtained with this type of software. Steven¹⁰ advocated that measurements on digital models were more valid than plaster models and reported that various malocclusions were obstacles to placing the caliper for measurements which affected the definite measurement points. However, digital models allowed for identifica-

tion of the measurement points by clicking the mouse point on the digital model.

Thus, as long as digital models are used carefully, it would be sensible to consider that the measurements on a digital model are more valid than those made on plaster models with calipers. However, the most recent innovation is the direct creation of a digital model by intraoral scanning of the patient's mouth. This system provides many advantages, especially the avoidance of making an impression, and it is convenient. Many studies showed that intraoral scanning has acceptable accuracy and reliability and can be an alternative diagnostic tool for clinical application. However, this system has some limitations due to intraoral conditions such as patient movement, saliva, and limited intraoral space which result in inaccurate scanning.¹⁸⁻²⁰

Many studies proved that a digital model from either model scanning or impression scanning can be a substitute for plaster models for all measurements and analysis in an orthodontic diagnosis. However, the skill of the operator in utilizing these new technologies is an important factor.

Conclusion

The use of digital models for a clinical diagnosis is sufficiently accurate for tooth size, segmental arch length measurement, and space discrepancy measurement in all groups of various degrees of tooth crowding. Nevertheless, more investigations should be undertaken to discover whether they are suitable for the clinical situation and result in similar treatment outcomes.

Conflicts of interest

The authors confirm there are no known conflicts of interest associated with this publication and there has been no significant financial support for this work that could have influenced its outcome.

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