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Original Article

Comparing the reliability and accuracy of clinical measurements using plaster model and the digital model system based on crowding severity

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Abstract

Background: This study aims to clarify whether 3Shape™ digital model system could be applied in orthodontic diagnostic analysis with certainty, especially under different crowding condition. Reliability, accuracy and efficiency of 3Shape™ digital model system were assessed by comparing them with traditional plaster cast.

Methods: 29 plaster casts with permanent dentition were transformed into digital models by 3Shape™ D800 scanner. All 29 models were categorized into mild-crowding (arch length discrepancy <3 mm), moderate-crowding (arch length discrepancy >3 mm and <8 mm), and severe-crowding group (arch length discrepancy >8 mm). Fourteen linear measurements were made manually using a digital caliper on plaster casts and virtually using the 3Shape™ Ortho Analyzer software by two examiners. Intra-class Correlation Coefficient (ICC) was used to evaluate intra-examiner reliability, inter-examiner reliability and reliability between two model systems. Paired t test was used to evaluate accuracy between two model systems. Kruskal−Wallis test followed by Mann−Whitney U test was used to evaluate the measurement differences between 3 groups in two model systems.

Results: Both intra-examiner and inter-examiner reliability were generally excellent for all measurements made on 3Shape™ digital model and plaster cast (ICC: 0.752−0.993). Reliability between different model systems was also excellent (ICC: 0.897−0.998). Half of the accuracy test showed statistically significant differences ($p < 0.05$) when digital models were compared with plaster casts. Furthermore, while assessing measurement differences between 3 groups in two model systems, the mandibular required space showed significant difference ($p = 0.012$) between mild crowding group (0.27 + 0.01 mm) and severe crowding group (0.20 + 0.09 mm). However, the differences were less than 0.5 mm and would not affect clinical decision.

Conclusion: Using 3Shape™ digital model system instead of plaster casts for orthodontic diagnostic measurements is clinically acceptable.

Keywords: Dental models; Imaging; Three-dimensional

1. Introduction

Successful orthodontic treatment is based on comprehensive diagnosis and treatment planning, and model analysis is a vital part for correct diagnosis. However, traditional plaster models have some shortcomings, such as storage space required, durability, and inefficient in terms of retrieval and transfer.

Conflicts of interest: The authors declare that they have no conflicts of interest related to the subject matter or materials discussed in this article.

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1990 digital model system OrthoCad™ was first introduced as a commercial product. After that, different digital model systems: such as E-model™, Suresmile™, Orthoproof™ and Ortholab™ came to the market from worldwide.

To testify the accuracy of digital model system replacing traditional plaster cast in orthodontic field, several studies had been performed for different digital model systems including OrthoCad™ system,[1−7] E-model™.[8,9] Most authors concluded these systems are valid alternative to traditional plaster study models in orthodontic diagnosis.

Aside from pure digital model service, some systems also provide accompanied software for orthodontic usage, one of which is 3Shape™ (Copenhagen, Denmark). From literature review, Lemos et al.[10] used R700 scanner (3Shape™) to transform plaster cast into digital model and test measurement reliability with 3Shape™ software by six selected measurements. Reuschl et al.[11] further investigated the reliability and validity of clinical measurements made on 3Shape™ digital models of dentition with no crowding or mild crowding. Anh et al.[12] compared the accuracy of two intraoral scanner scanning systems under four crowding situations and found larger scanning inaccuracies under severe crowding conditions.

Syed et al.[13] had evaluated the measurements accuracy and duration between 3Shape software (orthosystem) and plaster cast, the models were divided into 3 groups based on severity of crowding (group 1: <2.5 mm, group 2: 2.5−5 mm, and group 3: >5 mm). The results showed no statistically significant difference between the mesiodistal width measurements, arch length discrepancy and Bolton's values in all the three groups. However, space discrepancy >5 mm is not the condition we suspect to obstruct light from scanner. Severe crowding in our patient population are majority, and accurate space analysis for orthodontic diagnosis and treatment plan making are crucial.

Therefore, this study aims to clarify whether 3Shape™ digital model system could be applied in orthodontic clinical diagnosis with certainty, especially under real severe crowding condition.

2. Methods

Twenty-nine pretreatment diagnostic study model sets were enrolled in this study by stratified random sampling method. The subjects were classified into three groups according to the degree of crowding on single arch (minor crowding, arch length discrepancy <3 mm; moderate crowding, arch length discrepancy >3 mm and <8 mm; and severe crowding, arch length discrepancy >8 mm). Each stratum contains 9−10 sets of models.

These models were selected by 2 criteria: (1) Complete permanent dentition and fully eruption from first molar to first molar; (2) All teeth had normal morphology and no obvious dental abnormalities. All 29 plaster model sets were digitized using a D800 Scanner (3-shape™, Copenhagen, Denmark).

Two measuring methods were used: (1) measuring with digital caliper (accurate to 0.01 mm; Shanghai Taihai Congliang Ju Co., Lcd, Shanghai, China), (2) measuring digital model using 3shape™ measuring software (Ortho Analyzer), the computer was 14-inch screen with 1600 × 900-pixel resolution and 64-bit color. The zooming and rotation function were applied during virtual model analysis. Two well-trained examiners (L.R. and Y.L.) used both methods to do twelve horizontal measurements and two vertical measurements (#11 crown height and #35 crown height) (Table 1).

The two examiners took the measurement independently under a standardized workflow, and the required time was recorded. All measurements were performed to the nearest 0.01 mm.

Table 1
Measurement definition.

Variable	Definition
Max required space	Summation of the mesiodistal width of maxillary right and left first and second premolar, canine, lateral incisors and central incisors
Mand required space	Summation of the mesiodistal widths of mandibular right and left first and second premolar, canine, lateral incisors and central incisors
Max available space	Measured the parameters by the segmented arch approach with six segments from mesial side of maxillary right first molar to mesial side of left first molar.
Mand available space	Measured the parameters by the segmented arch approach with six segments from mandibular right first molar mesial side to left first molar mesial side.
Anterior Bolton	Percentage obtained by summing the width of the 6 mandibular anterior teeth divided by the by the sum of the widths of 6 maxillary anterior teeth
Overall Bolton	Percentage obtained by summing the width of the 12 mandibular teeth (first molar to first molar) divided by the by the sum of the widths of 12 maxillary teeth (first molar to first molar)
Overbite	Greatest amount of vertical overlap between upper and lower central incisors.
Overjet	Distance from the labial surface of the most anterior lower incisor to the labial surface of the most anterior of upper incisor.
Max inter-canine width	Distance between the cusp tip of maxillary canines
Max inter-molar width	Distance between the mesiobuccal cusp tip of maxillary first molars
Mand inter-canine width	Distance between the cusp tip of mandibular canines
Mand inter-molar width	Distance between the mesiobuccal cusp tips of mandibular first molars
11 crown height	Measured from the incisal edge to the gingival margin along the long axis of the maxillary right central incisor
35 crown height	Measured from buccal cusp tip to the gingival margin along the long axis of the mandibular left second premolar

For intra-examiner reliability evaluation, three parameters in different axis were selected (15 mesiodistal width, 35 crown height and maxillary inter-canine width) for repeat measurement two weeks later by each examiner.

All measurements were recorded and analyzed with SPSS version 20.0 (SPSS, Armonk, NY). Reliability of measurements for intra-examiner and inter-examiner was tested with the Intra-class Correlation Coefficient (ICC). Reliability and accuracy between two model systems were evaluated using data from single examiner. The reliability between plaster casts and digital models (system reliability) was tested using ICC. On the other hand, paired samples *t*-test was used at a 0.05 significant level to assess accuracy between two model systems. Kruskal—Wallis test was used to compare measurement differences between three groups, and Mann—Whitney U test with Bonferroni correction was used as post hoc test.

3. Results

Intra-examiner and inter-examiner reliability are generally excellent as reflected by ICC (Tables 2 and 3).

Reliability and accuracy between two model systems are shown in Table 4. System reliability was generally excellent with ICC range from 0.965 to 0.998. Half of the accuracy results show statistical significance. The greatest mean difference between plaster and 3-shape™ digital model is Mandibular required space (0.27 ± 0.05 mm).

As for the measurement differences between three groups, Kruskal—Wallis test revealed no statistical significance of all measurement except for the Mandibular required space measurement ($p = 0.012$) (Table 5). Post hoc test revealed statistical significance between severe crowding and mild crowding ($p = 0.008$). However, difference between severe crowding and moderate crowding ($p = 0.017$) and difference between mild crowding and moderate crowding ($p = 0.315$) did not reach to statistical significance level (Fig. 1).

The average time to measure the plaster casts was 19.19 min while the average time spent on measurements made on 3Shape™ digital model was 30.25 min.

4. Discussion

The key for digital models to replace plaster casts in the field of orthodontics should be test on two issues: 1. Can the scanner perfectly convert a plaster cast into a digital model? 2. Can a clinician obtain the same information from a digital model as from a plaster cast? Both approaches could possibly be affected by the degree of crowding in the dentition.

3Shape D800 scanner has multi-axis motion system that inclines and rotates the plaster model toward the light or camera to enhance scanning accuracy, and the manufacturer of D800 scanner claims that the accuracy of the scanning could achieve up to 15 μm under ISO 12836 standards. Hayashi investigated the accuracy and reliability of R700 scanner (3Shape™, Copenhagen, Denmark) using laser-based scanner

Table 3
Inter-examiner reliability of plaster cast and 3Shape™.

Variable	Plaster	3Shape™
	ICC	ICC
Max required space	0.799 (−0.157 to 0.950)	0.846 (−0.029 to 0.956)
Mand required space	0.816 (0.345—0.931)	0.846 (0.511—0.939)
Max available space	0.928 (0.145—0.981)	0.928 (0.253—0.980)
Mand available space	0.877 (−0.116 to 0.969)	0.826 (0.033—0.946)
Anterior Bolton	0.856 (0.691—0.932)	0.872 (0.730—0.940)
Overall Bolton	0.754 (0.475—0.885)	0.783 (0.534—0.898)
Overbite	0.972 (0.747—0.992)	0.975 (0.946—0.988)
Overjet	0.990 (0.975—0.996)	0.990 (0.978—0.995)
Max intercanine width	0.983 (0.913—0.994)	0.987 (0.973—0.994)
Max intermolar width	0.918 (−0.083 to 0.982)	0.928 (−0.047 to 0.985)
Mand intercanine width	0.975 (0.865—0.991)	0.983 (0.943—0.994)
Mand intermolar width	0.894 (−0.050 to 0.978)	0.887 (−0.055 to 0.976)
11 crown height	0.899 (0.787—0.953)	0.930 (0.851—0.967)
35 crown height	0.903 (0.796—0.954)	0.820 (0.616—0.916)

Table 4
Reliability and Accuracy between plaster cast and 3Shape™ (n = 29).

Variable	Mean difference	Pair t test	ICC
	(mm ± SD)	*p*	
Max required space	0.18 ± 0.05	0.002†	0.998 (0.995—0.999)
Mand required space	0.27 ± 0.05	0.000‡	0.998 (0.995—0.999)
Max available space	0.20 ± 0.08	0.022*	0.998 (0.996—0.999)
Mand available space	0.22 ± 0.09	0.025*	0.996 (0.991—0.998)
Anterior Bolton	−0.14 ± 0.06	0.021*	0.997 (0.993—0.998)
Overall Bolton	−0.24 ± 0.07	0.001†	0.997 (0.993—0.998)
Overbite	−0.16 ± 0.09	0.090	0.993 (0.984—0.997)
Overjet	−0.13 ± 0.09	0.151	0.994 (0.986—0.997)
Max intercanine width	0.23 ± 0.04	0.517	0.981 (0.960—0.991)
Max intermolar width	0.09 ± 0.02	0.103	0.998 (0.995—0.999)
Mand intercanine width	0.00 ± 0.00	0.264	0.965 (0.926—0.984)
Mand intermolar width	0.01 ± 0.00	0.016*	0.969 (0.935—0.986)
11 crown height	0.13 ± 0.16	0.702	0.990 (0.978—0.995)
35 crown height	0.06 ± 0.09	0.168	0.984 (0.966—0.993)

*$p < 0.05$; †$p < 0.01$; ‡$p < 0.001$.

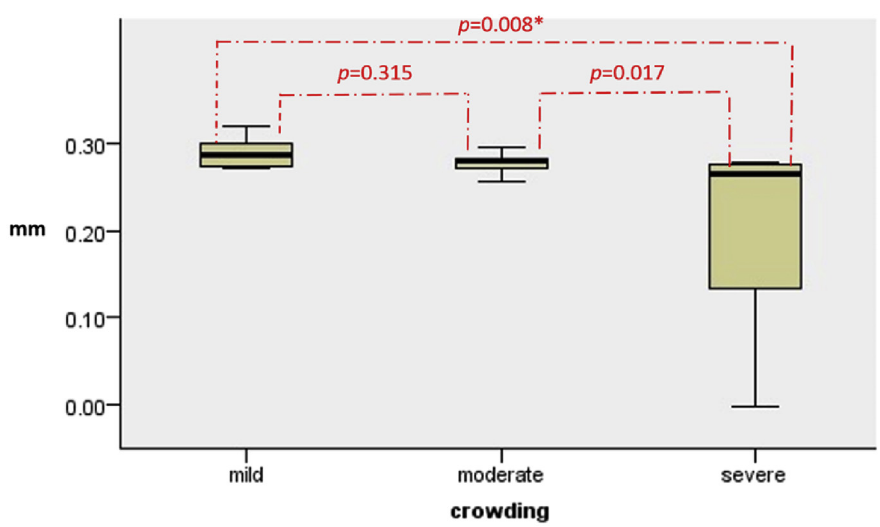
Table 2
Intra-examiner reliability.

Variable	Mean difference (mm ± SD)	Examiner 1	Examiner 2
		ICC	ICC
11 crown width (plaster)	0.08 ± 0.02	0.998 (0.997—0.999)	0.956 (0.908—0.979)
11 crown width (3Shape™)	0.05 ± 0.06	0.991 (0.982—0.996)	0.863 (0.698—0.937)
35 crown height (plaster)	0.09 ± 0.03	0.999 (0.996—0.999)	0.958 (0.910—0.980)
35 crown height (3Shape™)	0.07 ± 0.02	0.998 (0.996—0.999)	0.955 (0.905—0.979)
Max inter-canine width (plaster)	0.18 ± 0.05	0.999 (0.999—1.000)	0.981 (0.959—0.991)
Max inter-canine width (3Shape™)	0.15 ± 0.05	0.999 (0.998—0.999)	0.994 (0.987—0.997)

Table 5
Measurement difference between plaster cast and 3Shape™.

Variable	Group 1 (n = 10)	Group 2 (n = 10)	Group 3 (n = 9)	Kruskal—Wallis
	Mean difference	Mean difference	Mean difference	*p*
Max required space	0.16 ± 0.05	0.17 ± 0.06	0.18 ± 0.03	0.931
Mand required space	0.28 ± 0.01	0.27 ± 0.05	0.21 ± 0.09	0.012*
Max available space	0.20 ± 0.18	0.17 ± 0.08	0.21 ± 0.10	0.620
Mand available space	0.22 ± 0.07	0.23 ± 0.09	0.19 ± 0.01	0.576
Anterior Bolton	−0.14 ± 0.03	−0.10 ± 0.08	−0.14 ± 0.06	0.130
Overall Bolton	−0.24 ± 0.05	−0.23 ± 0.07	−0.22 ± 0.07	0.697
Overbite	−0.16 ± 0.09	−0.10 ± 0.19	−0.15 ± 0.04	0.780
Overjet	−0.11 ± 0.09	−0.13 ± 0.10	−0.13 ± 0.02	0.889
Max intercanine width	0.23 ± 0.02	0.25 ± 0.04	0.20 ± 0.09	0.973
Max intermolar width	0.10 ± 0.02	0.09 ± 0.03	0.09 ± 0.01	0.585
Mand intercanine width	−0.01 ± 0.01	0.00 ± 0.01	0.01 ± 0.00	0.263
Mand intermolar width	0.01 ± 0.00	0.01 ± 0.01	0.01 ± 0.00	0.727
11 crown height	0.13 ± 0.17	0.14 ± 0.08	0.13 ± 0.10	0.757
35 crown height	0.06 ± 0.03	0.07 ± 0.04	0.04 ± 0.13	0.116

Group 1: mild crowding dentition; Group 2: moderate crowding dentition; Group 3: severe crowding dentition (*$p < 0.05$).



*$p < 0.016$ (Mann-Whitney U test with Bonferroni correction)

Fig. 1. Comparison of measurement difference of mandibular required space in different crowding severity.

as gold standard. They found a maximum deviation of 0.05 mm between the laser-based scanner and R700, which was clinically acceptable. However, severely crowded dentition was not included in the samples.[14] According to the study be Anh et al., intraoral scanners which has free degree of picture capturing, produced less scanning precision in case with increased irregularity.[12] Clinically, lingually tilted teeth was often seen in a severely crowded mandibular arch, and extremely lingually tilted tooth were potentially to obstruct light from the scanner due to the limited degree of motion of the scanner, reducing its scanning accuracy.

The second important question is whether a clinician can obtain the same information from a digital model as they do from a plaster cast? Literature reviews have reported that accuracy and repeatability of dental arch measurements are influenced by tooth inclination, rotation, interproximal contacts, anatomic variations, and inter-examiner variability.[15,16] Shellhart et al. pointed out that measurement discrepancies can vary by as much as 1.5 mm when a digital vernier caliper is used on a plaster cast with mild crowding.[16] Bernabe also noted a 0.39 mm/0.51 mm difference in non-crowded/crowded plaster cast measurements.[17] In summary, crowding severity can surely affect the measurements from plaster model. But the measurement error was clinical acceptable for orthodontic diagnosis and treatment plan making. As for the information provided by Digital model analysis after scanning with 3Shape D800 scanner should be testified and compared.

4.1. Intra-examiner and inter-examiner reliability

A good measurement tool must give consistent results across time and different examiners. Therefore, we performed the intra-examiner and inter-examiner reliability test to evaluate the two measuring tools: plaster cast and 3Shape™ digital model. According to Roberts,[18] ICC results for the intra-examiner reliability of the two model systems were >0.75, which is categorized as excellent reliability. Mullen et al.[19] found that intra-examiner errors of both digital model and plaster cast were all statistically significant. In addition, the intra-examiner error was slightly greater while using digital model than while using plaster cast. They presumed that this difference was due to the use of a different version of software for the second measurements. In comparison to previous studies, our study indicates excellent reliability on intra-examiner measurements and the maximum measurement difference between first and second time was 0.23 mm (Max inter-canine width) (Table 2), which might not affect orthodontic treatment decision.

As for the inter-examiner reliability, ICCs of the two model systems were also excellent. The results might be related to the reference point definition training before formal measuring. According to our results, both plaster cast and 3Shape™ digital model system are reliable measuring tools regardless of different examiners or time point if pre-training was sufficient.

4.2. Reliability and accuracy between two model systems

According to Roberts,[18] the system reliability in this study was considered as the extent to which a new diagnostic measuring procedure (3Shape™ digital model system) and current gold standard (plaster cast) yield the same results under identical conditions. Accuracy was defined as the extent to which the new diagnostic measure procedure against the gold standard. The system reliability results between plaster cast and 3Shape™ digital model indicated excellent reliability with highest ICC 0.998 and lowest ICC 0.965.

Half of the accuracy tests showed statistically significant results between plaster cast and digital model (Table 4). The mean differences of measurement between two systems were all under 0.3 mm. According to the American Board of Orthodontics objective grading system (ABO OGS),[20] the smallest distinguishable parameter in all three dimension is 0.5 mm, which could be regard as clinical insignificant. Therefore, the differences in this study might be considered as clinical insignificant. But the notable data were that the mean values of space required of 3Shape™ digital model system were smaller than those of plaster cast, which was consistent with previous studies.[2,19,21–24] We attribute this finding to the physical barrier of the plaster cast; for example, the caliper tip could be hampered by neighboring teeth during the measuring process, which may jeopardize the precision of results.

4.3. Measurement differences between three groups

There exist measuring differences between different crowding severities when performing mandibular space measurements. Statistical significant differences ($p = 0.008$) were found between severe crowding group (mean = 0.21, SD = 0.09) and mild crowding group (mean = 0.28, SD = 0.01). These results are partly according to our anticipation. In our assumption, larger differences in measurements and large standard deviations in the severe crowding group were anticipated. However, the results confirm that the standard deviation in the severe crowding group was larger than that in the mild crowding group, but the difference in measurement was lesser than that in the mild crowding group.

The larger standard deviation may be due to the measuring error. While measuring using a digital model, the examiner needs to rotate through larger angle over the 2D screen for heavily tilted teeth. A different angle of view on the 2D screen may result in different measurements. As for the plaster cast, severe crowding leads to more physical barrier for the plaster cast and cause more difficulty while placing the caliper tip at the correct point on the plaster cast. Further study should be done with a larger sample size in different group to evaluate the measuring accuracy in severely crowded dentitions.

4.4. Efficiency between systems

The accuracy of dental model measurement depends heavily on the point identification. How to identify the three-dimensional relationship on a two-dimensional computer screen is the crucial factor while measuring. Stevens et al.[21] pointed out that unlike plaster cast that provides "real" three-dimensional representation, slight rotations of the digital model on the computer screen can quickly change the operator's perception. Examiners need to rotate virtual images to ensure that correct points are identified on digital models. This can hinder efficiency compared to work with plaster casts. Nevertheless, some authors[1,3,10] suggest that digital model systems are more efficient for Bolton ratio measurements than the manual method as these digital model systems provide automatic calculation function after measurement.

In conclusion, 3Shape™ digital model system are reliable measuring tools after sufficient pre-training for examiners. Also, it could be a viable option to replace plaster cast in the clinical orthodontic diagnostic field. But further attention should be taken when performing measurements on the severe crowding dentition.

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