

# Validity of Digital and Rapid Prototyped Orthodontic Study Models

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## ABSTRACT

**Background:** The integration of modern computer-aided design and manufacturing technologies in diagnosis, treatment planning, and appliance construction is changing the way in which orthodontic treatment is provided to patients. The aim of this study is to assess the validity of digital and rapid prototyped orthodontic study models as compared to their original stone models.

**Materials and methods:** The sample of the study consisted of 30 study models with well-aligned, Angle Class I malocclusion. The models were digitized with desktop scanner to create digital models. Digital files were then converted to plastic physical casts using prototyping machine, which utilizes the fused deposition modeling technology. Polylactic acid polymer was chosen as the printing material. Twenty four linear measurements were taken from digital and prototyped models and were compared to their original stone models "the gold standard", utilizing the paired sample *t*-test and Bland-Altman plots.

**Results:** Eighteen of the twenty four variables showed non-significant differences when digital models were compared to stone models. The levels of agreement between the two methods showed that all differences were within the clinically accepted limits. For prototyped models, more than half of the variables differed in non-significant amount. The levels of agreement were also within the clinically accepted limits.

**Conclusion:** Digital orthodontic study models are accurate in measuring the selected variables and they have the potential to replace conventional stone models. The selected rapid prototyping technique proved to be accurate in term of diagnosis and might be suitable for some appliance construction.

**Keywords:** Digital models, Rapid prototyping, Orthodontic diagnosis. (J Bagh Coll Dentistry 2017; 29(3):80-85)

## INTRODUCTION

Orthodontic study models are important part of diagnostic armamentarium, they provide a stable and accurate representation of human dentition and their surrounding structures<sup>(1-3)</sup>. Despite their importance, they are associated with drawbacks, such as considerable space required for storage, the heavy weight and brittle nature of gypsum products made them subjected to fracture and cumbersome in handling and long distance communication with other professionals<sup>(4-6)</sup>.

Researchers tried to find alternatives to conventional models with many approaches namely: photocopying<sup>(7-9)</sup>, digital photography<sup>(10)</sup>, hologram<sup>(11)</sup>, stereo-photogram<sup>(12)</sup>, three-dimensional contact digitizers<sup>(13,14)</sup> and optical scanners<sup>(15)</sup>. With optical scanners, it is possible to create digital models by directly scanning the patient's teeth or indirectly scanning the cast or impression<sup>(16,17)</sup>.

Digital models allow the orthodontists to perform space analysis and treatment setups virtually and they eliminate storage problems associated with stone models. Additionally, they open the way for computer aided appliance manufacturing<sup>(18-20)</sup>. However, for digital models to completely replace traditional models, they have to be accurate and it should be possible to re-

trieve a physical representation of the model if needed for legal purposes or appliance design<sup>(21,22)</sup>. Fortunately, with rapid prototyping, it is now possible to fabricate physical model from digital files, in this technology computer aided machines creates study models from substrate materials in an additive or subtractive manner depending on the original geometry of the digital models<sup>(23-25)</sup>.

Additive rapid prototyping or (three-dimensional printing) is the process of building solid object from digital file by incremental layering, the basic idea involves slicing the digital model into thin slices with sophisticated software and send these slices to a 3D printer controlled by computer<sup>(25)</sup>. Additive technology includes different manufacturing techniques namely: fused deposition modeling (FDM), stereolithography (SLA), digital light projector (DLP), poly jet photopolymer (PPP), selective electron beam melting (SEBM) and laser powder forming techniques<sup>(26,27)</sup>.

In additive manufacturing, fine details such as undercuts, voids, and complex internal geometries are efficiently reproduced, besides no or very little substrate material get wasted in the process. However, the techniques are time-consuming and rather expensive<sup>(28)</sup>. The subtractive technology utilizes computer numerically controlled machines (CNC) that have sharp cutting tools to mechanically cut away material and achieve the desired geometry, with all steps controlled by computer software programs<sup>(23)</sup>. Cutting tools

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could be burs, water jet, laser or electron beam cutting.

Subtractive manufacturing techniques take less time than additive but they are wasteful procedures as a large amount of material is wasted during manufacturing<sup>(29)</sup>. The digital models and its rapid prototyped replicas are becoming increasingly popular among orthodontic clinics as a part of modern trends toward incorporating modern technologies into every day practice.

However, for any new diagnostic set, it has to be accurate before it can be implemented into clinical practice. This study was conducted to assess the validity of digital models required with a structured light desktop scanner and their rapid prototyped replicas.

## MATERIALS AND METHODS

Thirty patients who fulfilled the selection criteria were chosen for this study. The selection criteria included; Angle class I malocclusion<sup>(30)</sup> with well-aligned dentition, no fillings, extractions, large carious lesions, attachments, prosthesis nor history of previous orthodontic treatment<sup>(18,31-33)</sup>. After describing the purposes of the study; signed ethical approval of participation was taken from each patient.

### Stone models preparation

Impressions for both arches were taken using alginate (Hydrogum®. Zhermack, Italy), with suitable disposable plastic tray. Impressions were disinfected with sodium hypochlorite (1/10)<sup>(34)</sup>, wrapped in a wet towel and stored in closed plastic bag. The bite was registered using wax (Base plate wax, China), warmed with hot water and rolled to arch form<sup>(35)</sup>.

Dental stone (Elite® model. Zhermack, Italy) was used to pour the impression according to manufacturer instructions. Time elapsed between impression taking and pouring was less than 1 hour<sup>(36)</sup>. Thin consistency of plaster of Paris was used to create the model bases, the base was then trimmed according to bite registration.

### Digital models preparation

Dental study models were sent to a laboratory equipped with desktop dental scanner (InEox5, Sirona®, Germany), which was connected to a computer that had Sirona InLap® software fully activated and functional to control the scanning process.

Scanning dental models involved in three steps; first maxillary and mandibular casts are scanned separately, the second step involves articulating the maxillary and mandibular arches by utilizing the 'bite registration algorithm'.

Finally, the digital models were exported in .stl (standard tessellation language) file format to be successfully integrated into space analysis software.

### Rapid prototyping

Digital models were sent by electronic mail to engineering facility equipped with three-dimensional printer (Micromake® China). The printing material used was polylactic acid (PLA) polymer.

### Measuring procedure

Linear measurements were taken (first molar width, canine width, central incisor width, inter-molar width, inter-canine width, posterior and anterior arch length), measurement were made on both arches and from right and left sides, which gave a total of 24 measurements.

Stone and prototyped models were measured using digital caliper with sharpened peaks according to the method described by Hunter and Priest<sup>(37)</sup>. Anatomical contact points and cusps tips were marked with a fine pencil to improve accuracy. Digital models were measured using OrthoSelect® (version 2.9) analysis software, zoom and rotation functions were utilized when needed to gain better visualization of landmarks.

### Statistical analysis

Paired sample *t*-test was used to compare between stone, digital and rapid prototyped models measurements in term of systematic errors (Table 1).

The Bland-Altman test<sup>(38,39)</sup> was used to assess the level of agreement between the three types of models in term of random errors (Table 2).

## RESULTS

When stone models were compared with digital models 18 out of 24 of the variables showed non-significant differences. Most of the variables appeared to be larger on digital models, indicated by the negative mean differences.

The mean differences in tooth width were (-0.1mm-0.07mm), for arch width (-0.4mm-0.03mm) and for arch length (-0.18mm-0.08mm). The biases were (-0.02mm, -0.21mm, -0.08mm) for tooth width, arch width, and arch length respectively. Limits of agreements were about ( $\mp 0.3$ mm,  $\mp 0.9$ mm,  $\mp 0.7$ mm).

Replicated models were compared to their original stone models (Table 1). More than half of the variables differ in non-significant amount with mean differences range between (-0.04mm-

0.05mm) for teeth width, (0.15mm-0.27mm) for arch width, (-0.08mm - 0.1mm) for arch length.

Bland- Altman plot revealed that tooth width had a negative bias (-0.001mm), indicating that it scored larger on replica while arch dimensions

were smaller as indicated by their positive bias (0.23mm,0.05mm). Limits of agreements were about ( $\mp$ 0.28mm,  $\mp$ 0.9 mm,  $\mp$ 0.5mm) for teeth width, arch width, and arch length.

**Table 1: Descriptive data and paired sample t-test**

Variables			Stone Models		Digital Models vs. Stone Models				Prototyped Models vs. Stone Models			
			Mean	SD	Mean	SD	Difference	P-value	Mean	SD	Difference	P-value
Maxilla	Teeth width	R6	9.74	0.58	9.84	0.57	-0.102	0.01*	9.79	0.61	-0.048	0.04*
		L6	9.72	0.65	9.71	0.63	0.001	0.96	9.75	0.63	-0.038	0.10
		R3	7.94	0.44	7.96	0.55	-0.020	0.52	7.94	0.42	-0.002	0.96
		L3	7.81	0.54	7.88	0.58	-0.073	0.04*	7.82	0.53	-0.012	0.66
		R1	8.71	0.67	8.66	0.62	0.054	0.13	8.71	0.62	0.004	0.89
		L1	8.79	0.71	8.72	0.68	0.072	0.03*	8.74	0.73	0.057	0.04*
	Arch width	ICD	34.72	3.23	34.88	3.29	-0.163	0.06	34.44	3.35	0.278	0.00*
		IMD	51.55	3.30	52.02	3.21	-0.466	0.00*	51.29	3.29	0.256	0.02*
	Arch length	RPAL	13.62	0.84	13.80	0.86	-0.180	0.00*	13.70	0.90	-0.085	0.17
		LPAL	13.80	0.79	13.89	0.87	-0.095	0.07	13.66	0.88	0.143	0.01*
		RAAL	23.59	1.84	23.54	1.76	0.051	0.40	23.50	1.76	0.090	0.04*
		LAAL	23.58	1.80	23.49	1.92	0.084	0.09	23.55	1.89	0.033	0.39
	Mandible	Teeth Width	R6	10.81	0.72	10.87	0.70	-0.066	0.06	10.76	0.71	0.049
L6			10.89	0.74	10.92	0.67	-0.030	0.41	10.91	0.73	-0.016	0.41
R3			6.90	0.48	6.89	0.54	0.002	0.94	6.88	0.47	0.018	0.58
L3			6.90	0.43	6.94	0.51	-0.039	0.21	6.92	0.44	-0.017	0.60
R1			5.35	0.36	5.38	0.37	-0.028	0.41	5.34	0.36	0.011	0.54
L1			5.35	0.36	5.38	0.37	-0.029	0.30	5.37	0.32	-0.022	0.37
Arch width		ICD	26.30	2.39	26.27	2.48	0.033	0.65	26.15	2.52	0.157	0.12
		IMD	45.13	3.23	45.35	3.36	-0.224	0.07	44.88	3.34	0.246	0.03*
Arch length		RPAL	14.23	0.74	14.35	0.80	-0.119	0.02*	14.24	0.78	-0.007	0.86
		LPAL	14.41	0.83	14.57	0.74	-0.161	0.06	14.27	0.78	0.140	0.06
		RAAL	17.77	1.12	17.88	1.06	-0.109	0.07	17.78	1.05	-0.011	0.74
		LAAL	17.59	1.23	17.70	1.33	-0.106	0.07	9.79	0.61	-0.048	0.04*

R: right, L: left, 6: First molar width, 3: Canine width, 1: Central incisor width, ICD: Inter canine width, IMD: Inter-molar width, PAL: posterior arch length, AAL: anterior arch length. All measurements in mm  
\*Statistically significant

**Table 2- Bland – Altman test**

Variable	Digital models VS Stone models		Prototyped models VS Stone models	
	Bias	Levels of agreement	Bias	Levels of agreement
Teeth width	-0.02mm	$\mp$ 0.3mm	-0.001mm	$\mp$ 0.28mm
Arch width	-0.21mm	$\mp$ 0.9mm	0.23mm	$\mp$ 0.9 mm,
Arch length	-0.08mm	$\mp$ 0.7mm	0.05mm	$\mp$ 0.5mm

**DISCUSSION**

Dental study model is the cornerstone in orthodontic diagnosis with long and proven history, but its associated drawbacks gave the rise to digital alternatives. However, the digital model has to be accurate to replace the stone model and physical replication should be possible if needed.

In this study, the accuracy of digital models scanned with locally available laboratory scanner was assessed in addition to the validity of rapid

prototyped models that were replicated with additive manufacturing technology.

A sample size of 30 model was considered sufficient to study the validity (40-42). The variables were selected to give a representative set of measurements from all aspects of the model (right buccal, left buccal, canine region, frontal and occlusal aspects), in order to make sure that there is no data missing in all aspects of digital models and no error in printed models in all planes of space (43,44).

Validity was considered as the extent to which digital and prototyped models measured against the stone models “the gold standard”<sup>(45)</sup>. The clinically acceptable limit of differences between the tested model and stone models is < 0.5 mm for teeth width, and < 5% for mean of arch dimensions<sup>(18,44, 46-49)</sup>. The mean differences of all variable indicating that some measurements were larger on digital models as compared with stone models other were smaller, this could be attributed to errors in landmarks identification<sup>(6, 42,50)</sup>.

Many causes of error that were reported in the previous studies were avoided in this study. The same cast that was scanned used for manual measurements and no differences could be attributed to the materials. The operator was well trained and calibrated and landmarks were carefully identified. Nevertheless, variation still exists, this could be explained by the difficulty of measuring three-dimensional objects on a two-dimensional computer screen<sup>(51-54)</sup>. Additionally, arch width suffered the greater range of differences among all variable. Jacquet et al.<sup>(55)</sup> explained that locating the tip of the cusp on digital models is difficult and may be affected by many technical features of the computer and software. Mean differences for all variables ranged between (-0.46mm-0.08mm), this is close to the range reported in previous studies<sup>(22,47,56)</sup>.

The biases and levels of agreement reported by Bland–Altman test indicated that all the differences within the clinically acceptable limits. Both models (digital and stone) can be used for diagnostic purposes interchangeably in well-aligned arches. For prototyped models, the mean differences of all variables ranged from (-0.08mm-0.27mm), this came in accordance to Kasprova et al.<sup>(43)</sup>.

Arch width suffered the greatest variation and it had a positive bias indicating that it was smaller on the prototyped replicas, also it had the widest levels of agreement. The cause of this variation is the measurements of arch width depend on the identification of the cusps tips which were rather difficult to identify on the prototyped models, since the occlusal surface is the last layer to be deposited by the printer head it will be subjected to the greatest variations.

The same finding was described by Keating et al.<sup>(41)</sup>. However, all differences lie within the clinically accepted limits and prototyped models are a valid alternative to stone models in term of orthodontic diagnosis<sup>(21,43,57)</sup>.

In conclusion; digital study models are valid alternative to stone models with clinically acceptable accuracy in measuring teeth width and

arch dimensions, and rapid prototyped models have acceptable validity and in term of diagnosis and it could be applicable in the construction of selected types of appliances.

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#### الخلاصة:

الخلفية: ان التوافق الحاصل بين علوم الحاسوب الحديثه وتقويم الاسنان من حيث التشخيص والعلاج وصناعه الاجهزه التقويميه, أحدث تغيرا جذريا في أساليب تقديم العلاج التقويمي للمرضى. الهدف من هذه الدراسه هو تقييم دقه النماذج التشخيصيه التقويميه والنماذج المصنوعه بتقنيه الطباعه ثلاثيه الابعاد عن طريق مقارنة النماذج الاعتياديه المصنوعه من المشتقات الجبسيه.

المواد والطرق: تتكون العينه من 30 نموذج تشخيصي , تمتاز الاسنان فيها بكونها حسنه الترتيب وتقع ضمن النمط الاول لسوء الاطباق. تم تحويل النماذج الجبسيه الى ملفات رقميه باستخدام جهاز الماسح الضوئي. النماذج الرقميه حولت الى مجسمات بلاستيكيه باستخدام طباعه ثلاثيه الابعاد التي تعتمد في عملها على تقنيه الصهر والصب والترسيب. تم استخدام بوليمر حمض اللاكتيك المتعدد كماده اساسيه في الطباعه. تم أخذ اربع و عشرون قياسا خطيا من كل نموذج من النماذج الرقميه والمطبوعه حاسوبيا وقورنت مع نفس القياسات المأخوذه من النماذج الجبسيه.

النتائج: مقارنة النماذج الرقميه والجبسيه لم تبين اي فرق معنوي في 18 من اصل 24 متغير. مستويات التوافق بين النموذجين اوضحت ان جميع الفروقات تقع ضمن الحدود المقبوله عمليا. بالنسبه للنماذج المصنعه حاسوبيا أكثر من نصف المتغيرات لم تبين أي فرق معنوي عندما قورنت مع النماذج الجبسيه. مستويات التوافق كانت أيضا ضمن الحد المقبول عمليا.

الاستنتاجات: النماذج الرقميه تتصف بدقه كافيه لقياس المتغيرات المختاره في هذه الدراسه. ومن الممكن استخدامها كبديل عن النماذج الجبسيه التقليديه بتقنيه الطباعه ثلاثيه الابعاد المستخدمه في هذه الدراسه تتمتاز بدقه كافيه لصناعه النماذج التشخيصيه. وقد تكون مناسبه لصناعه بعض الاجهزه التقويميه.

الكلمات الرئيسيه: النماذج الرقميه, طباعه ثلاثيه الابعاد, التشخيص التقويمي