Al-Rafidain Dental Journal
rden.mosuljournals.com

A Comparison Between Virtual Models Obtained by Intraoral Scanner and Their Three Dimensionally Printed Models

Ashraf Measar Mohamad, **Ammar Kh. Al-Noori**

[1] Al-Noor Specialized Dental Centre, Nineveh Health Department, Ministry of health and Environment
[2] Department of Prosthetic Dentistry, College of Dentistry, University of Mosul

Article information

Received: 24 Juley, 2021
Accepted: 29 August, 2021
Available online: 5 March, 2023

Keywords
Virtual Casts
Intra Oral Scanners
3D printed model

***Correspondence:**
E-mail
ashraf1985hasso@gmail.com

Abstract
Aims: Evaluate and compare the accuracy of virtual models and their three dimensionally printed (3D) models. **Materials and methods**: Reference models were prepared with four types of prostheses: 3-unit fixed bridge (FXD), single crown (SC), Cl I Kennedy classification (Cl I) and Cl III Kennedy classification (Cl III). Digital impressions of the reference model were created using the Trios intraoral scanner. Reference and 3D printed models were subsequently scanned using a laboratory optical scanner, and files were exported in a stereolithography file format. All datasets were superimposed using 3D analysis software to evaluate the accuracy. The Wilcoxon signed-rank test weas performed to compare the virtual and 3D printed groups in each type of preparation model .**Results**: The 3D printed casts showed a higher deviation from the reference cast (in all types of preparations) than the virtual cast of Trios IOS. There were significant differences between virtual and 3D printed cast samples in the Fixed bridge, Single Crown and Class I Kennedy Classification groups, while for the comparison between the virtual and 3D printed cast samples in the Class III Kennedy Classification group, we found that there were no significant differences. **Conclusions**: Intraoral scanners have a high accuracy level. The 3D printed models showed a significantly higher deviation than the digital impression with a clinically acceptable level of accuracy.

الخلاصة
الأهداف: تهدف الدراسة الى تقييم ومقارنة دقة النماذج الافتراضية ونماذجها ثلاثية الأبعاد المطبوعة.**المواد وطرائق العمل**: تم إعداد النماذج المرجعية بأربعة أنواع من الأطراف الاصطناعية: جسر ثابت مكون من 3 وحدات، تاج مفرد، تصنيف كيندي الفئة الاولى وتصنيف كيندي الفئة الثالثه. تم إنشاء الطبعات الرقمية للنموذج المرجعي باستخدام ماسح ضوئي داخل الفم. تم بعد ذلك مسح النماذج المرجعية والطباعة ثلاثية الأبعاد باستخدام الماسح الضوئي المخبري ؛ تم تصدير الملفات بتنسيق ملف الطباعة الحجرية المجسمة. تم تركيب جميع مجموعات البيانات باستخدام برنامج تحليل ثلاثي الأبعاد لتقييم الدقة. تم إجراء ختبار ويلكوكسن للعينات المرتبطة (المزدوجة) لمقارنة المجموعات الافتراضية والمجموعات المطبوعة ثلاثية الأبعاد في كل نوع من نماذج التحضير.**النتائج**: تُظهر القوالب المطبوعة ثلاثية الأبعاد انحرافًا أعلى عن النموذج المرجعي (في جميع أنواع التحضيرات) مقارنةً بالطبعات الافتراضية للماسح الضوئي Trios. توجد فروق ذات دلالة إحصائية بين القوالب الافتراضية وثلاثية الأبعاد المطبوعة في مجموعات تحضير الجسر الثابت والتاج الفردي والفئة الأولى كينيدي ، بينما بالنسبة للمقارنة بين عينات القوالب الافتراضية وثلاثية الأبعاد المطبوعه في مجموعة تصنيف كينيدي من الفئة الثالثة ، وجدنا أنه لا توجد فروقات معنوية.
الاستنتاجات: الماسحات الضوئية داخل الفم تتمتع بمستوى عالٍ من الدقة. أظهرت النماذج المطبوعة ثلاثية الأبعاد انحرافًا أعلى بكثير من الانطباع الرقمي بمستوى دقة مقبول سريريًا.

DOI: 10.33899/rdenj.2021.130918.1125

INTRODUCTION

The accuracy of the imprinting process is one of the most important factors in the creation of a dental prosthesis. The traditional imprinting process involves obtaining a dental impression using an elastomeric material, followed by the fabrication of a stone replica. [1]. In comparison to the actual tooth, the gypsum replica's accuracy ranges or enlarges, implying that the gypsum model's volume changes. [2]. Contamination of the impression by saliva and blood is one of the disadvantages of the traditional impression process. [3]. Due to insufficient storage or unanticipated stress imparted to the tray and impression during transportation or shipment until it reaches the dental laboratory, elastomeric impressions might be deformed. [4]. Following the rapid advancement of computer-aided design and computer-aided manufacturing (CAD/CAM) technology, as well as the rapid advancement of intraoral scanner (IOS) capability, the construction of dental prostheses and replicas has been quickly transformed to complete digital production. [5]. Virtual models created with an intraoral scanner in three dimensions (3D) can replace the requirement for a traditional impression and physical model creation. They have a number of advantages, including the ability to store data indefinitely and a decrease in patient discomfort caused by the use of impression materials. [6]. However, some restorations still require a physical model, as the model is needed to estimate the relationship between the restoration and the adjacent and opposing teeth. The physical model is also mandatory when fabricating prostheses that require manual application of wax-up on the model, such as casting gold alloy or heat-pressing lithium disilicate. [7]. Additive manufacturing is a technology in which the desired products are produced through the layer-by-layer accumulation of materials [8]. It eases the fabrication of complex structures that are difficult to fabricate by milling and allows immediate large-scale fabrication. In addition, the additive manufacturing method can save time and minimize labor [9]. Although several studies investigating the accuracy of dental models fabricated by digital workflow have been reported, most are limited to the diagnostic models used in orthodontics [10]. Further studies on the accuracy of digitally produced prosthodontic models are required [11].

This study aimed to compare and evaluate the accuracy of virtual casts obtained using intraoral scanner and the 3D printed models from them.

MATERIALS AND METHODS

***1. Experimental design*:**

The reference model scanned with high-definition laboratory scanner E1 to make the virtual reference model **(R.VM)**. The size of the comparison group was (n=5) samples. All samples were superimposed with the reference cast using 3D analysis software Geomagic control X from 3D systems to evaluate the accuracy of each group regarding the target area of interest. Wilcoxon Signed Ranks Test were performed to compare the accuracy of both groups in all types of preparation models.

2. Master Model Preparation (R.VC):

To be compliant with the optical scanning that was employed in the investigation, a dimensionally stable plastic model with opaque color was used. Partially Dentated Upper Model Jaw (A-3 Partially Dentate Upper Jaw; Frasaco, Germany) (Fig. 1). Cast was scanned with the laboratory scanner (E1; 3Shape, Denmark) to obtain the Reference virtual model. According to the assembly specifications, there are multiple scanning steps. The resulting Reference Virtual Models exported as Standard Tessellation Language STL files to be analyzed by the 3D analysis software Geomagic Control X. The master virtual cast and the selected target area for best fit alignment and comparison is shown in (Fig. 2).

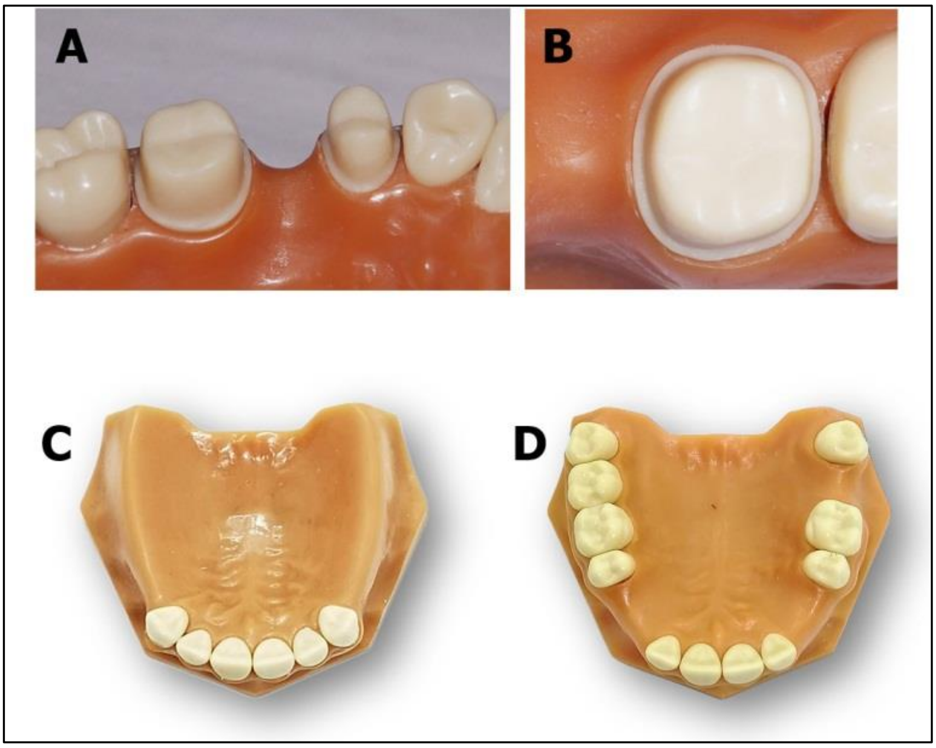

Figure (1): Reference Models. A. Three Units fixed bridge preparation. B. Single Crown preparation. C. Class I Kennedy Classification Upper Arch. C. Class III Kennedy Classification Upper Arch.

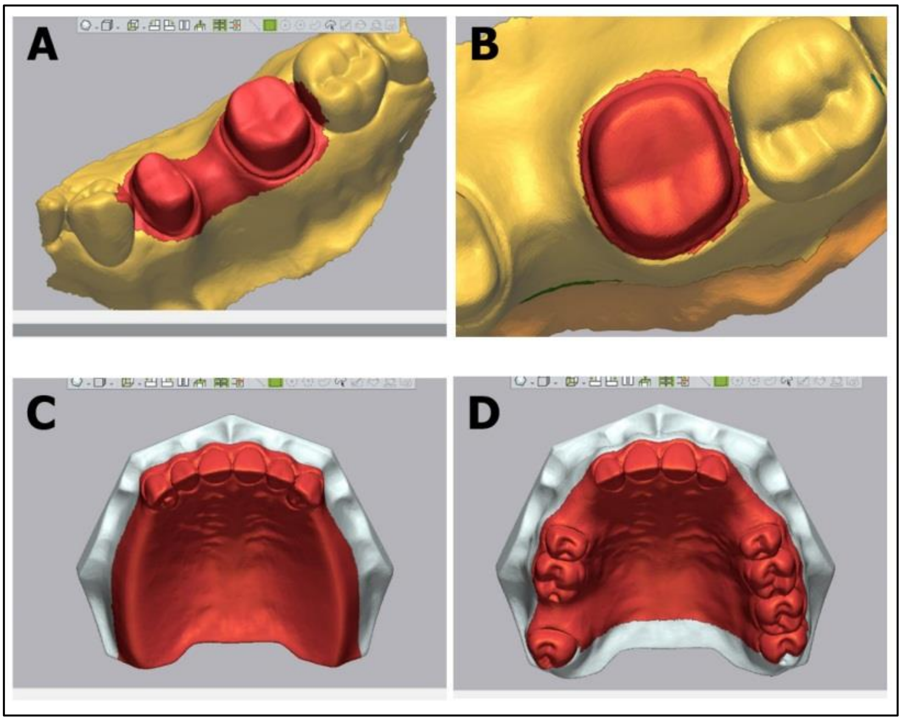

Figure (2): Virtual Reference Models. The red area represents the target area for the best fit alignment and 3D comparison with the measured casts on each group. A. Three Units fixed bridge preparation. B. Single Crown preparation. C. Class I Kennedy Classification Upper Arch. C. Class III Kennedy Classification Upper Arch.

3. Trios Intraoral Scanner Group

For the scanning of the upper dental arch, the proposed scanning path consists of three swipes: occlusal, buccal, and palatal, to ensure good data coverage of all essential areas. (Fig. 3). The scanner was hold by hand as near as possible to the model. Each master model scanned 5 times making 5 samples. The scanning files exported as STL files.

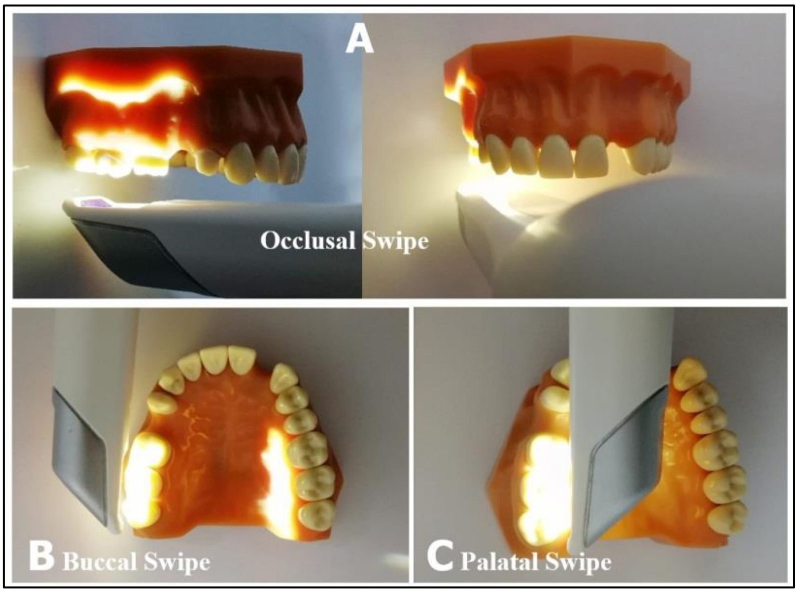

Figure (3): Recommended scanning path.

4. 3D Printed Models Group

The digital impressions of the reference model that were obtained by using an intraoral scanner (Trios3; 3Shape, Denmark). The datasets from each scan were automatically saved as STL files, The Sample size (n = 5) [12.13] .3D printed models were fabricated using a 3D dental model printer (Versus; Microlay, Spain) with stereolithography technology uses a scanning laser to build parts one layer at a time in a vat of light-cured photopolymer resin (Optiprint Model; Dentona, Germany). Post-processing involves removal of excess resin after printing (Fig. 4). The scanner was calibrated before each scanning session. The models were subsequently scanned with the reference scanner (E1; 3Shape, Denmark) in the recommended protocol. The 3D printed model placed on the scanning stage and fixed using the blue tag (Fig. 5). The target teeth have been determined and the primary scanning is done after that the important areas determined with green color to be rescanned in high-definition scanning then checked about any missed area or unclear spots to be rescanned again in adaptive scanning (Fig. 6). When the scan completed successfully the file exported in STL format to be ready for analysis (Fig. 7).

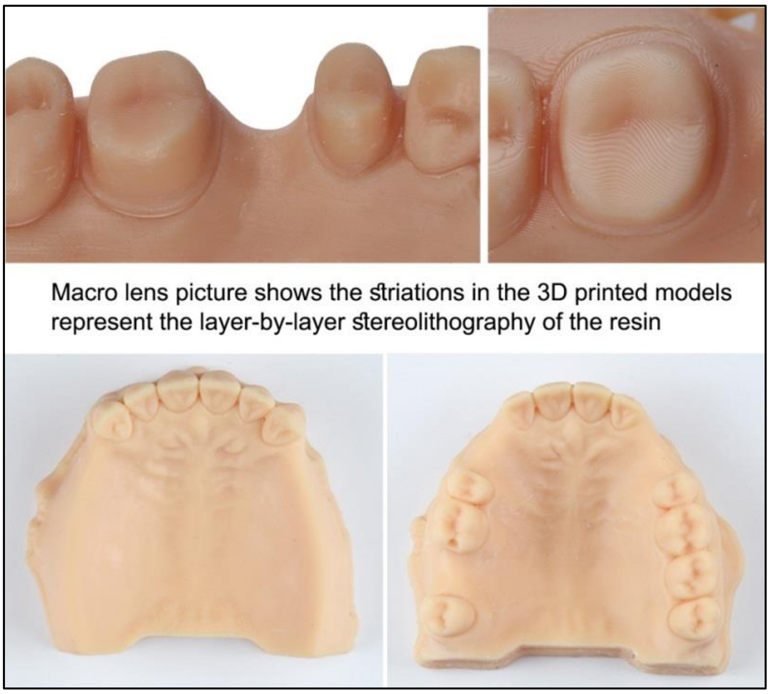

Figure (4): 3D printed models after removing of the excess resin and cleaned.

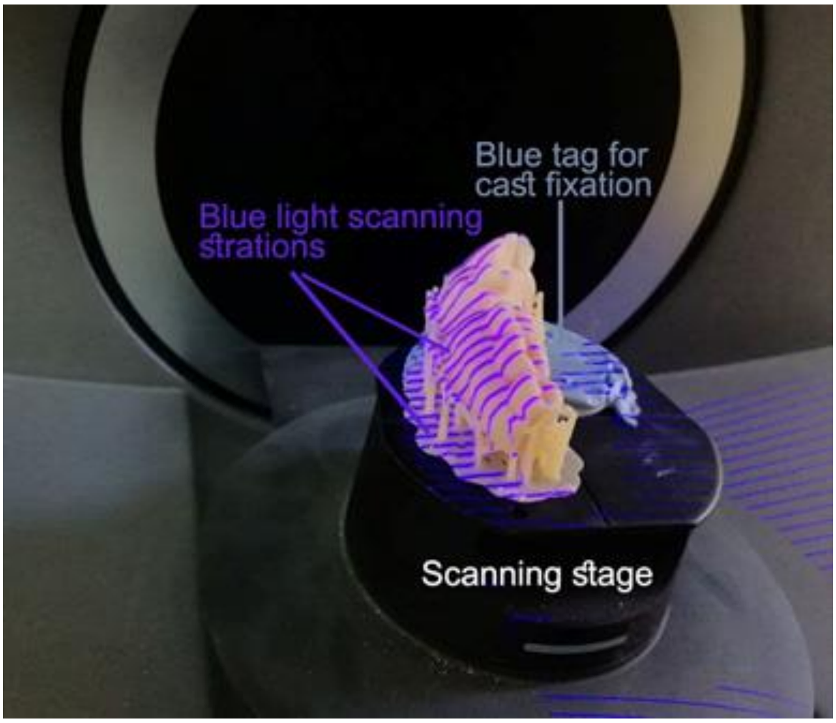

Figure (5): 3D printed model scanning with E1 scanner

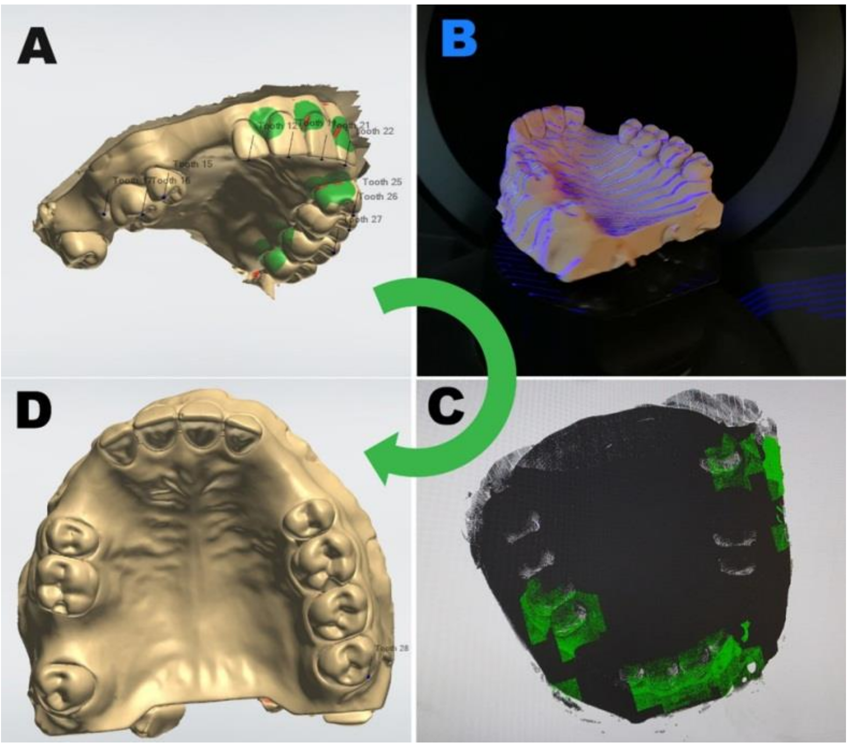

Figure (6): Adaptive scanning. A. Some missing unclear areas represented as red spots. B. The blue light striations of the scanner during adaptive scanning. C. The green color striations represent the adaptive scanning targeted areas. D. Completed Scanned cast.

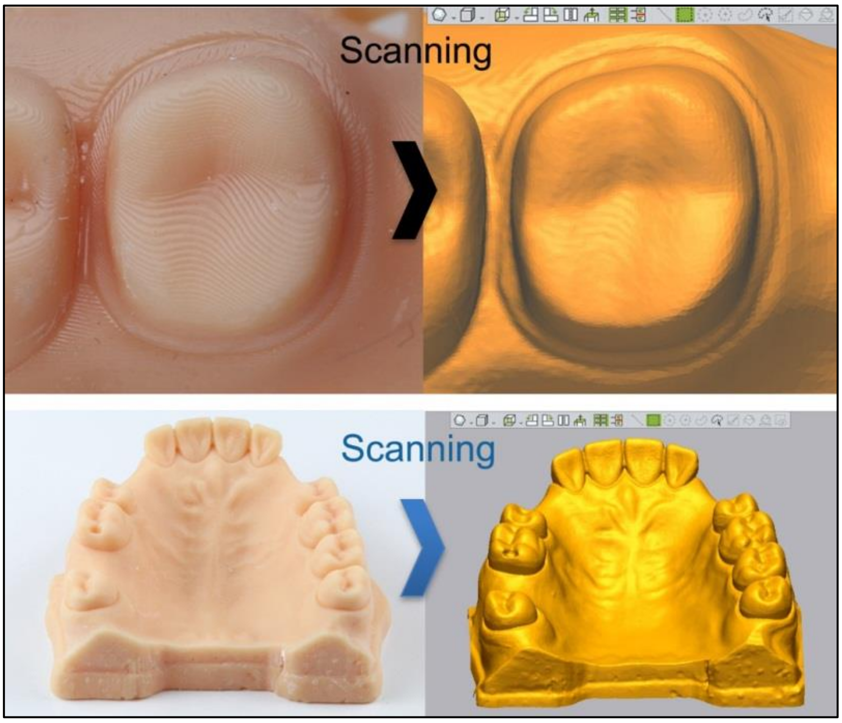

Figure (7): 3D printed models and their virtual 3D models after scanning with E1 scanner.

5. Three-dimensional analyses:

The study comparison the accuracy of the four model's preparation types was evaluated by superimposing the STL file data of the reference model with STL file data obtained from the Trios IOS group and 3D printed casts from Trios IOS (n = 5) for each type.

5.1 Three-dimensional Comparison Steps

The virtual reference cast's STL file is imported into the program and used as reference data. As measured data, the STL file of the virtual cast from Sample group is imported. Only the points in the target area are compared in 3D; this removes any variations outside of the area of interest, which are of clinical significance. With 20 color components, a color map depicting visual deviation was created (Fig. 8). The data containing the statistical analysis data and the color map information will be exported after the report is generated (Fig. 9).

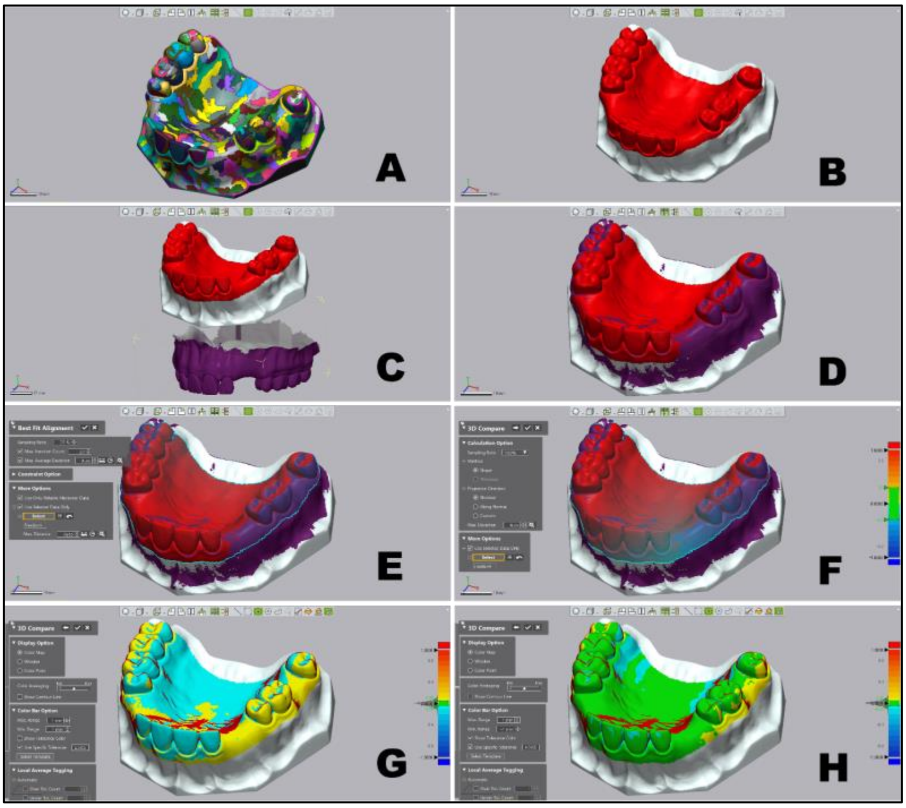

Figure (8): 3D comparison steps for the Cl III Kenedy Classification samples. A. Import reference data. B. Selection of target area. C. Importing measure data. D. Initial alignment automatically. E. Best fit alignment concerning the selected area. F. 3D compare concerning the selected area. G. Color map without showing the tolerance range. H. Color map with tolerance range in green color.

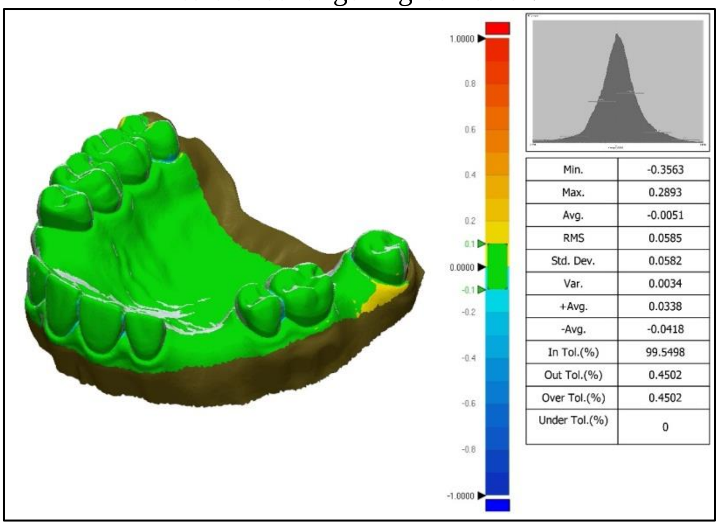

Figure (9): Report of superimposition of the R.V.M. with the virtual model obtained from scanning of the 3D printed cast from Trios IOS.

6. Statistical Analysis:

The statistical analysis was carried out using the SPSS (statistical package for social sciences) software version 19. Descriptive Statistics and Inferential Statistics including Shapiro-Wilk Test and Wilcoxon Signed Ranks Test

RESULTS

The average of deviation from the reference virtual model in the 3D comparison table results considered in the comparison between the virtual casts obtained by the direct intraoral scanning by TRIOS IOS and their 3D printed casts. The sample size (n = 20) about (5 samples) for each type of model preparations.

The 3D printed casts showed higher deviation from the reference cast (in all the types of preparations) than the virtual cast of Trios IOS, fixed bridge (4.5 ± 1 µm > 2.7 ± 0.6 µm), single crown (19 ± 3.6 µm > 4.5 ± 1.3 µm), Class I Kennedy Classification (14.5 ± 2.4 µm > 1 ± 1 µm) and Class III Kennedy Classification (9.6± 6 µm > 7 ± 1.3 µm) (Table 1).

Table (1): Descriptive Statistics. Mean, the median, the confidence limits (at the level of significance (0.05) Std. Deviation for the Trios IOS virtual and 3D printed casts

Trios	Groups	Mean	Median	95% Confidence Interval		Std. Deviation	Minimum	Maximum
				Lower	Upper			
Fixed bridge	virtual	.00276	.00290	.00196	.00355	.000638	.0021	.0138
	3D pr.	.00456	.00470	.003277	.00584	.001033	.0033	.0228
Single Crown	virtual	.00454	.00520	.002850	.00623	.001361	.0022	.0227
	3D pr.	.01976	.01950	015220	.02430	.003656	.0146	.0988
Class I Kennedy Classification	virtual	.00102	.00160	-.001448	.00348	.001988	-.0024	.0051
	3D pr.	.01456	.01430	.011569	.01755	.002408	.0115	.0728
Class III Kennedy Classification	virtual	.00700	.00770	.005386	.00861	.001300	.0051	.0350
	3D pr.	.00960	.00700	.001430	.01777	.006580	.0020	.0480

The statistical test (Shapiro-Wilk) was used to detect the extent to which the probability distribution of the studied groups conforms to the normal distribution. From observing the results of the (Table 2), we find that the (Single Crown - virtual Trios) group are not normally distributed so the non-parametric test will be more accurate.

From observing the results in the (Table 3) of the Wilcoxon Signed Ranks Test, we found that there are significant differences between virtual and 3D printed cast samples in Fixed bridge, Single Crown and Class I Kennedy Classification groups. While for the comparison between the virtual and 3D printed cast samples in Class III Kennedy Classification group, we found that there are no significant differences between them.

Table (2): Shapiro-Wilk test for the Trios IOS virtual and 3D printed casts

Trios		Tests of Normality		
		Statistic	df	Sig.
Fixed bridge	virtual Trios	.876	5	.294
	3D print Trios	.976	5	.912
Single Crown	virtual Trios	.768	5	.044
	3D print Trios	.968	5	.863
Class I Kennedy Classification	virtual Trios	.788	5	.064
	3D print Trios	.984	5	.953
Class III Kennedy Classification	virtual Trios	.855	5	.211
	3D print Trios	.885	5	.334

Table (3): Wilcoxon Signed Ranks Test for the Trios IOS virtual and 3D printed casts

Trios		Wilcoxon Signed Ranks Test		
		Mean	Statistic	Sig.
Fixed bridge	virtual Trios	0.00276	15	0.042
	3D print Trios	0.00456		
Single Crown	virtual Trios	0.00454	15	0.043
	3D print Trios	0.01976		
Class I Kennedy Classification	virtual Trios	0.00102	15	0.043
	3D print Trios	0.01456		
Class III Kennedy Classification	virtual Trios	0.007	10	0.5
	3D print Trios	0.0096		

DISCUSSION

The 3D printed casts showed higher deviation from the reference cast (in all the types of preparations) than the virtual cast of Trios IOS, fixed bridge (4.5 ± 1 µm > 2.7 ± 0.6 µm), single crown (19 ± 3.6 µm > 4.5 ± 1.3 µm), Class I Kennedy Classification (14.5 ± 2.4 µm > 1 ± 1 µm) and Class III Kennedy Classification (9.6± 6 µm > 7 ± 1.3 µm). The accuracy of a model fabricated in a digital workflow is determined by the type and technique of the intraoral scanner, the material and technology used in 3D printing, and the type of 3D printer. The findings of this study are in agreement with recent studies concluding that, although the virtual model obtained by the intraoral scanner showed results comparable to those of a stone model from conventional impression in terms of single crown, three-units bridge and complete arch, the 3D printed models showed the highest deviation mean values in the accuracy[7]. Many factors can affect the accuracy and final volumetric changes of the 3D printed casts as photopolymerization, which is usually accompanied by shrinkage of the material, can cause residual stress, distortion or skewing of a stereolithographically generated object. Two types of dimensional distortions can occur: cure-related shrinkage and thermal contraction or expansion. Cure-related shrinkage is caused by changes in the chemical bond distances of the non-polymerized monomer compared with those of the polymer (6-10 percent possible shrinkage), while thermal contraction or expansion occurs when temperature changes occur in the resin during exothermic polymerization. Laser overcuring bonds layers with each other. Although it is a necessary part in the process of creating a solid object, it may cause dimensional and positional errors in the object's z direction, which results in a deformed shape and a shift of the center position of the object[14]. The post-curing (by means of UV light and heat) of stereolithographically generated objects is necessary to solidify unreacted or partially reacted monomers, thus increasing the mechanical properties of the stereolithographically generated objects. This additional polymerization process could result in shrinkage or warping [15]. The clinically acceptable ranges of marginal fit differ, and the clinically relevant range of marginal discrepancies is unclear, although in a 5-year clinical study of 1000 restorations, it was concluded that 120 µm was the maximum allowable marginal gap[16]. According to the implant full-arch studies the acceptable threshold for the clinical fit between the implant platform and fixed prostheses may vary from 59 µm to 150 µm [17,18]. A deviation of 100 µm and above across the full arch could lead to in accurate and misfitting of the maxilla and mandible. Most of our study groups showed accuracy levels within the clinically acceptable range, according to previous studies[13].

CONCLUSIONS

With the Limitations of this study the following conclusions are achieved:

1- Trios IOS showed a high accuracy level in all types of preparations and span length.
2- 3D printed cast had significantly higher deviations from their virtual casts in all types of preparations within the clinically accepted limits.

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