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EVALUATION OF THE EFFECT OF DIFFERENT CONSTRUCTION TECHNIQUES ON REMOVABLE PARTIAL DENTURE FRAMEWORKS: CONVENTIONAL WAX PATTERN,3D PRINTING RESIN, AND METAL 3D PRINTING (COMPARATIVE VITRO STUDY)

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ABSTRACT

Background: Nowadays different construction techniques of removable partial denture farmwork are used to improve RPD frameworks by improving their mechanical and biological properties. The manual wax pattern technique is a multiple-step process while the 3D resin RPD framework is another construction technique produced from a virtual design created from Digital CDA software which will be invested and cast into a Co–Cr framework. Subtractive manufacturing and additive manufacturing are CAD systems that produce metal 3D printing frameworks.

Material and Method: Twenty-one designed cast models were divided into three groups based on the construction techniques used for the removable partial denture framework Group I: Seven frameworks fabricated using the conventional wax pattern technique Group II: Seven frameworks fabricated using the 3D printing castable resin technique

Group III: Seven frameworks fabricated using the metal 3D printing technique. The rest fit accuracy was compared between the three groups by calculating the thickness of the silicone adapted between the rest and the corresponding rest seat using a Digital microscope

Result: there was a statistically significant difference between Group III and both Group I and II while there was a statistically non-significant difference between Group I and II

Conclusion: Group III showed the best rest fit accuracy between the rest and its corresponding rest seat when compared with Group I and Group II while Group I showed slightly better rest fit accuracy than Group II but this difference was insignificant

KEYWORDS: Rest, Accuracy, Technique, Fit, Rest seat.

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INTRODUCTION

Removable partial dentures (RPDs) are commonly used to replace missing teeth, the primary aim of removable prosthodontic treatment is to produce a hard, will-fit, and comfortable denture for the patient but most removable partial dentures come with different problems and issues [1] sore spots and difficulty in chewing and speaking can be found in the RPD denture due to its poor adaptation and this problem will cause discomfort to the patient [2,3] RPDs can sometimes affect the retention, the stability and function due to its movement or shift during use[4]

Various construction techniques can be utilized to improve RPD frameworks by improving their mechanical and biological properties.[5] Manual wax pattern technique is a traditional fabrication technique of (RPD) frameworks, it is a multiple-step process involving the production of master gypsum casts after patient mouth preparation, surveying and blocking out the undesirable undercut of the master cast to form modified master cast which will be duplicated into refractory cast to be ready for wax pattern and sprue addition to be casted into a cobalt-chromium (Co–Cr) framework cobalt-chromium. [6,7]

Digital light processing (DLP), stereolithography (SLA), and three-dimensional (3D) printing are used to produce castable 3D resin RPD framework from a virtual design created from Digital CDA software which will be invested and cast into a Co–Cr framework[8.9]. One of the advantages of these methods is their accuracy, as well as the fact that the produced 3D resin framework is stronger during casting and more durable than the traditional wax pattern techniques. [10]

Subtractive manufacturing (SM) and additive manufacturing (AM) are two types of CAD systems used in dentistry. [11,12]

The most common SM technology is computer numerically controlled (CNC) milling, this method produces the object by using a milling machine to remove bulk material from solid blocks with all the steps controlled by a computer program [13].

AM includes different technologies such as stereolithography (SLA), selective laser melting (SLM), selective laser sintering (SLS), direct metal laser-sintering (DMLS), fused deposition modeling (FDM), selective electron beam melting (SEBM) and inkjet printing [14,15]

Selective laser sintering (SLS) is one type of (AM) that can transfer the virtual RPD framework design to the final metallic framework by consolidating the powder materials layers on top of each other. [16,17] Many authors confirmed in research that SLS is one of the successful processes for the fabrication of 3D metal RPD framework with good accuracy level [18] the disadvantage of this fabrication process is that it is expensive, and is not available in prosthetic laboratories.[19,20]

The aim of this study was to compare the rest accuracy fitness between three different construction techniques for removable partial denture frameworks.

MATERIALS AND METHODS

Sample Size Calculation

A two-sided, two-sample t-test with equal variance was conducted to determine the required sample size. To detect a mean difference of 0.3 ($\mu1 = 0.4$, $\mu2 = 0.7$) with 80% power and a significance level (α) of 0.05, assuming a standard deviation of 0.4 in three groups, the analysis determined that 7 subjects per group (total N = 21) would be needed.

Twenty-one designed cast models were divided into three groups based on the construction fabricated techniques used for the removable partial denture framework

Group I: Seven frameworks fabricated using the conventional wax pattern technique

Group II: Seven frameworks fabricated using the 3D printing castable resin technique

Group III: Seven frameworks fabricated using the metal 3D printing technique.

Cast Preparation :

A cast model obtained from an unidentified ready-made silicon mold that was already present in the Faculty of Dentistry, Misr University for Science and Technology represents a Kennedy Class I with a second premolar as the last standing abutment, and the design was drawn on the cast.The major connector used in this design was a lingual bar. A mesial rest seat and a I bar clasps were positioned in both left and right second premolars. Additionally, distal rest seats were positioned on the first premolars on both sides to act as an indirect retainer. The cast was placed on the surveyor to identify the desirable and undesirable undercut and detect the path of insertion of the framework. Relief under the lingual bar and edentulous area and block out of undesirable undercut was done by Blocking - out wax (Asblockwachs, BEGO ,LOT 029651214, Germany), this modified cast was placed on a duplicated flask and poured with liquid Agar Agar (Wiro gel M , BIGO,LOT 5214241114,Germany) to form a mold which was poured twice with refractory materials (Wirofine, BIGO, LOT 020693, Germany) to form two refractory casts one was used with Group I and the other cast was scanned to form 3D resin models

3D resin model construction

The refractory cast was scanned using the 3D scanner(Identic Hybrid; MEDIT Corp.,Seoul, Korea)to create a standard tessellation language (STL) file. This STL file was printed by a Digital Light Processing (DLP) 3D printer (Creality Halot-China) using 3D resin materials (Harz 3D Printed resin, Aleksandra ACO Prijica 16A, Podgorica) to form Twenty-one 3D resin models, seven 3D models for each group **(Figure 1)**

Fabrication of metal framework of Group I using Conventional wax pattern techniques :

Wax patterns of clasp, Rest, framework, and lingual major connector (Modellierwach-Start-Set BEGO , LOT 1001588, Germany) were applied to the refractory cast to the shape design **(Figure 2)**.

A sprue rods of 8 mm diameter was attached to the wax pattern after melting its end to ensure good attachment to the wax pattern. The wax pattern with its sprue was placed into an investment flask. The investment materials (Wirofine®, BIGO,LOT 020693, Germany) were mixed according to the manufacturer· instructions and poured into the flask. After setting the investment material and its complete hardness, the flask was placed in a furnace to burn out the wax pattern and the sprue.

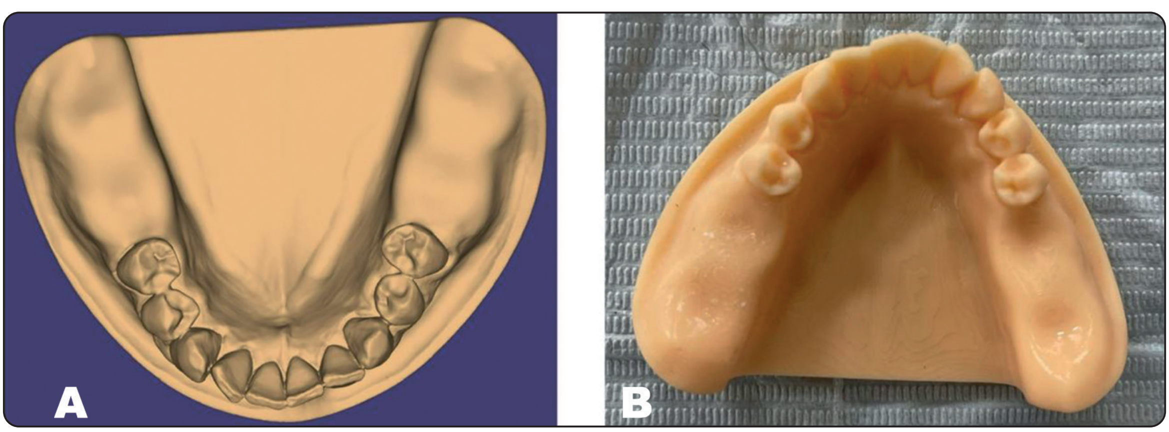

Fig. (1) a) Scanned refractory cast on the STL file - b) Printed 3D resin cast

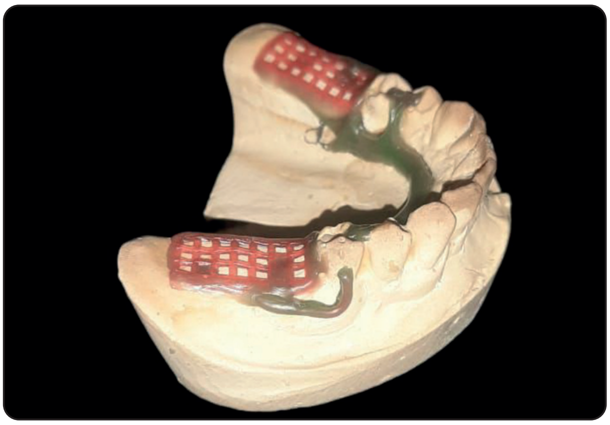

Fig. (2) Wax pattern design fabricated on the refractory cast

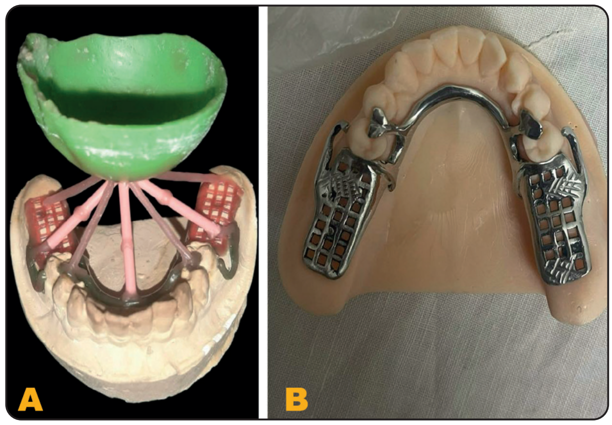

Fig. (3) a) The sprue rods attached to the wax pattern on the refractory cast b) Finished metal framework constructed by wax pattern technique on the 3D resin cast

The mold was cleaned and any excess wax was removed, metal cobalt-chromium (CO-CR) alloy (Biosil F:, Degudent, Hanau, Germany) was melted in a casting furnace and poured into the investment mold, after the metal was cooled the investment was broken and the framework was finished and polished. **(Figure 3)**

Fabrication of metal framework of Group II using 3D printing resin technique

The design of the RPD of Group II was designed by CAD software (Exocad Gmbh CAD/CAM software) **(Figure 4)** on the saved scan cast STL file**.**

The design was saved as an STL file and was printed using 3D printed castable resin(S-plastic cast 2.0; Graphy Inc., Seoul, Republic of Korea) by a Digital Light Processing (DLP) 3D printer (Creality Halot- China) **(Figure 5).**

The printed framework pattern was attached to a sprue end as in Group I and invested and cast into cobalt-chromium alloy. (Biosil F:,Degudent, Hanau, Germany). (**Figure 6)**

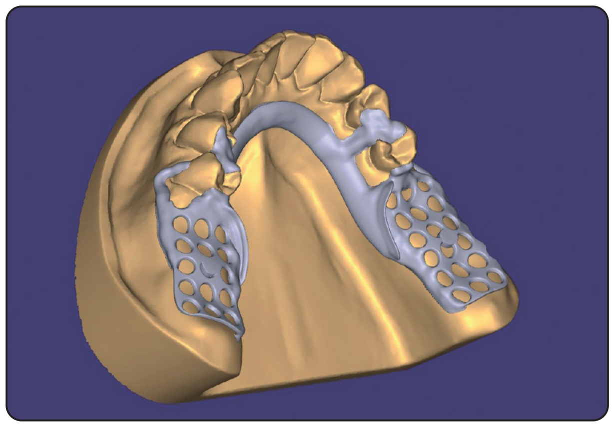

Fig (4) The RPD design by CAD software

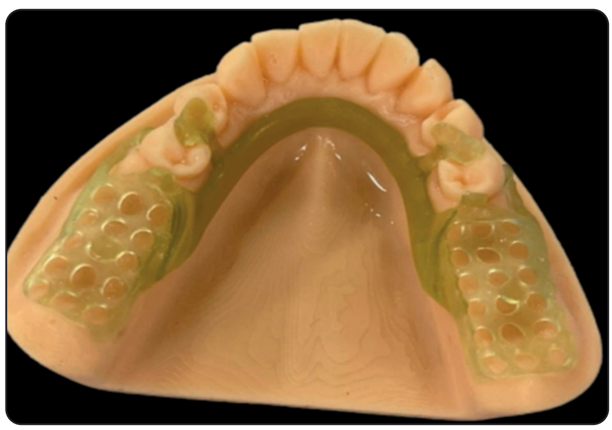

Fig. (5) The 3D castable resin printed pattern framework

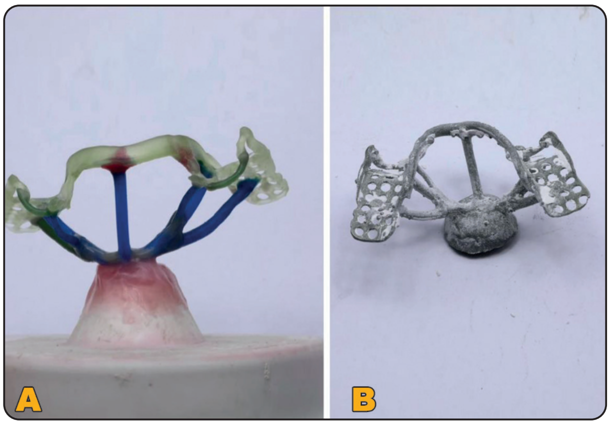

Fig. (6) a) Sprue attached to the 3D resin printed framework pattern - b) 3D resin printed farmwork after casting process

Fabrication of metal framework of Group III using Metal 3D printing technique

The Supported base structure was designed by CAD software and was incorporated into The saved design in (STL) file to support and preserve the precision of the future metal 3D printed framework. The saved design with the supported base structure was printed using CO-CR alloy powder (Cham Tiger.,Shinseki International Inc, Seoul, Republic of Korea) by Selective Laser melting (SLM) 3D printer (NCL-M2150X; Nanjng Chamtigher Laser Technology Co., Nanjing, China). The printed supported base was removed from the metal 3D printed framework and the surface was smoothed. The finished metal 3D printed framework was subjected to heat treatment to decrease stresses and improve its mechanical properties **(Figure 7)**

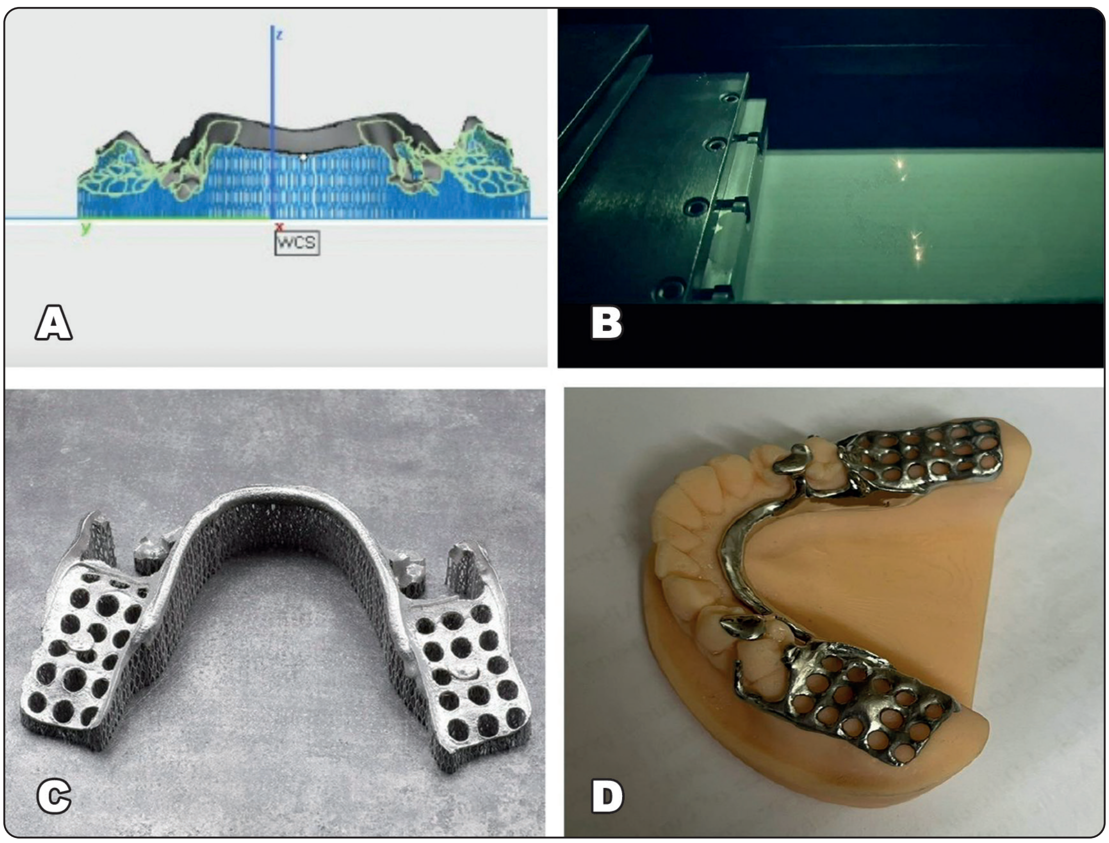

Fig. (7) a- Supported base designed by CAD software -:b-CO-CR alloy powder printed by Selective Laser melting (SLM) 3D printer- c) Metal 3D printed framework with its supported base -d) Finished and polished 3D printed framework

Evaluation of the rest fit accuracy :

The inner surface of the rest was painted with light body silicon impression materials(Zhmermack, Italy). The framework was adapted to the 3D resin cast by finger pressure until the silicon setting time was reached.

The adaptation of the rests was evaluated by measuring the thickness of the silicon materials, which represent the space between the rests and the rest seats This was done using a Digital microscope (KH-7700,Hirox, Tokyo, Japan) micrometer at a magnification power of 50 x. [21] The thickness of the silicon materials was measured at the central zone of the four rests within each framework. The average thickness of the silicon materials between the four rests and their corresponding rest seats in each framework was calculated for statistical analysis.

RESULT

Statistical Analysis

In this study, three main statistical tests were employed: 1) Normality tests using both Shapiro-Wilk and Kolmogorov-Smirnov methods to confirm the normal distribution of data across all groups ($p>0.05$) 2) One-way ANOVA to compare rest accuracy fitness between the three construction techniques, revealing significant differences ($p<0.0001$) 3) Tukey's multiple comparisons test for post-hoc analysis.

Analysis of a gap distance between rest and rest seat of different construction techniques on removable partial denture frameworks

According to (Table 1), and (Figure 8) a One-way ANOVA analysis was performed to compare the gap distance between rest and rest seats of different construction techniques on removable partial denture frameworks by calculating the thickness of silicone between the rest and rest seats in micrometer (µm). The results show that Group II (3D resin printed frameworks) recorded the highest mean value of 271.4µm, followed by Group I (conventional wax pattern frameworks) with a mean of 250.0µm, while Group III (Metal 3D printed frameworks) showed the lowest mean of 170.0µm. The analysis revealed a statistically significant difference between the groups ($p < 0.0001$).

The Tukey's multiple comparisons test, indicated by letter designations, shows that Groups I and II (both marked with "A") were not significantly different with each other, but both were significantly different with Group III (marked with "B").

TABLE (1) One Way ANOVA analysis of a gap between rest and rest seat of different construction techniques on removable partial denture frameworks:

	Group I Conventional wax pattern frameworks	**Group II 3D resin-printed frameworks**	**Group III Metal 3D printed frameworks**	**P-value**
M	250.0	271.4	170.0	**<0.0001***
SD	50.30	44.60	31.60	
SEM	10.49	9.300	6.589	
Tukey's multiple comparisons test	A	A	B	

M; Mean, SD; Standard Deviation, SEM; Standard Error of Mean, P; Probability Level
Means with the same letters in the same row were insignificant different using Tukey`s post hoc test
Means with different letters in the same row were significantly different using Tukey`s post hoc test
****; significant different using One Way ANOVA***

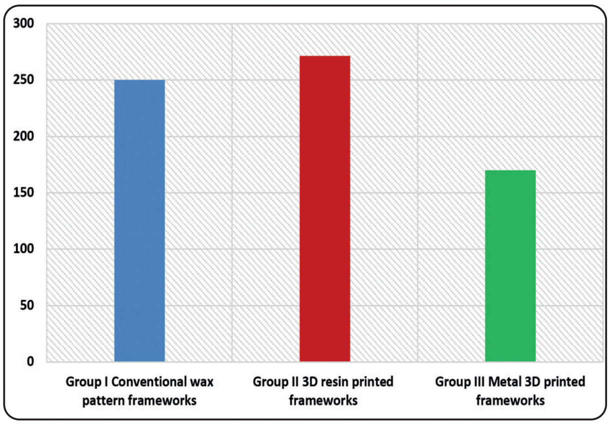

Fig. (8): Analysis of a gap distance between rest and rest seat of different construction techniques on removable partial denture frameworks:

DISCUSSION

The accuracy and adaptation of rest to its corresponding rest seat are important in the success of the removable partial denture as ill-fit rest may cause vertical movement during denture function which causes soreness and damage to the tissues as well as increased stress on the abutments causing tooth mobility by time and this will affect patient comfortable. [22,23]

Many methods were used to evaluate the rest accuracy of the removable partial dentures, one of the most popular methods is the visual and tactile examination by tactile sense or by naked eyes but this method is not accurate as it depends on the investigator's judgment which is different according to the individual evaluation. [24] The optical method with or without a replica using a light microscope or stereomicroscope is another method used to evaluate the rest accuracy, this method is more accurate than the visual and tactile examination. [25] Superimposition and color mapping using surface matching software is one of the recent methods for rest accuracy evaluation, this method is the most accurate compared with the previous methods. [26]

The optical method with a replica using a light digital microscope was used in this study because this method was more accurate than the visual and tactile ones. Although the superimposition and color mapping with surface matching software provide the best accuracy, this technique was not used in this study because it is specifically used for digitally fabricated frameworks. Since this study included two groups of digitally fabricated frameworks and one group of conventionally fabricated frameworks, the optical method was seen to be more suitable[27].

In this study it was found that there was a statistically significant difference between Group III (Frameworks fabricated using the metal 3D printing technique) and both Group I (frameworks fabricated using the conventional wax pattern technique) and Group II (frameworks fabricated using the 3D printing castable resin technique), also it was found that there is insignificant difference between Group I (frameworks fabricated using the conventional wax pattern technique) and Group II (frameworks fabricated using the 3D printing castable resin technique).

The metal 3D printed frameworks Showed the best rest fit accuracy to their corresponding rest seat when compared to both frameworks fabricated using conventional wax patterns and 3D printing resin technique this is due its the high metal precision [28], also this framework was printed from the design of software directly in single step techniques which reduce the number of laboratory steps that required for framework fabrication and this helped in minimizing the dimensional change and provide good dimension stability for the final metal framework [29,30]

Another significant factor that makes conventional wax pattern frameworks show poor rest fit when compared to the Metal 3D printed framework is its thermal expansion/contraction phenomena which lead to the expanding and contracting of wax patterns under temperature change during the investment and casting processing and this subject the wax to dimension change and affect its final dimension stability [31], also wax pattern may be distorted during handling due to the internal stress released and this affects the final framework accuracy[32,33].

In addition, the 3D printed resin frameworks showed poor rest fit when compared to the metal 3D printed frameworks this is because the 3D printed resin pattern undergoes polymerization shrinkage during the polymerization process and this shrinkage affected the final metal framework dimension stability [34,35]

The frameworks fabricated using the conventional wax pattern and frameworks fabricated using the 3D printing castable resin technique show insignificant differences in rest fit accuracy this is due to the fact that both techniques are subject to multiple laboratory processes before construction of the final metal framework as well as both subjected to shrinkage and dimension change during the different laboratory steps [36,37] although the different between them was statistically insignificant different ,the statistics record mean value of the gap distance between the rest and its corresponding rest seats of the frameworks fabricated by wax pattern techniques was slightly less than that fabricated by 3D resin printing techniques which indicated that the framework fabricate by wax pattern techniques shows slightly better rest fit accuracy when compared to framework fabricated by 3D resin printing techniques and this is due to the fact that the printed resin frameworks subjected to secondary curing process by ultra violet light curing to improve the properties of the resin materials and this post curing process lead to addition shrinkage due to the releases of internal stress which formed from the primary polymerization of the resin as well as the 3D resin pattern subjected to slightly incomplete burning out as the resin materials contain fillers and organic compound that cannot completely burn out leaving some residual resin in the mold and this contrast with wax pattern that burn completely without leaving any residual and this may affect the accuracy of the 3D resin final framework .[35,38]

One previous study came in agreement with this present study when the authors compared the accuracy between different framework-constructed techniques, they found that all techniques including the casting process showed high discrepancies due to its greater distortion during fabrication [39]

Bajunaid et, al, [40] proved in their study that the fit accuracy at the rests on its corresponding rest seats of the Removable Partial Framework constructed by selective lasering melting techniques is better than that constructed by traditional wax pattern techniques, the authors explained this outcome result as the traditional techniques are subjected to accumulative human error which affects its accuracy and this finding came in agreement with this present study.

CONCLUSION

1. Group III: Frameworks fabricated using the metal 3D printing technique show the best rest fit accuracy to their corresponding rest seat when compared to both Group I: Frameworks fabricated using the conventional wax pattern technique and Group II: Frameworks fabricated using the 3D printing castable resin technique
2. Group I: Frameworks fabricated using the conventional wax pattern technique show slightly better rest fit accuracy than Group II: Frameworks fabricated using 3D printed castable resin technique but this difference was insignificant

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