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Abutment Teeth Surface Roughness of Cobalt-Chromium Laser-Sintered Removable Partial Denture: An in Vitro Comparative Study

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ABSTRACT— Purpose: The objective was to compare abutment teeth surface roughness between two different Cobalt-Chromium removable partial denture framework processing be different techniques (casting 3D printed resin pattern and selective laser melting). **Methods:** twelve Cobalt-Chromium removable partial denture frameworks were constructed, divided into two equal groups, Group 1: 3D printed casted frameworks Group 2: selective laser melting frameworks. The abutment teeth surface roughness was estimated by using digital microscope with digital software before & after undergoing cyclic fatigue tests. **Results:** There was not a statistically significant difference in abutment teeth surface roughness behavior between the studded groups (3D printed RPD frameworks and SLM frameworks), but the difference became significant after the chewing simulation. **Conclusions:** both SLM and 3D casted cobalt chromium RPD frameworks provided acceptable abutment teeth surface roughness. Therefore, SLM-fabrication seems to be a viable alternative technology to fabricate cobalt chromium RPD frameworks.

Key words: removable partial denture, Co-Cr, selective laser melting, abutment teeth surface roughness.

INTRODUCTION

Removable partial denture (RPD) is a simple and Cost-effective prostheses that is widely used to replace missing teeth in order to restore both function and aesthetics for partially edentulous patients. This type of treatment plays an important role in life of millions of patients worldwide and improve their life quality(1)**.**

RPDs have many forms, numerous denture designs exist, from those that rely on bonding or clasping onto existing teeth. In any of these cases, the design depends on the nature of the device, as well as the material which made from(2)**.**

RPD frameworks are commonly made of Cobalt–Chromium (Co–Cr) alloys because of their low cost and adequate physico-mechanical properties and their effective corrosion resistance and biocompatibility(3).

Nowadays, the CAD CAM technology has become one of the most important dental developments happened at the twenty-one centuries. All dental labs started to shift their services to the digital manufacturing where less material consumed, saving time and effort and capability of mass production(4).

RPD frameworks can be fabricated by prototyping indirectly using polymer powders through Printing technology or directly using metal powder through Direct Laser Sintering technology [5]

A new additive manufacturing (AM) process depends on laser-sintering has been developed for processing 3-D metal objects. The laser-sintering technique combines computer-aided design (CAD) of any products and their subsequent fabrication using a highpower laser that fuses metal powder in a layer-by-layer [6].

Laser-sintering technology has different types, such as selective laser melting (SLM), selective laser-sintering (SLS), or direct metal laser-sintering (DMLS). SLM involves full melting of the metal powder; while, both SLS and DMLS involve partial melting of some the metal powder, particularly melting at the surface of the particle [7].

Insufficient data is available considering amount of Retention and Abutment Teeth Surface Roughness of Cobalt-Chromium Laser-Sintered RPD, so this study aimed to examine and evaluate the retention and abutment Teeth Surface Roughness of conventional and selective laser melting RPD before and after undergoing effect of cyclic fatigue tests.

MATERIALS AND METHODS

This study is an in-vitro comparative study. It was carried out on twelve Cobalt-Chromium removable partial denture frameworks according to the calculated sample size.
The sample size for this study was calculated according to[8] using the following equation:

$$N = \frac{(Z_\alpha) * (SD)}{(d)}$$

N = Total sample size.
Z_α= Is Standard normal variate and its equal 1.96 at $P< 0.05$
SD = Standard diversionofvariable.
d =Absolute error orprecision.

Zα	SD	D
1.96	3.55	2

$$\text{Total Sample size } N = \frac{(1.96)x(3.55)}{(2)^2} = 11.97 \approx 12 \text{ samples}$$ [9]

Twelve Cobalt-Chromium removable partial denture frameworks were divided equally into two groups (n=6/group) according to fabrication technique of RPD frameworks: -
Group A: six 3D printed resin pattern casted Co-Cr RPD frameworks.
Group B: six selective laser melting Cr-Co RPD frameworks (SLM).
A full upper dentulous silicone mould teeth former is converted to partially edentulous jaw model maxillary (Kennedy class I defect) by application of molding wax withinthe mold of bilateral first, second and third molars. Then the silicone mould was poured by type III stone to produce the traditional cast(**Fig.1 A, B, C**).

Rest seats were prepared on abutment teeth as follows: mesial occlusal rest seats on the first bilateral premolars (#14, 24) and mesial and distal occlusal rest seat on the second bilateral premolars (#15, 25).Guide planes were prepared on the distal proximal surfaces of teeth #15 and #25 using stones. All the teeth were numbered based on the Federation Dentaire International (FDI) teeth numbering system [10](**Fig.1 D)**.

The stone model was duplicated by using silicon rubber mold with epoxy resin material (Kimapoxy150, Egypt) . to produce the epoxy cast. The bilateral second premolars were built up using dental composite(Ceram.X Spectra ST, DENTSPLY Sirona, Germany)(**Fig. 2**).

All samples were designed using a CAD system. The CAD/CAM Scanning Spray(Enamelite, Keystone Industries, United State) was used to spray the epoxy resin cast prior to scanning for a more accurate scan.The epoxy resin cast was optically scanned using a desktop structured light extra oral scanner(DOF Inc swing 3D scanner, Korea)which rotates automatically to scan the cast from all directions and generates 3D model data. The RPD frameworkswere surveyed and designed digitally. (Fig. 3) by importing the master cast's (STL) format into a reverse engineering software Exocad(GmbH-align technology-European Union) by going through a sequence of digital procedures that mimic traditional laboratory steps. The combination of tools and force feedback sensations mimics working on a physical object and allows shapes to be designed and modified, sometimes by using the phantom arm in a freehand manner and at other times by precisely defining sizes, shapes, and positions. The software also allows the import of scan data to create reference objects or ‘‘bucks’’ onto which fitting objects may be designed digitally[11, 12].

3D-printed resin pattern RPD frameworks was fabricated by using a 3D printer(Any cubic photon,China) coupled with synergistic biocompatible photosensitive resin material in liquid form(Photosensitive liquid resin, Harzlabs, Europe) depending on STL file data. The printer created 3D printed resin RPD framework by selectively curing a polymer resin layer by layer in range between 25to 100 micron,15s exposure time and one second break with building angle 45° between the occlusal surfaces of the restsand the base plate of the sintering machine using an ultraviolet laser beam.The support structure of the resin pattern was medium (1, 3 mm)[13]. In order to prevent pattern distortion due to resin shrinkage, four reinforcement bars were added to the design data corresponding to the regions of the framework between teeth #14 and #24, between teeth #15 and #25 and the other two bars in the posterior region [14].

After printing the resin pattern framework, multiple post-curing stages were done, such as immersion of the pattern in the solvent (ethyl alcohol) to get rid of wet resin residue and final curing in a UV oven for complete hardening.The support is eliminated manually with carbide bur and rechecked for fitting on the cast (**Fig.4)**.

After printing the resin pattern frameworks were rapidly (within an hour) invested directly (as sprues was involved in the virtual design) with phosphate bonded investment (EXAVEST, china)under pressure 4 psiaccording to manufacturer's instructions as the investment ring and casted in conventional technique. The same spruing design was used for all resin patterns. The investment ring is placed in burnout furnace (Vulcan 3-550 5355740004 Burnout Furnace, DENTSPLY, Germany) where the printing resin was burned out at 240 °c for one hour. An electrometric centrifugal induction casting machine was used for casting. Cobalt–Chromium alloy (Argeloy NP Partial, ARGEN Corporation, San Diego) at 1200°c [11].(**Fig.5**).

A selective laser melting machine (VULCANTECH VM120, United Kingdom)was used to complete the 3D printing of the RPD frameworks using Co-Cr alloy powder (Starbond easy powder 30, Scheftner, Germany)of particle size 10 to 30 μm and composition 61% cobalt, 27.5% chromium, 8.5% tungsten, 1.6% silicon, and <1% other elements such as manganese, carbon, and iron was recommended by the SLM machine manufacturer.A 45◦ building orientation was selected. A linear support design with additional horizontal structures was used. Thelaser spot diameter of 0.08–0.1 mm, sintering speed of 1100–1200 mm/s, and layer thickness of 0.02 mm. The laser beam melted and fused the metallic powders together as the laser beam hit a thin layer of the material, it selectively joined or welded the particles togetheraccording to the 3D data fed into the machine forming the metallic RPD frameworks. After finishing and before removal of the support structures, a heat treatment was performed at 1200 ◦C for 30 min to get rid of residual stresses [15] (**Fig.6**).

A 3D-surface analyzer system optical profilometer (* JOYCHO digital microscopy, China)was used for contactless quantitative analysis for surface roughness of bilateral second premolars (#15, #25) between the middle and cervical thirds of the abutment teeth in the buccal surface before the fatigue cycles. The total number of abutment teeth was 24 samples (twelve samples for each group that were divided into 6 Right and 6 left second premolars for each group). All the abutment teeth were fabricated with the same mold and the same manner to save the same dimension for all abutment teeth before the fatigue cycles. Each group had its specific epoxy cast where the abutment teeth were fixed by means of horizontal screw in the epoxy cast. The abutment teeth were numbered (from 1 to 12) for 3D printed casted framework group and (from 13 up to 24) for SLMgroup. Each framework in each group was seated on the cast which contains two specific numbered abutment teeth for application of fatigue test, then the surface roughness of the abutment teeth is measured again for each sample (**Fig.7**).

Cyclic loading test:

To perform fatigue test for two RPD framework groups, through cyclic loading procedure, ROBOTA chewing simulator (Model ACH-09075DC-T, AD-TECH TECHNOLOGY CO., LTD., GERMANY) operated on servomotorwas used as shown in the epoxy resin cast was mounted and fixed to the lower part of the chewing simulator (**Fig.8**).The RPD frameworks of both groups were then placed on the corresponding casts and fixed in such a way that the upper part with its spherical tip applied a load on the horizontal bar at the geometric center of the RPD framework. The test conditions were maintained at room temperature (25 ± 2 ◦C). Samples were subjected to a revolution of 12,500 cycles, which run approximately 54 min tosimulate approximately three months of clinical function.

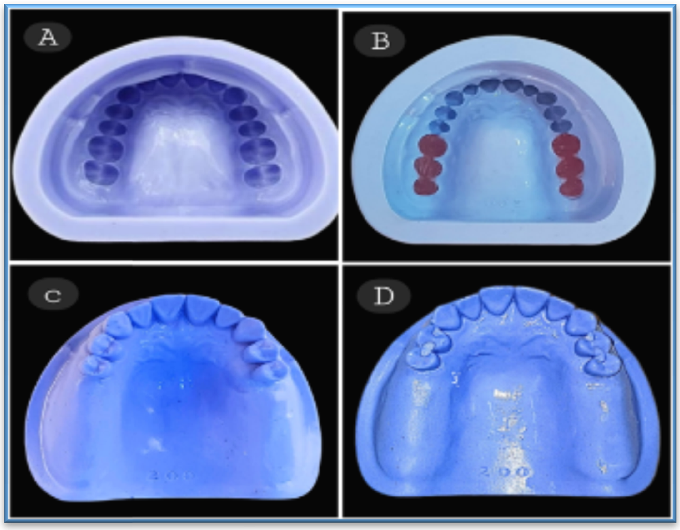

Fig.1 A, Silicone model mould. B, Bilateral molars blocked with molding wax. C, Stone cast. D, The rest seat preparation on the premolar abutment teeth.

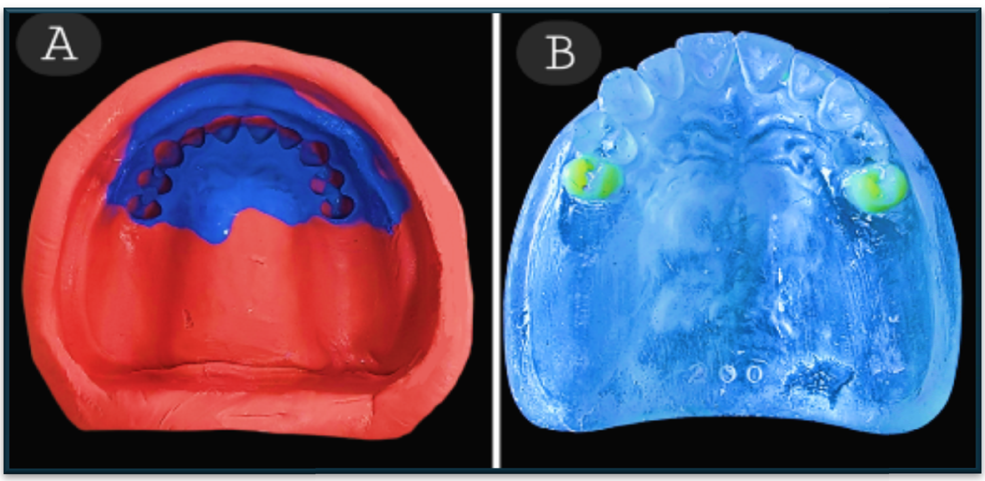

Fig.2 A, Silicone mold for fabrication of the epoxy resin cast. B, Epoxy resin cast with composite abutment.

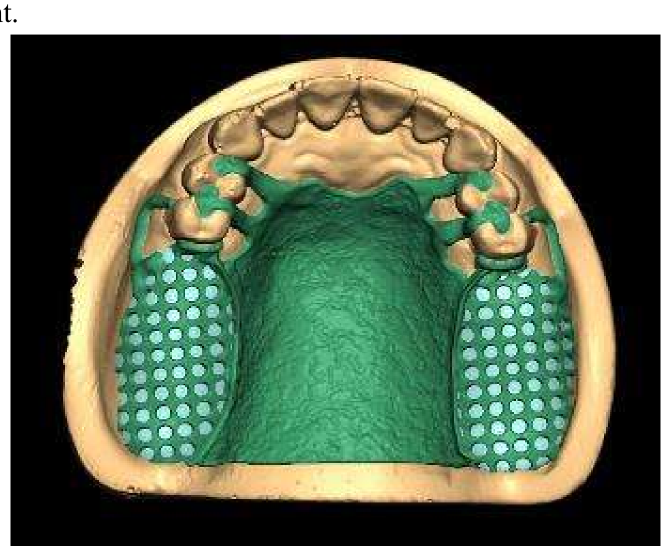

Fig.3 digital fabrication of RPD frameworks design

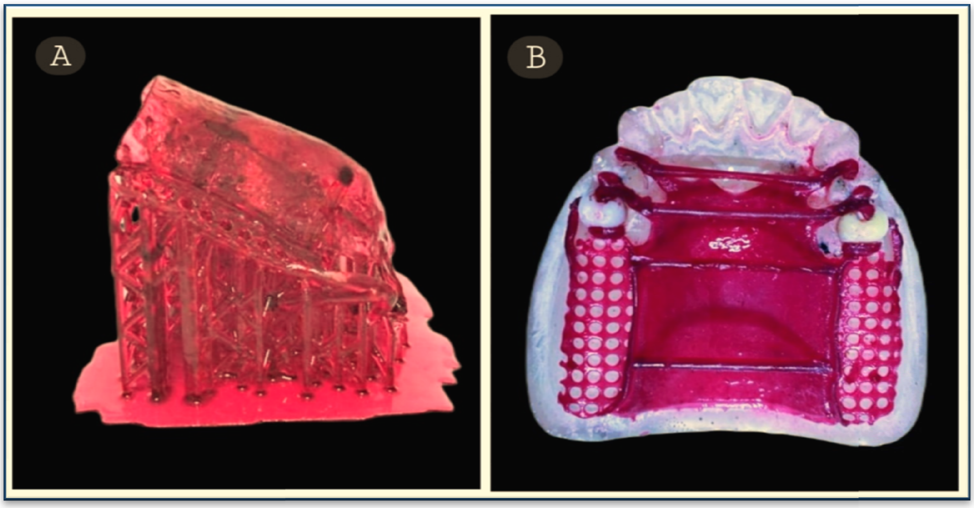

Fig.4 A, 3D printed resin RPD framework with support. B, 3D printed resin RPD framework four reinforcement bars fitted on the epoxy cast.

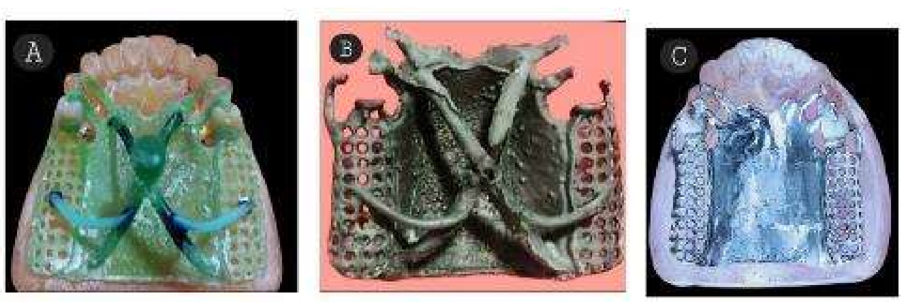

Fig.5 A: spruing of printed resin RPD framework. .B, 3D printed resin castedFrameworks after casting. c, the casted framework finished and fatted on the epoxy resin cast.

Fig.6 SLM CO-CR removable partial denture framework on the build platform with its support.

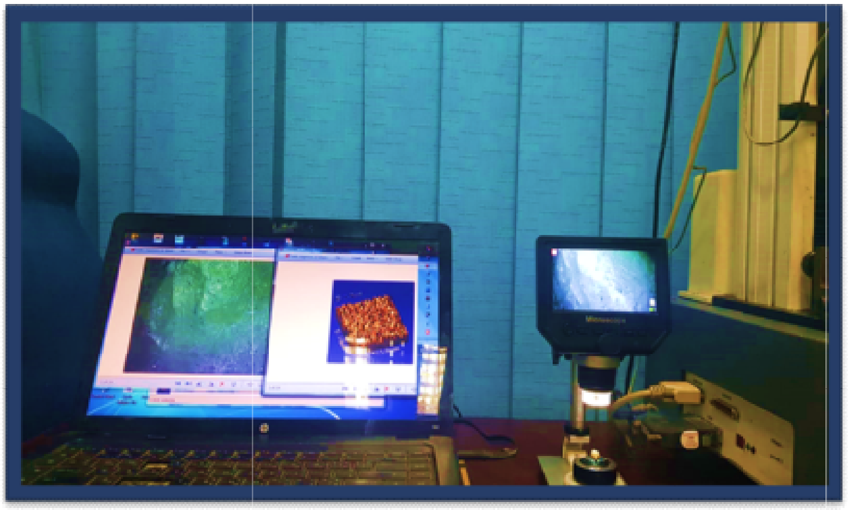

Fig.7 WSxM software was used to measure abutment teeth surface roughness (Ra).

Fig.8 spherical tip of the chewing simulator applied a load on the RPD framework.

STATISTICAL ANALYSIS

Data were collected, checked, revised, and organized in tables and figuresusing computer software Statistical Package for Social ScienceSPSS(IBM-SPSSver.26 for Mac OS) and Excel 2016.

Qualitative data were described using number and percentage. Quantitative data were described using median (minimum and maximum) for non-normally distributed data and mean± Standard deviation for normally distributed data after testing normality using Shapiro Wilk test. Theresults obtained were judged at the ($\leq$0.05) level.

.1Normality assessment for abutment teeth surface roughness before and after subjecting to cyclic fatigue tests:

* If the statistical significance at p-value > 0.05 (Normally distributed) therefore null hypothesis is accepted and the test used for analyzing the data was the paired sample T-test, and if the statistical significance at p-value ≤ 0.05 (Not normally distributed) therefore null hypothesis was rejected and the test used for analyzing the data was the Wilcoxon Rank-Sum test and Mann Whitney test.

Table.1 Demonstrated that there was no statistically significant difference (p-value > 0.05), which suggests that the distribution of the data for both groups is normal

Table (1): The Shapiro-Wilk test for normality regarding surface roughness:

Groups		**Shapiro-Wilk test * P value ****	**Normality Interpretation**
SLM Group	Before cycling fatigue testes	0.145	Normally Distributed
	After cycling fatigue testes	0.245	Normally Distributed
casting group	Before cycling fatigue testes	0.145	Normally distributed
	After cycling fatigue testes	0.179	Normally Distributed

.2. Descriptive analysis:

Table (2): Comparison of mean surface roughness values between and within studied groups, before and after cyclic fatigue tests.

	SLM group	**Casting group**	**Test of significance**	**Interpretation**
Before cyclic fatigue tests	0.289±0.0016	0.289±0.001		
After cyclic fatigue tests	0.292±0.002	0.34±0.001	0.049*	Significant
Test of significance	p= 0.01**	P= 0.041*		
****Interpretation**	Significant	Significant		

Evaluation of surfaceroughness between both groups.

- Casted group showed slightly higher Mean surface roughness value after cyclic fatigue tests than SLM group (0.34±0.001 and 0.292±0.002) respectively.
- There was a statistically significant difference between SLM and casted groups after cyclic fatigue tests (p=0.049)

Evaluation of surface roughness within each group.

There was a slight increase in the mean surface roughness value after application of cyclic fatigue tests of the fabricated RPD frameworks regarding both studied groups.

In this study there were statistically highly significant difference in abutment teeth surface roughness data for the SLM group as p-value (0.01) and significant difference for casted groups as p-value (0.041) after application of cyclic fatigue tests.

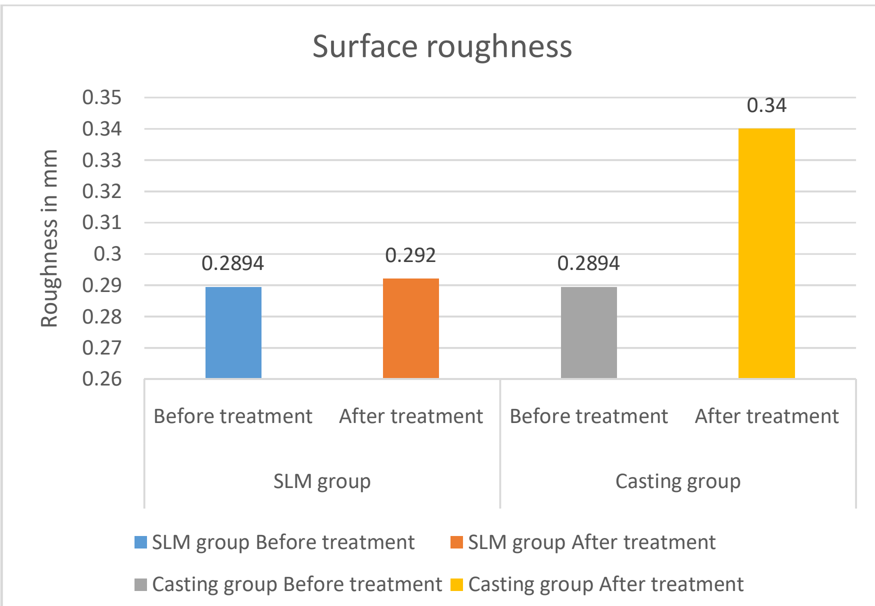

Fig 9The mean value of abutment teeth surface roughness for printed group andcasted group before and after cyclic fatigue tests.

Discussion of materials and methods:

SLM technology has recently become popular in the field of dental application and has many advantages, such as decreasing the risk of human error, rapid prototyping and less time - and material -consuming[16, 17] .This study was carried on comparingand describing the lab steps of fabrication an additive manufacturing technique to produce SLM and 3D printed casted CoCr framework.

Kennedy class I is one of the most popular partially edentulous occurrences, with individuals identified as having bilaterally missing posterior teeth. it requires considerable effort to restore its physical and mechanical properties. Therefore, evaluation of abutment teeth surface roughness is highly crucial for increasing patient satisfaction.[18].

Epoxy Resin cast was duplicated from stone cast as epoxy resin has many advantages, such as good dimensional accuracy, surface detail reproduction and transverse strength. therefore, the epoxy resin casts can bear the force during cyclic fatigue tests[19]. The second premolars were made of dental composite because its surface hardness is comparable to natural dental enamel [20]

3D desktop scanner was used in the present study as it has several distinct advantages such as high accuracy and is well known for their precision. The light scanner captures a series of pictures which were then used to produce a 3D version of the tooth or arch model. They are also easy to use as soon as the light exposure is set to an object the scan is ready to take place without any modifications. And they are safer than laser scanners as they don't use a focused light as laser have some eye safety concerns [21].

The palatal plate was selected in this study because it is most commonly used in Kennedy class I partially edentulous cases and when more than six front teeth are detected in the arch. It is also used to obtain maximum tissue support, as it covers half or more of the hard palate [22].

It was found that the broad stress distribution decreases the occlusal load bearded by the residual ridge, and this reduces the bone resorption..[23, 24] therefor, extra bilateral indirect retainers with mesial rests were used in the present study during designing the RPD framework to avoid the residual bone resorption and the abutment teeth mobility.

A liquid crystal display (LCD)-based stereolithography technology of the printing machine used a digital light projector to flash a single image of an entire layer all at once, making it faster than a SLA machine.[25]. Therefore, LCD technique was used in the present study

In the construction of 3-dimensional RPD framework design , support structures are essential for preventing harmful consequences such as collapsing, misshaping, and misalignment which affect the fitting of the RPD frameworks then they affect the retention[26].

In the construction of 3-dimensional RPD framework design A 45◦ building orientation was selected .it found that The optimal build direction provides higher precision for RPD frameworks[27].

In concept, the casting processing steps within a merely digital workflow under standardized conditions, they represent a critical source of error, whereas the CAM procedures seem more predictable [28]. In other words, using CAD/CAM technique rather than manual processing (CLW) technique is likely to result in more accuracy. This is expected in the AM construction of the RPD frameworks, because it provides a tangible benefit.

3D printed resin was used to maintain the same test parameters similar to SLM frameworks, such as orientation, the thickness and dimensions of the designed RPD frameworks for more reliable results. [29].

Cobalt-Chromium alloy was selected as an RPD framework material because of its high strength, heat resistance, non-magnetic, and favorable resistance to wear, corrosion, and tarnish[30] .Its high modulus of elasticity (E) offers the required strength and rigidity without requiring large cross-sections, lowering the weight of metal substructures. Co-Co alloy has excellent biocompatibility.[31]

The electric centrifugal induction machine was used in casting as it controls and assures the precision of fabricating various shapes and forms from molten metals [32].

SLM frameworks fabricated in the current study was segmented into cross-sectional layer 0.1mm thickness on slicing software because it was proven in previous investigations that finer STL export setting increases the number of triangles used in the geometry, which improves the quality of the circle and affect the study parameters potentiality[33]. SLM frameworks were exposed to post-processing heat treatment at 1150 ˚ C, in order to reduce stresses [34].

The fitting surface of the RPD frameworks wasn't finished or polished in order to decrease human error during manufacture and improve the validity of the present investigation. Based on a previous study, finishing, and polishing of the fitting surfaces could improve or negatively affect the fitness and trueness of the dental prostheses.[35]

In a square shape, the geometric center (centroid) is the point where the diagonals intersect each other. The diagonals are the lines that connect opposite corners of the square shape. The centroid is located at the exact center of the square[36]. Therefore, the metallic bars were fixed in the geometric center of the frameworks before cyclic fatigue tests.

Abutment teeth surface roughness is evaluated in the present study because tooth surface roughness plays an important role in oral health and various dental applications. Rough tooth surface led to retaining more plaque compared to a smooth surface and can contribute to the initiation and progression of dental caries and periodontal disease. Tooth surface roughness can affect the appearance of the teeth. Smooth and polished tooth surfaces reflect light evenly, giving a more aesthetically pleasing appearance [37].

The optical methods tend to fulfil the need for quantitative characterization of surface topography without contact because the optical profilometers are a non-contact, non-destructive measurement technique used to characterize the surface topography and objects roughness. Optical profilometer can capture surface details with high precision, often down to sub-nanometer resolution. It can capture 3D surface data rapidly, allowing for efficient measurement and analysis. This is especially useful when dealing with large sample sizes or when the time is a crucial consideration[38, 39]. Therefore, an optical profilometer was used in the present study for measuring the abutment teeth surface roughness.

Chewing simulation tests are commonly used in dentistry to assess the durability and functionality of RPDs through subjecting these RPDs to replicate the individual characteristics of a patient's chewing cycles. The resistance to wear, fracture, and long-term functionality can be evaluated [40, 41].

The ROBOTA chewing simulator was used in the present study because it is a hypothetical device which provide a controlled and consistent chewing cycles simulating the action of chewing food [42].

A previous study showed that a sequence of 12500 chewing cycles was used to simulate the function of a partial denture for three months in the patient mouth. Furthermore, the RPD frameworks were inserted and removed about 2880 times to simulate two years of RPD insertion and removal. [43].therefore the cyclic fatigue tests were used in the present study in the same way for more actual results.

In this study the mean of all measurements for maxillary RPD CO-Cr frameworks were collected as one record for each group to evaluate the overall mean changes that occurred for the tested samples before and after chewing simulation.

The available literature on the fitness of SLM frameworks that affect the abutment teeth surface roughness is rather inconsistent. In previous study, they assess the fit of SLM-framework RPI clasps to abutment teeth. They concluded that SLM-fabricated samples were substantially more accurate than cast samples. Because casted frameworks distortion may occur during clinical use .The use of high-shrinkage alloys for casted frameworks may cause distortion , the author also suggested that SLM frameworks performed better than casted frameworks with time as the surface treatment required after casting has been shown to cause metal loss of approximately 127 mg[44].

In the present study, our results showed that there was no difference in the abutment teeth surface roughness between the 3D printed cast and SLM frameworks before chewing simulation. This is because the abutment teeth' surface roughness depends on the roughness of the materials and the surface roughness of resin composite is directly related to particle size of the filler. Therefore, each abutment tooth in the current study was fabricated from the same type of dental composite and fabricated in the same mould.[45]

There was no previous study searched the abutment teeth surface roughness of SLM or casted RPD frameworks .but in same previous study which agrees with the current study, It was found that there is no significant difference in the surface roughness of the clasp arms between the SLM and 3D printed casted clasps and surface roughness of the clasps certainly affect the roughness of abutment teeth [46].

In the present study, there is a significant increase in the abutment teeth surface roughness observed in each group of RPD frameworks after cyclic fatigue tests. This may be due to increasing the friction coefficient between the internal surface of the retentive clasp terminal and the abutment teeth surface during the fatigue cycles that leads to an increase of the teeth surface roughness. Also each group of RPI clasps in the present study has the same abutment teeth dimension to avoid differences in the degree of wear and the friction coefficient which led to constant experimental sequences in our study [47, 48].

In the present study,it was found that the abutment teeth surface roughness in 3D printed casted group was more than which in SLM group, this may be due to SLM frameworks exhibiting higher density surfaces and smaller grain sizes leadsto smoother surface compared to 3D printed casted frameworks. the difference in microstructure demonstrates why the abutment teeth surface roughness of the SLM frameworks were less than the 3D printed casted frameworks after cyclic fatigue test .[49, 50].

In a previous study , it was demonstrated that RPD frameworks fabricated using DMLS were more flexible than casted frameworks .Therefore, DMLS frameworks less prone to cyclic fatigue that's reflect into less abutment teeth surface roughness after cyclic fatigue tests [51].

CONCLUSION

With the limitation of this in vitro study, it was concluded that:

- The result of abutment teeth surface roughness of the RPD frameworks for the two groups were equal before cyclic fatigue tests (as the abutments have the same materials and dimensions).
- The abutment teeth surface roughness of 3D printed RPD frameworks is more than SLM frameworks after cyclic fatigue tests.
- According to the result of this study, the CAD/CAM rapid prototyping RPD frameworks can be used as good alternative to CLW technique fabricated frameworks.

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