The effect of different fabrication techniques on porosity of cobalt-chromium cast removable partial denture farmworks

Fryad Mustafa Rasheed[1]; Rizgar Mohammed Ameen Hasan [1]

Background and Objective: Cobalt-chromium removable partial denture has been in use for years and despite of the advantages that cobalt-chromium provides, it has many disadvantages. In recent years with the development of dentistry science a cobalt-chromium removable partial denture is still used. The purpose of this study was to evaluate the overall porosity of conventional versus computer-aided design/computer-aided manufactured (CAD/CAM) and 3D-Printed removable partial denture (RPD) frameworks based on tests data analysis, and to evaluate the porosity of each technique's fabrication of the RPD frameworks.

Methods: Thirty ideal maxillary stone cast class II modification 1, divided in to three groups for construction of single palatal strap framework conventionally and digitally. For each group, removable partial dentures (chromium cobalt framework) were constructed conventionally and digitally. After finishing and polishing of the prosthesis, the porosity test was performed for each group and then compared to each other.

Results: As for the porosity test, the number of defects after finishing and polishing, shows that there are significant differences between the three groups depending on the value of the (F-test) which is less than ($P < 0.01$), The maximuim mean result was shown by group III, while the minimum result was shown by group I.

Conclusions: Within the limitations of this study, although both 3D-printing and CAD/CAM methods of framework fabrication revealed clinically acceptable adaptation, the conventional cast RPD groups revealed less overall porosity.

Keywords: conventional lost-wax, 3D Pinter, CAD/CAM techniques, Porosity.

[1]Department of Prosthodontic Dentistry, College of Dentistry, Tishik International University, Erbil, Iraq.
Correspondent Name: Fryad Mustafa Rasheed
Email:fryad_79@yahoo.com

Introduction

A removable partial denture is an indispensable treatment option for certain situations. Although various materials and techniques were developed in the laboratory dental field, the conventional metallic removable partial denture manufactured by lost wax technique is still used. This old technique is successful however it's inherited drawbacks. The conventional technique is time-consuming, requires multiple steps and is technique-sensitive.[1] which noted that, more steps were used, more chance for errors and ill-fitting dentures. Akl et al (2022) in three-part articles, reviewed and categorized multiple errors possible during the fabrication of a removable partial denture. He clarified that avoiding errors by good technique is easier than their treatment. In addition, they confirmed that errors are cumulative and so may result in denture remake.[2]

In recent years, rapid prototyping (RP), an additive material manufacturing technique, has developed rapidly in dentistry to fabricate frameworks of different prostheses, including RPDs. Commonly used RP techniques are stereo-lithography (SLA), three-dimensional printing (3D printer), selective laser sintering (SLS), selective laser melting (SLM), and fused deposition modeling (Torabi et al, 2015).[3] the additive rapid prototyping technologies can fabricate organic complex configurations which were very difficult to be milled with a subtractive method. Consequently, it is suitable for human anatomy structures and highly detailed prosthetic appliances such as removable partial denture (RPD), complete denture, maxillofacial prosthesis and implant surgical guide stents. [4,5]

Further, the Computer-aided design / computer-aided manufacturing (CAD/CAM) technology became one of the most important developments happened in the dental field. The manufacturing of dental restorations and devices using CAD-CAM subtractive behavior was successful in many situations and so used widely in a tooth or implant-supported fixed, removable prosthodontics and operative dentistry. Consequently, all dental laboratories started to shift their services to digital manufacturing where less material is consumed, saving time and effort and capability of mass production. [4,6]

The dental casting system aims to provide a metallic copy of the wax pattern as accurately as possible. Nevertheless, a wide range of variables may influence the final result and predictable outcomes are hardly achievable. While casting dental prostheses, problems frequently observed are incomplete casting and internal porosity.[7]

The present of this in-vitro study was conducted to evaluate and compare the porosity of the cast cobalt-chromium RPDs framework created using of three different techniques conventional lost-wax, additive manufacturing and CAD/CAM technology.

Methods

Preparation of the ideal casts

A standard maxillary dentulous stone cast is made by pouring class III dental stone into a standard plastic mold. The maxillary dentulous stone cast was converted into a Kennedy Class III modification-1 edentulous situation by removing second premolars and first molars bilaterally and rest seats prepared on first premolars and second molars. Then the stone cast was surveyed, designed and necessary teeth preparations were carried out. This prepared master cast was duplicated with Addition duplication silicon material and 30 master casts were fabricated following manufacturers recommendations by dental stone type III.

Fabrication of refractory casts

The duplication of the master die was done with addition silicon material (Addition VUL Canizing duplication silicon, Z-Dope. Lot No. 438878. Regular Type, Italy) in the duplicating unit following the manufacturer's instructions. The master die was carefully separated from the gel mould and removed. The refractory casts were made with phosphate bonded investment material (Shulur Dental. Shera Lot No. ISO 6873. Work soft, Germany) following the manufacturer's recommendations. Ten refractory casts were made for the conventional technique in this study.

Refractory casts were dried in a drying oven at 250°C for about 60 min and then immersed in hardener for 5-8 seconds. The casts were removed from the hardener, excess liquid was allowed to drain and placed back in the preheated oven in a vertical standing position for 10 min so that excess liquid could evaporate. All refractory casts became hard and smooth and its ready to wax-up and spruing.

Wax-up

The wax patterns for the frameworks were made from prefabricated wax forms to get a uniform thickness of various components. A single palatal strap maxillary major connector with 4 circumferential clasps on both maxillary right and left first premolars and on both maxillary right and left first molars and 4 occlusal rest seats next to edentulous spaces on the maxillary first premolars and first molars (Quadrilateral design) were designed. The planned design was transferred to the refractory cast before waxing-up. All wax forms were adapted lightly to the refractory cast and sealed, following the manufacturer's recommendations.

Regarding to 3D printer and CAD/CAM techniques 20 master casts were scanned using (10 for each group), and 3D digital casts of the master casts were acquired using a laboratory scanner and were clear and integrated, containing all anatomical structures required for RPD. Digital surveying was completed using the CAD software, which provided accurate positioning for RPD components. RPD framework components such as clasp, rest, and minor and major connectors were designed according to the principles of RPD framework. Using RPD designing software dental CAD 3.0 Galawy (Exocad) (Figure 1).

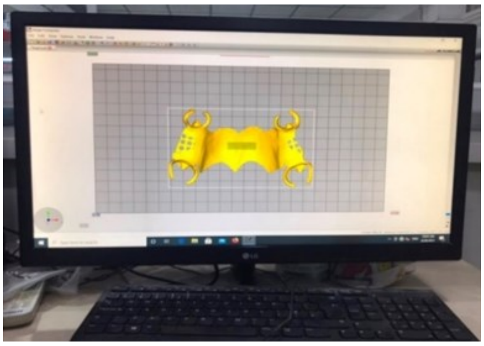

Figure 1: Three-dimension RPD

Then the design was sent to the printer additive machine ASIGA 3D printer machine. The additive process started to fabricate the resin framwork with polymer base methacrylate for DLP System, the construction of the resin framework was performed layer by layer (754 layers), each design had taken 3 hours to be completed and to become the resin frameworks (Figure 2).

Figure 2: The resin framework

About CAD/CAM technique were the 3D-RPD was finished; then transforms the digital data of the RPD into a physical product by milling machine with the aid of computer using a high-quality special bur which cut the frame from blank wax is called milling process (Zirkonahn Blank Wax, Lot No. 15659. Gray color, Italy). Using this procedure 10 wax frameworks were prepared (Figure 3).

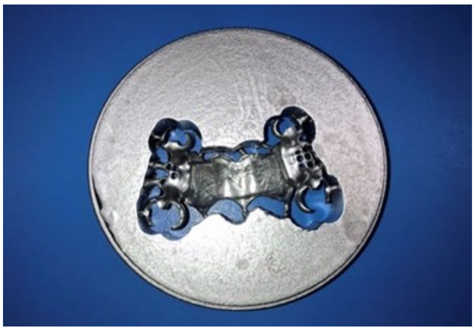

Figure 3: wax pattern after milling

Spruing

A top multiple spruing was used for these 3 techniques of the study. A cone-shaped wax sprue is attached to the central sprue from which 4 auxiliary sprues run to each corner of the wax pattern. Then through the sprues to the wax-up, an attempt was made to standardize the amount of alloy which will flow through per unit length of the sprue. Then the funnel former was positioned in the center of the wax framework 10 mm above the arch of the teeth and carefully waxed to the sprues. using 10 gauge round sprue.

Investing and casting

All refractory casts with wax patterns printed resin framework and milled wax pattern was within an hour using the phosphate bonded investment material (Shulur Dental. Shera Lot No. ISO 6873. Work soft, Germany) following the manufacturer’s instructions. The mould former was removed after 10 minutes and the investment mould was allowed to set for 30 min before preheating. Before burn out the procedure the mould along with the crucible and the required amount of alloy, was carefully balanced and adjusted in the centrifugal arm of the induction-casting machine centrifuge (Golloni

Fusus 72) Italy). The mould was then placed in a burn-out furnace. casting procedures carried out in an Induction casting machine following the manufacturer's instructions. The mould was allowed to bench cool to room temperature. Divesting was then carried out with a light hammer. The remaining investment material was removed by sandblasting. Sprues were cut-off with high-speed grinder using the high-speed cutoff discs. Polishing was then carried out with rubber polishing points, discs and wheels. The fitting surfaces of the clasps and the frameworks were not polished. All 30 frameworks (Figure 4) were evaluated for satisfactory fit on the master die at the following sites: Four retentive arms, four reciprocal arms, four occlusal rests, and one major connector.

Figure 4: Frameworks after finishing and polishing

Radiographic examination

The radiographs of the 30 frameworks were taken using 200 kV X-ray machine (EcoRay, product name: Beam Limiting Device, Model: SMS-CM-N, Korea). Films (DIRECTVIEW CR Cassette with PQ screen, USA) were exposed at 86 kV and 10 mA for 0.5s. The source-object distance was kept at 30 cm for all the specimens (Figure 5). DIRECTVIEW CR Cassette was transferred and put on Kodak Carestream Direct-View Max CR 975 System machine, UAS made. Then the cassette goes into the Direct-View Max CR machine to it is processing. After the processing, the image appears on the image viewer screen of the computed radiography system (Figure 6). In conclusion, the image sending to laser printers with dry film technology to print the capturing data on DRY-VIEW laser imaging films. The films were developed and drying come out in the laser printer machine, then the radiographs were examined for internal defects. All the radiographs were viewed independently in a semi darkroom with a high-intensity illuminator. The number of internal defects in each radiograph and the average number of defects in each group are recorded (Table 1). For statistical data analysis, the statistical software "SPSS-Version 5" was used.

Figure 5: EcoRay radiographic machine

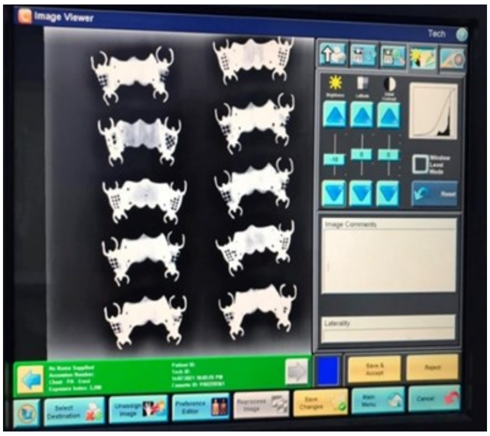

Figure 6: The image viewer screen

Result

The cast frameworks were evaluated for the defects observed after finishing and polishing on radiographic evaluation. The results obtained were tabulated and statistically analyzed using one-way analysis of variance (ANOVA) and Multiple Comparisons –LSD test. Results of radiographic evaluation showed that Group III had the maximum number of internal defects while Group I had the minimum number of internal defects (Table 1). On statistical analysis with ANOVA (Table 2), it was found that the average number of internal defects differed significantly between the three groups ($P < 0.000$). When the value of the F-test is significant, the (Multiple Comparisons -LSD) had been conducted to compare groups in pairs, as shown in Table (3), and there were the significant differences between (Group I - Group II) and (Group I - Group III), the significant differences can be seen in Figure (7).

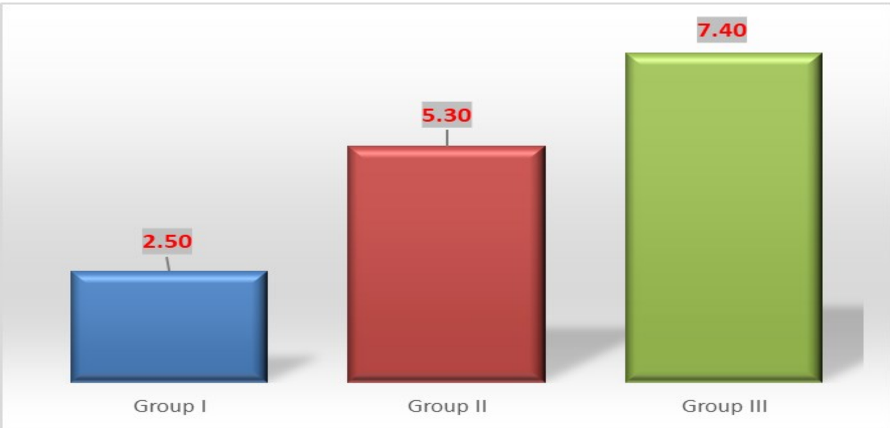

Figure 7: The maximum and minumum mean value defects No.

Sample No.	Number of defects		
	Group I	Group II	Group III
1	2	13	6
2	1	3	5
3	1	5	7
4	3	3	6
5	0	4	6
6	2	8	11
7	1	7	10
8	3	3	9
9	7	5	6
10	5	2	8
Mean	2.5	5.3	7.4

Table 1: Number of defects for all castings on radiographic evaluation

Table 2: Comparison of average number of defects on radiographic evaluation by ANOVA

	No.	Mean	Std. Deviation	Std. Error	F-test	p-value
Group I	10	2.50	2.121	0.671	9.324	0.000**
Group II	10	5.30	3.302	1.044		
Group III	10	7.40	2.011	0.636		
Total	30	5.07	3.194	0.583		

ANOVA: Analysis of variance; SD: Standard deviation

Table 3: Multiple comparison of average number of defects on radiographic evaluation by LSD test

Groups		Mean Difference (I-J)	Std. Error	p-value
Group I	Group II	-2.800*	1.139	0.021
	Group III	-4.900*	1.139	0.000
Group II	Group I	2.800*	1.139	0.021
	Group III	-2.100	1.139	0.076
Group III	Group I	4.900*	1.139	0.000
	Group II	2.100	1.139	0.076

LDS: Analysis of variance; SE: Standard error

Discussion

A radiographic unit provides an adequate source to detect large and small defects in base metal removable partial denture castings. An ideal framework should show no internal defects, to prevent fracture, dimensional stability and failures during use. The radiographic unit was also employed by some other authors to detect internal defects from metal frameworks (Rodrigues et al, 2002; et al, 2013; Swelem et al, 2014)

During the radiographic examination of a framework, the presence of a radiolucent area does not necessarily represent a critical structural defect, because less than optimum thickness may also appear as a radiolucent area and result in fracture of the framework. This explains the frequent breakage of these castings during use even though the metal framework apparently looks normal, and a major difficulty was experienced in the identification of the relationship between radiolucency of internal porosities and not similar localized radiolucencies's produced by surface indentations and regional reductions in the thickness of the framework[12,14].

In this study, a 200 kV EcoRay radiographic machine was used and 86 kV, 10 mA and 0.5 s exposure time produced the best contrast to show the internal defects in castings and the same was used as a standard for all the castings evaluated according to Viswambaran[13].

On radiographic examination, it was observed that maximum defects were present in the castings of Group III (mean=7.4) followed in decreasing order by Group II and Group I is minimum (mean=2.5), which had a minimum number of defects and this difference was statistically significant ($P < 0.0001$). When comparing between the groups there was a highly significant difference between Groups. One of the main factors to create internal porosity are the amount of gas produced during burn out of the pattern's material during the casting process. The additive resin pattern and blank wax pattern need more time in the furnace to burn out the patterns than the conventional wax patterns to evaporate the materials there to produce more gases. Usually, the cast metals present high porosities and internal defects due to gas inclusion during the fabrication process[15]. Powder quality of the additive technology (selective laser melting LSM) materials.

Except density, the shape and size distribution of precursor powder granules also have an important meaning for producing the low porosity of the 3D printed samples. Gong et al (2017) found that the small particles inclusion (about of 10 μm) in powder affected extra laser energy absorption resulting from the multiple scattering of laser[13]. In this study used a powder particles size about of 15 to 40 μm.

The thickness of the wax patterns is important for factories which produce internal porosity, a thick pattern becomes more porous than a thin uniform pattern. In my opinion the thickness of group III is more than other groups. These results were in agreement with Baltag et al, (2005) they found a porosity from a thick cross-sectional area because a bigger cross-section region inlet flow more than the small region, and the melt adopted an open-channel flow pattern, characterized by the fact that the free surface of the flow was directly exposed to and had pressure equal to that of the argon atmosphere in the mold; Once incorporated in the flow, gas can no longer escape through the investment because the melt rapidly forms a thin solidification layer in contact with the cavity wall[14]. Leinfelder et al, (1963) reported that uniformity of the casting pattern is one of the contributing factors to the development of porosity within dental castings[15]. In disagreement with Swelem et al, (2014) how reported that the light-polymerized patterns can produce clinically acceptable partial removable dental prosthesis frameworks similar to those fabricated from conventional wax patterns[10].

Conclusion

Within the limitation of this study it has been concluded that the conventional lost-wax technique produces less porosity while more porosity produces by CAD/CAM technique. Over all a conventional lost-wax technique was better than other groups.

Conflict of interest

The author reported no conflict of interests.

References

1.PHOENIX, Rodney D., et al. *Stewart's clinical removable partial prosthodontics*. Chicago: Quintessence, 2003.

2.AKL, Mohammed A.; STENDAHL, Charles G. Removable Partial Denture Frameworks in the Age of Digital Dentistry: A Review of the Literature. *Prosthesis*, 2022; 4.2: 184-201. https://doi.org/10.3390/prosthesis4020019

3.TORABI, Kianoosh; FARJOOD, Ehsan; HAMEDANI, Shahram. Rapid prototyping technologies and their applications in prosthodontics, a review of literature. *Journal of Dentistry*, 2015; 16.1: 1. https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4345107/#

4.BEUER, Florian; SCHWEIGER, Josef; EDELHOFF, Daniel. Digital dentistry: an overview of recent developments for CAD/CAM generated restorations. *British dental journal*, 2008, 204.9: 505-511. https://doi.org/10.1038/sj.bdj.2008.350

5.SUN, Yuchun; LÜ, Peijun; WANG, Yong. Study on CAD&RP for removable complete denture. *computer methods and programs in biomedicine*, 2009; 93.3: 266-272. https://doi.org/10.1016/j.cmpb.2008.10.003

6.KAPOS, Theodoros, et al. Computer-aided design and computer-assisted manufacturing in prosthetic implant dentistry. *International Journal of Oral & Maxillofacial Implants*, 2009; 24.

7.KUEH, S. T.; REZA, Fazal. Evaluation of physical properties and casting accuracy of chrome-cobalt alloys with different casting systems and investments. *Journal of Physical Science*, 2012; 23.2: 91-102.

8.RODRIGUES, Renata Cristina Silveira, et al. Comparative study of circumferential clasp retention force for titanium and cobalt-chromium removable partial dentures. *The Journal of prosthetic dentistry*, 2002; 88.3: 290-296. https://doi.org/10.1067/mpr.2002.128128

9.VISWAMBARAN, M.; SUNDARAM, R. K. Effect of storage time and framework design on the accuracy of maxillary cobalt-chromium cast removable partial dentures. *Contemporary clinical dentistry*, 2015; 6.4: 471. https://doi.org/10.4103/0976-237X.169841

10.SWELEM, Amal Ali, et al. Surface roughness and internal porosity of partial removable dental prosthesis frameworks fabricated from conventional wax and light-polymerized patterns: A comparative study. *The Journal of Prosthetic Dentistry*, 2014, 111.4: 335-341. https://doi.org/10.1016/j.prosdent.2013.06.023

11.GAPIDO, Cynthia G., et al. Fatigue resistance of cast occlusal rests using Co-Cr and Ag-Pd-Cu-Au alloys. *The Journal of prosthetic dentistry*, 2003; 90.3: 261-269. https://doi.org/10.1016/S0022-3913(03)00367-6

12.KOUTSOUKIS, Theodoros, et al. Selective laser melting technique of Co-Cr dental alloys: a review of structure and properties and comparative analysis with other available techniques. *Journal of Prosthodontics*, 2015; 24.4: 303-312. https://doi.org/10.1111/jopr.12268

13.GONG, Haijun, et al. Influence of small particles inclusion on selective laser melting of Ti-6Al-4V powder. In: *IOP Conference Series: Materials Science and Engineering*. IOP Publishing, 2017; p. 012024. http://dx.doi.org/10.1088/1757-899X/272/1/012024

14.Baltag, Ioana, Kouichi Watanabe, and Osamu Miyakawa. "Internal porosity of cast titanium removable partial dentures: influence of sprue direction and diameter on porosity in simplified circumferential clasps." *Dental Materials* 21.6 ,2005; 530-537. https://doi.org/10.1016/j.dental.2004.07.017

15. LEINFELDER, Karl F.; FAIRHURST, Carl W.; RYGE, Gunnar. Porosities in dental gold castings. II. Effects of mold temperature, sprue size and dimension of wax pattern. *The Journal of the American Dental Association*, 1963; 67.6: 816-821. https://doi.org/10.14219/jada.archive.1963.037