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Comparative Study Between Two Digitally Fabricated Removable Partial Frameworks

Ahmed Samir Saad[1]; Safaa Alsayed Asal[2]; Eman Abd El-Salam Shakal[2]; Ibrahim Ramadan El Torky[2]
[1]*BDS,MS, Faculty of Dentistry-Alexandria University; Alexandria-Egypt*
[2]*Professor of Prosthodontics Faculty of Dentistry-Tanta University; Tanta-Egypt*

Abstract
Aim: *Fit of Removable partial denture is a frequent problem with partially edentulous patients fabricated with conventional techniques The aim of this study was to compare between two removable partial denture (RPD) frameworks fabricated using computer aided design/computer aided milling (CAD/CAM) technology, one milled from poly-ether-ether-ketone (PEEK) and the other milled from cobalt chromium alloy (Co-Cr) as regards clinical and laboratory aspects.*
Materials and Methods: *Fourteen maxillary partially edentulous patients (class III modification 1 according to Kennedy classification) were randomly allocated into the two groups (n=7)., group A patients received RPDs directly milled from PEEK block while for group B, patients received RPDs directly milled from Co-Cr alloy block.*
All frameworks were evaluated clinically as regards fit of the guiding plate and palatal strap major connector using occlude spray and Duralay respectively. For laboratory evaluation, trueness with the CAD file and the overall misfit of milled frameworks of both groups to the virtual master cast were evaluated using GOM Inspect software. Data were statistically analyzed using t-test.
Results: *Regarding the clinical fit of palatal strap major connector and guiding plate, there was a statistically significant difference between the two groups indicating more fit of group B RPD frameworks.*
The trueness of both milled frameworks reported negative mean deviation values with no statistically significant difference.
There was a statistically significant difference between the two studied frameworks as PEEK frameworks (Group A) reported higher overall misfit values to the virtual master cast ($p < 0.001$).
Conclusion: *CAD/CAM directly milled Co-Cr RPD frameworks showed better results regarding clinical fit to oral tissues, trueness and digital fit to the virtual master cast.*

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I. Introduction

Several materials have been introduced, during last centuries, for removable partial denture fabrication. These include wood, ivory, porcelain, hard gold alloy, vulcanite thermoplastic polymer, polymethyl methacrylate (PMMA) and cobalt chromium (Co-Cr) alloys.

Over the last two decades poly-ether-ether-ketone (PEEK) become a versatile material that can be used in producing a variety of medical and dental prosthetics [1].

PEEK is a thermoplastic biomaterial with potentially excellent mechanical and thermal properties. With low elastic modulus, outstanding solvent resistance, and biocompatibility with bone, this polymer is a candidate to replace metals in the body. PEEK demonstrates higher strength than metals on basis of a per mass. [2]

Few studies have yet evaluated PEEK as a new restorative material for removable partial denture (RPD) framework fabrication.

Computer aided design/Computer aided milling (CAD/CAM) have been used in the recent years for the fabrication of onlays, inlays, fixed partial dentures, crowns, implant abutments, and maxillofacial prostheses.

Computer guided manufacturing process is done either by rapids prototyping (RP) or by milling from solid block. Many studies have been conducted evaluating 3D printed Co-Cr RPD. However, few studies have reported using direct milling to fabricate Co-Cr RPD.

This study was conducted to compare two different removable partial denture frameworks fabricated using computer guided milling technology; one of them fabricated from PEEK while the other fabricated from Co-Cr regarding laboratory and clinical aspects.

II. Materials And Methods

Fourteen partially edentulous patients with maxillary Class III modification 1 Kennedy's Classification were selected from those attended to the outpatient clinic, Prosthodontic Department, Faculty of Dentistry, Tanta University.

Patients were randomly allocated into two groups; Group A: patients received CAD/CAM RPD with PEEK framework, and Group B: patients received CAD/CAM RPD with Co-Cr framework.

Approval for this research was obtained from the Research Ethics Committee, Faculty of Dentistry, Tanta University. The purpose of this study was explained to the patients and informed consent were obtained according to the guidelines of human research adopted by the Research Ethics Committee, Faculty of Dentistry, Tanta University.

Primary impressions ,primary surveying and suggested mouth preparation were done in usual conventional sequence. Then, polyvinylsiloxane final impressions were made[1] **(Fig. 1)**. Final impressions were poured using fast set extra-hard type IV dental stone[2] to get the master casts (MC A,B). Each physical master cast was scanned using ZirkonZhan scanner[3] to create a virtual 3D model (3D M)**.** For the studied groups, it was saved as a reference STL file data for each group [STL file 1A, STL file 1B].

CAD for RPD framework

Using 3Shape Dental System (3SDS) software[4], RPD framework digital designing was done according to the planned design **(Table 1)**.

The STL file 2A and 2B of the frameworks produced by the CAD software , was imported to the milling machine **(Fig. 2)**. For group A, five axes dry milling machine[5] was used to mill RPD frameworks from PEEK blocks[6]**.**

- For Group B, EMAR Dental Series Milling machine[7] **(Fig. 3)** was used to mill RPD frameworks from Co-Cr block[8].with cooling water stream**.**
- Initial adaptation of the Co-Cr frameworks onto the master casts was done.

Scanning the RPD frameworks

Framework scanning was done using Smart Optics[9] desktop scanner to create a virtual 3D RPD frameworks {PEEK and Co-Cr)}. The Co-Cr frameworks were sprayed with SHERA[10] scanning spray before scanning to prevent reflections of scanning light by the metal surface**.**

- Each framework of both groups (A) and (B) was tried-in intraorally**.**

I-Laboratory evaluation

- **A. Evaluation of fit of the milled framework to the 3D model:**

Using GOM inspect software, evaluation of the fit of the framework to the virtual 3D-model was done as follow:

*a. At 17 points of measurements **(fig 5)***

i . 5 points at major connector (L1- L5)

ii. guiding plate/plane contact (4 proximal plates)

iii. at occlusal rest (four rests X 2 points (central and peripheral)

b. Overall fil to the 3D model

According to **Table 2**, each case of both groups (A and B), superimposition of the STL file 3 to the STL file 1 was done using point-to-point matching. The overall best fit alignment commands of GOM Inspect software was used to obtain color maps of dimensional deviations. **(Fig. 6 a,b)**

The mean values of the overall fit of the framework to the corresponding 3D-model were calculated and tabulated

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[1] Zhermack INC. 45021 Badia Polesine (Rovigo) Italy.

[2] Kimberlit, Protechno, Ginora, Spain.

[3] Zircon Zhan Italy

[4] 3SHAPE Dental Systems (3SDS), Corporation Italy

[5] VHF s1 Italy.

[6] JUVORA Italy

[7] EMAR Dental Series Cairo, Egypt

[8] Bloomden Hunan, China

[9] Smart Optics Germany T

[10] SHERA scan spray,Germany

B. Evaluation of trueness of the milled framework to the CAD design.

According **to Table 2**/ each case of both groups (A and B), superimposition of the STL file 3 to the STL file 2, were guided by the finishing lines, the overall best fit alignment commands of GOM Inspect software was used to obtain color maps of dimensional deviations (trueness).(**fig 7)**

The mean values of dimensional deviation of the milled framework to the CAD design were calculated and tabulated

II. Clinical evaluation of the milled framework before try-in to evaluate the fit of

a. the major connector using Duralay[11].

b. guiding plate using occlude spray[12].

1- Measurements at the major connector

The fit of the major connector of the finished RPD framework was verified using Duralay

– Duralay separating medium was sprayed to lubricate the fitting surface of the frameworks then Duralay material was mixed**-** and applied evenly onto the tissue surface of the mid palatal strap.

– The framework was completely seated with even finger pressure onto the occlusal rests until all occlusal rests were fully**-**seated in their respective rest seats**.**

The indexed points of measurements were allocated nearly at the same positions used to check the fit of the milled framework to the CAD design from L1 to L5 **(fig 8)**:

L_1*: Middle upper point; at mid palatal point of the anterior border of the major connector, 5 mm posterior to the beading line.*

L_2*: Middle lower point; at mid palatal point of the posterior border of the major connector, 5 mm anterior to the beading line.*

L_3*: At the left lateral side, 5 mm medial to the internal finish line midway anteroposterior.*

L_4*: At the right lateral side, 5 mm medial to the internal finish line midway anteroposterior.*

L_5*: Midway between L1 and L2 at the center.*

The thickness of duralay was measured using a micrometer caliper[13] to **(Fig. 9).**

b -Fit of the guiding plate

Each finished framework was tried inside the patient's mouth and the areas of interference between guiding planes of the abutment teeth and the related guiding plates were evaluated using *occlusion spray*[14] **(Fig. 10).** The presence or absence of interference between guiding plane and guiding plate was evaluated according to Dunham[3] as follow:

- Score (0): This means the absence of any interference where there was no show through in the occlusion indicating material at the guiding plate.
- Score (1): The presence of slight interference. Where there was minimal show**-**through of the occlusion indicating material.
- Score (2): the presence of heavy interference where there was total show through of the occlusion indicating material.

All the data were collected, tabulated, and statistically analyzed.

Table 1 RPD designing of the two studied groups

Component Parts		Clasp	Rest	Retention	Reciprocation
Second molar abutments	Group (A) (PEEK)	Circlet	MR	DB 0.02	palatal
	Group (B) (Co-Cr)	Circlet	MR	DB 0.01	palatal
Canine abutments	Group (A) (PEEK)	Occlusally approaching clasp	D ledge	MB 0.02	ledge
	Group (B) (Co-Cr)	Combination WW	D ledge	MB 0.02	ledge
Major connector	Midpalatal strap				
Denture base	mesh form				
Finishing lines	Bilateral, internal and external finishing lines between canine and second molar				

MR: mesial rest, DB: distobuccal, D: distal, WW: wrought wire, MB: mesiobuccal

[11] DuraLay, Reliance Dental Mfg. Co., Worth, Illinois, USA

[12] Bausch Arti-Spray Germany

[13] SHANGAHEN 0-25 mm CHINA micrometer caliper

[14] Bausch Arti-Spray Germany

Table 2: The used STL files used for digital evaluations

Step of work	The STL file (Group)
Scan of the master casts	STL file 1 (A, B)
CAD design and creation of virtual frameworks	STL file 2 (A, B)
Scan of the milled frameworks	STL file 3 (A, B)

Figure 1: Polyvinylsiloxane final impression

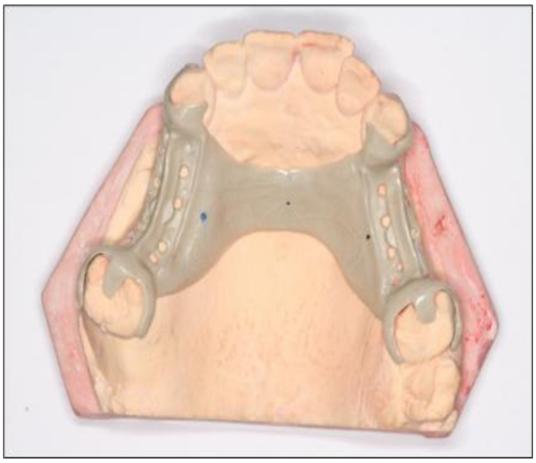


Figure 2: Milled PEEK framework seated onto the MC (A)

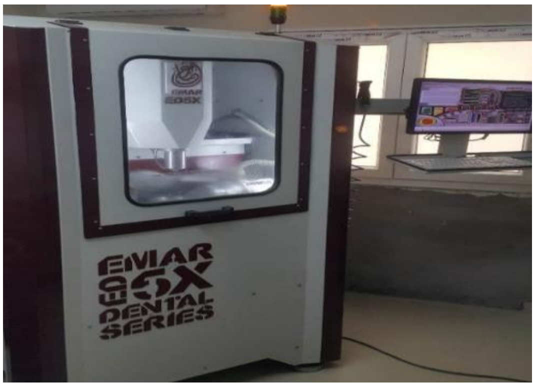


Figure 3 : EMAR Dental Series milling machine

Fig 4 :Wet milling of Co-Cr block

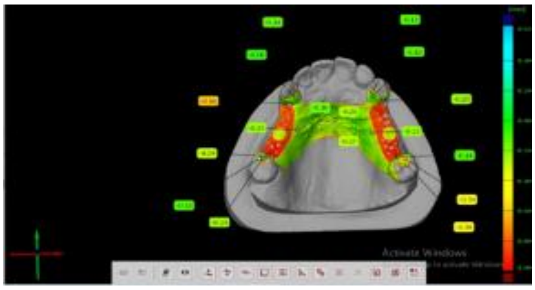
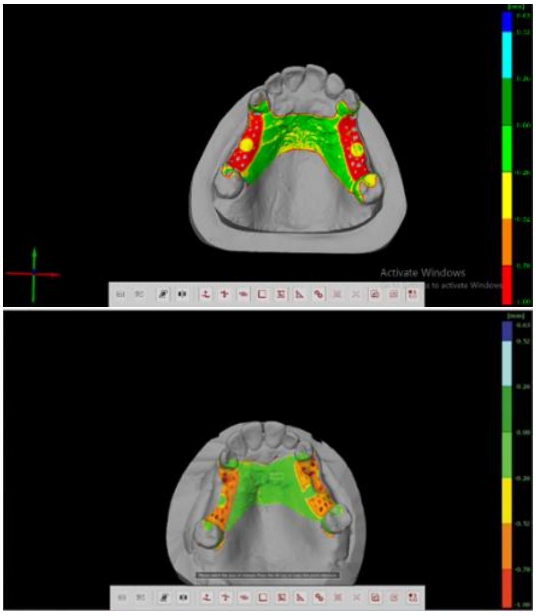
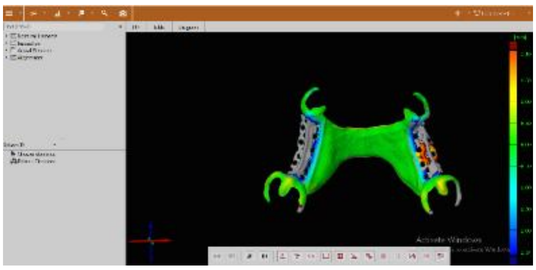


Figure 5: Evaluation of the framework fit at selected 17 points



Figures 6 a,b : Color map representing fitting relation between the virtual framework and the 3D model for both groups.



Figures 7: Color map representing the deviation of the milled frameworks in relation to the CAD

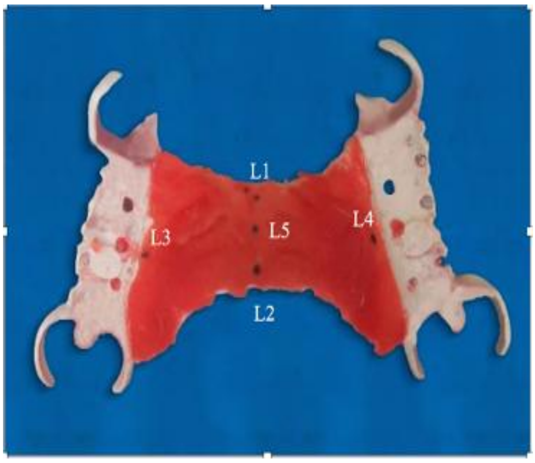
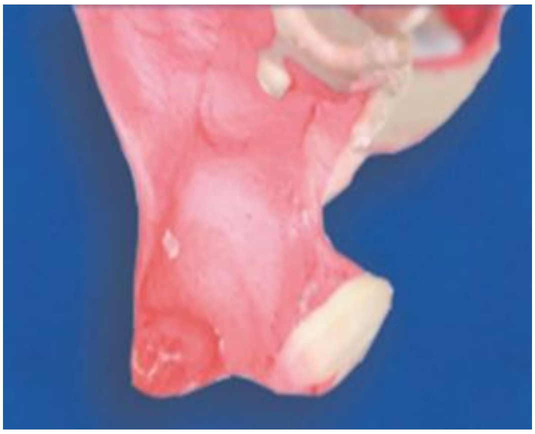


Figure 8: Five Index points for measurements of major connector fit

Figure 9: Measuring thickness of Dura lay using digital micrometer caliper



Figures 10: Inspection of fit at PEEK guiding plates

III. Results

I-Laboratory evaluations

A. Evaluation of fit of the milled framework to the 3D model

a. The fit of the milled framework to the 3D model measured at 17 points.

The 17 areas of measurements/each specim/ each group, were analyzed, comparison between groups was made. A gap from 0 to 50 μm was considered close contact (no gap)[6], and a gap from 50 to 311 μm was defined as a clinically acceptable fit[7]

As shown in Table 3, both groups reported (-ve) dimensional deviation in favor of Co-Cr (Group B). L1 point reported the least dimensional deviation for both groups (-0.22 + 0.05) and (-0.04+ 0.04) respectively. While L5 point reported the highest dimensional deviation for both groups (-0.36+ 0.09) and (-0.19+ 0.06) respectively.
Comparison of the mean of (-ve) dimensional deviation between the PEEK (Group A) and Co-Cr (Group B) frameworks to the 3D model at all reference points was statistically significant where p-value was < 0.0001 at L1,2,4 and = 0.001 at L3,5

b. Evaluation of the overall fit of the milled frameworks to the 3D model

PEEK frameworks (Group A) reported higher overall misfit values to the 3D model 0.07 ± 0.06 and **-** 0.04 ± 0.1 respectively.
There was a statistically significant difference between the studied frameworks regarding overall fit to the 3D model p-value 0.03 as shown in **Table 4.**

B. Results of the overall digital evaluation of trueness of the milled framework To the CAD design

When the trueness of the milled frameworks was evaluated in relation to the CAD design, both PEEK and Co-Cr frameworks reported negative mean deviation values in favor for Co-Cr frameworks as shown in (**table 5**).
There were no statistically significant differences between the two studied groups (p-value 0.66**).**

II- Clinical evaluations

i-Fit of the palatal major connector to the supporting tissues

On comparison of the Duralay thicknessesthat represent the gap between the palatal strap major connector and the supporting tissues - at the five reference points-between the two studied groups **(table 6)**, statistically significant differences were reported between the studied groups at all points of the measurements where P-value < 0.05.

ii-Guiding plate plane relation:

By comparing the two studied groups regarding the percentage of scoring for the guiding plane plate relation at all abutments it was clear that all abutments of Co-Cr (Group B) showed a higher percentage of score 2 indicating heavy contact when compared with PEEK (group A) with a statistically significant difference with p-value = 0.006 (**table 7)**.

Table (3): Comparison of the milled framework fit to the 3D model between the studied groups at 17 reference points.

		PEEK (n=7)	Co-Cr (n=7)	p-value
		Mean (mm)+ SD		
Major connector	L1	-0.22 + 0.05	-0.04 + 0.04	<0.0001*
	L2	-0.26 + 0.05	-0.08 + 0.08	<0.0001*
	L3	-0.30 + 0.10	-0.08 + .08	0.001*
	L4	-0.28 + 0.09	-0.09 + 0.07	<0.0001*
	L5	-0.36 + 0.09	-0.19 + 0.06	0.001*
Guiding plate/ plane contact		-0.32 + 0.03	-0.01 + 0.02	< 0.0001 *
occlusal rest fit		-0.28 + 0.09	-0.07 + 0.03	< 0.0001 *

**Significant difference at p-value <0.05*

Table 4: Comparison of the overall framework digital fit to the 3D model between both groups.

	PEEK (n=7)	**Co-Cr (n=7)**	**p-value**
	Mean(mm) ± SD		
Overall fit Deviation	0.07± 0.06	-0.04± 0.1	0.03*

**Statistically significant difference at p-value ≤ 0.05*

Table 5: Deviation of the milled frameworks to the CAD design in millimeters among the study groups.

	PEEK (n=7)	**Co-Cr (n=7)**	**p-value**
	Mean (mm) + SD		
Mean deviation	-0.02±0.02	-0.01 ±0.03	0.66 NS

NS: not significant p-value >0.05

Table 6: Comparison of the Duralay thickness among the study groups.

Reference points	PEEK (n=7)	Co-Cr (n=7)	p-value
	Mean (mm) ± SD		
L1	0.46±0.08	0.26 ± 0.05	0.0001*
L2	0.47 ± 0.10	0.29 ± 0.06	0.002*
L3	0.43 ± 0.19	0.18 ± 0.13	0.013*
L4	0.45 ± 0.21	0.21 ± 0.08	0.015*
L5	0.58 ± 0.19	0.32 ± 0.02	0.004*

**Statistically significant difference at p-value ≤0.05*

Table 7: Comparison of the fit score percentages of guiding plate between the two studied groups

Scores	PEEK (n=28)	Co-Cr (n=28)	(p-value)
	n (%)		
No withdrawal (score 0)	12 (42.9%)	4 (14.3%)	0.006*
Slight withdrawal (score 1)	15 (53.6%)	15 (53.6%)	
Total withdrawal (score 2)	1 (3.6%)	9 (32.1%)	

**Statistically significant difference at p-value ≤0.05*

IV. Discussion

One of the common problems in RPD is to ensure maximum fit accuracy in all framework components to their respective supporting areas to ensure maximum stability, better function, and preservation of supporting structures.

This misfit reflects the dimensional inaccuracies that occur during various stages -clinical and/ or laboratory- of the framework construction.[8]

Recently with the introduction of CAD/CAM technology, dental materials can be processed using this technology. Regarding using of Co-Cr alloy in CAD/CAM process, most studies were concerned about 3D printing using SLM or SLS technologies[9] and only a few studies dealing with milling in metals generally[10] and Co-Cr RPD specifically due to increased tool and machine wear caused by the high rigidity of the "solid" blank and high acquisition and maintenance costs which are considered the main disadvantages of this technique.

This study was conducted to compare PEEK and Co-Cr RPD frameworks, both of them were fabricated using direct CAD/ CAM technology as regards laboratory and clinical aspects.

The design of the frameworks for both groups was the same for standardization except for Group (B) RPDs, the wrought wire combination clasp was used as a direct retainer with 0.02 (0.5mm) undercut which was the same undercut size used with canine abutments of Group (A) patients who received PEEK RPDs where circlet clasp was used as a direct retainer for the canines as suggested by Saja et 'al.[11]

For Group (A), the RPD frameworks were fabricated from BioHPP which is a PEEK variant that has been specially optimized for the dental field, making it highly durable by adding fine ceramic filler allowing BioHPP to be suitable to produce high-quality dentures[12].

Fit accuracy of the major connectors of the studied groups was evaluated using two methods; digital fit to the virtual master cast using GOM Inspect software, and clinically.

To evaluate the fit accuracy of RPD frameworks to the cast , visual inspection, pressing tests have been reported in the literature.[13] However, these methods are limited because the measurements were made in specific locations, so they do not reflect the actual overall fit of the RPD framework. Our methodology is new; by using superimposition, we were able to obtain many data points and calculate the best possible fit between the virtual master model and the virtual RPD frameworks. Furthermore, the implementation of color mapping helped to identify the over-pressed or misfit areas of the frameworks.

Assessment of the milled frameworks to the 3D model was done before try-in without finishing or polishing to the intaglio surfaces or doing any adjustment to increase the validity of the study and minimize the induced human error during manufacturing that a study by Brudvik et al, reported an average of 127 µm of metal loss from the surface after finishing and polishing Co-Cr frameworks.[14]

The measuring software package for digital dimensional deviations measurement used in this study was the GOM Inspect freeware used in many published studies. [15]

Measuring gap distance between the milled framework and the virtual master cast was done at seventeen selected points, and an overall fit using GOM inspect software package guided by the study of Otto et al[16] who measured the gap distance between the complete denture base and the master cast overall and at a specific area as well. Also, Tasaka et al [17] measured the gap under clasps fabricated using four different CAD/CAM technologies at specific points using the same software used in our study.

Clinical evaluation of the major connector fit to the underlying soft tissue was done using auto polymerized fast set acrylic resin material (DuraLay*)* at the time of framework try-in at 5 determined points (L1-L5) for standardization. Auto polymerized fast set acrylic resin material *(DuraLay)* with the help of micrometer caliper was used to measure this space because the duralay material has a fine grain size that offers fast set, sufficient flow, superior accuracy that does not distort when being measured with a micrometer caliper.[18]

The guiding plane/plate relation was also clinically evaluated using contact indicating spray (occlude*)* because it is easily used, offers minimal thickness, adheres well to the metallic framework and also to the PEEK, cannot be washed away by excessive saliva, and easily removed from the framework by alcohol as described by Dukes. [19]

The results of superimposition of STL file 3 to its corresponding STL file 1 and measurements at 17 points reported discrepancies at L1 area which in agreement with the study comparing between four different types of digital manufacturing of RPD, Soltanzadeh et al[20] found that the biggest discrepancy was found at the anterior strap of the major connectors and they referred these results to inaccuracies during scanning of complete arch cases using digital scanners, or induced software errors while processing the STL files.[21]

Evaluating the fit of the framework to the cast at 17 specific points revealed that group B frameworks are more fit to the cast than group A as indicated by less gap distance measurements.

Also, the deviation of Co-Cr RPD which was less than that of PEEK RPD may be attributed to the differences in milling procedure which was wet in case of Co-Cr frameworks and dry milling for PEEK frameworks which was characterized by heat generation during milling. Arnold et al [22] stated that PEEK may allow temperature-related deformations, resulting in a secondary adjustment onto the cast.

The directly milled PEEK frameworks recorded more overall misfit with the 3D model with values of (0.07 ± 0.06) when compared to Co-Cr RPDs ones (0.45 ± 0.21) which were less than the average values reported by Brudvik et al [14] this is maybe because their study was performed with finishing and polishing to the intaglio surface of the prosthesis in contrast to our study, they reported 127 µm of metal loss from the surface after finishing and polishing Co-Cr frameworks.

Our results regarding the overall fit to the virtual master cast are comparable to the results obtained by Arnold et al[25] who studied the accuracy of fit of RPD frameworks of class III modification 1 with a design similar to that of our study. He studied the fit of four types of frameworks fabricated with different CAD/CAM techniques. In contrast to our study, he found that milled PEEK framework showed better fit than Co-Cr frameworks fabricated using selective laser melting.

In studying the fit results of the milled framework superimposition to the CAD design (STL file 2), the mean values of deviations of the PEEK RPDs **(group A)** which were milled in dry condition, were negative deviations when overall registration was made meaning that the milled frameworks were of smaller dimensions than the original CAD design.

The analysis of dimensional deviations within **Group B** (Co-Cr) RPDs showed also negative deviation values denoting that Co-Cr RPD frameworks that were fabricated using wet milling were of smaller dimensions when compared to original CAD design. The mean value of overall dimensional deviations of wet-milled Co-Cr RPDs was (-0.01 ± 0.03). There was no statistically significant difference between both groups.

Based on the dimensional findings observed for both groups, it can be assumed that the negative deviations from the CAD design for both groups were since the digital process of producing prostheses involves various steps, each of which can be a source of dimensional error. Errors can occur during the imaging, segmentation, or manufacturing phase. Salmi *et al*[15] found that different manufacturing methods may cause significant accuracy errors and recommended that clinicians using additive manufacturing in prosthesis fabrication should be aware of these errors that originate from the technology used, material, and instance of machine use. Thus, dimensional accuracy of CAD/CAM direct milling would require further research on material properties and its manufacturing technique both wet and dry types to obtain lower-dimensional deviations.

These results were similar to the study conducted by Arnold et al [22] and Ye et al [23] who found that CAD-RP frameworks exhibited the highest discrepancies among other techniques of fabrication, but were within clinically acceptable limits.

Regarding the guiding plates/planes fit, the results obtained from this study showed that more than 50 % of the PEEK and the cobalt-chromium RPD frameworks fulfilled score 1 which is a clinical success.

Regarding the degree of interference of the guiding plane/plate relation, there was a significant difference between the two studied groups. It was noticed that there was an increase in the degree of interference for the dentures constructed with Co-Cr framework [Group B], which is a correctable problem by a relief.

This attribution is similar to that supposed in a study comparing between PEEK clasps and Co-Cr clasp conducted by Saja et al[11] who stated that thermoplastic clasps might achieve clinically acceptable retention at dimensions differing from those of metal clasps, possibly requiring thicker clasp to engage a deeper undercut due to the relatively low rigidity of the thermoplastic material compared to metals and alloys. This principle also was confirmed by other studies. [24]

The similarity in score 1 for both groups with the percentage of 53.6 % which refers to the slight withdrawal of the occlude spray may be attributed to that both types of RPDs were fabricated with CAD/CAM technology which in general was proved to be accurate regarding the fabrication of RPD frameworks by many authors[25] owing to the minimal laboratory procedures required for CAD/CAM technique.

The other attribution for the apparent accurate fit of frameworks fabricated from Co-Cr alloy is that they were milled under wet conditions preventing heat generation and subsequent distortion. In contrary, PEEK frameworks were milled in dry condition with subsequent heat generation which was proved to affect to some extent dimensions of PEEK polymer [26]

By comparing the results of both groups regarding the clinical fit of the major connector, it was found that there was a statistically significant difference between the two groups. Reduced Duralay thickness of Co-Cr frameworks indicates more clinical fit than that of PEEK frameworks. This may be due to the same previous attributions of the accurate fit of Co-Cr frameworks regarding guiding plane plate relation.

It was noticed that the highest thickness of Duralay was at the center of the palate (L5) which was the deepest milling point. Readings at (L5) for the Co-Cr group were lesser than that for the PEEK group, this may be due to the more powerful spindle of metal milling machine.

The mean of space under 5 points of measurements for major connector in both groups was less in digital method than clinical one which may be attributed to the difference in nature between the oral cavity and stone cast like compressibility of the palatal mucosa which was pressed to a certain degree by the Duralay resin material.

Also, measuring fit to the cast involves fewer laboratory steps (scan, design, and milling) while clinically there were two more additional steps which were the final impression and pouring stone cast which increases the probability of dimensional errors.

V. Conclusion

- CAD/CAM milled Co-Cr frameworks showed better results regarding trueness, clinical fit to oral tissues, and digital fit to the virtual master cast.
- Co-Cr frameworks are more precisely fabricated than PEEK frameworks.
- Wet milling gets better results than dry one regarding dimensional accuracy. However, there was no statistically significant difference.
- Accurate and solid reference (finish lines in our study) for virtual models registration is of great importance as this could affect the obtained dimensional accuracy results.

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