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Scanning Electron Microscopy Evaluation of Different Polish Protocols on the Surface Biofilm of PEEK Removable Partial Denture (Split Mouth Study)

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Abstract
Objective: *To evaluate the influence of different polishing protocols on the surface topography of polyether ether ketone (PEEK) RPD frameworks fabricated by the CAD/CAM technique.*
Materials and Methods: *Six male patients were enrolled in this split-mouth study. All patients had mandibular Kennedy Class I arch form with remaining teeth extending from the first premolar on one side to the first premolar on the other side and opposed by a completely edentulous maxillary arch. Modified polyether ether ketone RPD frameworks were fabricated by CAD/CAM technique. According to the followed polishing protocol, each framework was divided into two sides (2 groups); group I (right side): polished using Abraso-Starglanz polishing system, and group II (left side): polished using Acrypol polishing system. Scanning electron microscopy was used for evaluation through Tri-stage scanning; the first scanning was performed before polishing (control), the second was performed after polishing, and the final was performed after two months of denture delivery. Data were collected and analyzed using Student's t-test and repeated measures ANOVA followed by post-hoc LSD at p-value ≤ 0.05.*
Results: *A significant decrease was found in the surface roughness between the unpolished and polished frameworks for both groups using both tested polishing systems (P<0.001). After two months of denture delivery, a significant increase in surface roughness was noticed for both polishing protocols. This increased value was still significantly lower than the values recorded before polishing for both protocols (P<0.001). Polishing with Abraso-Starglaz polishing paste had decreased the total surface roughness of frameworks more significantly than the Acrypol polishing paste.*
Conclusions*: Both used Abraso-Starglaz, and Acrypol polishing pastes produced a significantly smoother PEEK surface than that of the non-polished PEEK , and Polishing with Abraso-Starglaz paste was the most effective and promising polishing technique in the production of a highly smooth PEEK surface.*
Keywords*: Polyether etherketon ,PEEK ,mandibular kennedy class I, RPD framework, polishing protocol, surface roughness, CAD/CAM.*

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I. Introduction:

Dental Health Survey found that partially dentate adult's proportion is increased as a result of elderly individual's number rise within the population, or a shift from total edentulism to partial edentulism. Partially edentate patients demand the restoration of their missing teeth, oral health maintenance has progressed; thus people are suffering the loss of fewer teeth, leading to an increase in the necessity for treatment of partial denture (RPDs), preferably than a complete denture, that is widely used in clinical practice and, has an advantages [(1).] The conventional partial denture (RPDs) were usually fabricated from metal. such as cobalt-chromium or titanium, The partial denture (RPDs) metal-based frameworks advantageous over partial denture (RPDs) acrylic resin are that provide stiffness and high strength, are less bulky and used in thin sections, allows designs that minimize the gingival margins covering, conduct cold and heat for a more natural experience, allow for a stable denture base, and are resistant to corrosion [(2).]

The partial denture (RPDs) metal-based frameworks drawbacks comprise metal display causing esthetic issues, adverse tissue reactions, and biofilm production, [3] that give the means of microorganism colonization in the surface area, allowing the development of a biofilm, which also act as a reservoir for respiratory pathogens [4]**.** Due to the drawbacks of the partial denture (RPDs) metal-based frameworks, the use of metal-free materials has been introduced.

An encouraging polymer-based partial denture (RPDs) framework consists of a modified polyetheretherketone polymer peek that has a lot of benefits over those made of metal as improve esthetics because of their colour and translucency, have higher elasticity, are lightweight, are more cost-effective, have low water sorption and solubility [4]. The modified polyetheretherketone polymer (peek) RPD frameworks can be constructed by using computer-aided design and computer-aided manufacture (CAD/CAM) systems [5]

A previous study [6] concluded that frameworks constructed from modified polyetheretherketone polymer recorded higher surface roughness than frameworks constructed from chromium cobalt alloy regarding the surface roughness. Polishing is the process that is fulfilled after the finishing process to remove minute scratches from the surface of the prosthesis and obtain a smooth, light-reflective lustre [7]. Obtaining a polished surface is not only pivotal for esthetics, but it is a cornerstone in bacterial plaque accumulation, which has a direct correlation between surface topography and the formation of biofilm. An in-vitro study concluded that the laboratory-based protocols, both abraso-starglaz and acrypol polishing pastes produce a significantly smoother PEEK surface than that of the non-polished PEEK [8]. So this study aimed to clinically examine and evaluate the effect of polishing protocol on the microorganism biofilm on the PEEK removable partial denture by scanning electron microscope.

II. Materials and Methods:

Six male patients seeking prosthetic rehabilitation were enrolled in this study. This study was approved by a Local Research Ethics Committee and followed its clinical trials guidelines. The same operator and the same dental lab were responsible for all prosthodontic procedures for all patients. Data from clinical history and examination were collected on each patient. All patients were given instructions regarding oral hygiene.

Patient Selection:

Patients age from 40-60 years with mean age (50 years) with suitable oral hygiene measures, free from systemic diseases (from medical history). Mandibular Kennedy class Ⅰ arch form with the remaining teeth extending from the first premolar on one side to the first premolar on the other side (Fig. 1) and Completely edentulous maxillary arch covered by healthy, firm, dense mucosa verified by probing test without any remaining roots verified radiographically by panoramic view. They were of Angle's class Ⅰ maxilla-mandibular relationship with sufficient inter arch space as detected by tentative jaw relation, the abutment teeth were healthy with accepted value of clinical mobility by the periotest, and he abutments were periodontally healthy with crown/root ratio (C/R) 1:2 as verified by periapical radiograph.

Fabrication procedures for PEEK RPD:

For each patient Preliminary impressions were made for both arches using irreversible hydrocolloid impression material (Cavex, Netherlands, Holland) using a modified stock tray. And the impressions were poured in dental stone(Super-cal IV, COE laboratories Inc., USA)to obtain study casts on which record blocks and acrylic custom trays were made using auto-polymerizing acrylic resin(Super-cal IV, COE laboratories Inc., USA). tentative jaw relation was performed to evaluate the available inter-arch space and the existing mandibular abutments were equilibrated accordingly by enameloplasty.

The mandibular partially edentulous study cast was then fixed on thescanner table and scanned using 3D scanner (Ceramill map400, Amann Girrbach, Koblach, Austria) to obtain a virtual model which was digitally surveyed to determine the most acceptable path of insertion, draw the survey line on abutment teeth and determine the necessary mouth preparation. The design of the frameworks was planned on study cast symmetrically to standardize the study including; lingual plate major connector, RPA direct retainer on first premolars, and the abutment teeth were prepared to receive different components of RPD framework as mesial occlusal saucer shaped rest seats were prepared on mandibular first premolars & Proximal guiding planes of 1.5mm occluso-gingival height were prepared in the distal surface of mandibular first premolars.

The mandibular custom tray was border molded using heavy body rubber base impression and the anatomic final impression was made using medium body elastomeric impression material (Thixoflex M, Zhermack, Badia Polesine, Italy) to obtain a mandibular definitive cast, and the maxillary custom tray was border molded using green stick compound (Kerr U.K. limited, Netherlands) and the final impression was recorded using zinc-oxide eugenol impression material (Cavex, Netherlands. Holland) then a maxillary definitive cast was obtained from pouring with dental stone and maxillary record block was constructed on the maxillary final cast. The mandibular definitive cast was then fixed on the scanner table and scanned using the

3D scanner (Scanning Phase) to obtain the standard triangulation (STL) file format which was then imported into the CAD software used in this study (3Shape A/S, Copenhagen, Denmark) to start the (Designing Phase).

Secondary surveying of the virtual definitive cast was performed digitally according to the selected path of insertion , then all undesirable undercuts were blocked out and sealed into flattened surfaces. Relief under the saddle was created by selecting the STL data of the mesh-retainer part and lifted 0.5mm in an occlusal direction. All components of the framework were selected from a menu and placed in the correct position in the form of a spine of points. The width and thickness of any part of every component can be changed at these points (Fig. 2). A stereolithographic tentative resin pattern of the framework was made using rapid prototyping technology to evaluate the fitting of the designed framework intra-orally before milling.

Frameworks were milled from PEEK material (Milling Phase):

After accuracy evaluation of the 3D-printed resin framework for each case with intra-oral satisfaction, the 3D design was imported into the milling machine to begin the milling process of BioHPP dental disc directly to the desired framework design.BioHPP disc with thickness 98x20mm was used. then, the PEEK framework was removed from disc using carbide bur, was finished and cleaned (Fig.3), and tried on cast and then tried intra-orally for fitting accuracy checks.

Polishing protocol:

According to the polishing protocol followed in split mouth cases, each BioHPP framework divided into two sides (2 groups): Right side (group I) : polished using Abraso-Starglanz polishing system, and Left side (group II) : polished using Acrypol polishing system. The following sequence was used according to manufacturing instructions: In the right side of PEEK frameworks, Abraso-Starglanz polishing paste (Bredent GmbH & Co.KG, Senden, Germany) on brush wheel was used, around of clasp and lingual plate except fitting surface, with standard violecty 5000-10000 rpm for 1 minute, then Star brushes goat hair white was used to reach all surface area, and finally polishing Cotton buff was used to produce lustrous shiny surface. With the same previous sequence, the polishing procedure was applied to the left side of PEEK framework using Acrypol polishing system (Bredent GmbH & Co.KG, Senden, Germany). All the procedures of finishing and polishing were performed by the same operator to avoid operator variability (standardization).

Evaluation of PEEK frameworks surface topography:

Scanning electron microscopy (SEM) was used to evaluate the effect of the polishing technique on the surface topography and biofilm formation on the modified PEEK frameworks.

Tri-stage scanning (scanning sequence): the first scanning was performed for both sides of each framework before polishing which refer as control. and the second scanning was performed after polishing for each side separately (right & left) of each framework. Then the final scanning was performed after two months of denture delivery for each side separately (right & left) of each framework. Finally: registration of jaw relation , Mounting of maxillary and mandibular master casts , Setting of artificial teeth , finished and laboratory remount , then RPDs were delivered to the patient were instructed how to insert and remove the denture and also instructed for oral hygiene measures and follow up visits were scheduled

Statistical Analysis:

Data were tabulated, coded then analyzed using the computer program SPSS (Statistical package for social science) version 26.0. Descriptive statistics were calculated in the form of Mean ± Standard deviation (SD). Analytical statistics were calculated and the significance of difference between groups was tested using Student's *t*-test (paired) and Repeated measures ANOVA (Analysis of variance). A *P* value < 0.05 was considered statistically significant.

III. Results:

As shown in the (Table 1), the results of the study demonstrated that both applied polishing protocols had achieved a significant decrease of surface roughness that was recorded for all surfaces (shoulder, body of clasp, retentive arm, lingual plates) of the PEEK RPD frameworks. In addition, all surfaces showed significant increase of roughness values after biofilm, but still significantly decreased when compared to the values measured before polishing for both sides. The framework total surface roughness within right side after polishing using Abraso-Starglanz polishing system (46.75 ± 11.89) was significantly decreased compared to that before polishing process (127.95 ± 0.82) ($P < 0.001$).

After two months of denture delivery, the total surface roughness expressed significant increase (71.45 ± 8.38) compared to the after polishing value ($P < 0.001$). Within left side, post-hoc LSD test showed significant decrease of the total surface roughness when Acrypol polishing system was used. The roughness values before and after Acrypol polishing were 136.60 ± 2.96 and 74.00 ± 5.81, respectively. Also, it was noticed a significant

increase of the total surface roughness after denture delivery with Acrypol polishing (102.80 ± 13.36). For both sides, the increased roughness values after denture delivery were still significantly decreased when compared to the values measured before polishing process (P < 0.001).

Table 1. Comparison of roughness values for all surfaces before polishing, after polishing and after biofilm within right and left sides.

Surface	Side	Before Polishing	After Polishing	After Biofilm	P
Shoulder	Right side	21.80 ± 1.20	7.40 ± 2.19	12.00 ± 1.75	< 0.001*
			P1 < 0.001*	P2 < 0.001* P3 < 0.001*	
	Left side	26.25 ± 8.71	14.45 ± 4.66	21.30 ± 8.00	< 0.001*
			P1 = 0.001*	P2 < 0.001* P3 = 0.004*	
Clasp Body	Right side	28.00 ± 0.22	10.05 ± 3.34	15.50 ± 1.75	< 0.001*
			P1 < 0.001*	P2 < 0.001* P3 < 0.001*	
	Left side	136.60 ± 2.96	74.00 ± 5.81	102.80 ± 13.36	0.004*
			P1 = 0.001*	P2 = 0.004* P3 < 0.001*	
Retentive Arm	Right side	23.30 ± 6.68	8.80 ± 0.88	13.40 ± 2.96	0.001*
			P1 = 0.002*	P2 = 0.001* P3 = 0.003*	
	Left side	29.90 ± 1.20	15.25 ± 0.60	21.65 ± 3.01	0.005*
			P1 < 0.001*	P2 = 0.005* P3 = 0.007*	
Superior Lingual Plate	Right side	24.75 ± 5.97	8.75 ± 3.34	14.05 ± 4.98	< 0.001*
			P1 < 0.001*	P2 < 0.001* P3 = 0.001*	
	Left side	23.65 ± 2.57	13.55 ± 2.90	17.25 ± 4.11	< 0.001*
			P1 < 0.001*	P2 < 0.001* P3 = 0.001*	
Inferior Lingual Plate	Right side	30.10 ± 0.55	11.75 ± 3.89	16.50 ± 2.85	< 0.001*
			P1 < 0.001*	P2 < 0.001* P3 < 0.001*	
	Left side	24.85 ± 0.05	12.70 ± 1.20	18.80 ± 1.42	< 0.001*
			P1 < 0.001*	P2 < 0.001* P3 = 0.001*	
Total	Right side	127.95 ± 0.82	46.75 ± 11.89	71.45 ± 8.38	< 0.001*
			P1 < 0.001*	P2 < 0.001* P3 < 0.001*	
	Left side	136.60 ± 2.96	74.00 ± 5.81	102.80 ± 13.36	< 0.001*
			P1 < 0.001*	P2 < 0.001* P3 < 0.001*	

Data expressed as mean ± SD.

SD: standard deviation, P: Probability, P1: significance between (Before Polishing & After Polishing), P2: significance between (After polishing & After Biofilm), P3: significance between (Before Polishing & After Biofil, *:significance < 0.05, Test used: Repeated measures ANOVA followed by post-hoc LSD

IV. Discussion:

Patients' preference for nonmetallic materials and the drawbacks of metal-based RPD frameworks, encorages the use of alternative metal-free materials including high performance polymers (PEEK). PEEK is a highly biocompatible and bio-inert material, since it does not cause any adverse reaction nor release any ions or constituents to the human tissues with no inflammatory, toxic or mutagenic effects [(9).] Its special chemical structure ensures stable chemical and physical properties plus compatibility with modern imaging technologies. More importantly, the mechanical properties (Young's modulus and tensile properties) of PEEK are close to that of human cortical bone. All these properties have made PEEK considered a highly attractive material in medical and dental applications [(10)]

Clinical examination was used to verify selection of patients with healthy well-formed residual ridges to provide adequate and stable tissue support during the study periods. It was reported that, flabby ridge provide

easily displaceable tissues producing excessive lateral displacement of the prosthesis and adversely affect its support, retention and stability. The normal healthy, firm, dense and non-inflamed tissues can withstand physiologic mechanical forces and minimize the potential for tissue-ward movement of distal extension bases. Also, this tissue type enables these dentures resisting occlusal forces and lateral displacement to a large degree when vertical and horizontal stresses placed on them. Moreover, the sub mucosa provides a hydraulic cushion effect and improves tolerance of residual ridge to the applied forces **(11)**.

RPDs should improve the health of remaining dentition and surrounding oral tissues. However, longitudinal studies indicated that RPDs have been associated with increased abutment mobility For this reason, only cases with healthy abutment teeth and accepted values of clinical mobility were selected. Also, the abutments were periodontally healthy with favorable crown/root ratio (C/R) as high C/R indicates a tendency of a tooth losing some amount of its bone support and therefore becomes less resistant to masticatory load and lateral forces transmitted by RPD **(12)**.

Proximal guiding planes of 1.5mm occluso-gingival height were prepared in the distal surface of mandibular first premolars. It permits the RPD to rotate slightly around the mesial occlusal rest when downward forces occur on the artificial teeth. This slight movement allows release of the denture from the guiding planes thereby avoiding creating of torqueing or twisting forces on the abutment teeth. Also, the major connector design used in this study was a lingual plate instead of the conventional lingual bar for better withstanding of the torsional forces from the distal extension RPD and for using as indirect retainer with cingulum rests on canines **(13)**.

Two-body abrasion (grinding with burs, bonded adhesives, or coated abrasives) and 3-body abrasion (polishing pastes including aluminum oxide or diamond particles) are polishing methods used in the dental practice. A slurry of polishing paste in water leads to a finer abrasion and produces a light-reflective, high-gloss surface. Heimer et al, **(14)** reported lower surface roughness values when chairside polishing protocols were used with specimens polished by using the 3-body abrasion method, which produced lower surface roughness values than for those polished by using the 2-body abrasion method. So, in the present study, the 3-body abrasion was used.

For evaluation of the material surface characteristics after instrumentation, scanning electron microscopy (SEM) is one of the preferred methodologies. In this study, SEM was used to clearly observe changes on the surface of the PEEK material and examine its topography. It assesses descriptively the surface morphology depending on a large depth of field along with several sources of image contrast. It yields an excellent qualitative impression of surface topography. Also, SEM can be used to measure surface heights at given points and allows a quantitative evaluation of a number of surface topography characteristics. The evaluation of PEEK frameworks surface topography was done on both the lingual plate and clasps area because the lingual plate which covers the soft tissues of the periodontium and the hard tissues of teeth results in increased plaque accumulation. The RPD clasps harbor a highly diverse bacterial population and the bacterial community with the biofilm composition of the RBD clasps changed along time after RPD wearing **(15)**.

The results of this study showed significant decrease of the total surface roughness values using both tested polishing systems between the unpolished modified PEEK RDP frameworks and the polished frameworks. This finding is in accordance with the study results of Attayeb et al, **(7)** who concluded that, for the laboratory-based polishing protocols, both Abraso-Starglaz and Acrypol polishing pastes produced a significantly smoother PEEK surface than that of the non-polished PEEK. Kurahashi et al, **(16)** suggested that PEEK can be polished into a sufficiently smooth surface for use as a dental prosthesis. This compatibility may be attributed to the system or the protocol that was used for PEEK polishing process.

The present study revealed the effectiveness of both used protocols for polishing of the PEEK RPD frameworks. Both laboratory-based protocols used in this study represent 3-body wear using high-gloss polishing pastes. The benefit of using such polishing pastes is that the combination of the paste with water leads to a fine abrasive action and a high-gloss, light-reflective surface.

The results of the study showed that both applied polishing protocols had achieved a significant decrease of surface roughness that was recorded for all surfaces (shoulder, body of clasp, retentive arm, lingual plates) of the PEEK RPD frameworks. Kurahashi et al, **(16)** concluded that clinically acceptable surface roughness of PEEK was obtained using polishing agents with a soft polishing brush. After two months of denture delivery, significant increase of surface roughness was noticed when compared to that of after polishing process for both polishing protocols. However, this increased value was still significantly lower than the values recorded before polishing for both polishing protocols. This indicate the effectiveness of both used polishing protocols for PEEK RPD frameworks polishing even after intra-oral function.

The results of this study found that polishing with Abraso-Starglaz polishing paste had decreased the total surface roughness of PEEK RPD frameworks more significantly than the Acrypol polishing paste. Consequently, it was concluded that polishing with the Abraso-Starglaz polishing paste was the most effective and promising polishing technique in production of highly smooth PEEK surface than Acrypol polishing paste.

The variation in surface roughness values recorded with the two used polishing materials may be attributed to their structural composition. The perfect high smooth surface that was produced quickly with Abraso-Starglaz polishing paste. While polishing with Acrypol paste with slightly abrasive materials had produced perfect high luster with less smooth PEEK surface. This is compatible with Attayeb et al, [7] study. They concluded that the polishing of PEEK RPD framework using abraso-starglaz polishing paste was significantly effective more than acrypol polishing paste.

V. Conclusions:

Both used Abraso-Starglaz and Acrypol polishing pastes produced a significantly smoother PEEK surface than that of the non-polished PEEK. Polishing
with Abraso-Starglaz paste was the most effective and promising polishing technique in the production of a highly smooth PEEK surface than Acrypol paste.

Fig. (1): Mandibular Kennedy class Ⅰ arch form.

Fig. (2): Location of framework components.

Fig. (3). The BioHPP PEEK framework after finished milling.

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