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RESEARCH AND EDUCATION

Surface roughness of high-performance polymers used for fixed implant-supported prostheses

Burcu Batak, PhD, DDS,[a] Gülce Çakmak, PhD, DDS,[b] William M. Johnston, PhD,[c] and Burak Yilmaz, PhD, DDS[d]

ABSTRACT

Statement of problem. High-performance polymers have been recommended by their manufacturers as a framework material for implant-supported fixed prostheses. However, little is known about the surface roughness of high-performance polymers in different compositions and whether they require layering with a composite resin or acrylic resin on the tissue surface.

Purpose. The purpose of this in vitro study was to evaluate the surface roughness of different computer-aided design and computer-aided manufacture (CAD-CAM) high-performance polymers and the effect of polishing on their surface roughness.

Material and methods. Seventy high-performance polymer specimens (n=10) for 4 different polyetheretherketone (PEEK) brands (BRE, CP, ZZ, J), 1 polyetherketoneketone (PEKK) (PK), and 2 different fiber-reinforced composite resin (FRC) materials (T, TR) were milled from 7×8×30-mm CAD-CAM blocks. The surface roughness (Ra) of each specimen was measured on the same surfaces after milling (baseline) and after polishing by using a contact profilometer. Two-way repeated measures ANOVA (MIXED procedure) and the Bonferroni corrected *t* test (α=.05) were used to analyze the surface roughness data.

Results. No significant differences were found among high-performance polymers when the baseline surface roughness measurements of the materials were compared ($P>.05$). All materials (BRE, PK, CP, T, TR, ZZ), except for a PEEK material (J) ($P<.05$), had no significant differences in their surface roughness before and after polishing. After polishing, the surface roughness of the J PEEK material was higher than that of CP, PK, T, and ZZ ($P<.05$).

Conclusions. The surface roughness of high-performance polymers in different compositions after milling was similar. Polishing increased the surface roughness of only one PEEK (J) material. All surface roughness values were above the clinical acceptability threshold of 0.2 μm. (J Prosthet Dent 2021;126:254.e1-e6)

As a result of an increasing demand for fabricating metal-free restorations and parallel with the developments in computer-assisted design and computer-assisted manufacturing (CAD-CAM) technology and materials, CAD-CAM high-performance polymers (HPPs) have been introduced as alternative materials to titanium and zirconia.[1-8] HPPs have been increasingly used as a framework material for fixed and removable prostheses and for implant-supported prostheses. These materials have been reported to have favorable thermal and mechanical properties.[1,9-11]

Polyaryletherketones (PAEKs) and modified composite resin (MCR) polymers are currently available HPP materials.[6,11-17] Polyetheretherketone (PEEK) and polyetherketoneketone (PEKK) are 2 main groups of the PAEK polymer family that contain an aromatic backbone molecular chain, interconnected by functional ketone and ether groups.[1,2,10-12,16,18-20] PEEK and PEKK are high-temperature semicrystalline thermoplastic polymers with linear chain structures.[10-12,16,18-20] PEEK has been reported to be easily machinable, have low solubility and water absorption, and have high polishability and stability in terms of hardness, rigidity,

[a]Research Assistant, Department of Prosthodontics, Faculty of Dentistry, Ankara University, Ankara, Turkey.
[b]Associate Professor, Department of Prosthodontics, Faculty of Dentistry, Istanbul Okan University, Istanbul, Turkey.
[c]Emeritus Professor, Division of Restorative and Prosthetic Dentistry, College of Dentistry, The Ohio State University, Columbus, Ohio.
[d]Associate Professor, Department of Reconstructive Dentistry and Gerodontology, School of Dental Medicine, University of Bern, Bern, Switzerland; and Associate Professor, Department of Restorative, Preventive and Pediatric Dentistry, School of Dental Medicine, University of Bern, Bern, Switzerland; and Adjunct Professor, Division of Restorative and Prosthetic Dentistry, The Ohio State University, Columbus, Ohio.

Clinical Implications

The surfaces of the tested polymers were rough after milling and after polishing, suggesting a need to veneer the tissue surfaces with a composite resin or an acrylic resin to minimize plaque accumulation when used for fixed prostheses.

strength, and superior heat and chemical resistance, as well as low plaque affinity, good wear resistance, and no polymerization shrinkage.[2,4,11,17,21,22] PEKK has high durability under mechanical resistance conditions and has greater compressive strength than PEEK.[16] Similar to PEEK,[19,21] MCR materials also have a low elastic modulus, lower flexural strength, shock-absorbing behavior, and similar modulus of elasticity as bone.[13-15]

Currently, different brands of PAEK and MCR materials are available in different compositions. PEEK polymers are found in unfilled (pure 100% PEEK) and filled forms (80% PEEK with 20% inorganic fillers: nanoceramic filler or titanium dioxide filler) and as a ceramic-reinforced form with a semicrystalline arrangement of molecular chains.[2,4,7,20,23] PEKK includes 20% titanium dioxide fillers in its structure and has been marketed as pressable ingots and CAD-CAM blanks.[24] MCRs are available as fiber-reinforced composite resin (FRC) and Hi-Tech Fiber-Composite materials.[6] FRC is available as prepolymerized CAD-CAM blanks and is composed of interlaced multidirectional fiberglass in a matrix of epoxy resin in several layers.[6] Hi-Tech Fiber-Composite is a novel CAD-CAM material consisting of epoxy resin matrix reinforced with multidirectional fiberglass.

The surface roughness of dental materials plays a major role in bacterial plaque accumulation and adhesion.[25-31] Bacterial adhesion is increased on rough surfaces because of increased surface area[29,32]; therefore, materials with low surface roughness are essential for reduced bioadhesion.[32,33]

An Ra threshold of 0.2 μm has been reported as the clinical acceptability threshold for prostheses.[33] Above this level, biofilm formation increases, and below this level, surface roughness has no significant impact on biofilm formation.[33,34] Therefore, one of the main goals of surface finishing is to achieve a surface roughness of below 0.2 μm by using polishing techniques, devices, and materials.[25] Final surface roughness and surface quality were reported to depend on polisher type, velocity, contact pressure, polishing paste, dry or wet polishing, and laboratory or chairside polishing protocols.[35] Heimer et al[25] reported that chairside polishing methods presented lower surface roughness values than laboratory polishing methods, and PEEK specimens had tangentially higher surface roughness than polymethyl methacrylate (PMMA) and veneering composite resin (COMP).

Although surface pretreatments have been evaluated for achieving a strong and durable adhesion to HPPs,[10,19,20,36] information regarding the roughness of their surfaces and whether surfaces may remain non-veneered is lacking. Additionally, precise guidelines for polishing the HPPs in terms of surface roughness are limited. Therefore, evaluating the effect of polishing on the surface roughness of HPPs in different compositions can be beneficial for both clinicians and dental laboratory technicians because of the clinical importance of surface roughness on the longevity of restorations.[25] The purpose of this in vitro study was to measure and compare the surface roughness of different CAD-CAM HPP materials after milling and investigate the effect of polishing on the surface roughness of these CAD-CAM–fabricated HPPs. The null hypotheses were that the surface roughness of different CAD-CAM HPP materials would not differ and that polishing would not change the surface roughness of CAD-CAM HPP materials.

Table 1. Tested materials

Abbreviation	Brand Name	Manufacturer	Composition
CP	Coprapeek	White Peaks Dental Systems GmbH & Co KG	100% PEEK
ZZ	Tecno Med Mineral	Zirkohnzahn S.r.l	High-performance resin, special ceramic reinforcement PEEK
J	Juvora	Juvora Ltd	100% PEEK
BRE	BreCAM.BioHPP	bredent GmbH & Co KG	80% PEEK, 20% nanoceramic filler
PK	Pekkton®ivory	Cendres Métaux SA	80% PEKK, 20% filler including titanium dioxide
T	Trilor	Bioloren S.r.l, Saronno (VA)	Hi-Tech fiber-composite material consisting of epoxy resin matrix and multidirectional glass fiber reinforcement
TR	Trinia	SHOFU Dental Corp	Multidirectional interlacing of fiberglass and resin in several layers

MATERIAL AND METHODS

Seventy (7×8×30 mm) specimens from 7 different HPP brands (n=10) were milled from CAD-CAM blocks by using a 5-axis milling machine (Coritec 550i; imes-icore) and following the manufacturer's recommended protocols with a new set of burs for each block. The material composition and manufacturer information of the HPPs are displayed in Table 1. Previous similar studies were considered when determining the sample size.[25,28]

After milling, the sprues were removed by using a grinder (LD15C LD/ZR [Lithium Disilicate/Zirconia] Grinder Green Coarse Wheel Ceramic; Brasseler USA

Table 2. Tests of fixed effects

Effect	Num DF	Den DF	F Value	*P*
Material	6	63	4.44	<.001
Polishing	1	63	0.00	.992
Material×Polishing	6	63	4.86	<.001

Den, denominator; DF, degrees of freedom; Num, numerator.

Dental Instrumentation), and the surface was finished with a rubber polisher (Composite Polishing Kit; SHOFU Dental Corp) and polished with a goat-hair brush and composite resin polishing paste (Luminescence; Premier) for 60 seconds. A straight low-speed handpiece (EWL K9; KaVo) was used to polish the specimens, and all polishing procedures were conducted by the same operator (B.B.).

The surface roughness of each specimen was measured (Ra) by using a contact profilometer (Surftest SV-3100; Mitutoyo Corp) after milling (baseline) and after the polishing procedures were completed. The same surfaces were measured before and after polishing. The accuracy of the profilometer was examined periodically by using a calibration block. The tracing length was 13.3 mm, the number of points measured per specimen was 13 300, and the stylus speed was 1 mm/sec.

The surface roughness before polishing (baseline) and after polishing for each material and among materials at baseline and after polishing was compared. The data were analyzed with 2-way repeated measures ANOVA MIXED procedure by using a statistical software program (SAS Proprietary Software v9.3; SAS Institute Inc) and the Bonferroni corrected *t* test (α=.05).

RESULTS

The sample size and design used in the present study enabled the detection of significant differences among groups. The interaction between material and polishing had a significant effect on surface roughness (Table 2). Mean surface roughness values and standard deviations for HPP materials are displayed in Table 3, and the mean surface roughness values and 95% confidence intervals are displayed in Figure 1. When the baseline surface roughness measurements of HPP groups were compared with each other, no significant differences were found among them (*P*>.05). All materials (BRE, PK, CP, T, TR, ZZ), except for J (*P*<.05), had no significant differences in their surface roughness before and after polishing.

When the surface roughness measurements of HPP groups were compared with each other after polishing, the J PEEK material showed significantly higher surface roughness values than CP, PK, T, and ZZ (*P*<.05). However, no significant differences were found between J, TR, and BRE (*P*>.05). All surface roughness values before and after polishing were higher than the clinical acceptability threshold of 0.2 μm.

Table 3. Mean surface roughness values ±standard deviations (μm)

	Mean ±SD	
Material	Baseline	Polished
CP	0.958 ±0.302Aa	0.587 ±0.210Aa
ZZ	1.395 ±0.503Aa	0.711 ±0.319Aa
J	0.797 ±0.100Aa	1.649 ±0.951Bb
BRE	0.678 ±0.225Aa	1.186 ±1.412Aab
PK	0.613 ±0.112Aa	0.502 ±0.178Aa
T	0.877 ±0.177Aa	0.696 ±0.316Aa
TR	1.228 ±0.402Aa	1.209 ±0.345Aab

Different uppercase letters in same row and different lowercase letters in same column show statistically significant differences (*P*<.05).

DISCUSSION

The null hypothesis that the surface roughness of different CAD-CAM HPP materials would not differ was accepted because no significant differences were found among the surface roughnesses of different CAD-CAM materials before polishing. The null hypothesis that polishing would not change the surface roughness of CAD-CAM HPP materials was rejected. After polishing, significant differences were found between the surface roughness of the J and among the surface roughnesses of some CAD-CAM HPP groups.

Increased dental plaque and biofilm formation on rough surfaces have been reported.[31,34] Therefore, dental restorations should display a smooth surface. For clinical acceptability of prostheses, polishing should result in a final surface roughness below an Ra threshold of 0.2 μm.[25,33] The mean surface roughness values of the HPP materials used in the present study ranged between 0.613 μm and 1.395 μm after milling (before polishing) and between 0.502 μm and 1.649 μm after polishing, higher than the acceptable Ra threshold of 0.2 μm.

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.[25] A slurry of polishing paste in water leads to a finer abrasion and produces a light-reflective, high-gloss surface.[25,35] Heimer et al[25] 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. In the present study, the 3-body abrasion was used.

In previous studies,[11,37-40] PEEK specimens were sectioned from PEEK cylinders or disks with a low-speed diamond saw, and Çulhaoğlu et al[41] and Caglar et al[36] milled specimens from PEEK blocks. Similarly, HPP specimens in the present study were milled from blocks. Milling was preferred over sectioning to simulate the prosthesis fabrication procedure.

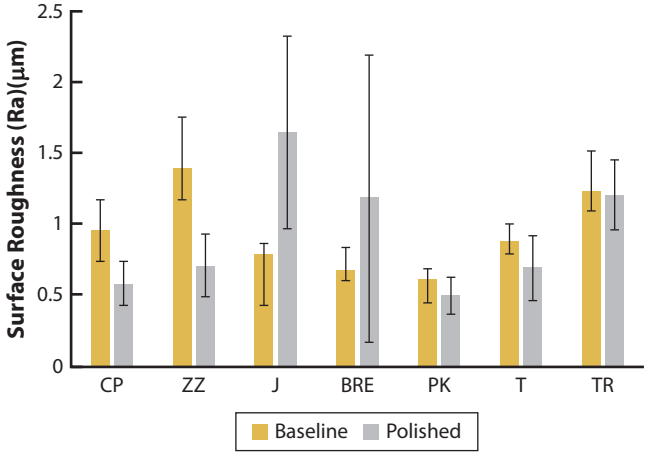


Figure 1. Mean surface roughness values and 95% confidence intervals (μm).

Surface roughness may be determined 2-dimensionally by using a contact profilometer with a diamond-tracing stylus or by using a noncontact 3D optical profilometer.[11] Sturz et al[42] used confocal laser scanning measurements to determine the surface roughness of materials. In the present study, as in other previous studies,[11,25,36,37,39-41] a noncontact profilometer was used to measure the surface roughness.

Previous studies[11,25,36,37,41] differ from the present study because initial mean Ra values were measured after using a standardized procedure with abrasive papers of different grits, and, generally, an automatic polishing machine was used to achieve a similar degree of surface roughness on all specimens. This was done to reduce possible surface roughness effects so that the differences in subsequent measurements after modification of the surface would only result from the properties and composition of the specific materials. In the present study, all HPP specimens were CAD-CAM milled, and the initial surface roughness values of the materials were measured without any treatment after the milling procedure. This method was preferred because of the lack of clarity among manufacturers' recommendations for surface treatments of these materials; some recommend the direct use of material after milling without performing any treatments. During communication, some manufacturers claimed that the surface roughness would increase if polished. The specimens were all milled in the same CAD-CAM milling machine by using identical milling burs.

Stawarczyk et al[11] measured the surface roughness of PEEK specimens after polishing with silicon carbide (SiC) abrasive papers P400 and P4000 with an automatic polishing device without any other treatments, reporting a mean surface roughness value of 0.03 μm. Heimer et al[25] evaluated the effect of different polishing protocols on PEEK, PMMA, and composite resin disks, reporting a mean surface roughness of PEEK specimens measured after polishing between 0.032 μm and 1.337 μm depending on the polishing protocol. Heimer et al[25] ground a control group of PEEK specimens with SiC P500, prepolished with fine pumice stone and goat-hair brushes, and repolished with grinding papers (P1200, P4000). The surface roughness of the control group was 0.032 μm. Hahnel et al[37] ground all specimens by using a standardized procedure with grinding paper (grit 1000 and 4000) and an automated polishing machine. All specimens were subsequently polished manually by using a polishing paste. In their study, PEEK and PMMA specimens showed significantly lower surface roughness than titanium and zirconia specimens ($P<.001$). The mean surface roughness for PEEK specimens was 0.04 μm. Tsuka et al[39] reported that the polished PEEK surface with no treatment had the lowest surface roughness (0.5 μm). Keul et al[40] polished PEEK specimens with SiC P500 up to P2400 with an automatic polishing device. The mean surface roughness (μm) calculated for the no treatment group was 0.043 μm. Çulhaoğlu et al[41] reported Ra values for the 1200-grit SiC-treated group to be 0.53 μm, and Caglar et al[36] reported the mean surface roughness for specimens polished with 600-and 800-grit SiC to be 1.11 μm. The mean surface roughness values of the HPP materials used in the present study ranged between 0.613 μm and 1.395 μm after the milling procedure (before polishing) and after polishing between 0.502 μm and 1.649 μm.

Sturz et al[42] reported a mean Ra of 0.277 μm for PEEK after grinding with 1000-grit SiC. The results of their study showed a significant increase in surface roughness after polishing in all groups except the ZrO group. These findings are consistent with those of the J group in the present study. J and BRE materials, in the present study, had broad confidence intervals for surface roughness after polishing. The variation in surface roughness of these 2 materials may be attributed to their structure. A recent clinical trial of the J material suggested roughening of the PEEK surfaces to increase the bond strength with the veneering resin.[43] The rougher surfaces may increase bond strength and should be further investigated. The presence of nanoceramic filler in the BRE material might have contributed to the variation in surface roughness after polishing.

Surface free energy can also play a role in bacterial adhesion and retention; however, the influence of surface roughness has been reported to be greater than that of surface free energy.[30,34] Quirynen et al[30] reported that an increase in the surface roughness of resin strips above an Ra value of 2 μm resulted in a substantial increase in the bacterial colonization on these surfaces in comparison with smooth strips (Ra=0.14 μm), while a change in the surface free energy had almost no impact. In the present study, only the Ra values were analyzed.

Considering the surface roughness values of all HPPs in the present study, veneering may be needed to minimize plaque accumulation, especially for fixed prosthesis surfaces adjacent to soft tissues. However, the surface roughness may help to increase bond strength with the veneering resin materials where veneering is necessary for esthetics. HPPs are also used in removable prosthodontics as prosthesis frameworks.[2] The fit of removable partial dentures has been reported to be clinically acceptable.[44,45] The observed surface roughness of tested materials on the tissue surface of removable prostheses may contribute to the retention of the prosthesis, which should be further investigated in future studies.

Surfaces treated in the present study should be further analyzed for their ability to bond to the overlying composite resin in future studies. Further clinical studies are needed to test the HPPs in terms of their surface properties and bacterial formation.

CONCLUSIONS

Based on the findings of this in vitro study, the following conclusions were drawn:

1. The surface roughness of HPPs in different compositions was similar after milling.
2. Polishing increased the surface roughness values of a PEEK group (J).
3. Regardless of the state of the surface being polished or not, all roughness values before and after polishing were above the clinical acceptability threshold.

REFERENCES

1. Stawarczyk B, Eichberger M, Uhrenbacher J, Wimmer T, Edelhoff D, Schmidlin PR. Three-unit reinforced polyetheretherketone composite FDPs: influence of fabrication method on load-bearing capacity and failure types. Dent Mater J 2015;34:7-12.
2. Zoidis P, Papathanasiou I, Polyzois G. The use of a modified poly-ether-ether-ketone (PEEK) as an alternative framework material for removable dental prostheses. A clinical report. J Prosthodont 2016;25:580-4.
3. Al-Rabab'ah M, Hamadneh W, Alsalem I, Khraisat A, Abu Karaky A. Use of high performance polymers as dental implant abutments and frameworks: a case series report. J Prosthodont 2019;28:365-72.
4. Zoidis P. The all-on-4 modified polyetheretherketone treatment approach: A clinical report. J Prosthet Dent 2018;119:516-21.
5. Han KH, Lee JY, Shin SW. Implant-and tooth-supported fixed prostheses using a high- performance polymer (Pekkton) framework. Int J Prosthodont 2016;29:451-4.
6. Passaretti A, Petroni G, Miracolo G, Savoia V, Perpetuini A, Cicconetti A. Metal free, full arch, fixed prosthesis for edentulous mandible rehabilitation on four implants. J Prosthodont Res 2018;62:264-7.
7. Zoidis P, Bakiri E, Polyzois G. Using modified polyetheretherketone (PEEK) as an alternative material for endocrown restorations: A short-term clinical report. J Prosthet Dent 2017;117:335-9.
8. Andrikopoulou E, Zoidis P, Artopoulou II, Doukoudakis A. Modified PEEK Resin Bonded Fixed Dental Prosthesis for a Young Cleft Lip and Palate Patient. J Esthet Restor Dent 2016;28:201-7.
9. Basaran EG, Ayna E, Vallittu PK, Lassila LV. Load bearing capacity of fiber-reinforced and unreinforced composite resin CAD/CAM-fabricated fixed dental prostheses. J Prosthet Dent 2013;109:88-94.
10. Schmidlin PR, Stawarczyk B, Wieland M, Attin T, Hämmerle CH, Fischer J. Effect of different surface pre-treatments and luting materials on shear bond strength to PEEK. Dent Mater 2010;26:553-9.
11. Stawarczyk B, Beuer F, Wimmer T, Jahn D, Sener B, Roos M, et al. Poly-etheretherketone-a suitable material for fixed dental prostheses? J Biomed Mater Res B Appl Biomater 2013;101:1209-16.
12. Najeeb S, Zafar MS, Khurshid Z, Siddiqui F. Applications of poly-etheretherketone (PEEK) in oral implantology and prosthodontics. J Prosthodont Res 2016;60:12-9.
13. Erkmen E, Meriç G, Kurt A, Tunç Y, Eser A. Biomechanical comparison of implant retained fixed partial dentures with fiber reinforced composite versus conventional metal frameworks: A 3D FEA study. J Mech Behav Biomed Mater 2011;4:107-16.
14. Zaparolli D, Peixoto RF, Pupim D, Macedo AP, Toniollo MB, Mattos MDGC. Photoelastic analysis of mandibular full-arch implant-supported fixed dentures made with different bar materials and manufacturing techniques. Mater Sci Eng C Mater Biol Appl 2017;81:144-7.
15. Bonfante EA, Suzuki M, Carvalho RM, Hirata R, Lubelski W, Bonfante G, et al. Digitally produced fiber-reinforced composite substructures for three-unit implant-supported fixed dental prostheses. Int J Oral Maxillofac Implants 2015;30:321-9.
16. Fuhrmann G, Steiner M, Freitag-Wolf S, Kern M. Resin bonding to three types of polyaryletherketones (PAEKs) – durability and influence of surface conditioning. Dent Mater 2014;30:357-63.
17. Liebermann A, Wimmer T, Schmidlin PR, Scherer H, Löffler P, Roos M, et al. Physicomechanical characterization of polyetheretherketone and current esthetic dental CAD/CAM polymers after aging in different storage media. J Prosthet Dent 2016;115:321-8.
18. Silthamitag P, Chaijareenont P, Tattakorn K, Banjongprasert C, Takahashi H, Arksornnukit M. Effect of surface pretreatments on resin composite bonding to PEEK. Dent Mater J 2016;35:668-74.
19. Stawarczyk B, Jordan P, Schmidlin PR, Roos M, Eichberger M, Gernet W, et al. PEEK surface treatment effects on tensile bond strength to veneering resins. J Prosthet Dent 2014;112:1278-88.
20. Stawarczyk B, Thrun H, Eichberger M, Roos M, Edelhoff D, Schweiger J, et al. Effect of different surface pretreatments and adhesives on the load-bearing capacity of veneered 3-unit PEEK FDPs. J Prosthet Dent 2015;114:666-73.
21. Kurtz SM, Devine JN. PEEK biomaterials in trauma, orthopedic, and spinal implants. Biomaterials 2007;28:4845-69.
22. Baschek G, Hartwig G, Zahradnik F. Effect of water absorption in polymers at low and high temperatures. Polymer 1999;40:3433-41.
23. Zoidis P, Bakiri E, Papathanasiou I, Zappi A. Modified PEEK as an alternative crown framework material for weak abutment teeth: a case report. Gen Dent 2017;65:37-40.
24. Bae SY, Park JY, Jeong ID, Kim HY, Kim JH, Kim WC. Three-dimensional analysis of marginal and internal fit of copings fabricated with poly-etherketoneketone (PEKK) and zirconia. J Prosthodont Res 2017;61:106-12.
25. Heimer S, Schmidlin PR, Roos M, Stawarczyk B. Surface properties of polyetheretherketone after different laboratory and chairside polishing protocols. J Prosthet Dent 2017;117:419-25.
26. Nakazato G, Tsuchiya H, Sato M, Yamauchi M. In vivo plaque formation on implant materials. Int J Oral Maxillofac Implants 1989;4:321-6.
27. Taylor R, Maryan C, Verran J. Retention of oral microorganisms on cobalt-chromium alloy and dental acrylic resin with different surface finishes. J Prosthet Dent 1998;80:592-7.
28. Alp G, Johnston WM, Yilmaz B. Optical properties and surface roughness of prepolymerized poly(methyl methacrylate) denture base materials. J Prosthet Dent 2019;121:347-52.
29. Mei L, Busscher HJ, van der Mei HC, Ren Y. Influence of surface roughness on streptococcal adhesion forces to composite resins. Dent Mater 2011;27:770-8.
30. Quirynen M, Marechal M, Busscher HJ, Weerkamp AH, Darius PL, van Steenberghe D. The influence of surface free energy and surface roughness on early plaque formation. An in vivo study in man. J Clin Periodontol 1990;17:138-44.
31. Kawai K, Urano M, Ebisu S. Effect of surface roughness of porcelain on adhesion of bacteria and their synthesizing glucans. J Prosthet Dent 2000;83:664-7.
32. Nassar U, Meyer AE, Ogle RE, Baier RE. The effect of restorative and prosthetic materials on dental plaque. Periodontol 2000 1995;8:114-24.
33. Bollen CML, Papaioannou W, Van Eldere J, Schepers E, Quirynen M, Van Steenberghe D. The influence of abutment surface roughness on plaque accumulation and peri-implant mucositis. Clin Oral Imp Res 1996;7:201-11.
34. Bürgers R, Gerlach T, Hahnel S, Schwarz F, Handel G, Gosau M. In vivo and in vitro biofilm formation on two different titanium implant surfaces. Clin Oral Implants Res 2010;21:156-64.
35. Hondrum SO, Fernández R Jr. Contouring, finishing, and polishing class 5 restorative materials. Oper Dent 1997;22:30-6.
36. Caglar I, Ates SM, Yesil Duymus Z. An in vitro evaluation of the effect of various adhesives and surface treatments on bond strength of resin cement to polyetheretherketone. J Prosthodont 2019;28:342-9.

37. Hahnel S, Wieser A, Lang R, Rosentritt M. Biofilm formation on the surface of modern implant abutment materials. Clin Oral Implants Res 2015;26:1297-301.
38. Tsuka H, Morita K, Kato K, Kawano H, Abekura H, Tsuga K. Evaluation of shear bond strength between PEEK and resin-based luting material. Journal of Oral Biosciences 2017;59:231-6.
39. Tsuka H, Morita K, Kato K, Kimura H, Abekura H, Hirata I, et al. Effect of laser groove treatment on shear bond strength of resin-based luting agent to polyetheretherketone (PEEK). J Prosthodont Res 2019;63:52-7.
40. Keul C, Liebermann A, Schmidlin PR, Roos M, Sener B, Stawarczyk B. Influence of PEEK surface modification on surface properties and bond strength to veneering resin composites. J Adhes Dent 2014;16:383-92.
41. Çulhaoğlu AK, Özkır SE, Şahin V, Yılmaz B, Kılıçarslan MA. Effect of various treatment modalities on surface characteristics and shear bond strengths of polyetheretherketone-based core materials. J Prosthodont 2020;29:136-41.
42. Sturz CR, Faber FJ, Scheer M, Rothamel D, Neugebauer J. Effects of various chair-side surface treatment methods on dental restorative materials with respect to contact angles and surface roughness. Dent Mater J 2015;34:796-813.
43. Nobre MDA, Guedes CM, Almeida R, Silva A, Sereno N. Hybrid polyetheretherketone (PEEK)-acrylic resin prostheses and the all-on-4 concept: a full-arch implant-supported fixed solution with 3 years of follow-up. J Clin Med 2020;9:2187.
44. Arnold C, Hey J, Schweyen R, Setz JM. Accuracy of CAD-CAM-fabricated removable partial dentures. J Prosthet Dent 2018;119:586-92.
45. Negm EE, Aboutaleb FA, Alam-Eldein AM. Virtual evaluation of the accuracy of fit and trueness in maxillary poly(etheretherketone) removable partial denture frameworks fabricated by direct and indirect CAD/CAM techniques. J Prosthodont 2019;28:804-10.

Corresponding author:
Dr Burak Yilmaz
The Ohio State University, College of Dentistry
Division of Restorative and Prosthetic Dentistry
Columbus, OH 43210
Email: Yilmaz.16@osu.edu

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