

Original article

Effect of polishing protocols on the surface roughness of polyetheretherketone

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(Received December 22, 2018; Accepted March 16, 2019)

Abstract: The purpose of this study was to evaluate the influence of various polishing protocols on the surface roughness of polyetheretherketone (PEEK) and identify an effective polishing method of dental prostheses at the chairside. The PEEK specimens were assigned to seven groups with different protocols: no additional polishing (NT); polishing using a rubber point (C); polishing using “silky shine” (S); polishing using “aqua blue paste” (A); protocol C followed by protocol S (CS); protocol C followed by protocol A (CA); and protocol C followed by protocols S and A (CSA). The surface roughness (Sa and Ra) of the polished surfaces was measured. The surface roughness decreased in the following order of groups: NT, C, S, CS, CSA, CA, and A. In Groups C and S, wide deep pits formed by abrasive grains of SiC paper were observed, whereas only fine linear structures were observed on the surface in other groups. With respect to the polishing protocol of PEEK, clinically acceptable surface roughness was obtained using a soft polishing brush and agent for more than 3 min.

Keywords; polyetheretherketone, dental prostheses, surface treatment, polishing agent

Introduction

Polyetheretherketone (PEEK) is an engineering plastic material widely utilized in industrial products owing to its stable physical properties and high abrasion resistance. It has been increasingly employed as a biomaterial for orthopedic and spine cages. In the field of dentistry, various PEEK applications, such as manufacturing implant bodies, implant superstructures, crowns, fixed partial dentures, and frameworks for removable dentures, have been implemented [1-4]. The demand for dental prostheses prepared using such materials will increase in the future due to increasing precious metal prices and problems of dental metal allergies.

A smooth surface is required for dental prostheses to facilitate tongue feeling and dental plaque adhesion to the dental prostheses. Even if it is sufficiently polished at the laboratory side, the surface of the prosthesis often needs to be polished again at the chairside post adjustment. It is reported that humans can distinguish between differences in roughness values of at least 0.5 μm [5], and the surface roughness of the final polished prosthesis should not exceed 0.2 μm , which is the threshold value for enabling dental plaque adhesion [6,7]. In addition, a rough occlusal surface results in a smaller occlusal contact area or mating surface (i.e., the real contact area), thereby increasing the influence of the abrasive wear. Therefore, polishing the surface of dental prostheses is necessary to decrease the surface roughness to the maximum extent.

The information available on polishing PEEK is limited, with only two studies involving both the laboratory and at the chairside [8,9]. However, there are various types of PEEK, and the available literature is unsatisfactory owing to a lack of comparison with polishing conditions of other dental materials. The purpose of this study was to evaluate the influence of various polishing protocols on the surface roughness of PEEK and identify an effective polishing method of dental prostheses at the chairside.

Materials and Methods

Materials

Table 1 shows the materials prepared and used in this study: non-filler-type PEEK; two types of rotating polishing instruments, the abrasive rubber point and the soft polishing brush; and two types of polishing agents, a liquid-type “silky shine” and a paste-type “aqua blue paste.”

Specimen preparation

PEEK specimens were prepared as cylinders of 10-mm diameter and 10-mm height. The specimens were designed on a computer and machine-milled (RXP500 DSC, Röders GmbH, Soltau, Germany). All specimens were manually trimmed, and the bases of the cylinders were polished under water using 800-grit abrasive SiC paper, followed by ultrasonic cleaning in 70% isopropanol for 15 min. Finally, all specimens were washed three times with distilled water.

Surface treatment modalities

Six PEEK surface-polishing protocols were prepared, and all procedures were randomly performed by a single practitioner (K.K.) to minimize outcome variability.

NT: No additional polishing

C: Polishing using a rubber point for 1 min at a rotation speed of 20,000 rpm

CS: Polishing using a rubber point for 1 min at 20,000 rpm, followed by polishing using “silky shine” and a soft brush for 1 min at 10,000 rpm

CSA: Polishing using a rubber point for 1 min at 20,000 rpm, followed by polishing using “silky shine” and a soft brush for 30 s at 10,000 rpm and polishing using “aqua blue paste” and a soft brush for 30 s at 10,000 rpm (in that order)

CA: Polishing using a rubber point for 1 min at 20,000 rpm, followed by polishing using “aqua blue paste” and a soft brush for 1 min at 10,000 rpm

S: Polishing using “silky shine” and a soft brush for 3 min at 10,000 rpm

A: Polishing using “aqua blue paste” and a soft brush for 3 min at 10,000 rpm

All rotating polishing instruments were attached to a dental micromotor (EWL K11, KaVo Dental, Biberach, Germany). Polishing was repeated by adding the respective polishing paste every 30 s. The rotation number and polishing time were determined based on the operation manual of the polishing agents and previous literature, respectively.

The specimens were washed with distilled water and dried after every polishing step. Post polishing, all specimens were ultrasonically cleaned in 70% isopropanol for 15 min, washed three times with distilled water, and then air-dried.

Ten specimens were prepared for each of the seven conditions mentioned above.

Surface roughness measurement

The specimens' mean surface height (Sa) and the assessed surface profile's mean deviation (Ra) were measured using a laser microscope (Optelics Hybrid, Lasertec Corp., Yokohama, Japan). Three points per base surface were measured, and the median value was used as the representative value of the specimen. Ra, the most widely used parameter in evaluating surface roughness, presents the average surface roughness in two dimensions, and Sa is obtained by extending Ra in three dimensions; thus, the influence of directional scratches becomes very small, making it possible to obtain a

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Color figures can be viewed in the online issue at J-STAGE.

doi.org/10.2334/josnusd.18-0473

DN/JST.JSTAGE/josnusd/18-0473

Table 1 Materials used

Material	Trade name	Manufacturer	Lot number	Composition
PEEK	JUVORA Dental Disc	Invisio Biomaterial Solutions, Lancashire, UK	Not registered	Polyetheretherketone
Abrasive rubber point	CeraMaster HP 13S	Shofu Inc., Kyoto, Japan	1217057	Diamond particle, synthetic rubber
Soft polishing brush	Flannel Disks No. 102	Polirapid, Singen, Germany	1117/051	Flannel
Polishing agent	Silky shine	Yamahachi Dental Mfg., Co. Gamagori, Japan	13066	Water, naphtha, aluminum silicate
Polishing agent	Aqua blue paste	Quest Corp., Komatsushima, Japan	70735	Water, ammonium oxide, water-soluble solvent, surfactant

Table 2 Surface roughness

Polishing Group	Sa (μm)		Ra (μm)	
	Mean \pm Standard deviation	95% Confidence interval	Mean \pm Standard deviation	95% Confidence interval
NT	$0.693 \pm 0.084^{\text{ABCDEF}}$	0.633-0.754	$0.653 \pm 0.109^{\text{abcdef}}$	0.575-0.730
C	$0.082 \pm 0.012^{\text{ADHIJK}}$	0.073-0.090	$0.080 \pm 0.017^{\text{aghijk}}$	0.068-0.092
CS	$0.018 \pm 0.004^{\text{BGL}}$	0.015-0.021	$0.018 \pm 0.006^{\text{bcd}}$	0.014-0.022
CSA	$0.016 \pm 0.005^{\text{CH}}$	0.013-0.020	$0.016 \pm 0.005^{\text{chm}}$	0.013-0.020
CA	$0.015 \pm 0.004^{\text{DIM}}$	0.013-0.018	$0.012 \pm 0.004^{\text{dip}}$	0.009-0.015
S	$0.028 \pm 0.012^{\text{EJN}}$	0.019-0.037	$0.031 \pm 0.014^{\text{ejp}}$	0.021-0.042
A	$0.011 \pm 0.001^{\text{FKLMN}}$	0.010-0.012	$0.009 \pm 0.002^{\text{klmp}}$	0.008-0.011

Values followed by the same superscript are statistically different ($P < 0.05$).

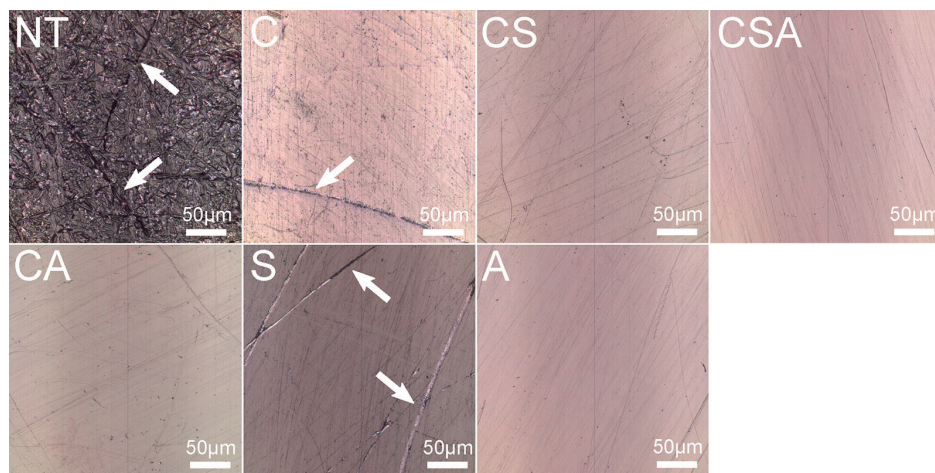


Fig. 1 Two-dimensional images of PEEK surfaces for each polishing protocol, obtained using a laser microscope. Arrows in the images for Groups NT, C, and S show deep pits on each surface. NT, no additional polishing; C, polishing using a rubber point for 1 min at 20,000 rpm; S, polishing using “silky shine” and a soft brush for 3 min at 10,000 rpm

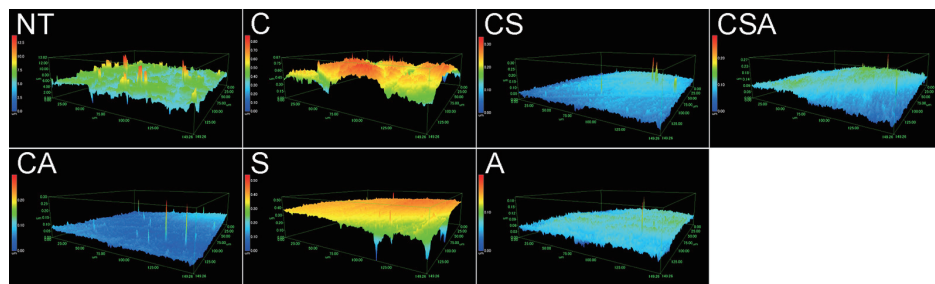


Fig. 2 Color-mapped three-dimensional images of PEEK surfaces for each polishing protocol, obtained using a laser microscope. Colors indicate the height of the scanned area: blue and red indicate low and high distances from a mean horizontal plane.

stable result.

The mean values of the seven groups were compared using the Kruskal-Wallis and Games-Howell *post-hoc* test. A significance level of 0.05 was used. The data were analyzed using the IBM SPSS Statistics, Version 24.0 software package (IBM Corp., Armonk, NY, USA).

Results

Table 2 shows the Sa and Ra values for every polishing protocol. Sa and Ra for Group NT showed the largest values, $0.69 \mu\text{m}$ and $0.65 \mu\text{m}$, respectively. These values were more than $0.5 \mu\text{m}$, which represents recognizable roughness. Among the polished groups, surface roughness decreased in the following order: Groups C, S, CS, CSA, CA, and A. The surface roughness of Groups C and S exceeded the threshold value of $0.2 \mu\text{m}$, whereas that

of the other groups was below $0.2 \mu\text{m}$, which is the threshold for bacterial adherence.

The surface roughness of the six polished groups was significantly lower than that of Group NT. Furthermore, the surface roughness of Group C was significantly higher than those of the other five polished groups. The Sa value of Group A was significantly lower than those of Groups CS, CA, and S, whereas its Ra value was significantly lower than those of Groups CS, CSA, and S.

The two-dimensional images captured using the laser microscope are shown in Fig. 1. In Group NT, roughness was observed throughout the surface. In Groups C and S, wide deep pits formed by abrasive grains of SiC paper were captured on the images, whereas only fine linear structures were observed on the surfaces in the other groups. Three-dimensional color-mapped images of the surfaces in Fig. 2 support this result. The find-

ings shown in Fig. 1 can be quantitatively evaluated. The forms of deep pits were observed in Group NT and C. Surface waviness appeared in the Group C. Groups CS, CSA, CA, and A showed similar surface patterns.

Discussion

Previous studies regarding PEEK polishing have focused only on a filler-containing-type PEEK (BioHPP). The PEEK used in the present study is non-filler type having high purity and excellent biocompatibility also in addition to stability at the nanoscale. There is no report on the polishing of non-filler type PEEK. Therefore, the present study focused on the polishing protocols for such PEEKs, which can be made easily available on the chairside. Six different types of polishing protocols were employed in this study, with acceptable polishing times and an acceptable surface roughness of approximately 0.2 μm .

Sturz et al. reported the average values of Ra and Sa for polishing filler-containing PEEK using 1,000-grit SiC paper to be 0.277 μm and 0.547 μm , respectively [8]. By adding high-gloss finish using a 1- μm diamond paste applied via a cotton buff, the authors decreased the Ra and Sa values to 0.073 μm and 0.148 μm , respectively. Furthermore, the Ra and Sa values of 50% inorganic nano-filled dimethylacrylate polished using the same protocol were 0.399 μm and 0.108 μm , respectively. Therefore, it has been suggested that PEEK becomes smoother than composite resin when both materials are polished with the diamond paste using the cotton buff. Heimer et al. also evaluated the surface roughness of the same type of PEEK, polished using P1,200 and P4,000 SiC abrasive papers as controls, through laboratory and chairside polishing protocols and found surface roughness to be $0.032 \pm 0.003 \mu\text{m}$ [9]. Polishing with mops using Abraso polishing paste (duration: 1 min; rotation speed: 3,000 rpm) as the laboratory-side protocol yielded the lowest surface roughness of $0.034 \pm 0.010 \mu\text{m}$. The surface roughness obtained upon polishing using a Prisma-gloss polishing paste (duration: 40 s only paste and 20 s paste with water in small amounts; rotation speed: 8,000 rpm) as the chairside protocol yielded the lowest surface roughness of $0.072 \pm 0.009 \mu\text{m}$. The polishing effect is reciprocally affected by the hardness of the PEEK, which is almost equal to or slightly more than that of acrylic resin, and polishing materials. The researchers speculate that the surface irregularities of PEEK are reduced by polishing because of the cutting action of the diamond particles in the rubber point; a similar effect is achieved by the surface plastic flow of the ingredients in protocols S and A. However, as “silky shine” and the “aqua blue paste” in these protocols are in the liquid/paste form and their hardness properties remain confidential, it is difficult to discuss their polishing effect from the perspective of material hardness.

In this study, the three-body abrasive wear mode of PEEK surface in Groups CS, CSA, CA, A, and S showed lower surface roughness than the two-body mode in Group C, as suggested in the two aforementioned previous studies [8,9]. Further, the effect of “silky shine” for thermoplastics was smaller than that of the polish used in the other five polished groups, and the surface roughness for the three polishing protocols that included “silky shine,” CS, CSA, and S, was high. In contrast, protocols that used the “aqua blue paste” for the resin/metal offered more effective polishing, especially when only the “aqua blue paste” was used for a long duration in Group A.

Compared with the polished surface roughness of other polymer materials used in dental prostheses, it has been reported that the average roughness of the thermoplastic resin polished using a paste-type polishing agent/compound in combination with the buff ranged between 0.12 and 0.28 μm [10–12]. In the present study, as the surface roughness of the six polished groups of PEEK was lower than that reported in previous works, the researchers suggest that the surface properties of PEEK are better than those of other thermoplastic resins. Additionally, it has been reported that the average roughness of acrylic resin polished using a paste-type agent/slurry ranged between 0.02 and 0.20 μm [13–16]; these values are larger than those of the five polished PEEK groups. It has also been reported that Ra and Sa values of the resin composites used as restorative materials that need to be polished in the oral cavity range between 0.1 and 0.3 μm and between 0.13 and 0.23 μm , respectively [17–21]. The abovementioned inferences and results obtained in this study suggest that PEEK can be polished into a sufficiently smooth surface for use as a dental prosthesis.

Although a multiple-step polishing protocol can provide a smoother surface, a single-step polishing protocol is preferable at the chairside to save time and expense [20]. In the actual polishing procedure, the following measures are also needed: reducing frictional resistance and minimizing change in temperature of the material surface during polishing, avoiding splashing the polishing agent, and ensuring that the polishing agent can be easily washed away after polishing to avoid bacterial adherence. Furthermore preferably, polishing should be performed while adding a soluble paste, such as the “aqua blue paste,” at regular intervals.

Thus, it can be concluded that clinically acceptable surface roughness of PEEK was obtained using polishing agents with a soft polishing brush; in particular, the polishing agent for resin/metal is more effective than that for thermoplastic resin.

Acknowledgments

PEEK materials were provided free of charge by Invibio Biomaterial Solutions. This work was supported by JSPS KAKENHI Grant Number JP16K11597.

Conflict of interest

The authors have no conflict of interest in the companies whose materials are mentioned in the article.

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