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Nine prophylactic polishing pastes: impact on discoloration, gloss, and surface properties of a CAD/CAM resin composite

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Abstract

Objectives To investigate discoloration reduction and changes of surface properties of a CAD/CAM resin composite after 14 days´ storage in red wine and polishing with nine different prophylactic polishing pastes (PPPs).

Materials and methods Rectangular discs ($N = 172$) were fabricated and polished (P4000) using GC Cerasmart (GC Europe) to investigate different polishing protocols with 1–4 related descending PPPs (22 in total): Cleanic/CLE-Kerr, CleanJoy/CLJ-Voco, Clean Polish/Super Polish/SPO-Kerr, Clinpro Prophy Paste/CPP-3M, Détartrine/DET-Septodont, Nupro/NUP-Dentsply Sirona, Prophy Paste CCS/CCS-Directa, Proxyt/PXT-Ivoclar Vivadent, and Zircate/ZIR Prophy Paste-Dentsply Sirona. Surface properties (roughness values (RV)/Ra, Rz, Rv, surface free energy (SFE), surface gloss (G), and discoloration (ΔE)) were analyzed before and after storage and additional polishing. Data were examined using Kolmogorov-Smirnov test, three-way ANOVA followed by Tukey-B post hoc, Mann-Whitney U, and Kruskal-Wallis H tests ($\alpha < 0.05$).

Results Regarding RV, CLE, followed by CCS, and CPP showed the highest values; the lowest presented SPO and DET ($p < 0.001$). No impact of PPP was observed on ΔE values ($p = 0.160$). The lowest SFE presented DET, followed by SPO; highest showed CCS followed by NUP and CPP ($p < 0.001$). Within G, lowest values were observed for CLE and NUP, followed by CCS, ZIP, and CLJ ($p < 0.001$); the highest presented SPO ($p < 0.001$). Polishing showed generally a positive impact on SFE values ($p < 0.001$–$p = 0.007$), except ZIP ($p = 0.322$) and CLE ($p = 0.083$). G increased and RV decreased after polishing ($p < 0.001$), except SPO, with no significant change for G ($p = 0.786$).

Conclusions Polishing with PPPs improves the surface properties and is generally recommended. The choice of PPP has a minor role in removing discolorations. Multi-step systems should be carried out conscientiously.

Clinical relevance The proper selection of PPP is essential for the clinical outcome of surface properties of prosthetic restorations. Not every polishing paste leads to the same final surface quality.

Keywords Prophylactic polishing paste · CAD/CAM resin composite · Surface gloss · Surface roughness · Surface free energy · Discoloration

Introduction

Tooth-colored ceramic and resin composite restorations offer an optimal solution for the increasing demand of esthetic and natural appearing restorations. The continuous development of Computer-Aided Design/Computer-Aided Manufacturing (CAD/CAM) technology and compatible materials has enlarged their range of application. With the help of an industrially standardized manufacturing process of the blocks, the physical, mechanical, and optical properties of the materials could be increased. This is especially true for CAD/CAM resin composites when compared to manually fabricated ones [1–4]. CAD/CAM resin composites are used either as long-

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term provisional or as definite restorations depending on the material brand, though the potential use as definitive restorations is increasingly in the focus of science. However, the mechanical and optical properties should be convincing over long-term use.

Most prosthodontically treated patients regularly undergo professional teeth cleaning in which the hygienist frees the teeth of discolorations and plaque deposits. In this procedure, a polish of all teeth and restorations with a prophylactic polishing paste (PPP) is usually performed. Depending on which material is used for the restorations, the wear behavior is different, e.g., resin composites show higher wear tendencies than ceramics, they lose their gloss more quickly and get rougher in a shorter time. That is why they should be re-polished more often [5–8]. A large number of different PPPs and polishing protocols are available. PPPs are offered as one-step or multi-step systems and can be used from coarse to fine depending on the degree of discoloration and necessity in order to clean and smoothen the surface [9–12]. After a prophylaxis, the patient expects a pleasant smooth and clean feeling on the teeth and restoration surfaces [13, 14]. Restorations with a smooth surface appear much more esthetically pleasing and are better accepted by patients [15, 16]. Additionally, increased surface roughness in restorative materials can lead to increased plaque accumulation. This accumulated biofilm can lead to discoloration of the restorative material, gingival inflammation, and the development of secondary caries, which significantly reduces the clinical longevity [9, 16–21]. A roughness value of 0.2 μm is described as the threshold for an increased biofilm accumulation, though the study was performed for titanium implant surfaces [22].

Nevertheless, there is very little information in the literature about the impact of different PPPs and compatible protocols concerning the reduction of discoloration rates, the surface roughness/depth, gloss, and surface free energy (SFE) of each individual polishing step. In addition, there are no studies available comparing the different PPPs and analyzing the impact of diverse polishing protocols on surface properties. The aim of this study was to investigate discoloration reduction and surface properties after a CAD/CAM resin composite is stored for 14 days in red wine followed by polishing with nine different PPPs. The null hypothesis investigated whether all PPPs show similar outcome, regarding discoloration rate, material gloss, SFE, roughness, and surface topographies.

Materials und methods

A total of 172 rectangular discs were fabricated out of the CAD/CAM resin composite material GC Cerasmart (GC Dental Products, Leuven, Belgium) to investigate the different polishing protocols with one to four related descending pastes (22 PPP in total). A first operator performed the fabrication and measurement of SFE and discoloration. Then, a second operator analyzed surface roughness, surface gloss, and scanning electron microscopy (SEM). All of the materials used are listed in Table 1. The CAD/CAM resin composite blocks were half-automatically cut into discs of 1.5-mm thickness with a low-speed diamond saw under constant water cooling (Secotom-50, Struers, Ballerup, Denmark) and mechanically polished (Tegramin-20, Struers) to high gloss with ascending silicon carbide papers (SiC) up to P4000 (Struers).

After initial measurements of optical and surface properties (Ra/Rz/Rv/gloss for $n = 14$ specimens; ΔE/SFE for $n = 172$ specimens), two of them were used for SEM measurement. The remaining 170 discs were afterwards stored for 14 days in red wine (Rioja, Spain) in an incubator at a constant temperature of 37 °C (HERA cell 150, Thermo Fisher Scientific, Waltham, USA). Following the storage time, all specimens were randomly divided into ten sub-groups (nine polishing protocols and one control group) and polished according to the PPP procedure/pastes. Manual polishing on both sides for 60 s with a latex-free rubber brush (Pro-Cup light blue, Kerr, Rastatt, Germany) was performed a hand piece at 3.000 rpm according to the nine polishing protocols in descending roughness order (course to fine or even super fine) beginning with the course PPP and one-step PPP. After final polishing, the remaining 14 discs of each PPP protocol were analyzed again to determine their surface properties.

Surface roughness and depth

Quantitative surface characterization was performed at 14 initial and all final polished specimens by using a profilometer (S6P, Mahr, Göttingen, Germany). The surface topography was measured within a field of 3 mm × 3 mm (50 orthogonal measurements). The roughness average (Ra), average maximum height of the profile (Rz), and maximum profile valley depth (Rv) were analyzed by software Mountains Map V7.2 (Digital Surf, Besançon, France).

Discoloration measurement

All specimens were measured for their optical properties as transmission and discoloration rates (ΔE) in a spectrophotometer (Lambda 35 PerkinElmer, PerkinElmer Inc., Massachusetts, USA). Before each measurement with the spectrophotometer, the device was calibrated to 100% transmission. The first measurement was performed before storing in red wine. All specimens were measured again after 14 days of storage in red wine, and the values served as the baseline for the longitudinal data of ΔE compared to values measured after the final PPP step. All ΔE values were finally analyzed using the Color Application Software (PerkinElmer Inc.).

Table 1 Summary of products, abbreviations (Abbr.), manufacturers, Lot. no., and material compositions in alphabetical order

CAD/CAM material	Manufacturer	Particle size	Abbr.	Composition	Lot. no.
GC Cerasmart	GC Europe, Leuven, Belgium		*GCC*	Bis-MEPP, UDMA, DMA, silica (20 nm), barium glass (300 nm)	H56719
Prophylactic polishing paste (PPP)					
Cleanic	Kerr, Rastatt, Germany		*CLE*	Titandioxide, glycerine, natriumfluoride < 0.25%, ethanol < 1%	6106420
CleanJoy	Voco, Cuxhaven, Germany	Coarse RDA 195; Medium RDA 127; Fine RDA 16	*CLJ*	Tenside TB < 2.5%, peppermint flavor < 2.5%, natriumfluoride < 2.5%	Coarse: 1641198 Medium: 1642311 Fine: 1643257
Clean/Super Polish (no. 360/361)	Kerr, Rastatt, Germany		*SPO*	Pumice mixture, flavor, colorant E122, preservatives, excipient	Clean polish: 6067984 Super polish: 5880346
Clinpro Prophy Paste	3 M, Seefeld, Germany	Coarse RDA 250; Medium RDA 170; Fine RDA 120	*CPP*	Natriumfluoride < 3; water 1–20; polyethylenglycol 5–25; glycerine 15–40; flavor 1–5; pumice 30–50; trinatriumorthophosphate < 5; silicic acid, sodium salt < 5	Coarse: 042216G Medium: 051916C Fine: 051916A
Détartrine 100ZF/150ZF	Septodont, Niederkassel, Germany	RDA 150; RDA 100	*DET*	Quartz 25–50%, glycerin 10–25%, ethanol < 2.5%, zircon in silicate	150ZF: 16158AB 100ZF: 16218AA
Nupro	Dentsply Sirona, Konstanz, Germany	Coarse; Medium; Fine	*NUP*	Novamin, glycerol 25–50%, natriumfluoride 2.5–10%, pumice, diatomite, natriumsilicate, methylsalicylate, mononatriumphosphate, natriumsaccharine, natriumcarboxymethycellulose	Coarse: 16061401 Medium: 16062908 Fine: 16062004
Prophy-Paste CCS	Directa, Upplands Vaesby, Sweden	Coarse RDA 250; Medium RDA 170; Fine RDA 120; Superfine RDA 40	*CCS*	Glycerine, hydrated silica, water, aluminiumhydroxide, sodium-dihydrogenphosphatedihydrate, titaniumdioxide, PEG-25 hydrogenated castor oil, sodium-methylparaben, sodium-saccahrin, flavor, prophylparaben	Coarse: 28197 Medium: 28217 Fine: 28096 Superfine: 28098
Proxyt	Ivoclar Vivadent, Schaan, Liechtenstein	Coarse RDA 83; Medium RDA 36; Fine RDA 7	*PXT*	Water, glycerine 41.0; sorbite, xylit 21.0; anorganic fillers 35.0; excipient 1.2; natriumfluoride 0.12; flavor and pigments < 1.68	Coarse: V16059 Medium: V03269 Fine: V32179
Zircate Prophy Paste	Dentsply Sirona, Konstanz, Germany		*ZIP*	Zirconiumsilicate, tin oxide, glyerol	160620

Surface free energy

The SFE was tested at room temperature by the sessile drop technique using a drop shape analysis system (DSA 25, EasyDrop, Krüss, Hamburg, Germany) with two different liquids of different polarity: distilled water and diiodomethane 99% (cat: 15.842-9, Sigma-Aldrich, Steinheim, Germany, lot. no.: S65447-448), separately. The water- or diiodomethane-drop is registered with a CCD-camera that makes a standardized digitalized photo after exactly 5 s. Surface energy is calculated on the basis of the contact angle measurements with water and diiodomethane according to the Ström database:

$$\cos\theta = \frac{\sigma \mathrm{S} - \sigma \mathrm{LS}}{\sigma \mathrm{L}}$$

with σL: surface free energy of the liquid; σS: surface free energy of the solid; and σLS: interface surface free energy.

Gloss measurement

The surface gloss of all 14 specimens per group was performed with a glossmeter (PICOGLOSS 560 MC-XS, Erichsen, Hemer, Germany) on five randomly chosen areas on each specimen. The measured values were expressed by mean gloss unit (GU). The device was calibrated for each group according to the manufacturer's instructions. For this, the device was placed on a gloss standard tile (black) and calibrated.

Scanning electron microscopy

For qualitative surface observations, SEM (LEO 1430, Zeiss, Germany) was used. One specimen per PPP after the final polishing step was analyzed three times operating at 10 kV with a working distance of18–21 mm. All specimens were sputter coated by gold-palladium with a sputter coater (SCD 005, Bal-

Tec, Liechtenstein) for 100 s. Additionally, all 22 pastes were dried on SEM sample holders for 28 days at 80 °C.

Statistical analysis

The measured data were analyzed using descriptive statistics. The normality of data distribution was tested using the Kolmogorov-Smirnov test. Three-way ANOVA followed by the Tukey-B post hoc test was computed to determine the significant differences among the tested groups. The differences between the groups were determined using the Mann-Whitney *U* and Kruskal-Wallis H tests. The statistical tests were performed with SPSS version 24.0 (SPSS Inc., Chicago, IL, USA). All *p* values smaller than 0.05 were considered statistically significant in all tests performed.

Results

The Kolmogorov-Smirnov test indicated violation of the assumption of normality for 61% of the tested groups. Therefore, for all further statistical tests, the no assumption of normal distribution was used. Table 2 provides the descriptive statistics for all tested PPPs and all individual surface parameters after the final polishing step.

Comparison of surface roughness and gloss values before discoloration storage

No differences in surface roughness and initial gloss values between the tested materials were found.

Comparison of all PPPs after last polishing step

With regard to the last polishing step, no impact of PPP was observed on the Δ*E* values ($p = 0.160$). In contrast, the choice of PPP showed an influence on Ra ($p < 0.001$), SFE ($p < 0.001$), and gloss values ($p < 0.001$). Since all roughness values Ra, Rz, and Rv show the same tendencies, the focus of the evaluation was placed on the Ra results.

When comparing the Ra values, polishing with CLE, followed by CCS, CPP, and NUP showed the highest values; the lowest Ra was obtained for polishing using SPO, DET, and PXT ($p < 0.001$). The lowest SFE was showed for DET, followed by SPO; the highest was observed for CCS followed by NUP, CPP, PXT, and CLJ ($p < 0.001$). With respect to gloss values, the lowest were observed for CLE and NUP, followed by CCS, ZIP, CLJ, CPP, and DET ($p < 0.001$). The highest gloss values presented the PPP SPO followed by PXT ($p < 0.001$).

Impact of polishing on individual surface parameters

Polishing showed a positive impact on SFE values for all tested PPPs ($p < 0.001$–$p = 0.007$), with the exception of ZIP ($p = 0.322$) and CLE ($p = 0.083$). The gloss values significantly increased and the Ra values decreased after polishing ($p < 0.001$). The exception was the PPP SPO, where no significant change in the gloss values was observed ($p = 0.786$).

SEM pictures

Figure 1 presents each dried PPP with all polishing steps separately. A visibly fine-grained paste structure can be seen in ZIP, CLJ, and the coarser polishing pastes of CCP and SPO. Coarser grain paste structures were found for NUP, CLE, and the fine pastes of CCS. The fine paste of CPP revealed organic components.

SEM images of the nine polished material surfaces after the final polishing step are presented in Fig. 2. CLE, CCS, NUP, CLJ, and ZIP showed a distinctly

Table 2 Descriptive statistics of all surface parameters tested after final polishing step for each PPP, separately

Final	Δ*E*	SFE	Gloss	Ra	Rz	Rv
CLE	2.44 ± 0.97a	48.72 ± 1.82bc	10.38 ± 1.58a	0.17 ± 0.04d	1.29 ± 0.29e	0.78 ± 0.20d
CLJ	2.44 ± 1.16a	49.46 ± 1.48bc	24.16 ± 3.74bc	0.11 ± 0.01bc	0.80 ± 0.09cd	0.49 ± 0.06bc
SPO	1.75 ± 0.80a	46.19 ± 2.95b	65.34 ± 3.96*e	0.07 ± 0.02a	0.52 ± 0.12a	0.32 ± 0.09a
CPP	2.88 ± 1.42a	50.53 ± 2.74c	25.98 ± 3.23bc	0.13 ± 0.02c	0.84 ± 0.12cd	0.47 ± 0.08bc
DET	2.49 ± 1.06a	41.38 ± 3.04a	28.20 ± 4.07c	0.06 ± 0.01a	0.57 ± 0.09ab	0.31 ± 0.06a
NUP	1.90 ± 0.86a	51.49 ± 3.07c	14.69 ± 1.32a	0.12 ± 0.01c	0.86 ± 0.09cd	0.48 ± 0.07bc
CCS	2.42 ± 0.92*a	55.2 ± 1.52d	21.69 ± 2.77b	0.13 ± 0.01c	0.94 ± 0.10d	0.54 ± 0.06c
PXT	2.53 ± 0.92a	50.14 ± 2.25c	54.62 ± 6.30*d	0.08 ± 0.01ab	0.67 ± 0.08abc	0.39 ± 0.05ab
ZIP	2.41 ± 1.08a	48.67 ± 2.14*bc	22.70 ± 4.70bc	0.09 ± 0.01ab	0.72 ± 0.07bc	0.40 ± 0.04ab

Letters a, b, c, d, and e present significant differences between the PPP within the parameters Δ*E*, SFE, gloss, Ra, Rz, and Rv

*Not normally distributed

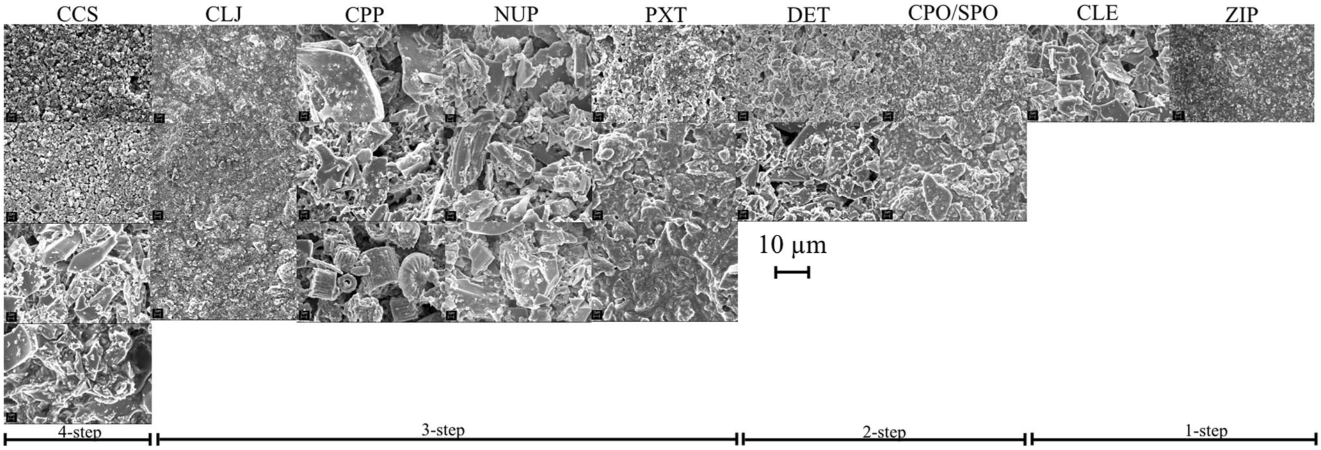

Fig. 1 SEM images of dried PPPs

irregular surface with partly visible streaks and minor structural defects. The most obvious irregular surface with scratches could be seen on CLE. On the other hand, SPO, DET, and PXT have more regular finer surface structures.

Discussion

With regularly performed professional teeth cleaning using specific products at 6-month intervals, the PPP must be suitable for various restorative materials since patients are usually supplied

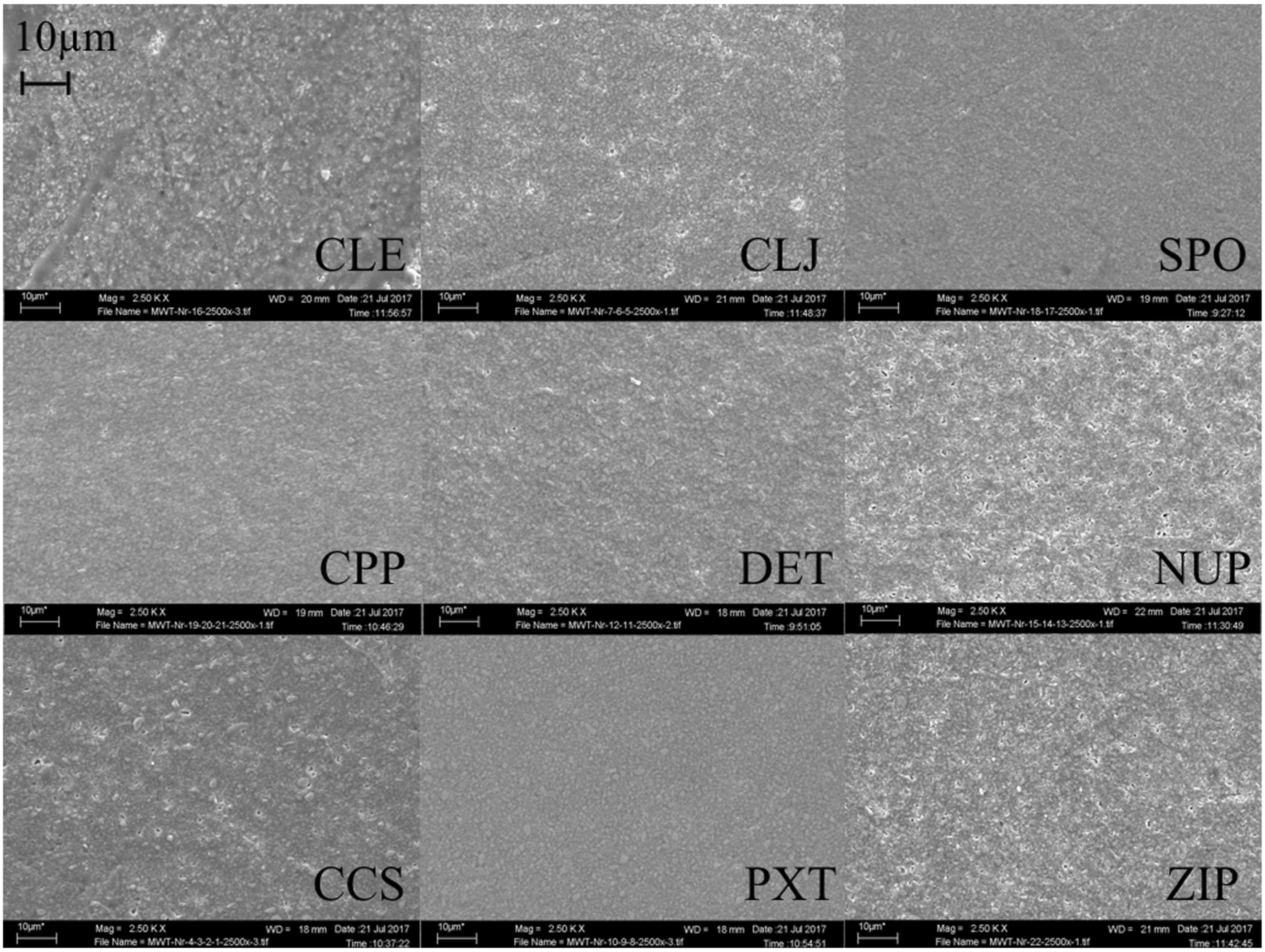

Fig. 2 SEM images of CAD/CAM surfaces after final polishing

with different materials intraorally. For relatively new CAD/CAM materials, in particular, there is no general recommendation from manufacturers regarding the preferred PPPs.

Numerous PPPs on the dental market are offered for professional teeth cleaning, some of which differ greatly in the composition and size and geometry of the polishing fillers. These differences can be clearly seen in the SEM images of the dried PPP. Regarding the size of the polishing grains and the geometry, in particular, the naked eye can see differences on the SEM images that seem to affect the results. For SPO, there are rounded and slightly smaller polishing grains, whereas CLE shows larger grains with tips. This could be a possible cause of the low surface roughness of SPO unlike CLE after the final polishing step. Generally, the polishing pastes are offered in descending surface roughness with a different number of polishing steps. The use of PPPs normally depends on the extent of the deposits and the degree of discoloration of the tooth and restoration surfaces. The PPPs with only one polishing step, like CLE, seem quite interesting in saving time and money in the dental practice. For ZIR, polishing with a fine PPP is usually recommended in practical applications. Therefore, in contrast to CLE, this paste is only to a limited extent regarded as a one-step system. In contrast, the PPP systems have several polishing steps, in which the practitioner can choose (depending on the patient) between different PPPs in descending order. Any polishing in the context of prophylaxis should, however, be completed with the finest paste to polish the surfaces as smooth as possible. In this investigation, only one CAD/CAM resin composite material was deliberately selected for examination to compare the different PPPs and polishing steps.

Apart from the large selection of PPP materials, the performance of professional teeth cleaning as well as the selection of products are highly dependent on the operator. The operator may use, for example, a polishing brush, a polishing cup, or both, except for the water-powder systems; the operator themselves can further determine the choice and amount of PPP used, the polishing pressure and the duration of the polishing time per surface. The optimum pressure is given in the literature as 2N [23, 24], whereas in practice, it is not realistic to constantly apply this pressure to every surface. In general, the contact pressure and the duration of the polishing vary to some extent on each surface. In the present study, the nature and implementation can also be considered as a limitation. Although the manual polishing of the specimens was carried out by only one experienced operator, standardization is hardly feasible since a small variation in the contact pressure or the movements performed during polishing cannot be avoided. The amount of PPP used may also vary slightly, as the consistency of the various PPPs is significantly different. In the present study, this could also have led to higher standard deviation of the results of all surface values analyzed.

In addition, the surface was polished for 1 min per specimen side with the specific PPP and a drop of distilled water in a circular motion, which does not clearly correspond to the clinical situation. During professional tooth cleaning, the polishing time per surface will be lower and thus the results could differ, if perhaps a shorter polish times, lower amount of PPP, or lower contact pressure were chosen. It has already been described in the literature that the changes in the surface roughness after polishing of resin-based materials are strongly material dependent and depend on the contact pressure as well as the duration of the respective polishing [24–26]. Since this study tried to use the same contact pressure as much as possible on the same material, this influence was probably rather inferior. However, significantly different results were seen between the different PPPs. Polishing with the different PPPs also had an influence on the surface parameters of the SFE, surface roughness, and gloss values in the present study.

Generally, the gloss of a restoration material has a decisive influence on esthetics and the color effect and, as already mentioned previously, depends crucially on the surface roughness [15, 16]. The rougher a material surface, the more light is scattered on its surface when a light beam strikes [27]. In addition, the influence of the number of fillers and filler size in the resin composite material on the gloss is high. For quartz fillers, it has been described that the gloss increases as the number of fillers decreases [28]. This can be explained by the fact that the light scattering by the larger number of refractions probably takes place at the border lines of the fillers integrated. The restoration thus takes on a dull appearance and the color effect changes [28]. The restoration surfaces should be smooth, as the surface roughness has an influence on the wearing comfort and well-being of the patient. The risk of increased plaque accumulation, which can lead to inflammation of the gums or secondary caries, also increases [29].

A closer look at the surface roughness and the influence of prophylaxis on the surface parameters showed that the use of PPP significantly influenced the surface roughness of indirect resin-based and ceramic materials [30]. The roughness increased significantly with an increased contact pressure at polishing of 4N instead of 2N and the gloss decreased, but these results were analyzed especially in direct microhybrid composite materials [24]. These results are therefore not exactly comparable to the results for CAD/CAM resin composite materials. A mechanical, as opposed to manual polishing, usually shows the best gloss for all materials [24]. A mechanical polishing was performed on the specimens in this study, which led to an initial high-gloss. Any further polishing could probably have significant effects, which could be confirmed in this study. For indirect resin composite materials, a correlation of the two surface parameters roughness and gloss could also be found in the literature [31]. As the roughness increases, the gloss decreases and vice versa. In another study, a strong correlation of microroughness and gloss was confirmed [32]. This correlation could not be clearly determined in the present study; however, the surface roughness values generally decreased significantly after polishing while the gloss increased significantly.

The highest final roughness values were found for CLE, followed by CCS and CPP. The surface roughness can be clearly seen in the SEM images (Fig. 2). No correlation can be drawn with the number of polishing steps, since CLE represents a one-step system, CCS a four-step, and CPP a three-step system. Moreover, it is very difficult to determine to what extent the compositions of individual PPPs have an influence. The SEM images, however, suggest that these pastes contain larger polishing fillers. After final polishing, SPO showed the lowest surface roughness, followed by DET and PXT. These pastes show slightly smaller polishing fillers than those mentioned above in the SEM pictures. In addition, the RDA value (relative dentine abrasivity) could play a role since lower RDA values are indicated for these PPPs (CPO/SPO 43.8/9.8, DET 150/100, PXT 83/36.7).

The PPPs also showed an influence on the gloss values and, apart from a PPP, increased significantly after polishing. The lowest gloss after final polish was found for CLE, followed by NUP, CCS, and ZIP. SPO and PXT showed the highest gloss. Although no correlation could be drawn at this point, as already mentioned previously, the surfaces with the roughest surfaces usually showed the lowest gloss and vice versa. This was visible for SPO presenting the lowest roughness values and the highest surface gloss. This could be due to the low RDA values of the two-step PPP SPO and the finer-grained structure with rounder polishing fillers.

Aside from polishing the surfaces with a PPP, even everyday teeth brushing has shown to have an impact on the roughness and gloss of various CAD/CAM materials. A significant material-dependent decrease in gloss and an increase in surface roughness were observed, with the tested ceramic showing the best gloss retention, in contrast to the resin-based CAD/CAM materials [5]. Comparing the results analyzed there, slightly lower final surface roughness was found after tooth brushing of the CAD/CAM material surfaces (e.g., Lava Ultimate (3M): 0.05 ± 0.006 μm) compared to after polishing with PPP in the present study (GC Cerasmart with the final least roughness with the PPP DET: 0.06 ± 0.01 μm). These roughness values, however, cannot be compared due to the different examination setup, as the toothpastes also contain, in contrast to the PPPs, finer polishing fillers. Other studies are also difficult to compare since none of the studies used comparable polishing protocols.

In the case of resin-based materials, it has already been described several times in the literature that the surface roughness of a material after polishing depends both on the composition of the material to be polished and on the composition of the PPP. In these studies, direct composite materials were mostly examined. The number of fillers, particle size, and hardness play an important role in roughness [33–38]. However, these results may differ from those of the CAD/CAM materials, although the chemistry is similar, but the fabrication method is completely different. In the present study, only one material was used to better compare the PPP. Differences in the individual PPPs were found, which could have led to different results. With regard for changing the surface parameters after polishing of CAD/CAM fabricated materials, there is little information or comparable investigations available.

Some studies have already reported a material-dependent increase in surface roughness after polishing and a simultaneous decrease in gloss [24, 39, 40], though, as mentioned previously, these investigated direct composites. Although the final polishing took place with a fine grain size, it was reported that even the fine PPP was unable to restore the initial gloss and smooth surface when the specimens had an initial high gloss (usually mechanical polishing of the specimens) [40]. Most of the studies analyzed, to the authors' best knowledge, involve only a few different polish pastes (e.g., Detartrine, Topex, Merssagen, Nupro, and Clinpro) in contrast to the nine polishing protocols analyzed here in one investigation. PPP in a medium or fine grain seem to cause a lower surface roughness than the coarse PPP [30, 39, 40]. Further studies showed that after the polishing of composites and compomers with pumice paste, the surface roughness does not change [13] and the roughness values improved [37]. The analyzed results of the present study confirm the results of the last study, as the roughness values after polishing improved. For all final roughness values of each PPP, the threshold of 0.2 μm, which is cited in the literature, was not exceeded [22, 41].

Concerning the influence of polishing on the SFE values, a positive influence was observed, apart from ZIP and CLE. The lowest SFE values were displayed by DET and SPO, which showed the lowest roughness and the highest gloss in the analysis of the other surface parameters. The highest SFE values were found for CCS and NUP. Again, it is difficult to establish a link based on the composition of the PPPs. Further investigations would be necessary.

Apart from the already mentioned surface parameters, e.g., gloss or roughness values, the tendency of resin-based restorative materials to become discolored plays a decisive role in the longevity of a prosthetic restoration. Concerning the influence of the polishing is important to be able to react to any discoloration. In a study with a lithium-disilicate ceramic (e.max CAD), a reduction of the translucency was found after a successful polishing with PPPs, which seemed to be strongly paste dependent [26]. However, these results cannot be compared with the results of this study because a different material class was tested. There was no influence found regarding polishing on ΔE values. Since the discoloration values were evaluated with the help of a specific computer software program from the measured translucency values and color spectra, there appears to be no influence on these values. All values measured were below the value of 3.3 reported in the literature, the value at which 50% of the observers considered the discoloration of the surface as unacceptable [42].

The specimens tested were stored for 14 days in red wine, since in the literature, this media usually presents the highest ΔE values after a longer period of aging. Perhaps the influence of a longer storage time or other storage medium such as curry would have been more apparent. These questions could be further investigated in another study.

Discoloration of composite specimens after storage in coloring food media, professional tooth cleaning with gentle water-powder devices, and subsequent post-polishing can result in a significant reduction in discoloration values [6, 7]. Post-polishing, however, is essential because of the resulting increased roughness after the water-powder treatment. The present study also showed a reduction in discoloration due to the PPP used, which, cannot be compared with the above-mentioned study. After any professional cleaning with a water-powder system, the surfaces should be polished, and here, is the influence of different PPPs on the surface properties is also important.

Given the results discussed previously, the null hypothesis based on the different PPPs is rejected. An exception was the discoloration values, which showed no significant differences between the PPPs in the final polishing results. This investigation focused mainly on the final polished values, being the clinically most important ones.

The present study illustrates that the proper selection of PPPs is essential for the clinical outcome of surface properties of prosthetic restorations. To conclude, not every polishing paste leads to the same final surface quality.

Conclusion

1. Polishing with PPPs had no impact on discolorations and therefore presented a minor role in removing them.
2. Polishing improved the surface properties and is generally recommended. Multi-step systems should be carried out conscientiously.
3. The lowest roughness and SFE values were presumably obtained after polishing with SPO and DET. SPO additionally presented the highest final surface gloss.

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Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

Ethical approval This article does not contain any studies with human participants or animals performed by any of the authors.

Informed consent For this type of study, formal consent is not required.

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