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RESEARCH AND EDUCATION

Impact of varnishing, coating, and polishing on the chemical and mechanical properties of a 3D printed resin and two veneering composite resins[1]

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ABSTRACT

Statement of problem. Three-dimensional (3D) printing enables the fast fabrication of definitive fixed dental prostheses (FDPs). However, data on the effects of surface treatments on their chemical and mechanical properties are lacking.

Purpose. The purpose of this in vitro study was to examine the influence of different surface treatments on a 3D printed resin in comparison with 2 veneering composite resins.

Material and methods. A total of 288 specimens were manufactured from a 3D printed resin (VarseoSmile Crown^{plus}) or veneering composite resins (GRADIA PLUS; VITA VM LC flow). Surfaces underwent varnishing, coating, polishing or remain untreated. Conversion rate (DC), surface roughness (SR), Martens parameter, flexural strength (FS), and 3-body wear (3BW) were determined (n=12). Statistical analysis was performed using Mann-Whitney-U, Kruskal-Wallis, and Spearman correlation tests (α=.05).

Results. After polishing, the 3D printed resin showed higher DC, SR, and 3BW but lower Martens parameters compared with veneering composite resins ($P<.007$). After goat hair brushing, the 3D printed resin showed lower FS than VITA-VCR ($P=.043$). For the 3D printed resin, goat hair brushing or GC-Varnish reduced SR, while VITA-Varnish showed the lowest 3BW ($P<.045$). For both veneering composite resins, goat hair brushing led to low SR and 3BW and high E_{IT} and FS ($P<.043$). Silicone polishing led to low E_{IT} of the 3D printed resin and low E_{IT} and FS of GC-VCR ($P<.009$). Coating resulted in a lower E_{IT} than the untreated surface and higher 3BW than GC-Varnish ($P<.030$).

Conclusions. The 3D printed resin showed higher DC, SR, 3BW and lower HM, E_{IT}, and FS values than the veneering composite resins. Polishing with a goat hair brush can be recommended for all tested materials. For the 3D printed resin, varnishing presents a promising alternative with regard to SR and 3BW. Silicone polishing and coating cannot be recommended. (J Prosthet Dent 2024;132:466.e1-e9)

The mechanical properties of 3-dimensionally (3D) printed resins for definitive fixed dental prostheses (FDPs), including flexural strength (FS), are acceptable for single-unit FDPs.[1] However, shear bond strength and biocompatibility are lower[2,3] compared with subtractively manufactured FDPs made from polymer-infiltrated ceramic, composite resin, or polymethyl methacrylate. For definitive FDPs, long-lasting color stability, low surface roughness, high mechanical properties, abrasion resistance,[4,5] and a high degree of conversion (DC)[6,7] associated with a material's biocompatibility[8–11] are required. The restoration's surface should be smooth and homogeneous, with the surface roughness (SR) not exceeding

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[1] Materials provided by BEGO GmbH Co KG, GC EUROPE NV, VITA Zahnfabrik H. Rauter GmbH Co KG, and Sirius Ceramics.

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Clinical Implications

The 3D printed resins for definitive restorations currently on the dental market exhibit weaker chemical and mechanical properties than traditional veneering composite resins. Therefore, surface treatments like polishing with goat hair brushing are essential to enhance their material properties.

0.2 µm to prevent plaque accumulation[12] while preventing wear of the restoration and antagonist.[13] Previous investigations have reported that resins are prone to color instability and discoloration,[14,15] with the discoloration rate of polymer-based materials depending on the material's composition, postprocessing, and surface treatment.[16] Surface treatment by polishing, varnishing, or coating has been suggested to improve the surface quality of polymer-based restorations.[4,12,17] Polishing is an established process, with improvements in esthetic appearance, microbial adherence to the material's surface, color stability, and mechanical properties being reported.[12,17–25] The application of a polymerizable and low-viscosity glaze material may also enhance the surface quality of dental restorative materials and improve their properties.[26–28] Previous investigations have examined the surface roughness and color stability of composite resins after the application of varnishes, reporting a smoother and more color-stable surface than with conventional polishing.[27,29,30] However, studies investigating varnishing or coating on 3D printed restorations are sparse.[12,17,31,32] Therefore, the aim of the present study was to evaluate different surface treatments on the chemical and mechanical properties of a 3D printed resin and compare these results with 2 veneering composite resins, conventional materials with a history of long-term use.[7,33] The null hypotheses were that neither the material nor the surface treatment would affect the DC, SR, Martens parameters, FS, or material loss after 3-body wear (3BW).

MATERIAL AND METHODS

Disk-shaped specimens (Ø12×1.2 ±0.2 mm) were manufactured to determine the DC, SR, Martens hardness (HM), elastic indentation modulus (E_{IT}), and FS (n=12); rectangular specimens (12×10×4 mm) were examined for 3BW (n=12) (Fig. 1). Three-dimensionally printed specimens (N=144) manufactured from photopolymerizing resin (VarseoSmile Crown^{plus}; BEGO GmbH Co KG) (Table 1) using a 3D printer (Varseo XS; BEGO GmbH Co KG) were cleaned in an ultrasonic bath (SONOREX DIGITEC DT 31H; BANDELIN electronic GmbH Co KG) with 96% ethanol (Otto Fischar GmbH Co KG) for 3 and 2 minutes and polymerized for 2×1500 flashes (Otoflash G171; NK Optik GmbH).

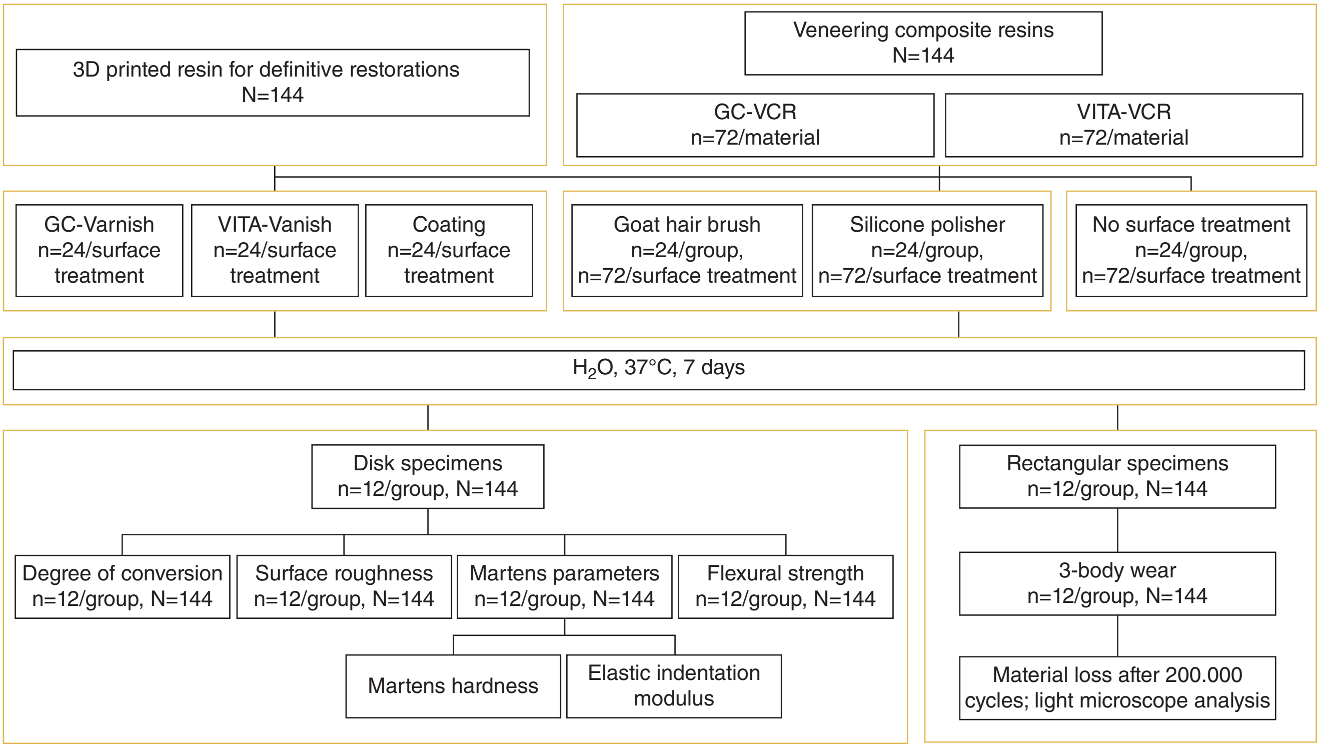

Figure 1. Study design.

Table 1. Material group, name, shade, LOT number, designation, manufacturer, and composition of materials used

Material Group	Product	Shade	LOT Number	Designation	Manufacturer	Composition (According to the Manufacturers)
3D printed resin	VarseoSmile Crown^{plus}	A1 Dentin	600311	3D printed resin	BEGO GmbH Co KG	Esterification products of 4,4′-isopropylidendiphenol Ethoxylated and 2-methylprop-2-enoic acid Silicon oxide Methylbenzoylformate Diphenyl (2,4,6-trimethylbenzoyl) phosphine oxide Inorganic fillers (30 to 50 wt%)
Veneering composite resin	GRADIA PLUS	HB-EL	211102A	GC-VCR	GC EUROPE NV	Barium glass (65 to 75%) Methacrylate monomer (15 to 25%) Silica (1 to 5%) Pigment (Trace) Initiator (Trace)
	VITA VM LC flow	ENAMEL	89760 98571	VITA-VCR	VITA Zahnfabrik H. Rauter GmbH Co KG	Multifunctional (meth-)acrylates (32 to 41%) Mixed oxides (silicon oxide, zirconia) (55 to 68%) Initiators and stabilizers (< 3%) Pigments (< 1%)
Surface varnisher	OPTIGLAZE color	Clear HV	2201131	GC-Varnish	GC EUROPE NV	Methylmethacrylate (30%) Multifunctional acrylate (60%) Silica (10%) Photoinitiator (Trace)
	VITA AKZENT LC	GLAZE	89830	VITA-Varnish	VITA Zahnfabrik H. Rauter GmbH Co KG	Methyl methacrylate and multifunctional methacrylates (30 to 40%) Urethane(meth-)acrylates (40 to 60%) Silicon oxide (8 to 11%) Ethyl-phenyl (2,4,6-trimethylbenzoyl) phosphinate (2 to 6%) Pigments < 2% other < 1%

Veneering composite resins (GRADIA PLUS; GC EUROPE NV [GC-VCR] and VITA VM LC flow; VITA Zahnfabrik H. Rauter GmbH Co KG [VITA-VCR]) (N=144, n=72) were polymerized in 2-mm increments in silicone molds by 1 operator (M.L.) according to the manufacturer's instructions (Table 2) and ground to identical dimensions using 30-µm-grit silicon carbide abrasive paper (Struers Waterproof Silicon Carbide Paper FEPA P#500; Struers GmbH). For experimental groups, specimens were treated using 2 different varnishes (OPTIGLAZE color; GC EUROPE NV [GC-Varnish], VITA AKZENT LC; VITA Zahnfabrik H. Rauter GmbH Co KG [VITA-Varnish]), coated with unpolymerized resin (VarseoSmile Crown^{plus}; BEGO GmbH Co KG), or polished with a goat hair brush (Rundbürste, Ziegenhaar, weiß; bredent GmbH Co KG) and polishing paste (Abraso Starglanz; bredent GmbH Co KG), or a silicone polisher (test polisher; Sirius Ceramics). Before varnishing or coating, the specimens were airborne-particle abraded (varnished groups: 50-µm alumina powder, 100 kPa, coated groups: 110-µm alumina powder, 150 kPa, distance: 10 mm, angle: 45 degrees, Basic quattro; Renfert GmbH), varnished or coated, and then light polymerized. The 3D printed resin and veneering composite resins that did not undergo surface treatment acted as controls. Specimens were stored in distilled water at 37 °C for 7 days in an incubator (HeraCell 150; Kulzer GmbH).

For measuring the DC, the Raman scattering of the unpolymerized resins ($R_{unpolymerized}$) and the polymerized specimens ($R_{polymerized}$) were recorded using a Raman spectrophotometer (inVia Qontor; Renishaw GmbH). The specimens were irradiated at a wavelength of 785 nm and a spectral resolution of 1 cm^{-1} with a diode laser through a ×50 microscope objective using a laser power of 100%, irradiation time of 10 seconds, and

Table 2. Technology, wavelength, polymerization time, and manufacturer of postpolymerization devices used

Name	Technology	Wavelength	Polymerization Time	Manufacturer
Otoflash G171	Flashlight, nitrogen atmosphere	Spectral range 300 to 700 nm Peaks at 480 nm and 530 nm	2×1500 flashes	NK Optik GmbH
Labolight DUO	Light-emitting diode (LED)	Spectral range 380 to 510 nm Peaks at 395 nm and 475 nm	GC-VCR: 2×3 min GC-Varnish: 90 s	GC EUROPE NV
bre.Lux PowerUnit 2	Light-emitting diode (LED)	Spectral range 370 to 500 nm	VITA-VCR: 2×360 s VITA-Varnish: 90 s	bredent GmbH Co KG

10 accumulations per run. Raman spectra were collected in the range of 1500 to 2000 cm^{-1} and analyzed by curve-fitting (WiRE 4.2 software; Renishaw GmbH). The peak heights were recorded at 1610 cm^{-1} and 1640 cm^{-1}. DC was calculated: DC (%)=100×[1 − $R_{polymerized}/R_{unpolymerized}$], with R=band height at 1640 cm^{-1}/band height at 1610 cm^{-1}. SR was measured using a contact profilometer (MarSurf M 400; Mahr GmbH) with 3 horizontal and 3 vertical measurements with a length of 6 mm and track spacing of 0.25 mm.

The data of the arithmetic mean roughness (R_a) were recorded. To investigate HM and E_{IT}, a universal hardness testing machine (ZHU 0.2; ZwickRoell GmbH Co KG) was used.[34] The apex of a diamond pyramid was pressed into the specimen surface using a load of 9.8 N for 10 seconds. HM and E_{IT} were calculated on the average of 3 measurements (testX-pert V12.3 Master; ZwickRoell GmbH Co KG): $HM = \frac{F}{A_s(h)}$, with HM: Martens hardness [N/mm^2], F: test force [N], A_s(h): area of the diamond indenter pyramid (26.43 for Vickers) penetrating the surface at distance h from its tip [mm^2]; $E_{IT} = (1 - v_s^2) \left(\frac{\sqrt[2]{A_p(h_c)}}{\sqrt{\pi S}} - \frac{(1 - v_i^2)}{E_i}\right)^{-1}$, with E_{IT}: elastic indentation modulus [kN/mm^2], $A_p(h_c)$: projected contact area under load [N/mm^2], v_s and v_i: Poisson ratio of specimen (0.3) and indenter, E_i: indenter's elastic modulus [N/mm^2], S: contact stiffness determined from the force removal curve. FS was determined according to DIN EN ISO 6872:2019 using the universal testing machine (Z010; ZwickRoell GmbH Co KG). Disk-shaped specimens were placed on 3 Ø3.2-mm steel balls forming an equilateral triangle with an edge length of 10 mm and a ball support circle of 120 degrees. With a crosshead speed of 1 mm/minute, load was applied on each specimen with a ⌀1.4-mm centered piston until failure. The following formula was used to calculate FS: $\sigma = -0.2387\,P\,(X - Y)/b^2$, with σ: biaxial flexural strength [MPa], P: fracture load [N], b: thickness of the specimen [mm], $X = (1 + v)\ln(r_2/r_3)^2 + [(1 - v)/2]\,(r_2/r_3)^2$, and $Y = (1 + v)\,[1 + \ln(r_1/r_3)^2] + (1 - v)\,(r_1/r_3)^2$, where v: Poisson ratio, r_1, r_2, and r_3: radius of the ball support, loaded area, and tested specimen [mm], b and r_3 were measured with a digital micrometer screw (Mitutoyo IP65; Mitutoyo) to a precision of 0.01 mm.

For 3BW, specimen wheels were ground using a lathe and a wear-in of 10 000 cycles (ACTA 3; SD Mechatronik GmbH). The abrasive slurry was mixed using 150 g ground millet (senegal millet; Dehner Gartencenter GmbH), 220 mL deionized water, and 0.5 g sodium azide (Merck KGaA). The specimen and antagonist stainless-steel wheel rotated in opposing directions with a 15% difference in circumferential speed, a contact pressure of 15 N, and an angular frequency of the specimen wheel of 1 Hz. The speed of the antagonistic wheel was calculated as previously.[35,36] The 3BW simulation was carried out for 200 000 cycles, with the abrasive medium being renewed every 50 000 cycles. A laser scanner (LAS-20; SD Mechatronik GmbH), set to a horizontal resolution of 40 µm and a vertical resolution of 0.8 µm, scanned the specimen wheels before and after simulation. Data were imported (GOM Inspect 2019; GOM GmbH) and volume loss was analyzed. The sample size of n=12 per group was based on similar previous studies that reported significant differences between groups for a similar or even smaller sample size.[7,12,36,37]

All data were descriptively analyzed. Normal distribution was tested with the Kolmogorov-Smirnov test. For nonparametric analyses, Mann-Whitney U, Kruskal-Wallis, and Spearman correlation tests were performed (α=.05) A statistical software program (IBM SPSS Statistics, v29.0; IBM Corp) was used for the analyses.

RESULTS

Nonparametric analyses were performed as all groups deviated from the normal distribution. The 3D printed resin showed a higher DC compared with GC-VCR (P<.001). For the 3D printed resin, silicone polishing or goat hair brushing led to higher DC than no treatment or application of VITA-Varnish (P<.011). Silicone polishing resulted in a higher DC than coating (P=.001). The application of VITA-Varnish showed the lowest DC (P<.001) (Fig. 2). After goat hair brushing or silicone polishing, veneering composite resins showed lower SR than the 3D printed resin (P<.001).

For the 3D printed resin, GC-Varnish generated lower SR than coating, no surface treatment, or polishing with a silicone polisher (P<.045). Goat hair brushing, VITA-Varnish, or coating resulted in lower SR compared with silicone polishing (P<.019). Goat hair brushing led to lower SR than no surface treatment (P=.006). Veneering composite resins polished with a goat hair brush led to the lowest SR, followed by silicone polishing, while no surface treatment showed the highest SR (P<.002) (Table 3). After goat hair brushing and no surface treatment, both veneering composite resins showed higher HM than the 3D printed resin (P<.006). After silicone polishing, GC-VCR showed the highest HM, followed by VITA-VCR and the 3D printed resin (P<.007).

For all surface treatments, the 3D printed resin showed lower E_{IT} compared with both veneering composite resins (P<.002). For the 3D printed resin, no treatment led to higher E_{IT} than the application of GC- and VITA-Varnish, coating, or silicone polishing (P<.030). The use of VITA-Varnish, coating, or polishing with a goat hair brush resulted in higher E_{IT} than silicone polishing (P<.009). For GC-VCR, silicone polishing resulted in the lowest E_{IT} (P<.001). For VITA-VCR,

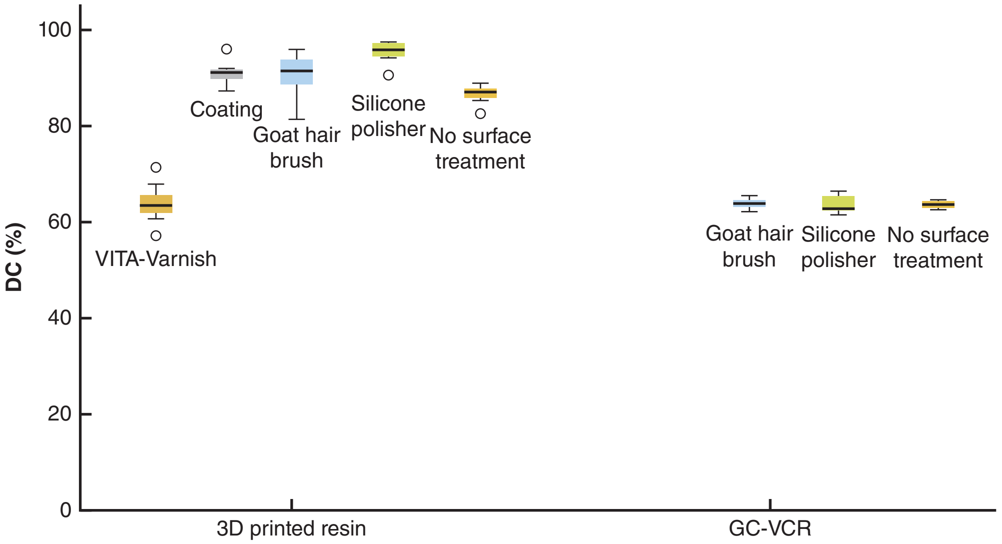

Figure 2. Degree of conversion (DC) as a percentage.

Table 3. Descriptive statistics of surface roughness R_a (µm), including median and interquartile range (IQR)

	3D Printed Resin	GC-VCR	VITA-VCR
GC-Varnish	0.303 (0.117)^{a}		
VITA-Varnish	0.550 (0.185)^{abc}		
Coating	0.558 (0.103)*^{bc}		
Goat hair brush	0.371 (0.038)^{abB}	0.152 (0.011)^{aA}	0.136 (0.048)^{aA}
Silicone polisher	0.781 (0.103)^{dB}	0.368 (0.057)^{bA}	0.479 (0.059)^{bA}
No surface treatment	0.615 (0.078)^{cdA}	0.681 (0.091)^{cA}	0.699 (0.099)^{cA}

*Deviation from normal distribution.

Lowercase letters indicate differences between surface treatments within one material group; Uppercase letters indicate differences between materials within one surface treatment.

treatment with a goat hair brush led to the highest E_{IT} ($P<.043$) (Fig. 3). After goat hair brushing and silicone polishing, VITA-VCR showed higher FS than GC-VCR ($P<.001$). After goat hair brushing, VITA-VCR showed higher FS than the 3D printed resin ($P=.043$). For GC-VCR, silicone polishing showed the lowest FS ($P\leq.001$). For VITA-VCR, goat hair brushing led to the highest FS ($P<.001$) (Table 4).

With the spikey millet leading to inhomogeneous surfaces partly characterized by deep pits (Fig. 4), volumetric material losses are presented for 3BW (Fig. 5). After goat hair brushing or silicone polishing, both veneering composite resins showed lower 3BW than the 3D printed resin ($P<.002$). After goat hair brushing, GC-VCR led to lower 3BW than VITA-VCR ($P=.006$). For the 3D printed resin, the application of VITA-Varnish resulted in the lowest 3BW ($P<.001$), and the application of GC-Varnish led to lower 3BW than the coating technique ($P=.011$). For GC-VCR, the surface treatment with a goat hair brush showed the lowest 3BW ($P<.001$). For VITA-VCR, treatment with a silicone polisher led to lower 3BW than no surface treatment ($P=.006$). The parameters tested showed the following correlations: a positive association between HM and E_{IT} ($\rho=.841$, $P<.001$), SR and DC ($\rho=.463$, $P=.023$), DC and 3BW ($\rho=.594$, $P<.001$) and a negative association between the Martens parameters and DC ($\rho=-.504/-.595$, $P<.001$) or 3BW ($\rho=-.275/-.307$, $P<.001$).

DISCUSSION

The aim of this investigation was to evaluate different surface treatments on the chemical and mechanical properties of a 3D printed resin and 2 veneering composite resins. While the surface treatment had no influence on HM, the hypotheses that the material or the surface treatment would not affect the DC, SR, Martens parameters, FS, or 3BW was rejected. The 3D printed resin showed a high DC (84.7 to 95.9%), indicating low residual monomer content and enhanced biocompatibility.[8,9] These findings were consistent with those of previous investigations examining 3D printed resins for interim restorations and denture bases.[6,10] The DC of the 3D printed resin was only compared with GC-VCR, as no peak at the aromatic C=C stretching mode could be detected for VITA-VCR. Consistent with a previous study,[7] the DC (62.6 to 64.5%) of GC-VCR were lower than those of the 3D printed resin, attributed to the

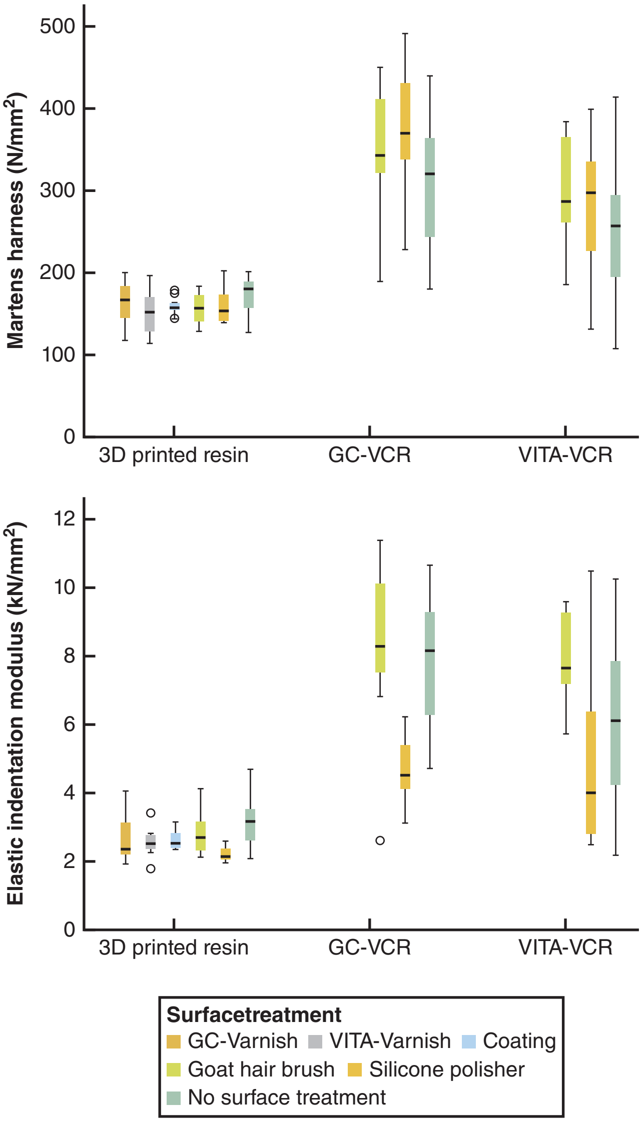

Figure 3. A, Martens hardness (N/mm^2), B, Elastic indentation modulus (kN/mm^2).

Table 4. Descriptive statistics of flexural strength FS (MPa), including median and interquartile range (IQR)

	3D Printed Resin	GC-VCR	VITA-VCR
GC-Varnish	116 (62.5)^{a}		
VITA-Varnish	100 (34.6)^{a}		
Coating	92.1 (45.8)^{a}		
Goat hair brush	122 (47.9)^{aA}	103 (12.0)^{bA}	145 (15.8)^{bB}
Silicone polisher	67.3 (79.2)^{*aAB}	85.5 (17.2)^{aA}	110 (28.5)^{aB}
No surface treatment	103 (34.6)^{aA}	103 (13.0)^{bA}	121 (24.8)^{aA}

*Deviation from normal distribution

Lowercase letters indicate differences between surface treatments within one material group; Uppercase letters indicate differences between materials within one surface treatment

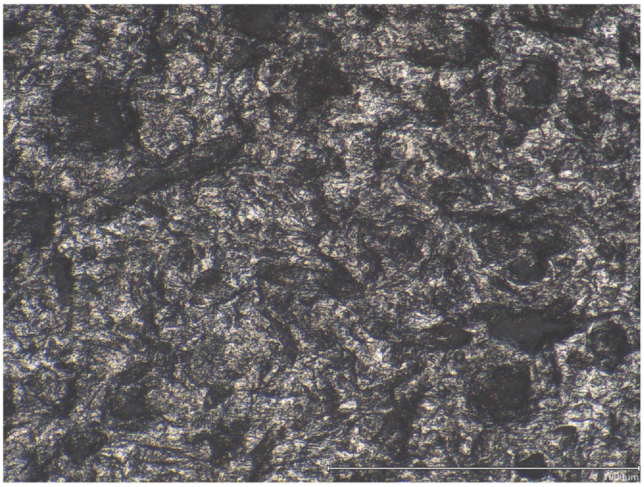

Figure 4. Inhomogeneous surface with deep pits of 3D printed resin after 200 000 cycles of 3-body wear (original magnification ×150, VHX-970F; KEYENCE).

higher filler content leading to fewer monomers undergoing polymerization. While resulting in a reduced DC, the higher filler content translated into both veneering composite resins presenting higher Martens parameters and is mirrored in the negative correlation. After polishing, the 3D printed resin showed higher SR than the veneering composite resins, indicating that traditional polishing protocols are not matched to novel 3D printed resins. With goat hair brushed veneering composite resins being the only groups that showed SR below 0.2 µm, the use of the 3D printed resin for definitive restorations cannot be recommended until an improved surface treatment has been developed. After goat hair brushing, VITA-VCR showed higher FS than the 3D printed resin. Polishing did thus not only enhance the surface properties by reducing SR but increased the mechanical properties by presumably eliminating surface faults that may act as fracture origins.[22] From a clinical standpoint, for the complete and partial veneering of metal frameworks, composite resins face high masticatory forces and considerable stress and require durable flexural strength to prevent fractures.[5] After polishing, VITA-VCR showed higher FS than GC-VCR. The lower maximum filler content in VITA-VCR may increase the flexibility and result in a higher resistance to fracture. The lower filler content in VITA-VCR could explain the lower HM after silicone polishing and the higher 3BW after goat hair brushing compared with GC-VCR. Furthermore, polished veneering composite resins presented lower 3BW than the 3D printed resin. This finding was consistent with the assumption that low surface hardness results in higher abrasion[35] and was confirmed by the negative correlation between Martens parameters and 3BW. Contrary to expectations, the microscopic analyses after 3BW did not show characteristic grinding marks,[35,36] and no differences could be detected among the 3 materials for SR, FS, or 3BW if no surface treatment had been performed, underlining the importance of tailoring the surface treatment to a

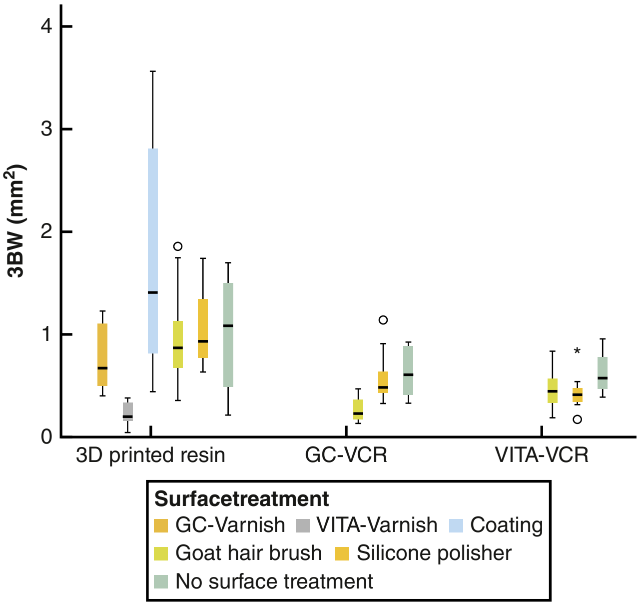

Figure 5. Three-body wear (3BW) (mm^3).

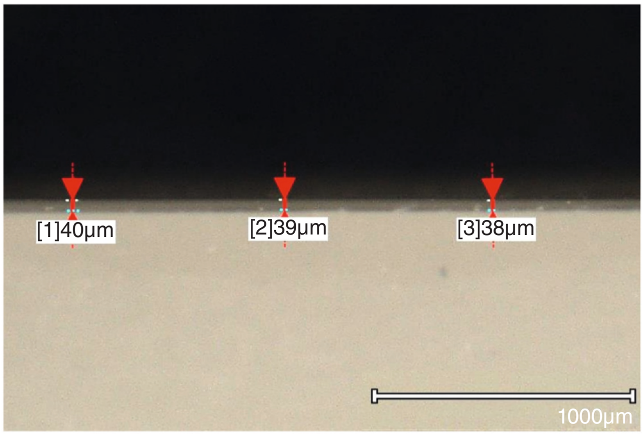

Figure 6. Layer thickness of VITA-Varnish after 200 000 cycles of three-body wear (original magnification ×50) (VHX-970F; KEYENCE).

resin's mechanical properties. For the 3D printed resin, polishing resulted in a higher DC than observed after no surface treatment, which may be explained by the removal of the oxygen inhibition layer. The application of VITA-Varnish led to lower DC, which could either be related to insufficient polymerization or to the material's composition. Further research on the polymerization of varnishes is warranted, especially as the Raman spectra for GC-Varnish showed no detectable peaks.

For the 3D printed resin, surface treatment with a goat hair brush or GC-Varnish resulted in a reduced SR in comparison with no surface treatment. Different varnishes for polymer-based materials have been reported to reduce SR, in parts even under 0.2 μm,[12,28] by decreasing surface porosities through the infiltration and refilling of micropores.[17] As silicone polishing, VITA-Varnish, and coating resulted in values that were similar to without surface treatment, these protocols cannot be recommended. For the 2 veneering composite resins, both polishing protocols led to reduced SR. Goat hair brushed veneering composite resins were the only groups that presented SR below the 0.2-μm threshold, where bacterial adhesion can be prevented.[12] This favorable outcome after goat hair brushing has been reported for interim restoration materials, where a goat hair brush generated a smoother, more homogenous surface than a silicone polisher.[23] For the 3D printed resin, GC-Varnish presents a promising alternative protocol. Polishing the 3D printed resin with a silicone polisher, applying varnishes, or coating resulted in reduced E_{IT}, suggesting reduced mechanical properties. GC-VCR also showed lower E_{IT} and FS after silicone polishing. Silicone polishers can reduce a resin's mechanical properties by creating microcracks on the material surface associated with increased temperatures.[24,25] The lower E_{IT} after coating of the 3D printed resin suggests issues with polymerization of this additional layer. Goat hair brushing yielded high E_{IT} and comparable or improved FS for both veneering composite resins, making it a recommended surface treatment. For 3BW, the application of VITA-Varnish resulted in the lowest abrasion. The layer thickness of the 2 varnishes determined in pretests ranged between 30 and 40 μm. With VITA-Varnish showing a mean vertical loss of 4 μm, 3BW only took place in the varnished layer, which acted as a protective coating, a finding supported by the microscopic analyses (Fig. 6). The higher abrasion for the coated specimens as well as their large scattering of 3BW results could indicate insufficient polymerization of the coating. The polymerization unit (Otoflash G171; NK Optik GmbH) used may, in contrast with polymerization during 3D printing, be unable to completely polymerize the liquid resin.[11] Polishing with a goat hair brush resulted in the lowest 3BW for GC-VCR, while the 2 polishing protocols showed comparable results for VITA-VCR. The smoother, more homogenous surface seems to possess a higher resistance to potential surface breakdowns[22] caused by the millet. The goat hair brush can thus be recommended to decrease 3BW for both veneering composite resins.

The limitations of this investigation included the number of examined materials and surface treatments and that no a priori power analysis was performed. Post hoc power analyses compared the coated 3D printed resin with the goat hair brushed veneering composite resins. The power of a 2-sided, 2-sample *t* test exceeded 96% for a sample size of 12 specimens, with an observed effect and pooled standard deviation of 24.8% and 1.7% (DC), 0.381 and 0.046 μm (SR), 142 and 46.2 N/mm^2

(HM), 5.43 and 0.907 kN/mm^2 (E_{IT}), 45.1 and 23.7 MPa (FS), 1.27 and 0.790 mm^3 (3BW). The group selection was based on their practical significance, with polished veneering composite resins representing conventional materials with a long-term record[7,33] and coating representing an easily implementable surface treatment for 3D printed resins requiring no further purchases and thus having the potential for widespread use. Future studies should focus on the polymerization of varnishes, as well as the esthetic properties connected to various surface treatments.

CONCLUSIONS

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

1. The 3D printed resin showed higher DC, indicating enhanced biocompatibility along with higher SR and 3BW after polishing and lower HM, E_{IT}, and FS compared with veneering composite resins. VITA-VCR showed higher FS after polishing, lower HM after silicone polishing, and higher 3BW after goat hair brushing than GC-VCR.
2. For the 3D printed resin, polishing resulted in a higher DC than observed after no surface treatment. VITA-Varnish showed a lower DC that was in the same range as observed for GC-VCR. Polishing with a goat hair brush or applying GC-Varnish resulted in a reduced SR, while VITA-Varnish showed the lowest 3BW. For the 3D printed resin, varnishing thus presents a promising alternative with regard to SR and 3BW. For both veneering composite resins, polishing with a goat hair brush led to a reduced SR, high E_{IT} and FS, and low 3BW, underscoring the significance of customized surface treatments. Polishing with a goat hair brush can be recommended for 3D printed resins and veneering composite resins. Silicone polishing led to low E_{IT} of the 3D printed resin and low E_{IT} and FS of GC-VCR. Coating resulted in a lower E_{IT} than observed for the untreated surface and higher 3BW than reported for GC-Varnish. Silicone polishing and coating can therefore not be recommended.

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