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Comparative evaluation of polishing protocols on the surface roughness of additively manufactured resin

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Abstract
Aim: To compare the effect of different chairside polishing protocols on the surface roughness of a permanent crown resin fabricated by additive manufacturing.
Materials and Methods: Seventy-five square specimens (10 × 10 × 2 mm) were 3D-printed in Saremco print CROWNTEC (A2) using a Masked Stereolithography (MSLA) printer (Phrozen Sonic Mini 4K). After standardized post-processing, specimens were randomly allocated to five polishing groups (n = 15): (a) Eve Diacomp paste polishing paste; (b) Sof-Lex XT polishing discs; (c) Universal polishing paste; (d) Intensive Unigloss paste; and (e) Intensive Unigloss polisher. Protocols were performed per manufacturers recommendations, with a handpiece at 5,000-7,000 rpm, bilateral 15 s, without pressure. Surface roughness (Ra) was measured using a contact profilometer. Representative surfaces were qualitatively imaged with field-emission scanning electron microscopy (FE-SEM). Data were analyzed in SPSS v23. Normality was assessed by Shapiro-Wilk; between group differences in non-normal data were tested with Kruskal-Wallis and Dunn multiple comparisons ($\alpha = 0.05$).
Results: Median Ra differed significantly among polishing protocols ($H = 21.86$, $p < 0.001$). The Eve Diacomp paste polishing paste yielded the lowest median Ra (0.310 µm), while the Sof-Lex XT disc group showed the highest (0.840 µm). Post-hoc comparisons indicated Eve paste produced significantly smoother surfaces than each of the other four systems; the other four did not significantly differ from one another. FE-SEM images corroborated profilometric findings, with Eve-polished surfaces displaying more homogenized topography and fewer directional grooves.
Conclusions: A one-step diamond polishing paste achieved lower surface roughness than multi-step discs and the tested rubberized polishing alternatives. Given the outcome of smoother finishes and procedural simplicity, one-step diamond polishing pastes may be preferred for rapid finishing of printed resin restorations.

Keywords: Polishing, surface roughness, 3D printing, additive manufacturing, permanent crown resin

1. Introduction
Additive manufacturing (AM) has rapidly expanded into prosthodontics, enabling the fabrication of permanent and interim restorations, occlusal splints, surgical guides, and custom trays with increasingly refined material chemistries and printer optics [1]. Within AM, vat-photopolymerization (VP) which includes Stereolithography (SLA), Digital Light Processing (DLP) is particularly relevant for polymeric dental resins because it supports high resolution and reproducible layer stacking [2, 3]. The emergence of permanent crown resins purpose-built for AM has accelerated adoption for definitive or long-term provisional indications in specific clinical workflows [4].
A critical determinant of clinical performance for polymeric restorations is surface texture. Surface roughness influences plaque retention, stain susceptibility, wear patterns and optical appearance [5]. Beyond esthetics and hygiene, surface finish also interacts with antagonist wear and the restoration's long-term gloss retention. Although subtractive CAD-CAM blocks and direct light-cured composites have been studied extensively with respect to finishing/polishing regimens, fewer controlled comparisons have focused on additively manufactured permanent resins [6, 7, 8].
Chairside polishing options span multi-step abrasive discs, rubberized silicone impregnated with abrasives, and one-step diamond pastes [6, 9]. Each system differs in abrasive size distribution, binder elasticity, and contact mechanics, which may interact with the layer-wise

morphology and monomer/oligomer network of printed resins. It is plausible that the optimal protocol for a milled composite or a light-cured nanohybrid does not translate directly to a printed permanent resin that exhibits a different microtopography after post-curing [10, 11].

The aim of this in-vitro study was to investigate the effect of different polishing techniques on the surface roughness of a 3D-printed permanent crown resin. The Null hypothesis was that there is no difference in surface roughness among polishing protocols.

2. Materials and Methods

2.1 Study design and sample size

This experimental, polishing protocol was design with 75 printed specimens (n = 15 per group). The group size was selected to allow comparison of five independent groups with sufficient power to detect a moderate effect size at $\alpha = 0.05$.

2.2 Specimen fabrication and post-processing

A permanent crown resin (Saremco print CROWNTEC; Saremco Dental AG, Switzerland; shade A2) was used. Specimens were CAD-modeled as 10 × 10 mm squares, 2 mm thick, exported as STL (Standard triangle language), and printed with an MSLA printer (Phrozen Sonic Mini 4K, Phrozen Technology, Taiwan) using manufacturer recommended parameters for layer thickness of 50µm and exposure of 405 nm UV (Ultra violet) light.

Immediately after printing, specimens were cleaned in 96% isopropyl alcohol in an ultrasonic bath for 3 min and air dried. Post-curing was performed for 5 min in a UV curing unit (Anycubic Wash & Cure 2.0, China). To standardize baseline surfaces prior to polishing, all samples were sequentially wet ground with silicon carbide papers (600, 800, 1000, 1200-grit; 30 s each) and then uniformly air-abraded (Easy Blast; 110 µm Al_2O_3; 2.5 bar). Schematic representation of the experimental workflow: specimen design and 3D printing, post-processing, allocation to polishing protocols, profilometric measurement (Ra), FE-SEM (Field-emission scanning electron microscop) imaging and statistical analysis are presented in Fig.1.

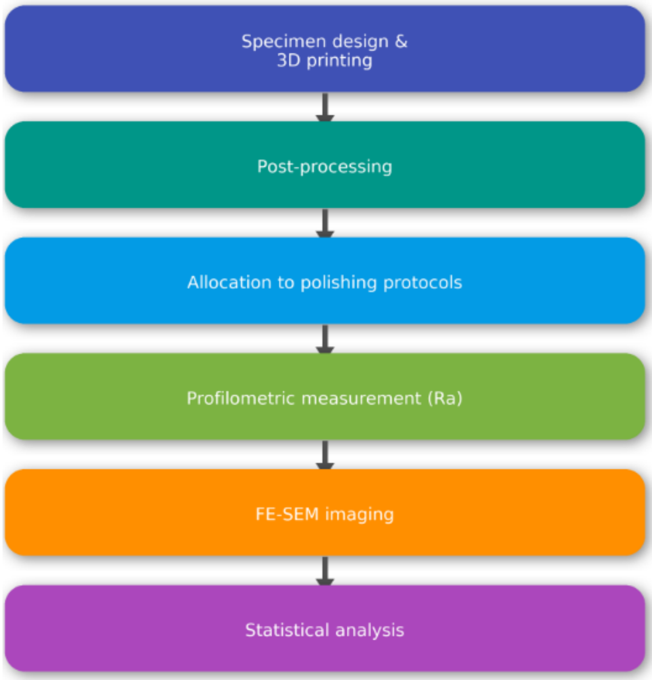

Fig 1: Schematic overview of the study workflow

2.3 Polishing protocols and group allocation

Specimens were randomly assigned to one of five polishing groups (n = 15 per group) presented in the Table 1.

Table 1: Materials for surface polishing of the printed resin: product details and compositions

Material group	Commercial name	Manufacturer	Composition	Lot No.
One-step paste	Eve Diacomp paste paste	EVE Ernst Vetter, Keltern, Germany	Extra fine diamond grit	432194
Multi-step disc	Sof-Lex XT disc	3M ESPE, St. Paul, MN, USA	Abrasive discs (Dark orange, medium orange, Light orange, Yellow)	NF 32134
One-step paste	Universal paste	Ivoclar Vivadent, Schaan, Liechtenstein	Loose abrasives (aluminum oxide-Al2O3) in paste	Z 024C6
One-step paste	Intensive Unigloss paste	Intensiv SA, Grancia, Switzerland	Diamond grit	ACC. 09.21.20934
One-step polymer polisher	Intensive Unigloss polisher	Intensiv SA, Grancia, Switzerland	Ultra fine diamonds	801901

All protocols were executed per the manufacturer's recommendations. To standardize effect, a single operator polished each specimen with a low-speed handpiece set between 5,000-7,000 rpm, with no applied pressure, for 15 s per surface. Abrasives were changed as required to avoid loading. Eve Diacomp paste, Universal and Intensive Unigloss paste were categorized as one-step paste protocols, Intensive Unigloss polisher as a one-step rubberized polishing protocol, and Sof-Lex XT as a multi-step disc protocol.

2.4 Surface roughness measurement

Surface roughness was quantified as Ra (µm) using a contact profilometer (Taylor Hobson Surtronic 25, Leicester, UK). Each specimen received three parallel traces before polishing (Ra_0) and after the polished surface (Ra_1); the mean of the three Ra values was recorded as the specimen's Ra. Instrument calibration was verified prior to measurements. The operator performing profilometry was blinded to group allocation.

2.5 Qualitative surface imaging

Representative specimens from each group before and after polishing were sputter-coated with Ag-Pd (80/20; ~45 Å; Polaron SC7620, 15 s at ~3 Å per second) and imaged by field-emission scanning electron microscopy (FE-SEM; ZEISS Gemini 500, Carl Zeiss, Oberkochen, Germany) at 3 kV, working distance ~4.1 mm, and 100× to visualize surface features corresponding to the profilometric results.

2.6 Statistical analysis

Data analyses were conducted in IBM SPSS v23 (IBM SPSS Statistics, Armonk, NY, USA). Data distribution was screened with the Shapiro-Wilk test. Because Ra values did not meet normality assumptions across groups, between-group differences were assessed with Kruskal-Wallis (H) followed by Dunn post-hoc tests for multiple comparisons (two-tailed). The significance level was $p<0.050$.

3. Results

Surface roughness differed significantly among the five polishing protocols (Kruskal-Wallis H = 21.86, $p<0.001$). Table 2 summarizes mean ± SD and median (min-max) Ra values by group.

Table 2: Comparison of surface roughness (Ra, µm) by polishing protocol

Group	Mean ± SD	Median (Min - Max)	Test statistic	p
Eve Diacomp paste	0.408 ± 0.226	0.310 (0.200 - 0.990) a		
Sof-Lex XT disc	0.771 ± 0.339	0.840 (0.270 - 1.460) b		
Universal paste	0.744 ± 0.196	0.729 (0.357 - 1.030) b	21.86	< 0.001
Intensive Unigloss polisher	0.826 ± 0.177	0.768 (0.591 - 1.130) b		
Intensive Unigloss paste	0.837 ± 0.260	0.777 (0.441 - 1.330) b		

(Kruskal-Wallis H test. Groups not sharing a same letter differ at α = 0.05 based on Dunn post-hoc.)

The median roughness value was 0.310 for the Eve paste, 0.840 for the Sof-Lex XT disc, 0.729 for the Universal paste, 0.768 for the Intensive Unigloss polisher, and 0.777 for the Intensive Unigloss paste; the median roughness values differed significantly among the groups ($p<0.001$). Post-hoc analysis showed Eve Diacomp paste produced significantly lower Ra than each of the other four protocols Sof-Lex XT discs, Universal paste, Intensive Unigloss polisher and Intensive Unigloss paste. No statistically significant differences were detected among Sof-Lex XT discs, Universal paste, Intensive Unigloss polisher and Intensive Unigloss paste (Fig. 2).

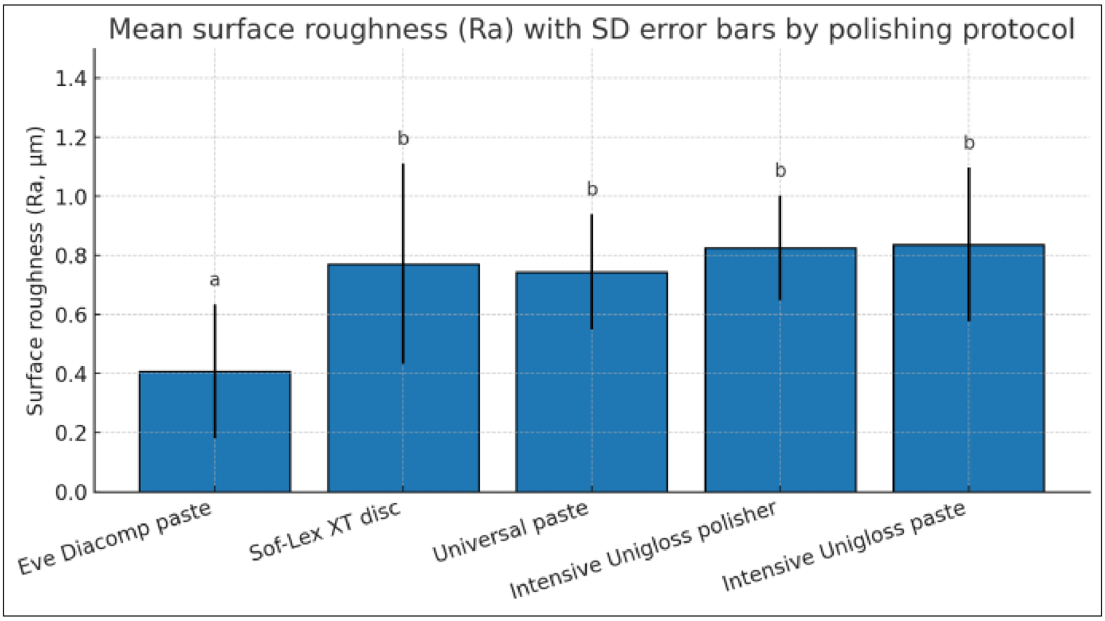

Fig 2: Box plot illustrating the distribution of surface roughness (Ra) across groups

Surface morphology was examined before and after polishing protcols by FE-SEM at 40×, and representative micrographs are shown in Figure 3. FE-SEM images of Eve Diacomp paste polished specimens exhibited a more uniform, homogenized surface with fewer directional scratches (Fig. 3 (A)(B)). In contrast, the Sof-Lex XT disc group showed discernible track marks consistent with multi-step abrasive polishing (Fir. 3 (G)(H)), and the Intensive Unigloss polishing group displayed localized micro-grooves and residual nodular features (Fig. 3 (C)(D)). The Universal paste (Fig. 3 (I)(J)) and Intensive Unigloss paste (Fig. 3 (E)(F)) showed intermediate patterns, with paste mediated smoothing but persistent micro valleys consistent with their higher Ra values.

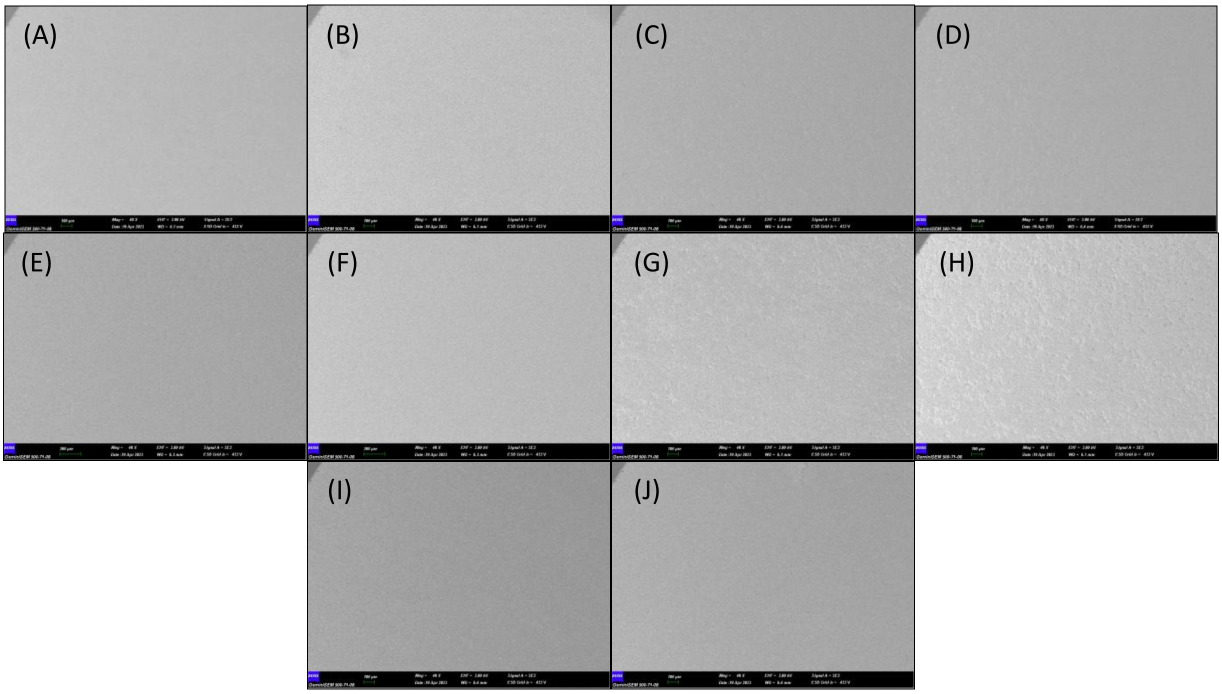

Fig 3: FE-SEM images (40×) of surface morphology before and after polishing
Before polishing: (A) Eve Diacomp paste paste, (C) Intensive Unigloss polishing, (E) Intensive Unigloss paste, (G) Sof-Lex XT discs, (I) Universal paste
After polishing: (B) Eve Diacomp paste paste, (D) Intensive Unigloss polishing, (F) Intensive Unigloss paste, (H) Sof-Lex XT discs, (J) Universal paste

4. Discussion

This in-vitro study showed that polishing protocol has a significant effect on the surface quality of an additively manufactured permanent crown resin. Among the five chairside systems tested, the one-step diamond paste (Eve Diacomp) produced the lowest surface roughness (Ra ≈ 0.31 µm), whereas the multi-step Sof-Lex XT discs yielded the highest (Ra ≈ 0.84 µm). The remaining three systems Universal paste, Intensive Unigloss polisher, and Intensive Unigloss paste exhibited intermediate range and did not differ significantly from one another. Qualitatively, FE-SEM micrographs corroborated the profilometric results: diamond-paste finishing generated a more homogenized, less directionally scratched microtopography than multi-step disc protocol or one-step rubberized polishing protocol. Together, these results reject the null hypothesis and indicate that, for the tested printed resin, a single-step diamond paste can outperform both multi-step discs and a rubberized diamond polisher in achieving a smooth finish under standardized conditions.

Printed restorative resins respond differently to finishing/polishing than milled or direct composites. Recent reviews and original studies emphasize that AM resins possess layer-wise topography and post-cure chemistries that distinguish them from subtractive blocks or light-cured nanohybrids. Della Bona *et al*. (2020) summarized stereolithography-based restorative materials and highlighted how printing parameters and post-curing shape surface features and performance. This underlying microstructure helps explain why polishing protocols optimized for milled composites do not transfer 1:1 to printed resins [12]. In a focused experimental study on a 3D-printed material for permanent use, was reported that the choice of finishing system significantly influenced both surface roughness and gloss, highlighting the material- and method-specific nature of finishing in additively manufactured resins [13].

Erturk-Avunduk *et al*. (2024) compared polishing systems across additively manufactured and conventional resin-based composites including a permanent printable resin (CrownTec) and reported that finishing system choice had significant effects on surface roughness, gloss, and color stability; broadly, diamond-containing and paste-based approaches performed favorably in achieving low Ra and acceptable optical properties [6]. Rojas-Rueda *et al*. (2025) examined 3D-printed crowns and showed that both polishing and varnish can lower roughness and improve gloss, with effects that persisted after simulated toothbrushing again reinforcing that surface-treatment selection materially changes outcomes in printed crowns [7]. Although specific materials and procedural steps vary between studies, the direction of effect is consistent with our results: paste based (diamond) protocols generally produce lower roughness than discs in additively manufactured resins.

While denture base formulations differ from permanent crown resins, studies on 3D-printed denture materials offer useful mechanistic insights. Al-Dulaijan *et al*. (2023) tested multiple chairside polishing protocols for 3D-printed acrylic denture base resins and reported that protocols meaningfully affected both Ra and Rz, with SEM images revealing layer-induced ridges and "edge stepwise" features as substrates for abrasion [11]. Those characteristic stair-steps common to VP processes make directional scratch patterns from discs more persistent unless the final stage fully removes prior tracks. This mechanism aligns with our FE-SEM observation that the disc protocol left discernible directional abrasions, whereas diamond paste produced more isotropic smoothing.

Beyond roughness, finishing modulates gloss and color in printed resins. Daghrery *et al*. (2023) showed that 3D-printed veneers exhibit roughness and gloss changes with staining/aging and that repolishing with Sof-Lex discs can partially restore surface properties, albeit with material-dependent efficacy [14]. Vichi *et al*. (2024) examined repolishing of a 3D-printed permanent resin following coffee staining and showed that selected repolishing protocols partially restored surface roughness and gloss to varying extents, reinforcing the finish sensitive behavior of printed resins optical properties [13]. Although the present study was not designed to assess optical outcomes, the finding of a lower post-polish Ra, with a one-step diamond paste supports the expectation of improved gloss retention and stain resistance, consistent with prior reports.

Traditionally, multi-step abrasive discs have been preferred for conventional composites. Recent studies on additively manufactured materials, however, suggest this protocols may not apply to printed resins. In the permanent printed material tested, disc-based protocols were not consistently superior; final roughness and gloss depended on the chosen method, including one-step diamond pastes and spiral/point polishers and no single disc sequence outperformed the others across all outcomes [13]. Similarly, in the previous study was found that system choice significantly affected surface quality, with diamond polishing options frequently producing competitive or superior finishes on printed materials [6]. Accordingly, our results that a one-step diamond paste outperformed the Sof-Lex XT disc protocol on a printed crown resin is consistent with the emerging evidence base. Current AM oriented studies repeatedly describe how layer-by-layer surfaces and post-cure network structures influence abrasion. Della Bona *et al*. (2021) highlighted the dependence of printed restorative performance on processing parameters and post-cure, which modulate resin hardness, cross-link density, and thus polishing response [12]. Building on this, Al-Dulaijan *et al*. (2023) visualized on SEM how stair-step ridges persist unless removed with a protocol capable of eliminating directional scratches rather than merely attenuating them [11]. From a mechanistic standpoint, the advantage of the diamond paste is plausible: a lubricated suspension of fine, angular diamond particles micro-cuts surface peaks while reducing directional scratching, whereas coated abrasive discs operate along a fixed path and tend to leave unidirectional striations. Some contemporary studies suggest that spiral wheels and certain multi-step systems can achieve very low Ra on printed materials when carefully executed. For example, Ali *et al*. (2025) compared LCD (Liquid crystal display) and DLP (Digital light processing) printed provisional crown and bridge resins and applied a multi-step chairside protocol coarse and silicone rubber wheel, goat-hair brush, Acrypol paste, high-lustre cotton buff, Abraso Starglanz paste and achieving post-polish Ra ≈ 0.24-0.26 µm in both printer groups meaning no significant difference, which is in the "very smooth" range for intraoral surfaces [15]. In a clinical context, Cal *et al*. (2024) presented printed permanent restorations finished chairside with medium fine grit spiral wheels (DiaCompPlus Twist, EVE), illustrating that spiral-wheel protocols can deliver clinically smooth finishes on additively manufactured resins; while primarily descriptive, the report documents the workflow and tool choice for printed definitive cases [16]. Our findings do not conflict with those reports; rather, they indicate that under standardized, time limited chairside conditions, a one-step diamond paste is the most reliable way to obtain a smooth finish on the printed resin we tested. Longer final grit times, adjusted pressures, or alternative disc designs could narrow the difference an interpretation supported by the repolishing literature, where selected disc-based steps have restored roughness and gloss after staining or simulated wear. Although many older papers anchor plaque-retention thresholds near Ra ≈ 0.2 µm, contemporary reports continue to link increased roughness with higher discoloration and lower gloss in printed materials, indicating subsequent effects on esthetic outcomes and hygienic maintenance. Daghrery *et al*. (2023) demonstrated that roughness increases tracked with gloss loss and color change after immersion aging; repolishing improved these properties [14]. In printed crowns, Rojas-Rueda *et al*. (2025) similarly found that surface treatment (polish or varnish) modulates gloss and roughness, with effects persisting after simulated toothbrushing, suggesting potential durability of the initial finishing advantage [7]. Applied clinically, achieving a lower post-polish Ra with a diamond paste may delay staining, slow gloss loss, and reduce biofilm retention; however, direct clinical trials on definitive printed crowns remain limited.

Our study has several limitations: only one resin and one printer/post-cure setup was used; only flat specimens, not anatomical crowns/onlays with margins and contours were manufactured; polishing was done by a single operator, inter-operator variability wasn't assessed; aging/wear was not performed (e.g. toothbrushing, thermocycling, staining) before/after polishing; the polishing protocol was time limited and standardized; didn't test longer/fewer steps or alternative sequences; didn't evaluate biofilm adhesion, staining behavior, or antagonist wear in functional tests, and build parameters (e.g. orientation/layer thickness) were not varied to see their effect on polishing outcomes.

Conclusion

This in-vitro study showed that polishing protocol significantly affects the surface roughness of a 3D-printed permanent crown resin, with a one-step diamond paste yielding the lowest Ra and a multi-step disc the highest. FE-SEM observations corroborated the profilometry, revealing a more uniform microtopography after diamond-paste polishing than after disc or rubberized systems. Within these limits, a one-step diamond paste appears a practical first option for finishing printed resins, while broader validation across materials, clinical geometries, and aging conditions is warranted.

Acknowledgments

Not available

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