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Evaluation of the Effects of Different Polishing Techniques on the Optical and Mechanical Properties of Resin-Based Restorative Materials

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Abstract

Background: In screw-retained implant-supported prostheses, restorative materials seal screw access holes, requiring mechanical stability and aesthetic integration. Their effectiveness depends on surface properties, influenced by polishing techniques, which impact clinical success. However, limited research has examined how different polishing protocols affect their optical and mechanical properties. This study evaluated the color change, surface roughness, and hardness of resin-based restorative materials after one-step, two-step, and multi-step polishing.

Methods: Ninety disk-shaped specimens (10 × 2 mm) were prepared from Stark Bulk Fill Composite (SBF), Zenchroma One Shade Universal Composite (ZOS), and Ruby CompNano Composite (RCN) materials. The specimens were divided into 3 subgroups based on polishing techniques (n = 10): Group 1, one-step polishing; Group 2, two-step polishing; and Group 3, multi-step polishing. Initial color, translucency, hardness, and roughness measurements were conducted, followed by repeat measurements. Data were analyzed using two-way ANOVA with a significance level of $P < .05$.

Results: Ruby CompNano exhibited the highest color stability among the tested materials, while one-step polishing resulted in more discoloration. Translucency values were unaffected by the materials and polishing procedures but decreased after coffee immersion. Multi-step polishing produced the smoothest surfaces, whereas surface roughness increased in the one- and two-step groups. Hardness values decreased across all groups after immersion, except for the OneShade Universal Composite, where multi-step polishing maintained hardness.

Conclusion: Multi-step polishing techniques were found to be more effective in minimizing surface roughness and preserving color stability and hardness, with the Ruby CompNano composite being the material with the highest color stability.

Keywords: Color change, micro hardness, optical properties, resin-based composite, surface roughness, translucency

What is already known on this topic?

- *In screw retained implant-supported prostheses, composite resins are commonly used to seal access holes, and their long-term success is influenced by surface properties.*
- *Surface roughness, hardness, and color stability of resin-based materials are crucial for maintaining esthetics and minimizing biofilm accumulation.*
- *Previous studies have evaluated polishing protocols mainly on conventional composites, with limited comparative analysis of newer bulk-fill or nanohybrid materials.*

What this study adds on this topic?

- *This study provides a comparative evaluation of three different polishing protocols (one-step, two-step, and multi-step) across three contemporary resin-based restorative materials.*
- *The findings demonstrate that multi-step polishing yields superior outcomes in terms of color stability, surface smoothness, and hardness retention, particularly for nanocomposites.*
- *It highlights the clinical relevance of selecting proper polishing techniques to optimize esthetic and mechanical outcomes in implant-supported restorations.*

INTRODUCTION

Resin-based composites are commonly utilized in dentistry due to their optical and mechanical properties, which closely resemble those of enamel and dentin. Their reparability and strong clinical performance also make resin-based composites a preferred

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choice for restorative applications. Understanding the various characteristics of resin-based composites prior to clinical application aids in selecting the most suitable restoration.[1]

The optical properties of restorative materials are influenced by finishing and polishing techniques, and over time, discoloration may occur due to intrinsic or extrinsic factors.[2] Resin matrix composition, filler amount, and filler particle size are intrinsic factors affecting discoloration, including in the resin matrix itself. Extrinsic factors are the type of coloring agent, exposure time, and compatibility of the material with the resin matrix, and coloration occurs by the absorption of these substances.[3] Discoloration of composite resins can cause both patient and clinician dissatisfaction. Therefore, the success of an aesthetic restoration also depends on the color stability of the materials used.

The degree of discoloration can be influenced by surface roughness.[4] The surface properties of restorative materials, including surface roughness, gloss, and hardness, are critical for meeting the aesthetic and functional needs of a restored tooth. Surface roughness refers to minor irregularities on the material's surface, typically resulting from the manufacturing process or inherent material properties. The surface roughness of composites impacts plaque accumulation, which in turn influences the restoration's durability and aesthetic appearance.[5] The finishing and polishing processes for resin-based composites must be carefully refined to achieve optimal aesthetics and ensure long-lasting restoration. Finishing eliminates scratches created by burs and provides a smooth surface, while polishing is the final step, minimizing surface roughness and imparting a glossy, enamel-like appearance to the restoration. An inadequately finished or polished surface, or one that remains rough, can contribute to discoloration over time.[6]

Enhancing finishing and polishing techniques effectively reduces surface roughness and enhances surface hardness.[7] In modern dentistry, a variety of finishing and polishing materials are available, including diamond burs, carbide finishing burs, ceramic diamond rotary instruments, and rubber or silicone discs embedded with aluminum oxide.[8] With numerous polishing protocols and various commercially available resin-based composites, it is essential to assess whether these materials can provide outcomes comparable to traditional composites and to identify the most suitable finishing and polishing protocols to mitigate potential drawbacks.

Surface hardness is a crucial mechanical property that plays a key role in preserving a restoration's stability and durability. Surface hardness is utilized to estimate a material's wear resistance and to assess the extent of abrasion caused by opposing teeth or other dental materials. Hardness can affect the material's clinical performance and long-term durability, and factors affecting surface hardness include polishing quality and technique, material composition, amount of filler, and aging of the material due to exposure to various beverages.[9]

The abutment screw holes of implant-supported screw-retained prostheses pose a significant aesthetic and functional challenge for prosthodontists. Although screw-retained implant prostheses offer advantages such as retrievability and predictable load distribution, the presence of an access hole remains a drawback, particularly in the anterior region where aesthetics are paramount. Currently, there is a lack of comprehensive studies investigating optimal techniques for sealing screw access holes while maintaining the long-term aesthetic and mechanical integrity of the restoration. The screw hole must be adequately closed to ensure the clinical success and longevity of the prosthesis. However, aesthetic concerns are often overlooked in favor of preserving function. Many commonly used dental restorative materials are relatively translucent, making them incapable of fully concealing the dark, underlying metal oxide layer covering the screw hole.[10]

Moreover, composite materials used for sealing screw holes can undergo discoloration over time, potentially compromising the aesthetic appearance of the prosthesis, especially in highly visible anterior restorations. Additionally, screw-retained restorations may present aesthetic limitations when the access hole is located on the facial aspect of the crown due to suboptimal implant positioning. Consequently, ensuring an aesthetically acceptable and mechanically durable restoration is critical for long-term patient satisfaction.[11,12] Given these aesthetic and mechanical challenges, evaluating the optical and mechanical properties of resin-based restorative materials used to seal screw holes is essential. This study aimed to assess the color change, surface roughness, and hardness of different resin-based restorative materials following various polishing protocols (one-step, two-step, and multi-step) and subsequent immersion in a coffee solution. The null hypothesis of this study states that neither the type of resin-based restorative material nor the polishing technique applied will have a significant effect on the optical (color change, translucency) and mechanical (surface roughness, hardness) properties of the materials.

MATERIALS AND METHODS

Since this study is an in vitro investigation that does not involve human participants, neither ethical approval nor informed consent was required. A power analysis was conducted using the G*Power software (version 3.0.10; Heinrich Heine University Düsseldorf), which indicated that a minimum of 10 samples was necessary to achieve the highest power level (power=80, α=0.05).

Sample Preparation

A 10 × 2 cm disc-shaped template was positioned within a silicone mold, with glass sheets placed on the top and bottom surfaces.[13,14] Using the resulting disc-shaped mold, composites were light activated with an LED-curing unit (Valo, Ultradent Product Inc., South Jordan, USA) (1200 mW/

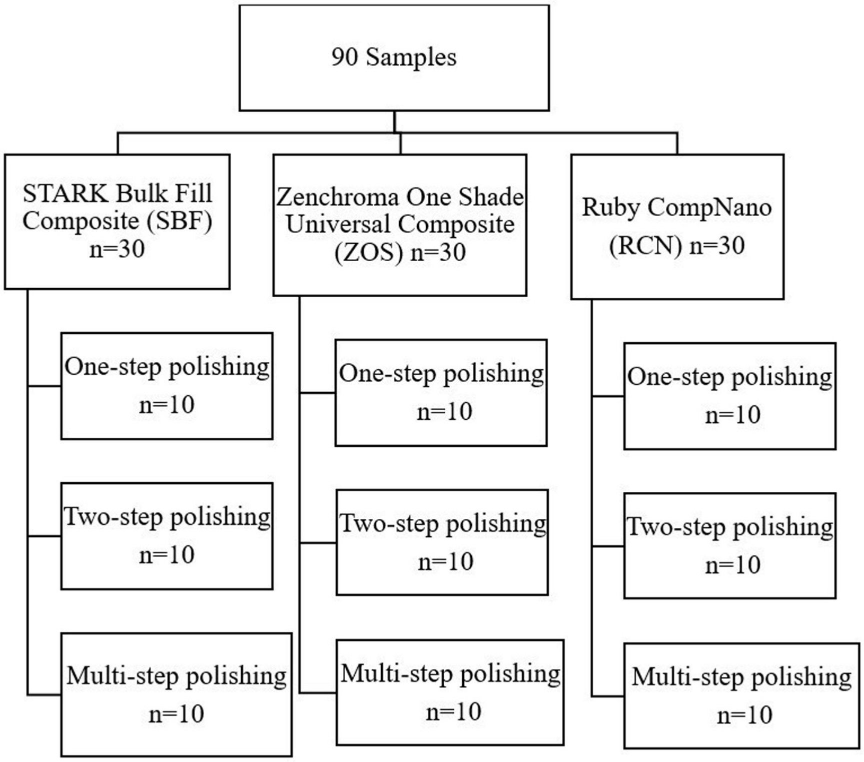


Figure 1. Study groups.

cm^2) in accordance with the manufacturer's instructions. A total of 90 discs were prepared from 3 different resin-based restorative materials, each group consisting of 30 specimens: Stark Bulk Fill Composite (President Dental, Germany) (SBF), Zenchroma One Shade Universal Composite (President Dental, Germany) (ZOS), and Ruby CompNano Composite (RC; Rubydent, Istanbul, Türkiye) (RCN). These materials were selected due to their differences in composition and filler characteristics, which may influence their response to polishing and staining. By including a bulk-fill composite (SBF), a nanohybrid composite (ZOS), and a nano-filled composite (RCN), this study aimed to evaluate how different formulations behave under various polishing protocols and staining conditions, particularly in sealing screw access holes in implant-supported restorations. The prepared samples were divided into 3 subgroups to be subjected to different polishing techniques.

Polishing Procedures

The polishing kits used in this study were selected to represent different stepwise polishing protocols commonly applied in clinical practice. The OptraGloss kit (one-step) was chosen for its simplified, time-efficient approach, Nova Twist (two-step) for its balance between efficiency and surface smoothness, and Super-Snap (multi-step) for its ability to achieve a highly refined surface through progressive polishing. These kits allow for a comparative evaluation of how different polishing steps influence the optical and mechanical properties of composite resins. Polishing procedures were performed by a single operator using a low-speed handpiece (DPS Line M4, KMD, Europe, Bilbao-Vizcaya, Spain) at the recommended rotational speed, following the manufacturer's guidelines. Each polishing system was applied for 30 seconds under water cooling, and the samples were subsequently rinsed with water for 10 seconds and air-dried. A similar protocol

Table 1. Composite Resins Used in the Study and Their Properties

Material	Organic Matrix	Filler Rate	Filler Type	Manufacturer
Stark Bulk Fill Composite	UDMA TEMDMA	0.005-40 μm	77% by weight (57% by volume) inorganic filler	President Dental, Germany
Zenchroma One Shade Universal Composite	UDMA Bis-GMA TEMDMA	0.005-3.0 μm	Glass powder, silicon dioxide inorganic filler	President Dental, Germany
Ruby CompNano Composite	BIS-GMA	0.05-0.9 μm	Silica, zirconia, barium glass particles	Rubydent, İstanbul, Türkiye

Table 2. Polishing Materials and Procedure

Material	Manufacturer	Procedure
OptraGloss Composite Kit	Ivoclar Vivadent, Schaan, Liechtenstein	One step polishing with diamond high-gloss polisher spiral wheel
Nova Twist- Polishing Kit	President Dental, Germany	Pre-polishing with diamond particles embedded rubber spirals (Medium grit) followed by high-shine polisher diamond particles embedded rubber spirals (Fine grit)
Super-Snap Rainbow Polishing Kit	Shofu Dental Corporation, Japan	First contouring with Black (Coarse) disposable silicon carbide disk. Then finishing with Violet (Medium) disposable silicon carbide disk After polishing with Green (Fine) aluminum oxide grit Super-Polishing was made with Red (Super Fine) aluminum oxide grit

has been reported in previous studies evaluating polishing effects on resin-based composites.[15]

Each polishing kit utilized different abrasive instruments: the OptraGloss kit contained a diamond-impregnated spiral polisher, the Nova Twist kit used diamond-embedded rubber spirals with medium and fine grit, and the Super-Snap kit incorporated silicon carbide and aluminum oxide discs in a multi-step sequence. The study groups are illustrated schematically in Figure 1, while composite resin properties and polishing tool details are provided in Tables 1 and 2.

Color Evaluation

Before the samples were subjected to cyclic immersion in coffee solution, L*, a*, and b* values were recorded by color measurement with a spectrophotometer (VITA Easyshade® V, Germany) and these were taken as baseline values. According to the protocol of Barakah and Taher,[16] the samples were soaked for 14 days in a coffee solution prepared with hot water and instant coffee (Nescafe Gold, Nestle) at a ratio of 15 g coffee and 500 mL water, changed every 24 hours. The samples removed from the coffee solution were rinsed with distilled water for 1 minute and then air-dried. Subsequently, a second color measurement was performed to calculate the ΔE value. All measurements were conducted by the same clinician, using a white background for color measurements and gray and black backgrounds for translucency measurements. Three color measurements were taken from each sample, and the color difference (ΔE00) was calculated using the following formula:[17]

$$\Delta E00 = [(\Delta L^*/KL\ \ SL)^2 + (\Delta C^*/KC\ \ SC)^2 + (\Delta H^*/KH\ \ SH)^2 + RT\ (\Delta C^*/KC\ SC)\ (\Delta H^*/KH\ SH)]^{1/2}$$

ΔL*, ΔC*, and ΔH* refer to the differences in gloss, chroma, and hue between the compared samples. SL, SC, and SH correspond to the brightness, chroma, and hue components, respectively. Parametric factors (KL, KC, and KH) adjusted for different imaging conditions were set to "1."

Translucency values were measured by applying the following formula:[18]

$$TP = [(Lw^* - LB*)^2 + (aw* - aB^*)^2 + (bw^* - bB^*)^2]^{1/2}$$

Table 3. Distribution of ΔE Measurements According to Material and Polishing Procedures

Material	Polishing procedures	Mean (SD)
Stark Bulk Fill Composite	One-step	9.98 (1.76)^{aA}
	Two-step	5.88 (1.09)^{bA}
	Multi-step	5.56 (1.05)^{bA}
Zenchroma One Shade Universal Composite	One-step	9.35 (3)^{aA}
	Two-step	4.72 (1.01)^{bA}
	Multi-step	4.1 (1.04)^{bAB}
Ruby CompNano Composite	One-step	4.55 (0.82)^{aB}
	Two-step	2.61 (0.3)^{bB}
	Multi-step	2.71(0.57)^{bB}

[a,b]Refer to differences between polishing procedures.
[A,B]Refer to differences between materials.

Surface Roughness Measurement

The samples' surface roughness (Ra) was assessed before and after immersion in the coffee solution using a contact profilometer (MarSurf M 300 C; Mahr GmbH, Göttingen, Germany) in compliance with EN ISO 4288 standards. The profilometer was configured with a needle tip radius of 5 µm, a needle travel speed of 0.5 mm/s, a scan length (Lt) of 1.75 mm, and 5 cut lengths of 0.250 mm.[19] For each sample, 3 measurements were taken at 4 different locations on the polishing surface in a clockwise direction, and the arithmetic mean of these measurements (Ra, in µm) was calculated. All measurements were performed by the same operator to ensure consistency.

Vickers Hardness Measurement

All samples' surface microhardness was evaluated using a microhardness tester (Shimadzu HMV-2000, Japan), where a pyramid-shaped indenter applied a force of 100 g to the surface for 15 seconds.[20] The samples' surfaces were measured before and after immersion in the coffee solution. Three measurements were taken for each sample and averaged.

Statistical Analysis

The assumption of normal distribution was assessed using the Shapiro-Wilk test, while the homogeneity of variance was evaluated with Levene's test, and the sphericity assumption

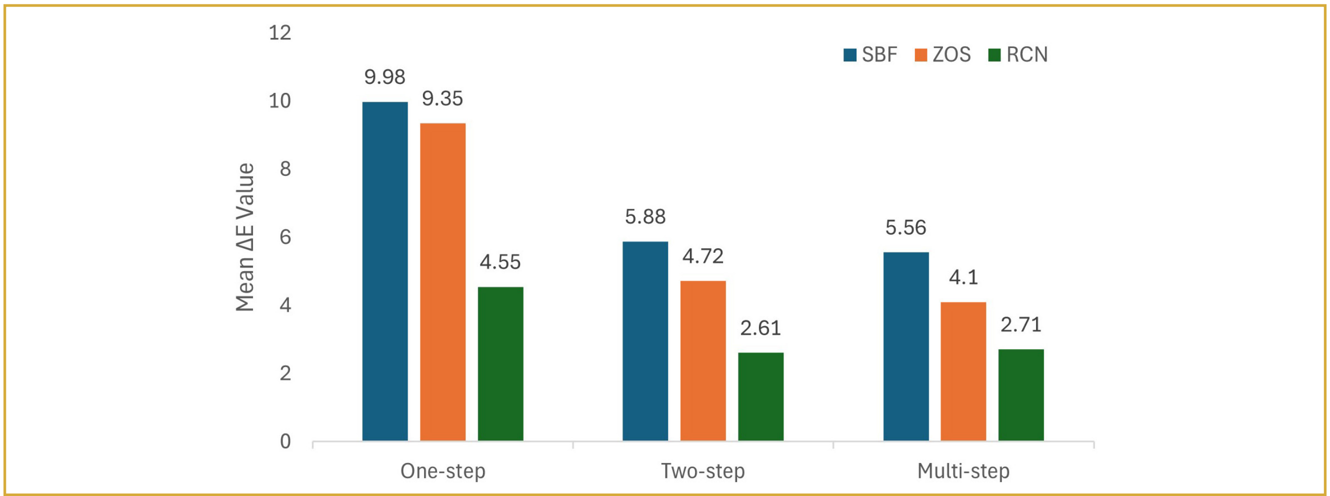


Figure 2. Histogram plot of ΔE measurements.

was checked using Mauchly's W test. Two-Way ANOVA was employed to analyze the interaction effect of the difference between the 3 independent groups where the assumption of normality was met, and the Two-Way Repeated Measures ANOVA (Greenhouse-Geisser Statistics) test was used to examine the interaction effect of the difference between the independent and dependent groups. Post Hoc Bonferroni tests were utilized to identify the group(s) responsible for the observed differences. Statistical analyses were performed using the IBM SPSS 25 software program.

RESULTS

Color and Tranclucency Results

When coloration values (ΔE) were compared according to material and polishing procedures, statistically significant differences were found between the groups ($P < .05$). According to materials analyses, statistically significant differences were obtained between the one-, two-, and multi-step polishing groups in SBF, ZOS, and RCN materials ($P < .05$). In the one- and two-step polishing groups, the ΔE values of the SBF and ZOS materials were higher than the ΔE values of the RCN material. In the multi-step polishing group, the ΔE values of the SBF material were higher than the ΔE values of the RCN material. According to surface treatment analysis, the ΔE values of the one-step polishing group were higher than the ΔE values of the two- and multi-step polishing groups (Table 3). The histogram plot of ΔE measurements is found in Figure 2.

Table 4. Distribution of Translucency Measurements According to Time, Material and Polishing Procedures

Material	Polishing Procedures	TP0 Mean (SD)	TP1 Mean (SD)	Difference Mean (SD)
Stark Bulk Fill Composite	One-step	6.11 (1.86)	6.05 (2.92)	1.54 (0.98)
	Two-step	8.38 (2.63)	6.92 (1.51)	2.38 (2.05)
	Multi-step	7.14 (1.38)	6.15 (1.66)	1.98 (1.62)
Zenchroma One Shade Universal Composite	One-step	11.03 (1.27)	10.05 (2.09)	1.24 (1.39)
	Two-step	11.47 (2.19)	10.26 (1.19)	1.57 (1.42)
	Multi-step	12.62 (2.13)	11.69 (1.97)	2.57 (1.36)
Ruby CompNano Composite	One-step	8.2 (1.92)	6.29 (0.68)	2.05 (1.42)
	Two-step	7.32 (2.01)	6.33 (2.12)	2.3 (1.59)
	Multi-step	9.35 (2.02)	6.95 (2.42)	2.4 (1.39)

TP0: Translucency Parameter at baseline, TP1: Tranclucency Parameter after coffee

As a result of the comparison of translucency measurements according to time, material, and surface treatment, a statistically significant difference was determined only between translucency measurements according to time ($P < .05$). The first measurement values of translucency (TP0) were significantly higher than the last measurement values (TP1) (Table 4). The histogram plot of initial translucency measurements is found in Figure 3, and after in coffee in Figure 4.

Surface Roughness Results

As a result of the analyses, statistically significant differences in roughness measurements were observed in the main interaction of time, and the interaction of time and polishing procedures ($P < .05$). No significant difference was obtained in the other interactions ($P > .05$). The initial roughness values were lower than the final roughness values, and the roughness values in the one-step polishing groups were the highest, followed by the two- and multi-step polishing groups, respectively (Table 5). The histogram plot of surface roughness measurements is found in Figure 5, and after in coffee in Figure 6.

Vickers Hardness Results

As a result of the comparison of hardness measurements according to time, material, and polishing procedures, statistically significant differences were obtained in terms of hardness measurements in the main interaction of time and the interaction of time, material, and polishing procedures ($P < .05$). According to the material and surface treatment analysis, statistically significant differences were observed between the first and second measurements in all polishing

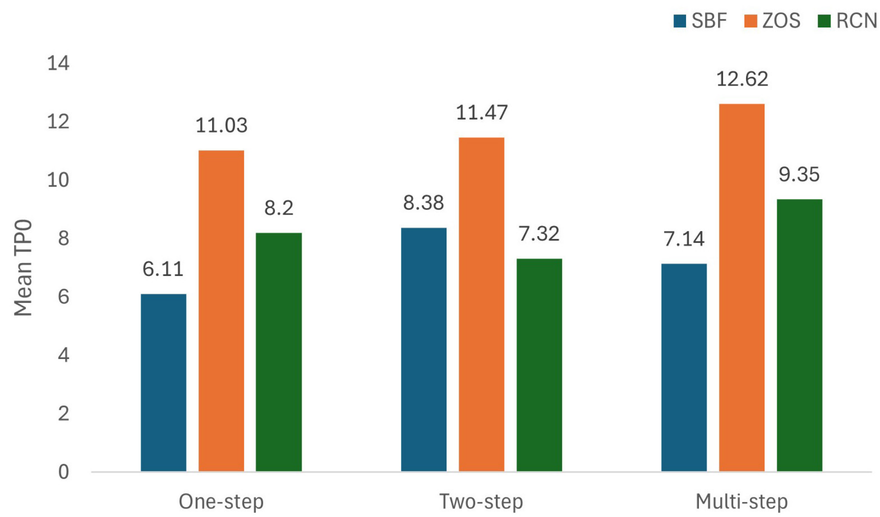


Figure 3. Histogram plot of initial translucency measurements.

procedures applied to the SBF and RCN groups, and between the first and second measurements in the one- and two-step polishing procedures applied to the ZOS group ($P < .05$). The first measurement hardness values (HV) were higher than the last ones. It was only in the multi-step polishing groups of the ZOS material that no significant difference was obtained between the first and last measurement HV, and immersing in coffee did not cause any change in HV (Table 6). The histogram plot of hardness measurements is found in Figure 7, and after in coffee in Figure 8.

DISCUSSION

In this study, the color change, surface roughness, and hardness properties of resin-based restorative materials after different polishing techniques (one-, two-, and multi-step) and after immersion in the coffee solution were compared. Given that statistically significant differences were identified between both polishing techniques and materials, the null hypothesis that materials and polishing techniques would not make a difference in optical and mechanical properties was rejected.

Resin-based composites tend to discolor in the mouth after prolonged use,[21] and bulk-fill composites contain a higher proportion of organic matrix compared to conventional composites. While these materials are expected to achieve a higher degree of conversion, the increased organic matrix content in bulk-fill composites may contribute to greater staining.[15] A monomeric matrix with high levels of triethylene glycol dimethacrylate (TEGDMA) can result in increased water absorption, leading to the discoloration of the material.[16] In the current study, the SBF group exhibited the lowest

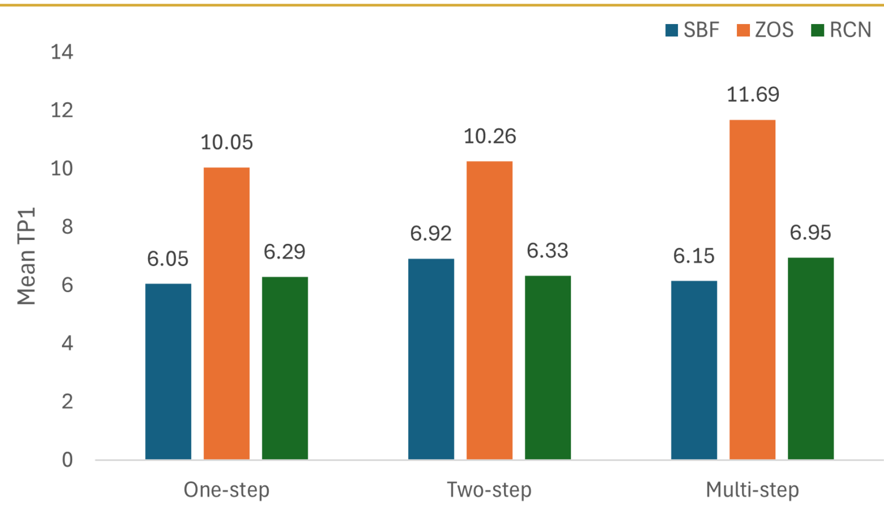


Figure 4. Histogram plot of translucency measurements after in coffee.

Table 5. Percentage Increase in Surface Roughness (% SRI) and Roughness (Ra) Values (µm) at Baseline and After Coffee Solution

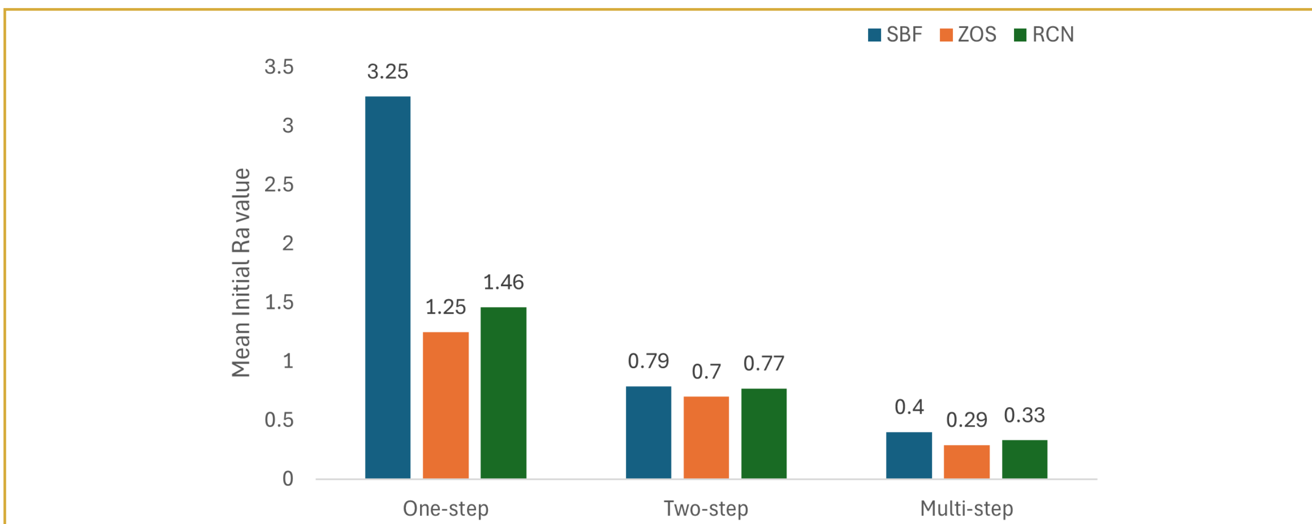
	One-Step	Two-Step	Multi-Step
Stark Bulk Fill Composite	SRI 29% Initial Ra value: 3.25 ± 1.32 Ra value after coffee: 4.19 ± 1.26	SRI 24% Initial Ra value: 0.79 ± 0.13 Ra value after coffee: 0.98 ± 0.07	SRI 20% Initial Ra value: 0.4 ± 0.07 Ra value after coffee: 0.48 ± 0.08
Zenchroma One Shade Universal Composite	SRI 71% Initial Ra value: 1.25 ± 0.39 Ra value after coffee: 2.14 ± 0.96	SRI 21% Initial Ra value: 0.7 ± 0.12 Ra value after coffee: 0.85 ± 0.15	SRI 58% Initial Ra value: 0.29 ± 0.1 Ra value after coffee: 0.46 ± 0.19
Ruby CompNano Composite	SRI 65% Initial Ra value: 1.46 ± 0.89 Ra value after coffee: 2.41 ± 1.15	SRI 48% Initial Ra value: 0.77 ± 0.22 Ra value after coffee: 1.13 ± 0.29	SRI 72% Initial Ra value: 0.33 ± 0.08 Ra value after coffee: 0.57 ± 0.18

color stability among the tested materials. The SBF and ZOS groups showed more color changes after immersion in coffee compared to the RCN group.

The composition of the organic matrix and fillers influences the staining and color stability of composites while finishing and polishing procedures significantly affect surface properties.[22] For implant-supported prostheses, especially in the anterior region, achieving optimal color adjustment is essential to ensure seamless esthetic integration with surrounding dentition. The differences in color change (ΔE) observed in this study indicate that material selection and polishing techniques play a significant role in preserving esthetic harmony in implant restorations. Abrasion of the organic matrix and the dislodgement of surface filler particles modify the surface topography, leading to increased roughness and reduced gloss. Proper finishing and polishing procedures help restore favorable optical properties by smoothing the surface and exposing the filler particles.[23] In this study, the groups with the multi-step polishing procedure exhibited the lowest ΔE values compared to those with one- and two-step procedures.

The translucency of a material is measured by its translucency parameter, which represents the color difference observed between material samples of uniform thickness placed over black and white backgrounds.[24] The translucency of resins is influenced by intrinsic factors, including the composition of the resin matrix, characteristics of filler particles, type of chemical initiators and inhibitors, degree of polymerization, and presence of opacifiers and coloring agents.[25] In this study, regardless of the polishing techniques, the initial translucency values of all samples were significantly higher than the translucency values measured after immersion in coffee.

Inadequate finishing procedures can negatively affect the clinical performance of restorations by increasing wear rates and making them more susceptible to plaque accumulation. The surface roughness of restoration depends on the type of resin-based composite used and is further influenced by factors such as the type, shape, size, and distribution of filler particles, the interface between the organic matrix and fillers, and the specific finishing and polishing techniques applied.[26] Composites with smaller filler particles generally exhibit lower surface roughness and higher gloss after polishing.[27] In this study, the ZOS and SBF groups, which had



SRI: Surface Roughness Increase

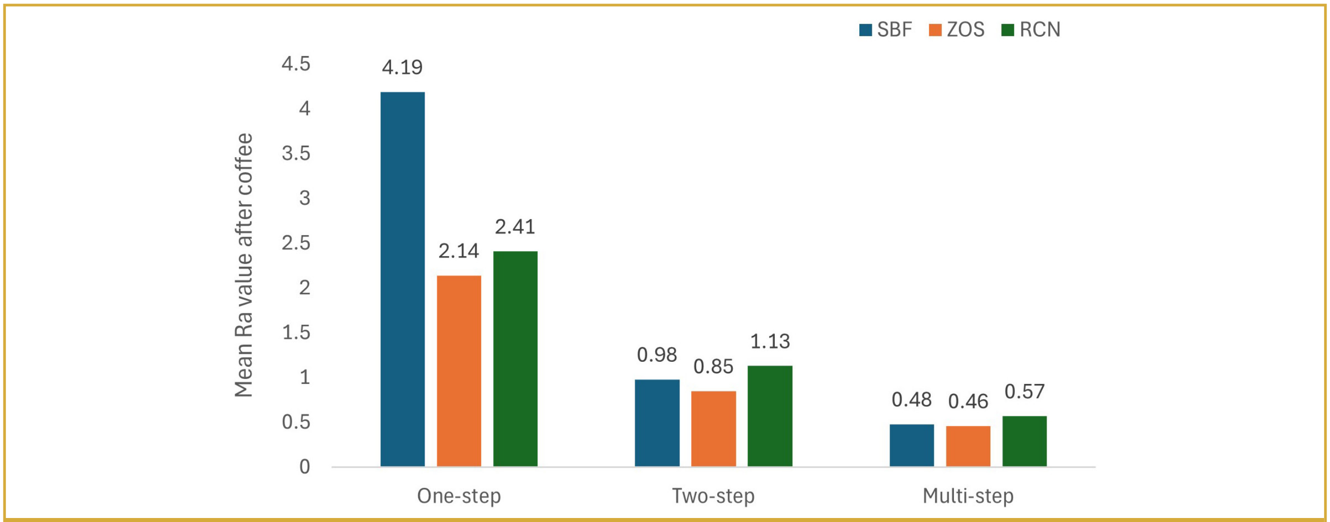


Figure 6. Histogram plot of roughness measurements after in coffee.

smaller particle sizes than the RCN group, showed lower surface roughness values.

A smooth surface is crucial not only for functional purposes but also for achieving optimal aesthetic outcomes.[23] Patel et al,[28] in their study investigating the effect of different polishing methods on the surface roughness of nano-hybrid composites, reported that restorations were visually smooth and clinically acceptable when the Ra value was less than 1 μm. In the present study, since the Ra values of the specimens with two- and multi-step polishing were less than 1 μm, both systems can be considered suitable for clinical use.

The HV of materials are significantly influenced by factors such as filler volume fraction, resin type, composition, and degree of polymerization.[29] Erdemir et al,[30] in a study evaluating the effect of polishing systems with different stepped applications on microhardness, reported that the applied polishing systems did not show a significant effect on microhardness values in any group. In the present study, a statistically significant decrease in HV was observed in the SBF and RCN materials after soaking in coffee in all one-, two-, and multi-step polishing groups, while no change in HV was observed in the ZOS material when the multi-step polishing procedure was applied.

Table 6. Percentage Decrease in Hardness (% HD) and Hardness Values at Baseline and After Coffee Solution

	One-Step	Two-Step	Multi-Step
Stark Bulk Fill Composite	HD 33% Initial HV: 68.11 ± 5.51 HV after coffee: 45.25 ± 5.21	HD 10% Initial HV: 69.24 ± 6.55 HV after coffee: 62.07 ± 6.18	HD 15% Initial HV: 63.61 ± 7 HV after coffee: 53.65 ± 6.54
Zenchroma One Shade Universal Composite	HD 28% Initial HV: 45.98± 4.4 HV after coffee: 33.07 ± 3.19	HD 16% Initial HV: 51.55 ± 4.99 HV after coffee: 43.19 ± 5.18	HD 2% Initial HV: 54.37 ± 3.53 HV after coffee: 52.8 ± 5.51
Ruby CompNano Composite	HD 12% Initial HV: 54.48 ± 4.33 HV after coffee: 47.72 ± 1.07	HD 15% Initial HV: 55.83 ± 5.51 HV after coffee: 46.92 ± 4.21	HD 13% Initial HV: 61.14 ± 4.18 HV after coffee: 52.91 ± 6.16

HD: Hardness Decrease, HV Hardness values.

The failure of dental implants can result from systemic conditions, inadequate oral hygiene, smoking, and peri-implantitis, which are often linked to microbial leakage at various implant components.[31] In addition to the implant-abutment interface, microbial colonization, and microleakage may occur through the abutment screw hole in two-piece implant-abutment complexes, further emphasizing the importance of proper sealing in implant-supported restorations to ensure long-term clinical success.[32] In this study, composite materials polished with the multi-step protocol exhibited lower surface roughness values, which may enhance their sealing ability by reducing microleakage risk and bacterial adhesion. These findings suggest that selecting appropriate finishing and polishing protocols is crucial for improving the longevity of composite seals in implant-supported restorations.

Quirynen et al[33] and do Nascimento et al[34] bidirectional microbial infiltration and fluid movement within implants, which can serve as reservoirs for bacteria. These are predominantly anaerobic oral bacteria, often associated with an unpleasant odor. Research has shown that hollow spaces in abutment screw holes can act as sites for microleakage and bacterial accumulation.[35] To prevent or reduce this microleakage, it is essential to seal the abutment screw hole with a material that provides both functional durability and aesthetic stability, particularly in anterior restorations where visibility is a concern.

Composite resins are among the most commonly used materials for this purpose, as they effectively seal the screw

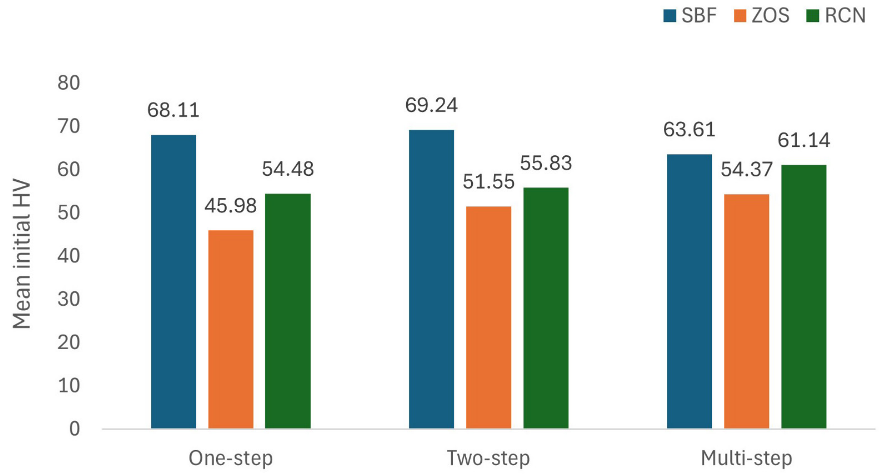


Figure 7. Histogram plot of initial hardness measurements.

hole and protect the screw head.[36] The long-term success of implant-supported prostheses depends not only on their mechanical stability but also on the optical and surface properties of restorative materials. In this study, the multi-step polishing technique resulted in smoother surfaces, which may contribute to reducing bacterial adhesion and enhancing the longevity of implant-supported restorations. Surface roughness, influenced by resin composition and polishing techniques, affects biofilm retention and staining, which are critical for both hygiene and long-term esthetics in implant restorations. Particularly in anterior regions where visibility is a concern, achieving a smooth surface is essential for maintaining esthetic stability. Additionally, improper finishing and polishing may contribute to microleakage around the screw access hole, potentially leading to bacterial colonization and peri-implant complications.[37]

Yu et al[38] observed increased leakage when finishing procedures were carried out under dry conditions. In implant-supported restorations, maintaining the integrity of the composite seal is particularly important, as increased microleakage may facilitate microbial colonization through the abutment screw hole, ultimately leading to peri-implantitis. Given these considerations, optimizing the polishing techniques used for composite resins in implant prosthetics is crucial for improving both biological and aesthetic outcomes.

This study has some limitations, as it is an in vitro investigation that does not replicate intraoral conditions and may yield results that differ from those observed clinically. Factors such as saliva and enzymes present in the oral cavity were not taken into account. Furthermore, coffee was selected as the staining solution in this study. However, beverages with varying pH levels and temperatures may influence the color, surface roughness, and microhardness of restorative materials differently. Future studies should include in vivo evaluations to better replicate clinical conditions. Additionally, assessing the effects of different beverages and aging methods,

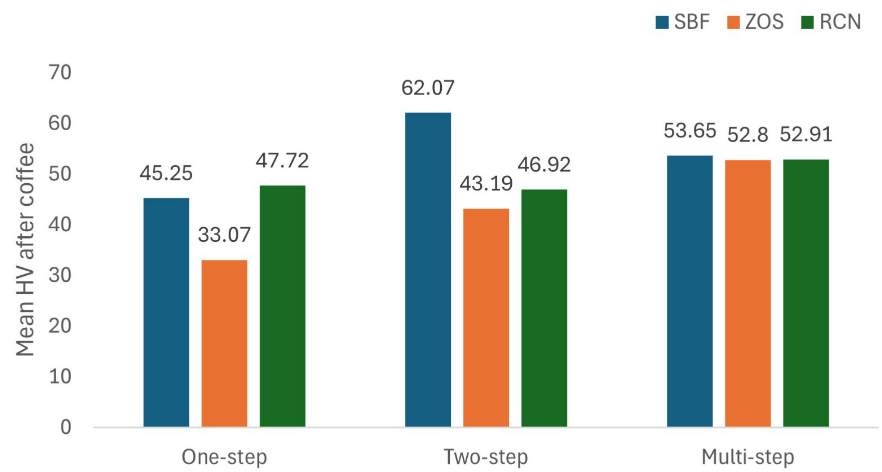


Figure 8. Histogram plot of hardness measurements after in coffee.

such as thermal cycling, could provide further insights into the long-term performance of composite resins, particularly in implant-supported restorations. Moreover, incorporating advanced analytical techniques, such as spectrophotometric or scanning electron microscopy analyses, could further clarify the material changes occurring over time, offering more scientific evidence on the performance of available restorative materials.

Considering the limitations of this study, the following conclusions were drawn:

1. Material composition and polishing protocols played a key role in maintaining color stability, with multi-step polishing reducing discoloration more effectively.
2. Translucency was primarily affected by coffee immersion, leading to decreased translucency values over time, regardless of material type or polishing method.
3. Surface roughness increased after polishing, but multi-step polishing produced the smoothest surfaces, which is essential for minimizing plaque accumulation and maintaining esthetics in implant-supported restorations.
4. Coffee immersion negatively affected the hardness of most materials, but multi-step polishing helped preserve mechanical properties in some cases, emphasizing the clinical importance of proper finishing protocols. These findings emphasize the importance of selecting appropriate composite materials and polishing techniques to enhance the longevity and esthetic stability of implant-supported restorations.

Data Availability Statement: The data that support the findings of this study are available on request from the corresponding author.

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