

Effect of Different Surface Finishing Processes on the Optical Properties of Zirconium Oxide Ceramics

Farklı Yüzey Bitirme İşlemlerinin Zirkonyum Oksit Seramiklerin Optik Özellikleri Üzerindeki Etkisi

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Abstract

Objective: Zirconium oxide ceramics are widely used in dentistry due to their excellent mechanical and aesthetic properties. This study investigated the optical properties of zirconium oxide specimens applied with different surface finishing processes

Materials and Methods: The study was conducted under *in vitro* conditions. Thirty zirconium oxide discs (diameter = 15 mm, thickness = 1.2 ± 0.2 mm) were produced and randomly divided into three groups: glazing (Control, Group C), grinding and polishing with EveDiacera (Group L), and grinding and polishing with a polishing paste (Group P). L, a*, and b* values were measured with a spectrophotometer, and color difference (ΔE_{00}), translucency parameter (TP), whiteness index (WI), and modified metamerism index (M-MI) were calculated. Data were analysed using ANOVA, Tukey HSD, paired t-tests, and Mann-Whitney U tests ($p < 0.05$).

Results: The mean ΔE_{00} values were 2.04 for Group C, 2.15 for Group P, and 1.81 for Group L. No significant differences were observed in ΔE_{00} among the groups ($p > 0.05$). Post-treatment TP values significantly decreased in Groups P and L ($p < 0.001$), and a significant difference was found between Group C and Group L ($p = 0.0017$). WI values did not differ significantly between groups ($p > 0.05$), although Group L showed a significant reduction after treatment ($p = 0.036$). No significant differences in M-MI were observed under 4200K ($p = 0.112$) or 5000K ($p = 0.325$) illumination.

Conclusion: Different surface finishing processes affect the translucency and whiteness of zirconia, while metamerism remained unaffected under various lighting conditions.

Keywords: Dental zirconia, metamerism, optical properties, translucency, whiteness index

Öz

Amaç: Zirkonyum oksit seramikler, mükemmel mekanik ve estetik özellikleri nedeniyle diş hekimliğinde yaygın olarak kullanılmaktadır. Bu çalışmada, farklı yüzey bitirme işlemleri uygulanmış zirkonyum oksit örneklerinin optik özellikleri incelenmiştir.

Materyal ve Metot: Çalışma *in vitro* koşullarda gerçekleştirilmiştir. Otuz adet zirkonyum oksit disk (çap = 15 mm, kalınlık = 1,2 ± 0,2 mm) üretilmiş ve rastgele üç gruba ayrılmıştır: glaze uygulanmış grup (Kontrol, Grup C), EveDiacera ile taşlama ve polisaj yapılan grup (Grup L) ve taşlama ve polisaj pastası yapılan grup (Grup P). L, a ve b değerleri spektrofotometre ile ölçülmüş; renk farkı (ΔE_{00}), yarı saydamlık parametresi (TP), beyazlık indeksi (WI) ve modifiye metamerik indeks (M-MI) hesaplanmıştır. Veriler ANOVA, Tukey HSD, eşleştirilmiş t-testi ve Mann-Whitney U testleri ile analiz edilmiştir ($p < 0,05$).

Bulgular: Ortalama ΔE_{00} değerleri Grup C için 2,04, Grup P için 2,15 ve Grup L için 1,81 olarak bulunmuştur. Gruplar arasında ΔE_{00} açısından anlamlı bir fark gözlenmemiştir ($p > 0,05$). İşlem sonrası TP değerleri Grup P ve Grup L'de anlamlı şekilde azalmış ($p < 0,001$) ve Grup C ile Grup L arasında anlamlı bir fark bulunmuştur ($p = 0,0017$). WI değerleri gruplar arasında anlamlı farklılık göstermemiştir ($p > 0,05$), ancak Grup L'de işlem sonrası anlamlı bir azalma görülmüştür ($p = 0,036$). M-MI değerlerinde ise 4200K ($p = 0,112$) veya 5000K ($p = 0,325$) aydınlatma altında anlamlı bir fark gözlenmemiştir.

Sonuç: Farklı yüzey bitirme işlemleri, zirkonyanın yarı saydamlığını ve beyazlığını etkilerken, çeşitli aydınlatma koşullarında metamerizm etkilenmemiştir.

Anahtar Kelimeler: Beyazlık indeksi, dental zirkonya, metamerizm, optik özellikler, yarı saydamlık

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INTRODUCTION

Monolithic zirconium restorations produced with computer-aided design and computer-aided manufacturing (CAD/CAM) technology are widely used due to their excellent mechanical properties and the absence of veneer chipping.¹

Surface finishing processes have a critical impact on the color stability and long-term success of these restorations. These processes are performed to decrease the abrasiveness of the restoration, to minimise the abrasive effect on the natural teeth, and to ensure hygiene by preventing bacterial adhesion to the restoration surface.^{2,3} The most commonly used surface treatments are glazing and polishing.⁴ The glaze process should be applied only if no changes are to be made on the occlusal surface, as changes made to the restoration will cause the glaze layer to be removed and result in roughness.⁵ Polishing, unlike glazing, can be applied repeatedly and performed chairside or in the laboratory with a variety of discs, polishing kits, and polishing pastes.⁶

Applying these surface treatments may alter the material's optical and mechanical characteristics, potentially compromising the longevity of the restoration.⁷ The optical properties of monolithic zirconium material are related to many parameters that affect the aesthetic integrity of the restoration. Color difference (ΔE), translucency parameter (TP), whiteness index (WI), and metamerism index (MI) are frequently evaluated parameters.⁸⁻¹⁰ These parameters elucidate the interaction of the material with light and thereby influence its visual perception. However, there is limited research comparing the effects of different polishing and glazing procedures on multiple optical parameters of monolithic zirconia, particularly under *in vitro* conditions.^{3,11-12}

Unlike many previous studies that primarily assessed surface treatments of zirconia in terms of mechanical properties, such as flexural strength, fracture resistance, or surface roughness, or focused on staining susceptibility, phase transformation under various polishing protocols,¹³⁻¹⁵ the present study aims to focus on the optical outcomes relevant to clinical esthetic success. Although surface roughness is important, it does not fully capture the visual harmony of a restoration within the oral environment, especially under varying light conditions.¹⁶ Therefore, by evaluating color change, translucency, whiteness index, and metamerism, this study provides valuable insight into how different finishing protocols affect the visual integration of zirconia restorations. The null hypothesis was that different surface finishing procedures would not have a significant effect on the optical properties of zirconia samples.

MATERIALS AND METHODS

Ethics Committee Approval: This study was conducted entirely under *in vitro* conditions and did not involve human participants or animal subjects. Therefore, ethics committee approval was not required, in accordance with institutional and national guidelines.

Preparation of Samples: A power analysis was performed using G*Power 3.1 to determine the minimum required sample size for detecting differences in optical parameters (ΔE_{00} , TP, and WI) among the groups. Assuming an effect size of $f = 0.40$ based on previous studies evaluating surface treatment effects on zirconia optical properties, with $\alpha = 0.05$ and a desired power of 0.80, the required sample size was calculated as 9 specimens per group for one-way ANOVA.¹ Therefore, 10 specimens were included in each group in the present study. In this study, 30 zirconium dioxide discs (4Y-TZP; Upcera HT Zirconia, Shenzhen Upcera Dental Technology, China) with a diameter of 15 mm and a thickness of 1.2 ± 0.2 mm were fabricated.¹⁷ Discs were produced by the milling technique and sintered according to the manufacturer's standard protocol (final sintering temperature 1500–1530°C). A digital calliper (Mitutoyo Corp, Japan) was used to verify the dimensions of all specimens. Samples were randomly assigned to the groups using a simple randomization method.

Preparation of Sample Surfaces: Three surface treatments were applied to zirconium dioxide discs ($n = 10$): glazing (Group C), grinding followed by finishing and polishing with the EveDiacera system (Group L), and grinding followed by polishing with a polishing paste (Group P). Only one surface of each disc was treated to ensure standardization.

In Group C, a thin layer of glaze (IPS Ivocolor Glaze Paste, Ivoclar Vivadent, Schaan, Liechtenstein) was applied according to the manufacturer's instructions, and the glazed surface was fired in a ceramic furnace (Vacumat 6000 MP, Vita Zahnfabrik, Bad Säckingen, Germany).

In Group L, grinding and polishing were performed using diamond-impregnated instruments. This process comprised four stages. Initially, surface grinding was carried out with a gray-colored grinding stone to roughen the surface mechanically. Then, three polishing discs from the DIECERA Set HP 321 (EVE Ernst Vetter GmbH, Keltern, Germany) were applied sequentially. The coarse disc was used to remove surface irregularities, the

medium disc to improve surface uniformity, and the fine disc to achieve a glossy finish. Each step was performed at approximately 10,000 rpm for 20 seconds using constant pressure by the same operator. After each step, specimens were rinsed with water and air-dried.

In Group P, polishing was performed using a diamond-containing polishing paste (Dura-Polish Dia, Shofu Inc., Japan). The paste was applied to one surface only using a felt wheel operated by the same operator for consistency. Polishing was performed at approximately 10,000 rpm for 60 seconds under standardized pressure. After polishing, all specimens were rinsed with water and air-dried.

Color Measurement: A digital spectrophotometer (Vita Easyshade V, Vita Zahnfabrik, Bad Säckingen, Germany) was used, and it was set to 'block' mode. The probe was positioned in the centre of each disc, and L, C, H, a*, and b* values were recorded on gray, white, and black backgrounds under different light sources (D65 (6500 K daylight), F2 (4200 K fluorescent), and D50 (5000 K midday sun)). These measurements were used to calculate the ΔE_{00} , TP, WI, and M-MI. Each measurement was repeated three times, and the mean values were recorded for analysis. The spectrophotometer was calibrated according to the manufacturer's instructions before each measurement.

Measurement of Optical Parameters: To calculate the color change values, the recorded data were placed in the CIEDE2000 (ΔE_{00}) color difference formula, and the color difference between each sample before and after the treatment was determined. The CIEDE2000 formula is as follows:

$$\Delta E_{00} = \sqrt{\left(\frac{\Delta L'}{k_L S_L}\right)^2 + \left(\frac{\Delta C'}{k_C S_C}\right)^2 + \left(\frac{\Delta H'}{k_H S_H}\right)^2 + R_T \left(\frac{\Delta C'}{k_C S_C}\right) \left(\frac{\Delta H'}{k_H S_H}\right)}$$

Where $\Delta L'$ is the lightness difference, $\Delta C'$ is the chroma difference, $\Delta H'$ is the hue difference, S_L , S_C , and S_H are weighting functions, k_L , k_C , and k_H are correction terms (usually set to 2,1,1), and R_T is a rotation term accounting for the interaction between chroma and hue differences.

TP was calculated by inserting the previously obtained L*, a*, and b* values into the following formula:

$$TP = [(L_b - L_w)^2 + (a^*_b - a^*_w)^2 + (b^*_b - b^*_w)^2]^{1/2}$$

L_b , a^*_b and b^*_b represent the values measured on a black background, while L_w , a^*_w and b^*_w represent the corresponding values measured on a white background. An increase in the TP value indicates a higher level of translucency of the zirconia material. The translucency perceptibility and acceptability thresholds were 50%:50% perceptibility (TPT) 0.62 and acceptability (TAT) 2.62.¹⁸

The obtained L, a*, and b* values were also used to calculate the WI using the following formula:

$$WI = 0.511x L - 2.324x a^* - 1.100x b^*$$

The WI value increases as the sample appears lighter and closer to neutral chromaticity (i.e., lower a* and b* values), indicating higher perceived whiteness. In this study, differences in the WI (ΔWI) were assessed using the whiteness 50%:50% perceptibility (WPT) and 50%:50% acceptability (WAT) thresholds, which were determined in previous research and correspond to 0.72 ΔWI units and 2.60 ΔWI units, respectively.¹⁹

The M-MI is calculated by dividing the color difference (ΔE_{ab}) under the test light by the color difference under the reference light source. Since the 6500K light source was taken as the reference in this study, the MI between the 4200K and 5000K light sources and 6500K was determined by dividing the ΔE_{ab} value measured under these illuminations by the ΔE_{ab} value between the same groups measured under 6500K illumination.²⁰ The following equation shows this calculation:

$$M-MI_{4200K} = \Delta E_{ab}(4200K) / \Delta E_{ab}(6500K)$$

$$M-MI_{5000K} = \Delta E_{ab}(5000K) / \Delta E_{ab}(6500K)$$

If there is no metameric effect between samples, the MI value equals 1, indicating that the color differences observed under various illumination sources are identical to those observed under the reference light.²¹

Statistical Analysis: Before analysis, all data were examined for outliers and distribution characteristics. Data were analysed using SPSS (Version 23, USA). The data were analysed for normality using the Shapiro-Wilk test. Parametric tests were preferred for comparisons of color change and TP values. One-way ANOVA was used to compare the groups. Since a significant difference was detected in the ANOVA for translucency values ($p=0.002$), a Tukey HSD post hoc test was performed to determine differences between group pairs. Paired t-test was used to evaluate the changes in TP and WI before and after the procedure within each group. As M-MI represents an intra-sample illumination-dependent ratio rather than a direct intergroup color difference, comparisons were made between Groups P and L to evaluate metameric behavior associated with surface finishing. Since normality could

not be achieved in M-MI analyses, the Mann-Whitney U test was used to compare Group P and Group L. Statistical significance was set at $p < 0.05$.

RESULTS

The optical properties of zirconium oxide disks subjected to three different surface finishing processes were compared in this study. As shown in Table 1, no statistically significant difference was found between the groups regarding the mean color change values after the tests ($p = 0.743$). The mean ΔE_{00} values were measured as 2.04 ± 0.68 in Group C, 2.15 ± 0.82 in Group P and 1.81 ± 0.53 in Group L (Table 1).

Table 1. Color difference (ΔE_{00}) values after the treatment.

Groups	ΔE_{00}	p-value
Group C (Glaze)	2.04 ± 0.68	
Group P (Polish Paste)	2.15 ± 0.82	0.743
Group L (EveDiacera)	1.81 ± 0.53	

ΔE_{00} : Color difference; ΔE_{00} : Color difference according to CIEDE2000; Values are presented as mean \pm standard deviation; ANOVA was used for intergroup comparisons.

When the post-treatment translucency values were evaluated, a significant difference was observed among the groups ($p = 0.002$). According to the Tukey HSD test results, a significant difference was found between Group C and Group L ($p = 0.0017$). The differences between Group P and the other groups were not significant ($p > 0.05$). In addition, a significant decrease was observed between the TP values before and after the treatment in Group P and Group L ($p < 0.001$). The mean values and standard deviations of the TP before and after the treatment for all groups are presented in Table 2.

Table 2. TP values before and after the treatment.

Groups	TP (before the treatment)	TP (after the treatment)	ΔTP	p-value (intragroup)
Group C (Glaze)	2.93 ± 0.66	2.36 ± 0.75	0.57	0.12
Group P (Polish Paste)	2.94 ± 0.59	1.72 ± 0.48	1.22	<0.001*
Group L (EveDiacera)	2.91 ± 0.63	1.25 ± 0.67	1.66	<0.001*

TP: Translucency parameter; Values are presented as mean \pm standard deviation; Paired t-test was used for intragroup comparisons; Intergroup comparison of post-treatment TP values: ANOVA ($p = 0.002$); Tukey HSD showed significant difference between Group C and Group L ($p = 0.0017$); *Statistically significant at $p < 0.05$.

No significant difference was observed between the groups in initial and post-test WI values ($p > 0.05$). However, a significant decrease in post-treatment WI was observed in Group L ($p = 0.036$) (Table 3).

Table 3. WI values before and after the treatment.

Groups	WI (before the treatment)	WI (after the treatment)	p-value (intragroup)
Group C (Glaze)	27.12 ± 1.61	25.66 ± 2.22	0.077
Group P (Polish Paste)	26.70 ± 0.92	24.06 ± 1.4	0.540
Group L (EveDiacera)	25.64 ± 1.96	23.81 ± 1.35	0.036*

WI: Whiteness index; Values are presented as mean \pm standard deviation; Paired t-test was used for intragroup comparisons; Intergroup comparison of post-treatment TP values was performed using one-way ANOVA ($p = 0.12$); *Statistically significant at $p < 0.05$.

As shown in Table 4, the mean M-MI values of Group P were 1 ± 0.28 under 4200K illumination and 0.9 ± 0.3 under 5000K illumination, while the corresponding values for Group L were 0.87 ± 0.34 and 0.83 ± 0.46 , respectively. According to the Mann-Whitney U test, no significant difference was observed between the two groups under either 4200K ($p = 0.112$) or 5000K ($p = 0.325$) illumination conditions, indicating that the different surface finishing protocols did not affect the metameric behaviour of zirconia.

Table 4. M-MI values of Group P and Group L under different illumination conditions.

Illumination (K)	Group P (Polish Paste)	Group L (EveDiacera)	p-value (intergroup)
	M-MI values	M-MI values	
4200K	1 ± 0.28	0.87 ± 0.34	0.112
5000K	0.9 ± 0.3	0.83 ± 0.46	0.325

M-MI: Modified metameric index; Values are presented as mean \pm standard deviation; Mann-Whitney U test was used.

DISCUSSION AND CONCLUSION

This study comparatively examined the effects of different surface finishing processes on the optical properties of monolithic zirconia, and the main findings, summarized in Tables 1–4, showed significant changes, particularly in translucency and WI. It was determined that the polishing application performed with grinding and polishing with EveDiacera caused a significant reduction in translucency values and caused a decrease in the WI after the process. In contrast, no significant difference was found between the groups in the comparisons made regarding the MI. Based on these results, the null hypothesis established for this study was partially rejected.

In this study, Group C (2.04 ± 0.68) and Group P (2.15 ± 0.82) exhibited a change above the clinically acceptable threshold value of 1.8,²² while Group L (1.81 ± 0.53) showed a color change close to the threshold value. These findings are consistent with previous studies evaluating the effect of surface finishing on zirconia color stability and may be related to glaze application and inducing micro-irregularities creating a superficial layer that modifies light interaction.^{4,7,23}

The findings showed that the different surface finishing processes applied had significant effects on the TP. A significant decrease in translucency values was observed, particularly after polishing with the grinding and polishing system. Similarly, in a study examining the effects of artificial aging on the translucency characteristics of monolithic zirconia, rubber polishing resulted in the most significant change in translucency.²⁴ However, the Δ TP values were below the acceptable threshold for all groups (<2.62), and in the control group, they were below the perceptibility threshold (<0.62).

Our findings demonstrated a decrease in WI, which is consistent with the results previously reported by Arslan and Degirmenci.²⁵ The Δ WI value measured in Group P (2.64) was above the clinically acceptable threshold (>2.60).¹⁹ In contrast, the Δ WI values for Groups C and L remained below the threshold. This finding may be attributed to the polishing paste procedure reducing light reflection on the surface, thereby leading to a lower perception of whiteness. From an esthetic perspective, alterations in the WI may adversely impact the visual compatibility of the restoration with adjacent natural dentition.

Light sources used in MI evaluations play a critical role in revealing the color behaviour of the material under different lighting. Similar to this study, MI research on zirconium oxide restorations commonly employs D65 (6500 K daylight), F2 (4200 K fluorescent), and D50 (5000 K midday sun) illuminants.^{10,26} No significant change in metameric behaviour was detected under different lighting conditions, indicating that color stability was maintained.

Although surface roughness was not directly measured in this study, the optical properties alterations observed after the different finishing protocols can be interpreted in well-established relationships between surface topography and light scattering. Previous studies have demonstrated that grinding and multi-step diamond polishing tend to increase micro-irregularities and alter surface morphology, which increases diffuse light scattering and consequently reduces translucency and whiteness.^{1,2}

This *in vitro* study offers insights into how various surface finishing protocols affect the optical properties of monolithic zirconia; however, it also has certain limitations. Firstly, the experimental design was limited to zirconia discs rather than anatomically shaped restorations, which may not fully replicate the clinical geometry and light interactions of actual dental crowns. In addition, long-term clinical ageing effects, such as wear, staining, and temperature changes, were not incorporated, which could further influence the optical properties outcomes over time. Moreover, microstructural analyses such as SEM or XRD were not included, as the primary aim of the study was to evaluate optical outcomes rather than characterizing phase or surface morphology changes. Future studies should examine the long-term clinical effects of surface finishing on different generations of monolithic zirconia under simulated oral conditions, including thermal cycling, wear, and staining.

In conclusion, this study demonstrated that surface finishing protocols significantly influence the optical properties of monolithic zirconia. Polishing with a multi-step diamond-impregnated system led to a clinically noticeable decrease in both TP and WI, which may compromise the aesthetic integrity of the restoration. In contrast, glazing provided more favourable optical stability. Although metamerism did not differ significantly, the findings highlight that surface finishing is critical for maintaining visual consistency under varying light. Clinicians should therefore prefer glazing when no adjustments are required or use polishing methods that minimally affect optical properties.

Ethics Committee Approval: This study was conducted entirely under *in vitro* conditions and did not involve human participants or animal subjects. Therefore, ethics committee approval was not required, in accordance with institutional and national guidelines.

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