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Original article

Effect of Surface Treatments on the Translucency and Color Stability of Zirconia-Based Dental Restorations

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Abstract

This in vitro study aimed to investigate the effects of hydrofluoric acid etching and sandblasting on the TP and ΔE values of zirconia-based dental restorations. Twenty zirconia discs were randomly divided between the hydrofluoric acid and sandblasting groups. A spectrophotometer was used to measure color coordinates and translucency before and after surface treatment. Statistical analysis consisted of paired and independent-samples t-tests and two-way analysis of variance (α=0.05). For translucency and color stability, neither surface treatment had a significant effect ($P>0.05$). Sandblasting resulted in a higher mean ΔE than hydrofluoric acid etching, as the difference was not statistically significant. Optical properties of zirconia were primarily dictated by its intrinsic material characteristics rather than its surface condition.

Keywords. Zirconia, Surface Treatment, Translucency, Color Stability, Sandblasting.

Introduction

In contemporary dentistry, achieving optimal esthetic outcomes represents a critical challenge in restorative treatment planning, driven by increasing patient demands for restorations that closely replicate the optical properties of natural dentition. Complex optical phenomena, including the reflection, absorption, scattering, and transmission of incident light, dictate the visual appearance of natural teeth. Therefore, the esthetic and clinical success of all-ceramic restorations is primarily determined by their capacity to simulate the complex light-transmission characteristics of natural teeth, with translucency serving as a critical determinant of their natural appearance [1].

Translucency was defined as the property of a material to transmit light in such a way that individual structures beneath the material cannot be clearly distinguished from one another [2]. Translucency is one characteristic that plays a core role in defining our natural-looking restorations in dental materials science, impacting brightness, perception of depth, and color blending ability with adjacent teeth. However, a material with too low translucency can lead to an opaque and unnatural appearance, while a hyper-translucent structure results in poor masking ability with compromised structural integrity [3]. The translucency parameter (TP) is a visual characteristic that affects how restorations appear to be similar to natural teeth [4]. Color stability is one of the major esthetic characteristics of zirconia-based restorations. It is related to the degree of color change of these materials over time by exposure to the oral environment and some staining agents. Color stability evaluation of dental ceramics is frequently done using spectrophotometry [5]. Color change ($\Delta E00$) evaluation enables researchers and dentists to objectively assess the performance of restorative composites after some years in different environments. The clinical acceptability threshold ($\Delta E00 \leq 1.8$) value helps to determine if color alterations observed are clinically noticeable and would be acceptable, guiding decisions in material choice and patient care [6].

Among all modern restorative materials, zirconia-based ceramics have been one of the most used biomaterials owing to their high mechanical strength, fracture resistance, chemical stability, and biocompatibility. Zirconia-based restorations have been widely used in fixed prosthodontics, implant prostheses, and monolithic restorations since their introduction into dental practice in the late twentieth century. The transformation-toughening mechanism that is inherent to yttria-stabilized tetragonal zirconia polycrystal (Y-TZP) offers amazing fracture resistance against crack propagation, thus making zirconia one of the most suitable materials for load-bearing restorations [7]. Despite these mechanical advantages, the inherent opacity of conventional zirconia has historically limited its use in highly aesthetic areas, especially in anterior restorations where translucency is of utmost importance. The main reason for the optical limitations of conventional zirconia is light scattering at grain boundaries, phase interfaces, and internal defects. The translucency of zirconia ceramics is influenced by factors such as grain size, porosity, crystalline phase distribution, and density [8]. The advent of high-translucent zirconia formulations has recently been achieved via yttria modification, fine-grain engineering, and inexpensive sintering technologies. The increase in cubic phase fraction has been demonstrated to improve translucency via diminishing birefringence and light scattering. But, these alterations can reduce mechanical strength, and the aesthetic characteristic should always be balanced with functional properties [9].

Surface treatment procedures can also affect the optical properties of zirconia restorations, alongside inherent material characteristics. A variety of surface treatments are often used in clinical practice to increase bonding strength, enhance wettability, and change the morphology. The commonly used procedures are air abrasion (also known as sandblasting), grinding, polishing, laser treatment, and chemical etching. Such interventions can vary surface morphology, thereby changing the reflection and light scattering behavior [10]. Sandblasting with aluminum oxide particles is a common clinical practice to improve micromechanical retention among zirconia surfaces and resin cements. Nevertheless, such

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processes can also create surface defects, including micro-cracks and phase transformation that may affect both mechanical and optical properties. In contrast, hydrofluoric acid (HF) etching has been studied as an alternative surface treatment for zirconia due to its use on silica-based ceramics despite this material's relatively low chemical reactivity with HF [11]. Although zirconia translucency could be improved by the utilization of surface treatments, the relationship is still debatable. While some studies indicate that increased surface roughness promotes diffuse light scattering, which decreases translucency, others report limited effects because of the uncontrolled contribution of internal microstructure factors. In addition to factors such as hydrolytic stability, color stability of restorations is also determined by modifications in surface properties that occur within the oral environment [12].
To accomplish improved clinical results, it is important to understand how the translucency and color stability of zirconia respond following various surface treatments. This information can help clinicians and dental technicians choose adequate surface modification protocols that retain esthetic properties while maintaining mechanical performance [13]. Despite the increasing clinical use of zirconia-based restorations and the routine application of surface treatment protocols, there is insufficient consensus regarding how commonly used surface treatments, particularly sandblasting and HF etching, affect the translucency and color stability of zirconia restorations [14]. The inconsistent findings reported in the literature create uncertainty when selecting surface treatment protocols that preserve both esthetic and functional properties. Therefore, further investigation is required to clarify the influence of these surface treatments on the optical performance of zirconia-based restorations [15].Therefore, the current study aimed to assess the influence of two procedures often used for surface treatment, sandblasting and HF etching, on the translucency parameter and color stability of zirconia-based restorations. The null hypotheses were that neither sandblasting nor HF etching of zirconia-based dental restorations would have a statistically significant effect on the translucency and color stability of zirconia.

Methods

Study Design

The present study aimed to investigate the effects of two widely applied surface treatment methods, including sandblasting and hydrofluoric acid (HF) etching, on the translucency parameter (TP) and color stability (ΔE) of zirconia-based dental restorations in a laboratory in vitro experimental study. The materials and devices used in the study are presented in (Table 1).

Table 1. The materials and devices used in the study.

Material	Manufacturer	Composition	Function
Zirconia discs (Zircad)	Ivoclar Vivadent	Y-TZP zirconia	Ceramic-based restoration
Hydrofluoric acid (5%)	Ultradent	HF gel	Chemical etching
Alumina particles (50 µm)	3M ESPE	Al_2O_3	Sandblasting
Distilled water	Lab grade	-	Cleaning
Spectrophotometer	Vita Easyshade	-	Color measurement

Specimen Preparation

Twenty discs of monolithic zirconia (Zircad, Ivoclar Vivadent; Schaan, Liechtenstein) were made in the A2 shade. A specimen with a diameter of 12 mm and a thickness of 1.2 mm was used. After reaching the densification with the help of sintering, all specimens were fully sintered according to factory-recommended sintering schedules after fabrication. The specimens were ultrasonically cleaned in distilled water for 10 minutes after sintering to remove any surface contaminants and then air-dried at room temperature prior to surface treatment. Figure 1 represents a zirconia sample.

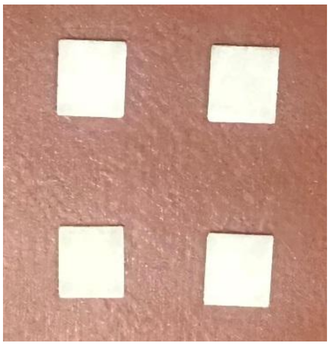

Figure 1. Representative images of the zirconia sample

Experimental Groups

The specimens were randomly assigned to two equal groups (n = 10) based on the surface treatment protocol: HF group: 5% hydrofluoric acid surface treatment. SB group: sandblasting (airborne-particle abrasion surface treatment).

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Surface Treatment Procedures

The HF group received a 5% hydrofluoric acid gel (Ultradent Products Inc., South Jordan, UT, USA) uniformly applied on the zirconia surface for 20 minutes. The samples were washed in distilled water for 60 seconds and air-dried after etching. In the group assigned to sandblasting, zirconia surfaces were treated with 50-µm aluminum oxide (Al_2O_3) particles (3M ESPE; St. Paul, MN; USA) at a pressure of 2.5 bar for 10 seconds in an airborne-particle abrasion device. The nozzle was held perpendicular to the surface of the specimen and remained at a distance of about 10 mm. The specimens were washed in distilled water and air-dried after the treatment.

Optical Measurements

Color stability measurements were conducted with the aid of a calibrated dental spectrophotometer (Vita Easy Shade, VITA Zahnfabrik, Bad Säckingen, Germany). The color difference (ΔE00) was calculated using the CIEDE2000 (La Commission Internationale de l'Éclairage) L*a*b* system with the CIE standard illuminant D65. For each specimen, the color coordinates were obtained from an enclosed area of the surface before and after treatment according to the following formula [6]:

$$\Delta E_{00} = \sqrt{\left(\frac{\Delta \grave{L}}{k_L \cdot SL}\right)^2 + \left(\frac{\Delta \grave{C}}{kc \cdot Sc}\right)^2 + \left(\frac{\Delta \grave{H}}{k_H \cdot S_H}\right)^2 + \left(R_T\left(\frac{\Delta \grave{C}}{k_C \cdot S_C}\right)\left(\frac{\Delta \grave{H}}{k_H \cdot S_H}\right)\right)}$$

where ΔL = the lightness difference, ΔC = the chroma difference, ΔH = the hue difference, and k_L, S_L, k_C, S_C, k_H, and S_H are the constants of the coefficient. The final ΔE00 values were evaluated against the perceptibility threshold, defined as the minimal visually detectable color change (ΔE00 = 0.8), and acceptability threshold, marked as the beginning of unacceptable color difference (ΔE00 = 1.8) [16]. The translucency parameter (TP) was calculated for all specimens in relation to standard white and black background droplets under uniform light conditions. TP was computed using the equation below [17]:

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

where the subscripts B and W represent measurements obtained over black and white backgrounds, respectively.

Statistical Analysis

Data were analyzed using IBM SPSS Statistics software (SPSS, Version 27.0; IBM Corp., Armonk, NY, USA). The assessment of data normality was performed through the Shapiro–Wilk test. To compare the translucency parameter within each surface treatment group before and after treatment, a paired-samples t-test was performed. Comparisons of the translucency parameter and color change (ΔE) between the hydrofluoric acid and sandblasting groups were conducted using an independent-samples t-test. The measured optical properties were analyzed using a two-way analysis of variance (ANOVA) to determine the relationship between surface treatment and evaluation time. Statistical significance was set at $p < 0.05$.

Results

Translucency parameter results (TP)

The mean translucency parameter (TP) values for both surface treatment groups before and after treatment are presented in (Figure 2). Prior to surface treatment, the hydrofluoric acid (HF) group demonstrated a higher mean TP value (2.33 ± 0.73) than the sandblasting (SB) group (1.53 ± 0.75); however, this difference was not statistically significant (P = 0.1558). Following surface treatment, the SB group exhibited a higher mean TP value (1.45 ± 0.81) than the HF group (1.09 ± 0.19), although the difference also failed to reach statistical significance (P = 0.3035). Within-group comparisons revealed no statistically significant differences between baseline and post-treatment TP values in either the HF group (P = 0.9218) or the SB group (P = 0.8282). These findings indicate that neither hydrofluoric acid etching nor sandblasting produced a significant alteration in the translucency parameter of zirconia specimens. Two-way analysis of variance demonstrated that surface treatment had no significant overall effect on translucency (P = 0.4506). In contrast, evaluation time showed a statistically significant influence on TP values irrespective of the surface treatment employed (P = 0.03), indicating that translucency values differed between baseline and post-treatment measurements when both groups were analyzed collectively.

Table 2. Comparison of translucency parameter results (TP) test results (Mean±SD) between both surface treatment groups

Variables		**Before**	**After**	***P value***
Surface treatment	*HF*	*2.33±0.73*	*1.09±0.19*	*0.9218 ns*
	SB	*1.53±0.75*	*1.45±0.81*	*0.8282 ns*
	P value	*0.1558 ns*	*0.3035 ns*	

**; significant (p < 0.05) ns; non-significant (p>0.05)*

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Translucency parameter results (TP)

The mean color change (ΔE) values are presented in (Table 3). The sandblasting group exhibited a greater mean color change (5.35 ± 2.48) than the HF group (3.94 ± 1.42). Nevertheless, the difference between the two surface treatment protocols was not statistically significant (P = 0.1361). These findings suggest that although sandblasting tended to induce greater color alteration than hydrofluoric acid etching, neither treatment produced a statistically significant difference in color stability.

Table 3. Comparison of color change (ΔE) results (Mean±SD) between the two surface treatment groups.

Variables		**Mean±SD**	***P value***
Surface treatment	HF	3.94±1.42	0.1361 ns
	SB	*5.35±2.48*	

**; Significant (p < 0.05)   ns; non-significant (p>0.05)*

Discussion

The purpose of the present in vitro study was to evaluate the effect of two zirconia surface treatment protocols (Hydrofluoric acid etching or airborne-particle abrasion) on the translucency parameter and color stability of zirconia-based restorations. The results showed that neither surface treatment had a significant impact on translucency or color stability, thus supporting the proposed null hypotheses. The translucency parameter (TP) is commonly used as a measure of material translucency. The optical property that influences the apparent mimicry of restorations to natural teeth is called the translucency parameter (TP). The color difference between the reflected colors of a material at a specific thickness when compared with a black and white background was used to evaluate it [18]. It can be calculated using the CIELab formula or the CIEDE2000 formula [19]. The translucency of material increases with increasing light transmittance. Translucency depends on a number of factors such as particle size, density, crystalline structure, type of substance, pigment, opacity, porosity, and distribution of oxygen space [20].

Translucency is an important optical factor in determining the esthetic integration of ceramic restorations with natural dentition. While surface treatments provide an opportunity to change the external morphology of zirconia, results of the present study would indicate that these changes may not translate into clinically relevant alterations in light transmission. Such observation may arise from the consideration that the optical response of zirconia is largely dominated by intrinsic microstructural features, such as grain size, crystalline phase distribution, porosity, and refractive index mismatch, rather than superficial surface alterations [21]. The lack of a noticeable advantage for hydrofluoric acid etching over sandblasting is in agreement with the limited chemical interaction of hydrofluoric acid with polycrystalline zirconia [22]. In contrast to other silica-based ceramics, zirconia does not contain a glassy or amorphous matrix that is selectively dissolved by hydrofluoric acid, which accounts for the little surface change and insignificant optical property alteration of the HF-treated bodies.

Likewise, even though airborne-particle abrasion increases surface roughness and micromechanical retention, the resulting superficial irregularities may be insufficient to significantly alter the total light transmission through the zirconia specimens [23]. The results revealed that evaluation time significantly affected translucency values, whereas the surface treatment protocol did not. This finding suggests that factors unrelated to the type of surface treatment, such as repeated optical measurements, specimen hydration, or subtle alterations occurring during specimen handling, may have contributed to the observed temporal variation. Because no significant interaction attributable to the treatment method was detected, the clinical relevance of this time-dependent change appears limited. Regarding color stability, the sandblasting group demonstrated numerically greater ΔE values than the hydrofluoric acid group; however, the difference was not statistically significant. Increased surface roughness produced by airborne-particle abrasion may enhance diffuse light scattering and increase susceptibility to pigment retention, thereby explaining the higher mean ΔE values. Nevertheless, the variability within the groups prevented these differences from reaching statistical significance. Overall, the present findings suggest that commonly used surface treatment procedures exert minimal influence on the optical properties of zirconia restorations. Consequently, clinicians may select either hydrofluoric acid etching or airborne-particle abrasion primarily according to bonding requirements without expecting substantial changes in translucency or color stability. Future investigations incorporating larger sample sizes, artificial aging, thermocycling, and long-term staining protocols are recommended to further clarify the effects of surface treatments on the esthetic performance of contemporary high-translucency zirconia materials. These findings align with previous studies emphasizing that improvements in zirconia translucency are primarily achieved through material composition modifications rather than surface treatments.

Conclusion

Within the limitations of this in vitro study, neither hydrofluoric acid etching nor sandblasting significantly affected the translucency parameter or color stability of zirconia-based dental restorations. Although sandblasting produced greater color change than hydrofluoric acid etching, the difference was not statistically significant. Surface treatment type had no significant overall effect on the optical properties of zirconia, indicating that the intrinsic microstructural characteristics of the material play a more dominant role in determining its translucency and color stability. These findings suggest that

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both surface treatment methods may be used clinically for bonding purposes without adversely affecting the esthetic performance of zirconia restorations. Further investigations incorporating artificial aging, thermocycling, and larger sample sizes are recommended to validate these findings under conditions that more closely simulate the oral environment.

Conflicts of Interest

The author declares that there is no conflict of interest regarding the publication of this manuscript.

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