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EFFECT OF DIFFERENT SURFACE TREATMENT PROTOCOLS ON THE COLOR AND TRANSLUCENCY OF ZIRCONIA CERAMICS WITH DIFFERENT TRANSLUCENCIES

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ABSTRACT

Objectives. To evaluate the effect of polishing, glazing (add-on) and auto glazing on the color and translucency of three types of monolithic zirconia ceramics with different translucencies.

Materials and Methods. 84 sintered zirconia discs were divided into 3 groups (n=28) according to the type of zirconia: 3Y-TZP (HT), 3Y-TZP multilayered (HTML), and 5Y-PSZ multilayered (UTML). Each group was subdivided into 4 subgroups according to the surface treatment protocol: milled (M), polished (P), glazed (add-on) (G), and auto glazed (AG). Color difference (ΔE) and translucency parameter (TP) were assessed by spectrophotometer. Statistical analysis revealed normal data distribution. One way analysis of variance (ANOVA) test was performed followed by Tukey`s Post Hoc test.

Results. Polishing in all groups had ΔE values of 1 or less. Glazing and auto glazing had ΔE values below 3.3 in groups HT and UTML, while in group HTML they were above 3.3. Within each surface treatment, group UTML recorded the lowest ΔE, followed by group HT, and group HTML recorded the highest value.

Group UTML had significantly the highest translucency among surface treatment methods. Subgroup P values were significantly the highest and subgroup G values were significantly the lowest, in groups HT and UTML. In group HTML, polishing had higher translucency than glazing but without significant difference.

Conclusions. Polishing caused the least color change in all groups and enhanced the translucency of groups HT and UTML. An inacceptable color change could be detectable after glazing (add-on) and auto glazing of monolithic HTML zirconia.

KEYWORDS. Translucent zirconia, Polishing, Glazing, Color change, Translucency.

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INTRODUCTION

A dental restoration is considered successful from esthetic perspective when its optical properties mimic those of natural dentition. [1] Color of dental ceramics is crucial for the success and longevity of the restorations. It is greatly influenced by surface roughness. [2] Surfaces having different degrees of roughness cause differences in hue, chroma and value. Modifications of surface affect the value mostly, the smoother the surface, the higher its value. [3,4]

Another key factor for the success and longevity of the esthetic restorations is translucency. Simply the translucency relies on the behavior of the incident light when it falls on an object in the form of transmission, reflection, refraction, scattering, and absorption. The object is considered translucent if the light is scattered and most of it is diffusely transmitted, while the object is opaque if most of light is absorbed and diffusely reflected. [5]

Zirconia ceramics have been widely used in fixed restorations due to their excellent mechanical properties and biocompatibility.[1,6] Monolithic zirconia restorations may face challenges regarding esthetic shade matching, color and translucency.[7-10] The shade matching of these restorations is affected by several clinical and laboratorial factors such as the cement shade, substrate color, and different fabrication technique. [11-14] While the color and translucency are affected by intrinsic factors, as microstructure, surface roughness and processing technique, and by extrinsic factors, as surface finishing, occlusal adjustments, brushing, and aging. [1,6,15,16]

The surface of zirconia including its compositional microstructure and roughness is considered critical, it has influence on the bacterial adhesion and abrasion of the natural antagonist. In other words, the surface structure influences the transmission, absorption, reflection, and scattering of light and thus has a major impact on the optical appearance of the restoration. [17]

Zirconia has been classified according to its chemical compositional microstructure by **Güth et al.** [18] into the well-known 4 generations (gen): 1st gen 3Y-TZP [3 mol% Yttrium oxide, 0.25% Aluminium oxide]; 2nd gen 3Y-TZP [3 mol% Yttrium oxide, 0.05% Aluminium oxide]; 3rd gen 5Y-PSZ [5 mol% Yttrium oxide, 0.05% Aluminium oxide]; 4th gen 4Y-PSZ [4 mol% Yttrium oxide, 0.05% Aluminium oxide]. The increase in the mol% Yttrium oxide and controlling the sintering temperature and sintering time have been accompanied by an increase in the cubic content resulting in enhancement of optical properties namely the translucency. [19, 20] The higher translucency is attributed to the isotropic nature of the cubic phase as compared to the tetragonal one, where the larger crystals together with the less grain boundaries and fewer residues allow more even incident light passage through the material in all spatial directions. [5] As stated by **Arcila et al** [21] there are 31% and 20% increase in cubic phase of 3rd gen. and 4th gen. respectively than that in 3Y-TZP.

Multilayering concept of the pre-colored monolithic zirconia has been widely applied among the different generations. This concept offers polychromatic restorations with gradience in their translucency. Also, it protects the restorations from reduction in its strength due to staining. [22]

Surface treatment of ceramic restorations to decrease surface roughness and produce a shiny smooth surface is one of the important factors that influences both color and translucency. The commonly used methods are polishing and glazing. Polishing includes successive mechanical steps using specific polishers. Glazing can be subdivided into two categories; Add-on glaze which involves the firing of layer of glaze paste/spray on the surface, and Auto glaze which includes heating the zirconia without adding any material to the surface up to the glazing temperature. [3, 23]

The effect of different surface treatments on color and translucency of different generations of monolithic zirconia is not well understood.[1] Therefore, this study has been carried out to close this research gap. The null hypothesis was that there would be no significant difference between polishing, glazing (add-on) and auto glazing surface treatments in the three tested zirconia types.

MATERIALS AND METHODS

Ethical approval

This study was approved by research ethics committee at Faculty of Dentistry, Cairo University (#21223).

Samples' grouping

A total of 84 sintered discs were divided into 3 equal groups according to the type of zirconia. Each group was further subdivided into 4 subgroups according to the surface treatment protocol (n=7). The sample size was calculated based on statistical analysis of previous study results to have adequate power to apply a statistical test of the null hypothesis.[1]

Samples' preparation

A cylinder of 14 mm length and 10 mm diameter was designed using 3D Builder software (Microsoft 3D Builder U.S.A) and the saved STL file was exported to MillBox Dental CAM software (DWX-4W CAM software, Roland DGA, California, USA).

Cylinders were milled from A3 shaded monolithic zirconia blanks of 14 mm thickness; 3Y-TZP translucent zirconia (Katana HT, Kuraray Noritake Dental Inc., Japan), 3Y-TZP translucent multilayered zirconia (Katana HTML Plus, Kuraray Noritake Dental Inc., Japan), and 5Y-PSZ translucent multilayered zirconia (UTML, Katana, Kuraray Noritake Dental Inc., Japan) using a 5-axis milling machine (DWX-52D 5-Axis, Roland DGA, California, USA). For the multilayered zirconia, care was taken during nesting to include all the layers of the blank to mimic the clinical situation. [24]

Dry milling protocol was followed as it is the recommended processing technique for delivering zirconia restorations with high translucency. [25] Three oversized cylinders (16.8 mm length and 12 mm diameter) were milled from each type of zirconia to overcome the 20% post sintering linear shrinkage. [26] Isomet (IsoMet4000, Buehler, Lake Bluff, USA) set at 2,500 rpm was used to section each cylinder into 10 oversized discs of 1.2 mm thickness using 0.4 mm thick blades made of cubic boron nitride (CBN). This process produced 30 zirconia discs from each type of zirconia where 28 discs were selected, and their dimensions were confirmed by a digital caliper (Digital Vernier Caliper IP54, USA).

Discs were cleaned in an Ultrasonic Cleaner (Pt dent Ultrasonic Cleaner CD-4830 3L, techno flux, China) filled with distilled water for 10 min, air-dried and then sintered in the furnace (Wiessen Zirconia sintering furnace; Germany) following manufacturer's sintering recommendations.

The discs' dimensions were verified using the digital caliper following the sintering process, yielding discs with a diameter of 10 mm and a thickness of 1 mm.

Samples' surface treatment

The sintered discs were divided into 3 equal groups (n=28): Group HT, group HTML, and group UTML. Each group was further subdivided into 4 subgroups (n=7) according to the surface treatment protocol as follows:

Sub-group M: milled samples without surface treatment to be the baseline for color and translucency measurements.

Sub-group P: milled samples were subjected to polishing. Polishing was done using the Diacera polishing kit (Diacera polishing kit for zirconia EVE Ernst Vetter GmbH) following the recommended manufacturer's instructions. Two successive step polishing protocol was applied, first step using the green medium grit rubber polisher (10.000min^{-1}) and the second step using the pink fine grit rubber polisher (6.000min^{-1}). Each polishing step was carried out in 60 seconds under constant pressure and in one direction. Finally, the surface was finished using a goat wheel polishing tip. [27]

Sub-group G: milled samples were subjected to glazing (add-on). Using a clean brush, the disc's surface was coated with clear glaze (Cerabien ZR, Kuraray Noritake Dental Inc., Japan). Next, in accordance with the manufacturer's instructions, the discs were put into the porcelain firing furnace (Programat P200 - Dental Porcelain Furnace) for the glazing cycle (850°C high temperature, 65°C/min heating rate, and 1 min holding duration). [28]

Sub-group AG: milled samples were subjected to auto glazing. The same firing process as glazing but without the application of any material to the surface.

Color and translucency tests

The color measurements were performed via Agilent Cary 5000 laboratory spectrophotometer (Agilent Technologies, USA). These measurements were taken at the baseline (before surface treatment) and after surface treatment. Accordingly, all subgroups in the three groups had undergone the colorimetric analysis twice except for subgroup (M).

The color measurements were done according to Commission Internationale de l'Eclairage (CIE) 1976 *L*a*b** color space (CIELAB) in the reflectance mode of the spectrophotometer which was equipped with an integrating sphere and aperture diameter of 5 mm.

The mean value of the three sequential measurements of L*, a*, and b* were recorded. L* denotes the lightness of the color, a* denotes the chromaticity of red-green, and b* denotes the chromaticity of yellow-blue. [29] The degree of color difference between the compared discs was expressed in ΔE^* units. These measurements were performed using the CIELAB formula $\Delta E^*ab = [(\Delta L^*)2 + (\Delta a^*)2 + (\Delta b^*)2]^{1/2}$. [30]

ΔE of value equal to or less than 1 cannot be noticed by human eye and ΔE of value more than 1 and less than 3.3 is categorized as perceptible but within the clinically accepted range while ΔE of value more than 3.3 is categorized as unacceptable. [30]

The translucency measurements were performed for each sample over a white backing with a specified parameters (CIE L*= 88.81, a*= -4.98, b*= 6.09) and black backing with the specified parameters of (CIE L*= 7.61, a*= 0.45, b*= 2.42) relative to the CIE standard illuminant D65. The translucency parameters (TP) values were obtained by calculating the color difference of the specimens over black and white backgrounds by using the following equation: $TP= [(Lb-Lw)\ 2+ (ab-aw)\ 2+ (bb-bw)\ 2]^{½}$. Then initial and final data were collected before and after applying the tested surface protocols: polishing, glazing (add-on) and auto glazing, and percentage of change was calculated according to the following formula [31]

$$\text{Percent change of (TP)} = \frac{\text{(TP) after surface finishing - (TP) before surface finishing}}{\text{(TP) Before surface finishing}} \times 100$$

The color and translucency measurements at 555 nm wavelength were chosen to compare the samples because this is the wavelength at which the human eye is most sensitive. [32]

Statistical Analysis

All data were presented as mean &standard deviation. Data were presented with two tables & two graphs. Statistical analysis was performed with SPSS 16 ® (Statistical Package for Scientific Studies), Graph pad prism & windows excel.

Exploration of the given data was performed using Shapiro-Wilk test and Kolmogorov-Smirnov test for normality which revealed that the significant level (P-value) was insignificant as P-value > 0.05

which indicated that all data originated from normal distribution (parametric data) resembling normal Bell curve.

Accordingly, comparison between different groups was performed by using One Way ANOVA test followed by Tukey`s Post Hoc test for multiple comparisons.

RESULTS

Color evaluation

Color changes comparison between different groups and subgroups has been presented in Table (1), Figure (1).

- Comparison between different groups within each type of surface treatment tested revealed signifcant difference between them (P<0.0001) as:

Subgroup P: there was a a signifcant difference between all groups as HTML (1.12 ± 0.05) was signifcantly the highest, while UTML (0.95 ± 0.04) was signifcantly the lowest.

Subgroup G: group HTML (3.87±0.1) was signifcantly the highest, while group HT (3.17±0.16) and group UTML (3.14±0.15) were signifcantly the lowest with inisgnifcant difference between them.

Subgroup AG: there was a a signifcant difference between all groups as group HTML (3.51±0.16) was signifcantly the highest, while group UTML (2.64±0.12) was signifcantly the lowest.

- Comparison between different subgroups within each group revealed signifcant difference between them (P<0.0001) as:

In group HT: there was a signifcant difference between all subgroups as subgroup (P) (1.01 ± 0.04) was signifcantly the lowest, while subgroup (G) (3.17 ± 0.16) was signifcantly the highest.

In group HTML: there was a signifcant difference between all subgroups as subgroup (P) (1.12±0.05) was signifcantly the lowest, while subgroup (G) (3.87 ± 0.19) was signifcantly the highest. In addition the color difference in subgroups (G) and (AG) showed the highest values in comparison to baseline which are clinically not acceptable (ΔE^*_{ab}>3.3).

In group UTML: there was a signifcant difference between all subgroups as subgroup (P) (0.95±0.04) was signifcantly the lowest, while subgroup (G) (3.14 ± 0.15) was signifcantly the highest.

TABLE (1) Mean and standard deviation of color changes in polished, glazed (add-on) and auto glazed surface treatments in all groups and comparison between them using One Way ANOVA test:

Group	**Δ E**						**P value (One Way ANOVA test)**
	Polished (P)		**Glazed (Add-on) (G)**		**Auto glazed (AG)**		
	M	**SD**	**M**	**SD**	**M**	**SD**	
HT	1.01 aA	0.04	3.17 aB	0.16	2.91 aC	0.14	<0.0001*
HTML	1.12 bA	0.05	3.87 bB	0.19	3.51 bC	0.16	<0.0001*
UTML	0.95 cA	0.04	3.14 aB	0.15	2.64 cC	0.12	<0.0001*
P value (One Way ANOVA test)	<0.0001*		<0.0001*		<0.0001*		<0.0001*

Mean with different superscript letters (small per column / capital per raw) were signifcantly differemnt as P<0.05.
Mean with the same superscript letters (small per column / capital per raw) were insignifcantly differemnt as P>0.05.

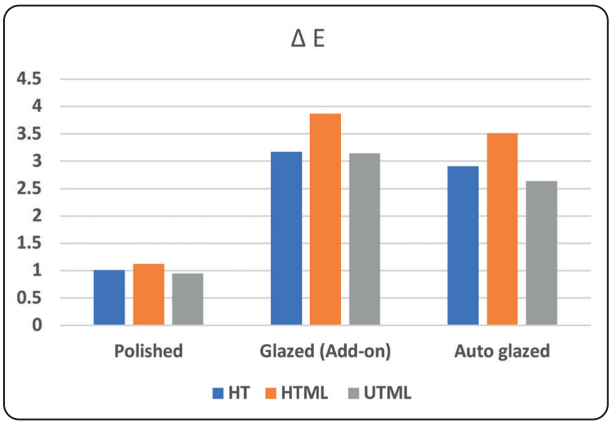

Fig. (1) Column chart representing color changes of all groups.

Translucency evaluation:

Translucency comparison between different groups and subgroups has been presented in Table (2), Figure (2).

- Comparison between different groups within each type of surface treatment tested revealed signifcant difference between them (P<0.0001) as:

Subgroup (M): group **HTML** (6.11 ± 0.28) and group **HT** (6.5 ± 0.29) were signifcantly the lowest with insignifcant difference between them, while group **UTML** (7.49 ± 0.34) was signifcantly the highest.

Subgroup (P): there was a signifcant difference between all groups as group **HTML** (6.24 ± 0.28) was signifcantly the lowest, while group **UTML** (7.6 ± 0.34) was signifcantly the highest.

Subgroup (G): group **HTML** (5.88 ± 0.26) and group **HT** (6.22 ± 0.28) were signifcantly the lowest with insignifcant difference between them, while group **UTML** (6.92 ± 0.31) was signifcantly the highest.

Subgroup (AG): group **HTML** (6.08 ± 0.27) and group **HT** (6.47±0.29) were signifcantly the lowest with insignifcant difference between them, while group **UTML** (7.06±0.32) was signifcantly the highest.

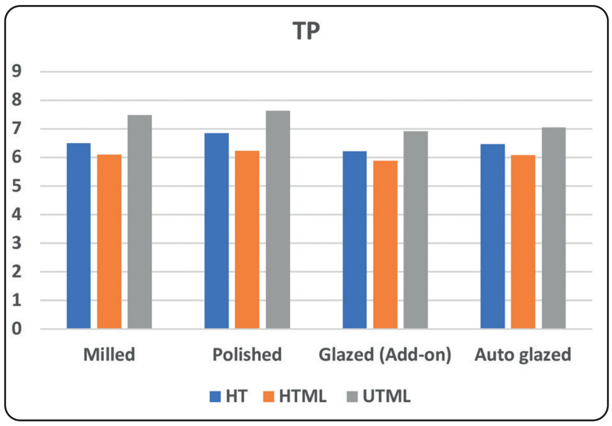

Fig. (2) Column chart representing translucency of all groups.

TABLE (2) Mean and standard deviation of translucency in milled, polished, glazed (add-on) and auto glazed surface treatments in all groups and comparison between them using One Way ANOVA test

	Translucency Parameter (TP)								P value (One Way ANOVA test)
	Milled		Polished		Glazed (Add-on)		Auto glazed		
	M	SD	M	SD	M	SD	M	SD	
HT	6.50 aAB	0.29	6.85 aA	0.31	6.22 aB	0.28	6.47 aAB	0.29	0.005*
HTML	6.11 aA	0.28	6.24 bA	0.28	5.88 aA	0.26	6.08 aA	0.27	0.12
UTML	7.49 bAB	0.34	7.63 cA	0.34	6.92 bC	0.31	7.06 bBC	0.32	0.001*
P value (One Way ANOVA test)	<0.0001*		<0.0001*		<0.0001*		<0.0001*		

Mean with different superscript letters (small percolumn / capital per raw) were signifcantly differemnt as P<0.05.
Mean with the same superscript letters (small percolumn / capitall per raw) were insignifcantly differemnt as P>0.05.

- Comparison between different subgroups within each group revealed the following:

In Group HTML: there was insignificant difference betweeen all subgroups as P>0.05.

In Group HT: Subgroup **(P)** (6.85 ± 0.31) was signifcantly the highest, while subgroup **(G)** (6.22 ± 0.28) was signifcantly the lowest. Both subgroup **(M)** and subgroup **(AG)** revealed insignifcant difference.

In Group UTML: subgroup **(P)** (7.63 ± 0.34) was signifcantly the highest, while subgroup **(G)** (6.92 ± 0.31) was signifcantly the lowest.

DISCUSSION

Zirconia restorations in its monolithic translucent forms have gained popularity in prosthetic dentistry.[6] Polychromatic multilayered zirconia has been considered a great add to the library of esthetic monolithic restorations. [22] Also, the increase in the cubic content has caused a remarkable enhancement of the translucency of monolithic zirconia. [19,20] Thus, combining the increasing in cubic content together with multilayering would be expected to reveal a restoration with highly appealing esthetics. Accordingly, three types of monolithic restorations were chosen in this study: 3Y-TZP translucent zirconia (group HT), 3Y-TZP translucent multilayered zirconia (group HTML), and 5Y-PSZ translucent multilayered zirconia (group UTML).

The choice of the thickness of the produced discs in this study relied on the minimum thickness recommended by the manufacturer for crowns in the esthetic zone including the premolar region. 1mm thickness was specified for group UTML. [26] Although groups HT and HTML can be produced at less thickness, 1 mm thickness was applied to all samples in this study for the standardization. Also, 10 mm was the standardized disc diameter to allow for the inclusion of all the layers of groups HTML, UTML in the sample.

Different surface treatment methods have been applied to monolithic zirconia restorations with the aim of enhancing the surface smoothness and accordingly improving both the color and the translucency of these restorations. [3] Polishing of monolithic zirconia has been remarkably increasing lately for their ability to provide smooth glossy surfaces that are comparable to the glazed ones. [33] However, there is no conclusive evidence in literature supporting one method over the other when it comes to the color and translucency properties of different monolithic zirconia restorations. Accordingly, three tested methods have been selected in this study: the two commonly applied polishing and glazing (add-on) methods, and the auto glazing method.

The detectability of the human eye to variations in color is critical. The quantitative evaluation of the difference in color between before and after surface treatment of discs was expressed in ΔE. The perceptibility threshold and acceptability threshold are two important visual tools for assessing the color difference between dental materials and/or dental structures. These two parameters are indicated through their 50:50% values; the perceptibility threshold represents the smallest color difference that can be noticed by 50% of the observers, while the acceptability threshold represents the smallest color difference clinically acceptable for 50% of the observers. [34] The perceptibility threshold was detected at value of ΔE more than 1 while the acceptability threshold was detected at value of ΔE below 3.3. [30]

Translucency is mandatory to reproduce the natural appearance of the vital tooth in the final restoration, accordingly measurement of the Translucency Parameter (TP) before and after the application of surface treatment method was done for the tested zirconia discs. Translucency Parameter was determined by calculating the color difference of the same sample against white and black background by using laboratory spectrophotometer. [31]

The null hypothesis of the current study had been rejected based on the results as both the color and translucency were significantly affected by the applied surface treatment whether it was polishing, glazing (add-on) or auto glazing in the three tested zirconia types. Moreover, in each subgroup, there were significant differences between the recorded values of 3 zirconia types.

The results of this study are in accordance with the conclusion drawn in the systematic review conducted by **Al Nassar TM** [6] in 2022 that the optical properties of monolithic zirconia such as color and translucency may be significantly affected by different surface treatments. Also, in 2023, **Toma et al** [5] concluded in their study that polishing and glazing, as surface treatments, influence the optical properties of multilayered zirconia.

Upon investigating the color of different groups and subgroups, the results showed significant influence of the surface treatment method on three zirconia groups (HT, HTML, UTML). Polishing caused the lowest changes in color, and glazing (add-on) had the highest color changes, while auto glazing results were inbetween them.

The recorded values of color changes (ΔE) due to polishing in the three tested zirconia types were equal to 1 or less, therefore considered satisfactory as according to **Sakaguchi et al** [30], they were just below the perceptibility threshold. However, the values of ΔE due to add-on glazing and autoglazing varied such that those of group UTML and group HT were considered clinically perceptible. While those of group HTML were above 3.3 and were considered clinically unacceptable.

The findings of this study could be explained by the difference in nature between the three applied surface treatments. Polishing was carried out using polishers only without the addition of any chemical paste. On the other hand, glazing (add-on) procedure was held at high temperature after applying the glazing paste where the observed color changes could be related to the chemical breakdown of this paste during firing. Moreover, the color changes that accompanied the auto glazed zirconia proves that the process of heat treatment itself might cause structural changes. [3]

Kim et al. [3], demonstrated that polishing and glazing of Yttria-stabilized tetragonal zirconia diminishes the brightness and causes a perceptible color difference. In their study, the tested zirconia samples were liquid colored before carrying out the surface treatment method whether polishing or glazing which could be the reason behind the contradiction to the results of the current study. Also, **Kurt and Bal** [29] examined liquid colored zirconia after polishing with and without a paste and after glazing. They found that the highest color shift was detected in zirconia samples treated with polishing with a paste, whereas no significant difference was found between polishing without a paste and glazing. Furthermore, **Li et al.** [1] found that zirconia crown polishing produced the most color change.

Regarding the translucency of different groups. group **UTML** had signifcantly the highest translucency in all the types of surface treatments tested in this study. This is correlated to the cubic content of zirconia. Cubic grains are considerably larger than tetragonal grains. Where the greater the cubic content, the less is the light scattering from the grain boundaries and the higher is the translucency. [35]

In the two groups having the same cubic content, group **HTML** had less translucency than group **HT**. **Choi et al.** [36] evaluated the translucency of different translucent monolithic zirconia materials through hydrothermal aging and explained the reason behind this finding. In monolayered zirconia, cubic zirconia formation could be enhanced by the presence of certain metal oxides such as the coloring pigments, resulting in a small increase in the translucency due to the reduced light scattering from the grain boundaries of cubic zirconia. While the multilayered forms of translucent monolithic zirconia showed a small decrease in the translucency which could be attributed to the changes in the surface morphology resulting in increased light scattering.

The surface treatment protocols affected the translucency of different groups where subgroup P was significantly the highest and subgroup G was significantly the lowest, in group HT and group UTML. While in group HTML, polishing had higher translucency than glazing but without significant difference. This may be attributed to the applied polishing protocol resulting in fine lustered surface with reduced light scattering and increased translucency. This was consistent with the findings of **Li et al.,** [1], who found that polishing greatly decreased surface roughness and enhanced translucency. On the other hand, brushing the glaze liquid resulted in the formation of a wavy surface with higher light scattering. Also, **Toma et al.,** [5] stated that the mean translucency values for polished multilayer translucent zirconia before aging were higher than that of the glazed ones.

The results of the current study are in disagreement with **Teja et al.,** [37] who reported that the even distribution of the glaze on the surface resulted in less surface roughness in comparison to polishing and accordingly better translucency. Moreover, **Ali et al.** [31] assessed the translucency of polished versus glazed cubic ultra-translucent multi-layered zirconia and found that glazing enhanced the translucency of UTML zirconia. They stated that polishing is technique sensitive, and the polishing steps must be applied with great care to reach the targeted smoothness.

In all tested zirconia types, auto glazing exhibited significant decrease in color changes and non-significant increase in translucency as compared to glazing (add-on) surface treatment. These results highlight the influence of using the glazing paste and introduces auto glazing surface treatment as a possible alternative to glazing whenever applicable.

This study showed that proper polishing reduces color changes and enhances translucency. However, invitro investigation is considered a limitation. Further investigations are necessary to evaluate the effect of the clinical complex factors.

CONCLUSIONS

Within the limitations of this study, the following conclusions can be drawn.

1. Polishing caused the least amount of color change of high translucent, high translucent multilayered and ultra-translucent multilayered zirconia.
2. Polishing enhanced the translucency of high translucent and cubic ultra-translucent multilayered zirconia.
3. An inacceptable color change could be detectable after glazing (add-on) and auto glazing of monolithic HTML zirconia.
4. Auto glazing was an acceptable surface treatment method in high translucent and ultra-translucent multilayered zirconia.

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