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EVALUATION OF TRANSLUCENCY PARAMETER AND MICROSTRUCTURAL CHARACTERIZATION OF THREE TYPES OF TRANSLUCENT ZIRCONIA AFTER LASER TREATMENT (AN IN VITRO STUDY)

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ABSTRACT

Objectives: This study evaluates translucency parameter (TP) and microstructural characterization of three types of translucent zirconia (Y-TZP) after Er:YAG laser treatment. **Materials and Methods:** For this evaluation, test specimens were prepared from Cercon Translucent Zirconia (ht) (Dentsply, Sirona, USA), Cercon High Translucent Zirconia (xt) (Dentsply, Sirona, USA) and Cercon Ultra Translucent Zirconia (xtml) (Dentsply, Sirona, USA) that were divided into control (untreated) group and laser treatment group. Laser treated specimens were subjected to Er:YAG laser with following parameters: wavelength of 2940 nm, frequency of 10 Hz, energy of 200 mj and a power of 2W for 10 seconds. The specimens from both groups were subjected to TP measurements using a spectrophotometer. For the characterization, zirconia discs from each group were analyzed using X-ray diffraction (XRD) and Energy Dispersive X-Ray Analysis (EDX).

Results: The results revealed significant decrease in the average TP in all groups after laser surface treatment: (5.65 and 5.32) for groups IA and IB respectively, (8.54 and 8.05) for groups IIA and IIB respectively, and (12.12 and 11.21) for groups IIIA and IIIB, respectively. For XRD analysis, results showed appearance of a monoclinic phase after laser treatment. Elemental composition by EDX analysis showed the presence of Carbon (C), Oxygen (O), Aluminum (Al), Ytteria (Y) and Zirconium (Zr). The results were analyzed using the Kolmogorov-Smirnov test, Shapiro-Wilk test and Two-way ANOVA test ($P \leq 0.05$).

Conclusion: Er: YAG Laser surface treatment significantly affected the TP and XRD analysis.

KEY WORDS: Translucency Parameter, Er: YAG laser, EDX and XRD.

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INTRODUCTION

Nowadays, patients' interest towards esthetic dentistry has increased. Zirconia is one of the tooth-colored materials with several advantages: good esthetic characteristics, excellent mechanical and biological behaviors. Therefore, zirconia has extensive applications as a restorative material in various clinical situations.[1-3]

Several variations of zirconia have been developed, with each new material intended to provide some quality improvement over previous versions. Recently, the use of monolithic yttria-stabilized tetragonal zirconia polycrystal (Y-TZP) for indirect restorations has been developed to overcome the problems of veneered zirconia fixed dental prostheses (FDPs).[2]

Computer-aided design/computer-aided manufacturing (CAD/CAM) tools are used to mill monolithic zirconia FDPs from blocks, and they can be polished or glazed for improved aesthetic results.[3-5]

Monolithic zirconia FDPs offer significantly improved strength and chip resistance. To achieve a more aesthetically pleasing and translucent restoration and to match zirconia's success in terms of physical qualities, various varieties of monolithic zirconia have been developed. The stabilizer that is used most frequently is yttria (Y_2O_3).[4]

In order to increase translucency, this was achieved by having a substantially lower alumina percentage than traditional zirconia. Therefore, the addition of 3% mol Yttria to zirconia leads to the formation of Translucent Zirconia higher Yttria concentration of 5% mol increased the cubic phase content, and this is known as High Translucent Zirconia. Addition of 8% mol Yttria content will result in complete stabilization of cubic phase zirconia and will produce Ultra translucent zirconia.[4,5]

Translucency of esthetic dental materials can be measured by using either the Translucency Parameter (TP) or Contrast Ratio (CR) using the Spectrophotometer. The TP represents the color difference between a material of uniform thickness on a black and a white background. Zirconia-based ceramics are known for their low translucency if compared to the other all-ceramic materials. However, recently, novel zirconia-based ceramics have been launched in the dental markets with manufacturers' claims of higher translucency.[6]

The TP represents the color difference between a material of uniform thickness on a black and a white background and corresponds directly to a common visual assessment of translucency.[7,8] The Commission Internationale de l'Eclairage (CIE) recommends calculating color difference (ΔE) based on CIELAB color parameters. The CIE L*a*b* system is an approximately uniform color scale in which the differences between points plotted in the color space correspond to visual differences (ΔE) between the colors plotted. The CIE L*a*b* color space has the L* axis on the vertical plane and represents the value (or brightness) of the color. On the horizontal plane: the a* axis, red is a positive value and green is negative; and the b* axis, yellow is positive, whereas blue is negative.[7,8]

There is no agreement about the best surface treatment to promote surface roughness, increasing wettability and to obtain optimum adhesive bond strength between zirconia and resin. Sandblasting, Air abrasion, Co_2 laser surface treatment cause microcracks on zirconia surface that reduces bond strength and render the phase transformation of zirconia.[5,6,9]

The purpose of this study was to evaluate translucency parameter and microstructural characterization of three types of translucent zirconia (Y-TZP) after Er:YAG laser treatment.

MATERIALS AND METHODS

Three types of Yttrium-Stabilized Polycrystalline Zirconia (Y-SPZ) (Fig.1) blocks were used: Cercon Translucent Zirconia (ht) (Dentsply, Sirona, USA), High Translucent Zirconia (xt) (Dentsply, Sirona, USA) and Ultra Translucent Zirconia (xtml)

Fig. (1): The three types of Zirconia discs (a. For translucent zirconia b. High translucent zirconia c. Ultra translucent zirconia).

(Dentsply, Sirona, USA). Discs were divided into two main groups according to surface treatment: Control (untreated) group (group A) and Laser surface treatment (group B) n=60 per group. Discs were milled in a uniform thickness of 2mm and a uniform diameter of 6mm.

Specimens Preparation

Zirconia specimens were designed by Sirona Blender Software (Sirona blender software_version 19, USA) and milled by Sirona MC X5 milling bur (Milling bur_MC x5, USA) in InLab MC X5 milling machine (Milling machine_MC x5, USA) with a uniform thickness of 2mm and a uniform diameter of 6mm. Afterwards, all discs were glazed by the application of thin layer of High Flu overglaze (High Flu overglaze, DentsplySirona, USA) before sintering. Zirconia discs were sintered using Inlab profire (inLab Profire_ DentsplySirona, USA) for 6 hours with gradual increase in temperature with a rate of 3˚C/min till reaching 1500˚C and holding this temperature for 2 hours followed by gradual decrease in temperature by 5˚C/min till complete cooling at 25˚C.[10]

Laser Surface Treatment

Twenty prepared specimens of each type of zirconia representing group (B) were subjected to Erbium-doped Yttrium Aluminum Garnet (Er:YAG laser) (Fotona laser device, fotona, Slovenia) (Fig.2). The device used was adjusted to the following parameters: wavelength of 2940 nm, frequency of 10 Hz, energy of 200 mj and a power of 2W for 10 seconds.

Fig. (2): Zirconia specimens treated with Er:YAG laser

Translucency Parameter (TP) Measurement

Translucency Parameter was determined by calculating the color difference of the same specimen against white (W) and black (B) background by using Spectrophotometer (Spectrophotometer_UV-Shimadzu 3101 PC, Japan) (Figs. 3,4). TP was measured according to the (CIE) L*a*b* color scale.[11] Measurements were carried out at wavelengths ranging from 240nm to 2600nm intervals. A 2-degree observer function was used with CIE illuminant D65. Measurements were conducted according to the following equation.

TP = [(LB-LW) 2 + (aB- aW) 2 + (bB-bW) 2] ½

Where, L* refers to the brightness, a* refers to greenness, and b* refers to blueness.

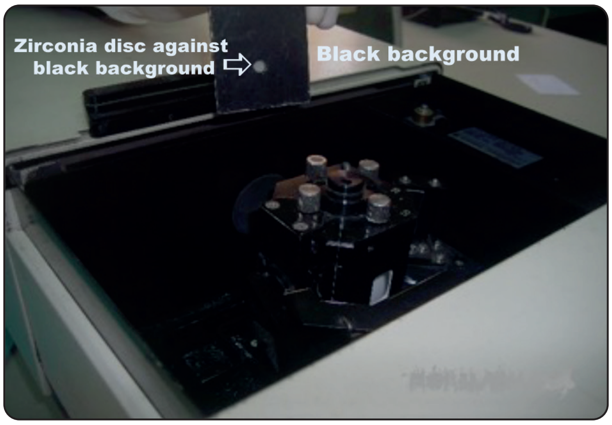

Fig. (3): Disc against black background

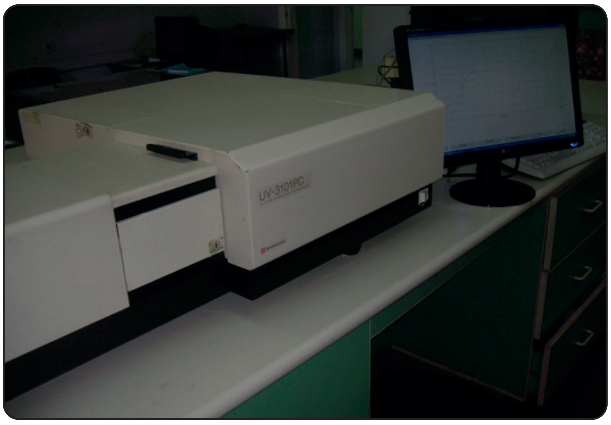

Fig. (4): Spectrophotometer

Specimens' Characterization

Characterization of specimens were done for the control (untreated) and laser treated groups by X-ray diffraction (XRD) (XRD_BRUKER Co,Germany) and Energy Dispersive X-Ray Analysis (EDX) (EDX_JOEL,Finland).

Statistical analysis

Numerical data were explored for normality by checking the distribution of data and using tests of normality (Kolmogorov-Smirnov and Shapiro-Wilk tests). All data showed normal (parametric) distribution. Data were presented as mean and standard deviation (SD) values. Two-way ANOVA test was used to study the effect of zirconia type, surface treatment, and their interactions on different variables. Bonferroni's post-hoc test was used for pair-wise comparisons when ANOVA test is significant. The significance level was set at $P \leq 0.05$. Statistical analysis was performed with IBM SPSS Statistics for Windows, Version 23.0. Armonk, NY: IBM Corp.

RESULTS

Results of Crystalline phase identification by XRD analysis

The XRD pattern shown in (Fig.5) of Zirconia specimens of the control (untreated) (Group A) have crystalline diffraction peaks at 2θ values of 21.2°, 50.1°, and 59.8° corresponding to (−111), (022), and (131) planes, respectively, according to (JCPDS No. 37-1484). Typical peaks of Y-TZP were observed in the 2θ range between 20 and 80. The main peak of the patterns was detected at about 21 to 22 corresponding the tetragonal zirconia.

The XRD pattern shown in (Fig.6) of Zirconia specimens after laser treatment (Group B) has crystalline diffraction peaks at 2θ values of 21.4, 59.4 and 60.4 originate from the crystal planes (-111), (131) and (202) of tetragonal zirconia (JCPDS No. 50-1089), respectively. And the diffraction peak with 2θ values of 50.2 and 55.3 can be assigned to the crystal planes (022) and (112) of tetragonal zirconia. While the peak at 2θ value of 23.4 corresponds to the crystal planes (-111) of monoclinic zirconia (JCPDS No. 37-1484).

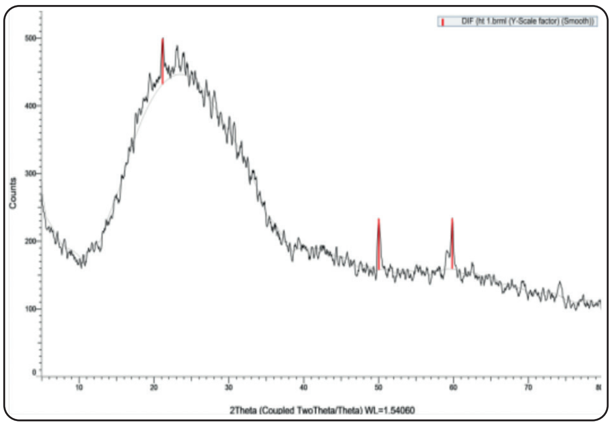

Fig. (5) XRD pattern of zirconia specimens for control (untreated) Group A

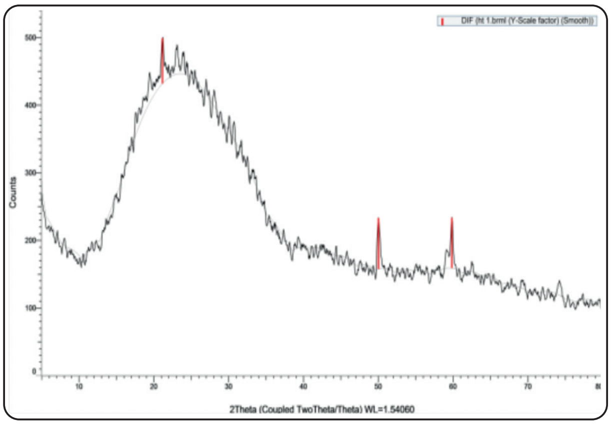

Fig. (6): XRD pattern of zirconia specimens after laser surface treatment Group B

Results of Elemental composition analysis by EDX analysis

EDX composition (atomic %) and spectrum of the three zirconia types for Groups A and B are listed in (Table 1), respectively. EDX elemental analysis of Zirconia specimens of both Groups A and b were the same showing the presence of Carbon (C), Oxygen (O), Aluminum (Al), Ytteria (Y) and Zirconium (Zr).

Results of Translucency Parameter measurement

The results revealed significant decrease in the average TP in all groups after laser surface treatment: (5.65 and 5.32) for groups IA and IB respectively, (8.54 and 8.05) for groups IIA and IIB respectively, and (12.12 and 11.21) for groups IIIA and IIIB, respectively.

Whether with control or Laser surface treatment**;** there was a significant difference between the TP of all zirconia types (*P*-value <0.001). Pair-wise comparisons revealed that ultra translucent zirconia showed significantly the highest mean TP (12.12 and 11.21) for IIIA and IIIB, respectively. High translucent zirconia showed significantly lower mean value (8.54 and 8.05) for IIA and IIB, respectively. Translucent zirconia showed significantly the lowest mean TP (5.65 and 5.32) for IA and IB, respectively.

Statistical analysis for the means and standard deviation (SD) values of the average TP of the three investigated zirconia before and after laser treatment (Groups A and B) respectively, are listed in (Table 2)

TABLE (1) EDX elemental analysis of The Three Types of Zirconia specimens for groups A and B.

Element	Translucent (atomic percent)	Hight translucent (atomic percent)	Ultra translucent (atomic percent)
C*	52.85±0.61	53.20±0.62	50.78±0.53
O*	37.08±0.53	36.12±0.52	36.12±0.52
AI*	0.75±0.02	0.76±0.02	0.76±0.02
y*	0.54±0.03	1.02±0.03	2.12±0.03
Zr*	9.05±0.05	8.90±0.05	7.62±0.04

Spc_001 ***Fitting ratio 0.0503***

TABLE (2) The means and standard deviation (SD) values of the average translucency parameter between before and after laser treatment groups in each material type

Surface treatment	Translucent I		High translucent II		Ultra translucent III		P-value	Effect size (Partial eta squared)
	Mean	SO	Mean	SO	Mean	SO		
Control	5.65^{C}	0.16	8.54^{B}	0.19	12.12^{A}	0.29	$<0.001^{*}$	0.992
Laser	5.32^{C}	0.14	8.05^{B}	0.16	11.21^{A}	0.16	$<0.001^{*}$	0.990
P-value	0.010+		<0.001+		<0.001+			
Effect size (Partial eta squared)	0.247		0.407		0.706			

: Significant at P ≤ 0.05, Different superscripts in the same row indicate statistically significantdifference between zirconia types

DISCUSSION

The materials evaluated in this study were; Translucent Zirconia (cercon_Dentsply Sirona,USA), High Translucent Zirconia (cercon_Dentsply Sirona,USA) and Ultra-translucent Zirconia (cercon_Dentsply Sirona,USA). Cercon Zirconia was chosen as the manufacturer claims higher translucency.

Nowadays, there have been high demands for restorations with adequate translucency and strength. This has led to the introduction of numerous recent zirconia ceramic materials. Zirconia is one of the tooth-colored materials with acceptable esthetics, excellent mechanical and biological behaviors. This in turn provided numerous indications for zirconia in various clinical situations.[1,2,12]

However, the aesthetic effects of zirconia are significantly affected by its opaque look. Hence, porcelain layering materials were suggested to improve the appearance. However, this issue was not entirely resolved despite changes in the veneering method. With yearly rates ranging from 0 to 54%, porcelain chipping has been identified as one of the most common technical issues in veneered zirconia crowns. The materials evaluated in this study were; Cercon Ultra translucent zirconia, Cercon High translucent zirconia and Cercon Translucent zirconia. Ultra translucent zirconia and High translucent zirconia were chosen as the manufacturer claims higher translucency, while Translucent zirconia served as the control.[13,14]

In our study, the results of the XRD analysis before laser treatment revealed the appearance of only the tetragonal phase of the zirconia. However, after laser treatment a new monoclinic phase appeared in addition to the tetragonal phase. This might be due to the laser energy that might have stimulated the tetragonal monoclinic transformation.

The EDX elemental analysis results of the three types of zirconia for Yttria and Alumina, respectively were: (2.12±0.03 and 0.76±0.02) for Ultra translucent zirconia and (1.02±0.03 and 0.76±0.02) for High translucent zirconia, (0.54±0.03 and 0.75±0.02) for Translucent zirconia. These results show an increase in the Yttria content over the alumina percentage moving from the translucent, High and finally to the Ultra translucent zirconia. This might have played a role in increasing the translucency among the three zirconia types.

The results of the EDX analysis of this study were in accordance with **Ghodsi et al** paper which stated that increasing yttria dopant content increases the translucency. In addition, they stated that the developments of reduced alumina content zirconia ceramics led to more translucent zirconia.[15]

From the various optical properties that might affect dental restorations, translucency plays an important role in simulating natural dentition. However, mimicking the optical features of natural teeth is not an easy task which might be due to the heterogeneous tooth structure. Natural enamel is very translucent and able to transmit up to 70% of light, while dentin transmits only up to 30% of light. There are few research assessing the translucency of enamel, mostly because of the difficulty of attaining pure enamel specimens of adequate size and thickness for measurement. In addition, the translucency of enamel varies with age, gender and tooth shade. **Ryan et al., 2010** found human enamel and dentin translucency parameter values of 11.6 ± 0.3 and 6.6 ± 2.2, respectively for 2 mm thickness samples.[16,17]

Translucency parameter (TP) values of 1mm thickness human dentin and enamel have been reported as 16.4 and 18.7 respectively. For translucent zirconia of different types, TP of 1 mm thickness is approximately 11.2 to 15.33 which is less than the measured parameter for 1mm thickness lithium disilicate (16.89). With all efforts to improve the translucency of dental zirconia over the last decade, it has been generally accepted that over 0.5mm of thickness, the translucent zirconia remains predominantly opaque, **Kwon et al.,2018**. In the present study the use of 2 mm thickness may attribute with the decreased TP of zirconia specimens.[18]

In this study, the average TP was significantly decreased after the laser treatment : (5.65 and 5.32) for groups IA and IB respectively, (8.54 and 8.05) for groups IIA and IIB respectively, and (12.12 and 11.21) for groups IIIA and IIIB, respectively.

In addition, this might be attributed to the appearance of a monoclinic phase as evident by the results of XRD analysis. The monoclinic phase of the zirconia has a different refractive index and different size when compared with the tetragonal phase of zirconia.

CONCLUSION

Within the limitations of this study, the following conclusions could be drawn:

- Er: YAG Laser surface treatment significantly decreased the translucency parameter of ultra translucent zirconia.
- Er:YAG Laser can be considered a promising zirconia surface treatment in other mechanical and physical tests, that will be published later this year.

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