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EFFECT OF SANDBLASTING AND CO2 LASER SURFACE TREATMENTS ON THE SURFACE HARDNESS AND TOPOGRAPHY OF ZIRCAD CERAMIC MATERIAL

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ABSTRACT

Background: Zirconia-based ceramics are widely used in dental restorations due to their excellent mechanical properties, biocompatibility, and aesthetic appeal. **Purpose of the study:** Surface treatments such as sandblasting and CO2 laser irradiation are commonly used to modify the surface characteristics of zirconia ceramics, improving the hardness of zirconia ceramic materials.

Materials and methods: IPS e.max ZirCAD® Prime disc was cut, prepared 30 specimens were prepared and divided into 3 groups with different surface treatments (10 Samples each) and treated by sandblasting , CO2 laser treatments 3Watt and 4Watt.Surface hardness was tested by Vicker hardness tester and surface topography was measured by atomic force microscope for each group and statistical analysis was done.

Results: Regarding surface hardness, a significantly higher mean value was recorded in Group (3 watt) (1100.78±68.93), in comparison to a significantly lower mean value (944.63±15.96) in group (4 watt).Meanwhile Surface topography by the atomic force microscope images for different groups revealed the absence of cracks on the surface of zirconia specimens treated with CO2 laser or sandblasting with evidence of micropores in the group treated with sandblasting, 3 watt output with the absence of these micropores in group treated with 4 watt that showed a carbonization layer with no evidence of irregularities.

Conclusions: Different surface treatment affects the properties of ZirCAD ceramic material. The application of CO2 laser surface treatment resulted in lower hardness of zirconia, while sandblasting surface treatment showed higher hardness. As the CO2 Laser energy level increases, the hardness decreases.

KEYWORDS: Zirconia, Sandblasting, CO2 laser, surface treatment, surface hardness.

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INTRODUCTION

Zirconia-based ceramics, such as Zircad, are extensively used in dental restorations for their excellent mechanical properties, biocompatibility, and aesthetic appeal. Surface treatments like sandblasting and CO2 laser irradiation are commonly employed to modify the surface characteristics of these ceramics to improve bonding with other materials and achieve desired aesthetic outcomes.

To meet the growing and functional demand for aesthetic treatments in dentistry, new materials and techniques have been developed that improve the properties, resulting in minimally invasive tooth preparation and conservative methods of prosthetic fabrication. Therefore, all-ceramic Monolithic zirconia restorations have been a material of choice for both posterior and anterior regions. [1,2].

Currently, dental esthetics are in great demand by patients. This context has increased interest in metal-free monolithic (full contour) zirconia restorations. Aside from its esthetic qualities, it also has a high level of biocompatibility, inert and excellent mechanical properties, which overcome the limitations of porcelain fused to metal crowns and bridges by using metal coping, which completely blocks the passage of light and requires sufficient amount of porcelain veneer to cover. To avoid over-contoured restorations, sufficient tooth preparation is required [2,3].

A revolutionary advancement in dentistry occurred during the last quarter of the 20th century to introduce the Computer-Aided Design/ Computer-Aided Manufacturing (CAD/CAM) system. Resulting in a new age that started with the appearance of Various types of ceramic material, which provided us with high-strength ceramic-like zirconia with flexural strength 900-1200 MPa and fracture strength of roughly (9-10) MPa(m)1/2. [4,5].

Most ceramics require different surface treatments; in order to create an optimum micromechanical bond, standard surface treatment methods such as hydrofluoric acid on the inner surface of the restoration are considered ineffective since zirconia is crystalline and does not contain a glass phase [6,7].

Studies on surface treatment of zirconia have been in the literature for years have shown that other surface treatment methods including air abrasion with alumina-oxide particles or silica coating, surface abrasion with diamond burs, and selective infiltration etching are considered ideal surface treatment methods for zirconia ceramic restoration as they create surface micro porosities without affecting material strength. The development of laser technology is also used nowadays for zirconia surface treatment, but Nd:YAG, Er:YAG, and CO2 have shown varying degrees of success in enhancing zirconia surface roughness [8,9]. Hardness is considered essential factor for the long-term success of any restoration [10,11].

Ceramic materials undergo fabrication procedures and clinical adjustments that can lead to flaws and defects, potentially causing catastrophic failure under clinical loading and moisture. Different surface roughness from finishing procedures can also reduce material strength[12].

For example, pressable materials undergo sandblasting during divesting. Sandblasting is a complex procedure that has always been problematic and may lead to damage on the ceramic surface and the growth of microcracks[13].

Wolf et al. highlighted the importance of various factors in sandblasting, including the size, shape, and mass of particles, as well as the kinetic energy of their collision with a ceramic surface[14].

The effect of the processing procedures, such as polishing, grinding, and glazing, on the mechanical properties of various dental materials has been extensively studied by numerous studies [12, 15, 16, 17].

Therefore, this study was carried out to evaluate the effect of surface treatment with sandblasted technique and CO2 laser technique with different parameters on the hardness, and surface topography of ZirCAD Prime.

MATERIALS AND METHODS

Specimen fabrication

IPS e.max ZirCAD® Prime disc was cut via (Isomet 4000), to obtain 30 zirconia specimens having a square shape with dimensions (12mm length x 12mm width x 2.4 mm thickness) prior sintering cycle, the zirconia disc was prepared for cutting by placing it in a special holder with screws , to be placed inside the Isomet machine for cutting, the first cut was done in vertical direction till the end of the disc, to obtain multiple slices having a full thickness of the disc, followed by the second horizontal cut for the base of each slice to exclude 4mm from the base of each slice, finally, each slice was cut into multiple specimens having the square shape of (12mm length, 12mm width, 2.4mm thickness) prior sintering cycle, The 20% shrinkage occurring during sintering was considered in the isomer cut of specimens, as the dimensions prior sintering was mentioned before, a digital caliper was used to standardize the zirconia specimens after final cut before sintering.

According to the manufacturer's recommendations, the zirconia specimens were sintered in a high temperature furnace. A digital caliper was used to standardize the zirconia specimens' dimensions after sintering.

All zirconia specimens were placed in pink acrylic molds that were fabricated with Polyvinylchloride (PVC) water tubes of (25 mm internal diameter, 12 mm length) dimensions at which acrylic resin bases were made to hold zirconia specimens.

Zirconia specimens cleaning:

Zirconia specimens were placed in an ultrasonic cleaner in a solution composed of deionized water for 3 minutes, and then air dried to be prepared for different surface treatments [8,34].

Surface treatment:

Sandblasting :

Sandblasting was done to ten zirconia specimens with 50 μm Aluminum oxide particles using an airborne particle-abrasive device, The specimens were mounted at a distance of 10 mm in a holder, Sandblasting was done for 15 seconds, with 3.5 bar pressure.

To standardize the distance between the surface of the specimen and the nozzle, the nozzle was stabilized on a customized holder, at a 10 mm distance, the distance was determined by using a ruler and the holder was used to hold the nozzle perpendicular to the specimen's surface during air abrasion. All specimens were subjected to surface topography examination.

CO2 Laser:

The surface of 20 zirconia specimens was divided into 2 subgroups , n=10 (3 Watt and 4 Watt) treated by CO2 laser working at 10.6 µm, energy level was applied at a continuous, focused mode. The application tip's diameter was 1 mm and its length was 12 mm. The zirconia specimens were stabilized manually, the laser was run in a continuous mode and the tip of the laser was held manually perpendicular to the zirconia surface, Movements were performed in a lateral direction with an irradiation time of 10 seconds for each specimen.

Surface Topography examination:

Five specimens of each group (sandblasting, 3 watt CO_2, 4 watt CO_2 laser) were subjected to surface topography measurements using atomic force microscope Autoprobe cp-research head manufactured by Thermomicroscope operated in contact mode using Silicon Nitride probe model MLCT manufactured by Bruker. Scan area (10 x 10) μm^2, scan rate 1 Hz and number of data points 256 x 256. Proscan 1.8 software was used for controlling the scan parameters and IP 2.1 software for image analysis.

Hardness measurement:

Five specimens for each group were subjected to Hardness testing using Digital Vickers hardness tester (NEXUS 4000 ™ , INNOVATEST, model no.4503, Netherlands) with 300 gm and a dwell time of 15s. Each surface had three indentations and the mean was calculated. Hardness was calculated as follows: $VHN=1.854P/d^2$, where P is the indentation load and d is the length.

Statistical analysis

Statistical analysis was performed using a commercially available software program (SPSS 20-Statistical Package for Scientific Studies, SPSS, Inc., Chicago, IL, USA) for Windows. Numerical data were summarized using mean and standard deviation, confidence intervals and range. Data were explored for normality by checking the data distribution and using Kolmogorov-Smirnov and Shapiro-Wilk tests.

RESULTS

I-Hardness

A significantly higher mean value was recorded in Group (3 watt) (1100.78±68.93), in comparison to a significantly lower mean value (944.63±15.96) in group (4 watt). Sandblasting group recorded the lowest mean value (846.15±15.15). The difference between groups was highly statistically significant (p=0.000). Post hoc test showed a significant difference between the 3 groups (Table 1, Fig.1)

TABLE (1a) Descriptive statistics of Hardness value and comparison between groups (ANOVA test)

Groups	Mean	Std. Dev	95% Confidence Interval for Mean		Min	Max	F value	P value
			Lower Bound	Upper Bound				
Sandblasting	846.15[c]	15.15	827.34	864.96	832.57	867.33	47.24	.000*
3 Watt	1100.78[a]	68.93	1015.19	1186.37	1009.03	1179.17		
4 Watt	944.63[b]	15.96	924.81	964.45	928.14	970.21		

Significance level p≤0.05, *significant
Post hoc test: means with different superscript letter are significantly different

TABLE (1b) Detailed results of Bonferroni's post hoc test for pairwise comparison of hardness

(I) Groups	(J) Groups	Mean Difference (I-J)	Std. Error	95% Confidence Interval		P value
				Lower Bound	Upper Bound	
Sandblasting	3 Watt	-254.63000-*	26.420	-328.06	-181.20	.000*
	4 Watt	-98.48200-*	26.420	-171.92	-25.05	.009*
3 Watt	Sandblasting	254.63000*	26.420	181.20	328.06	.000*
	4 Watt	156.14800*	26.420	82.71	229.58	.000*
4 Watt	Sandblasting	98.48200*	26.420	25.05	171.92	.009*
	3 Watt	-156.14800-*	26.420	-229.58	-82.71	.000*

Significance level p≤0.05, *significant

VI- Surface Topography

The atomic force microscope images for different groups revealed the absence of cracks on the surface of zirconia specimens treated with CO_2 laser or sandblasting with evidence of micropores in the group treated with sandblasting, 3 watt output with the absence of these micropores in group treated with 4 watt that showed a carbonization layer with no evidence of irregularities.

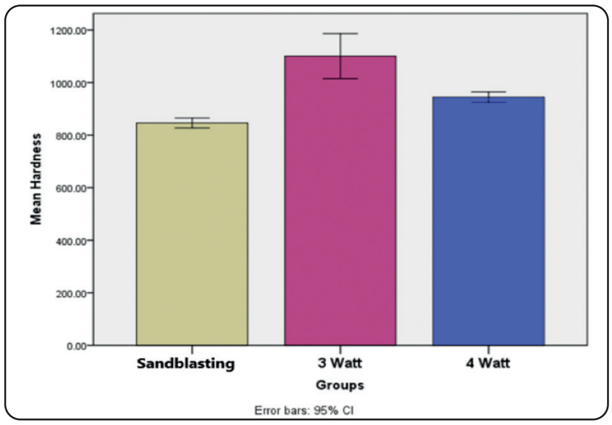
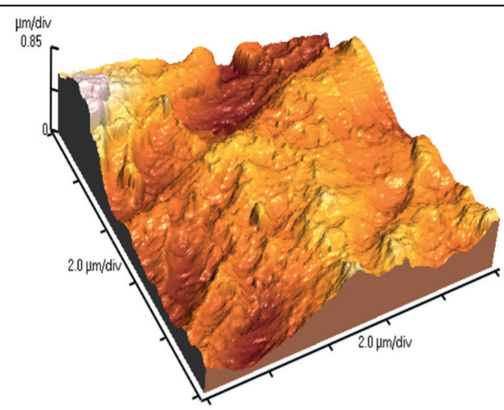
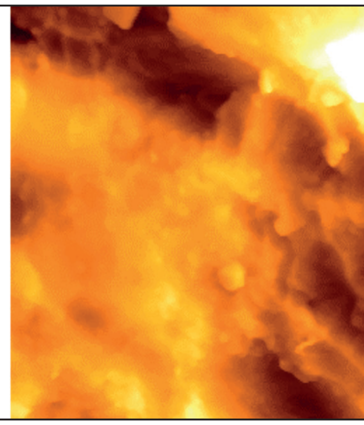


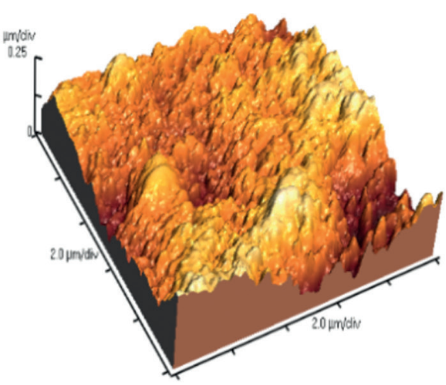
Fig. (3) Bar chart illustrating the mean value of Hardness in different groups

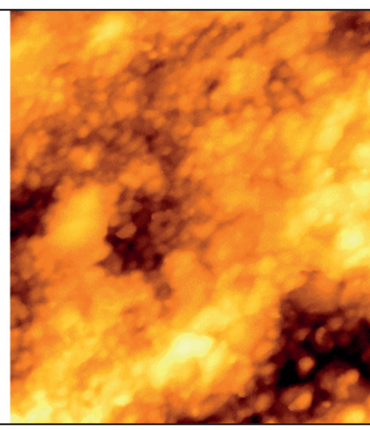




Three-Dimensional image representative for roughness pattern with Sand-blast group

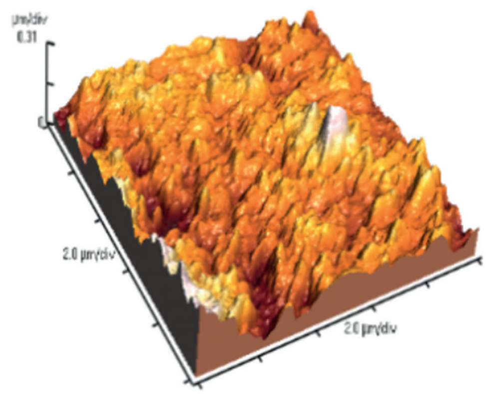
AFM image of sandblasting group showing presence of micropores connected to each other with narrow fine lines.



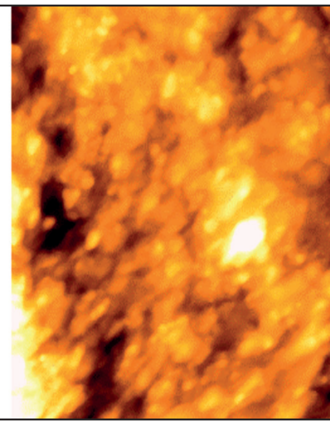


Three-Dimensional image representative for roughness pattern with 3 watt CO_2 laser group

AFM image of CO_2 Laser (3 watt) showing presence of microexplosion in the form of crystal ice.



Three-Dimensional image representative for roughness pattern with 4 watt CO2 laser group



AFM image of CO2 Laser 4 watt showing microexplosion the form of crystal ice.

DISCUSSION

Nowadays, with the intervension of new CAD/CAM technologies and the production of multi-layer monolithic zirconia restorations, milling full contour restorations without veneering are possible to provide high esthetic results in comparison to the highly opaque substructures, The monolithic multi-layered zirconia restoration's design aims to mimic the shade gradient observed in natural teeth: where the incisal area of a crown is most translucent, growing in chroma and opacity towards the gingival region [18]

Monolithic zirconia restorations were developed to address the issue of porcelain fracturing in porcelain-veneered zirconia-based restorations which is considered the most common reason for failure. Due to the superior properties of monolithic zirconia, For instance, its high mechanical strength, flexural resistance, and long-term stability make it suitable for esthetic crowns, and bridges to overcome the problem of chipping occurring in bi-layered restorations [19].

The primary role of sandblasting is to increase the roughness of zirconia ceramic surface to achieve a micromechanical interlocking by increasing the penetration of the resin-based material to the inner surface of zirconia ceramic restoration and in situ it's polymerization, Nowadays various types of LASERS are used for zirconia surface treatment for the same purpose, example carbon dioxide laser (CO2) is commonly used as it enhances surface roughness by the warming effect of the material surface resulting in conchoidal tears which is the reason for increasing bond between restoration and composite resin cements [20].

The development in ceramic technologies created a new disc of polychromic, multilayer, and hybrid composition of zirconia (IPS e.max® ZirCAD® Prime) utilizing Gradient Technology (GT) which is a brand-new, distinctive manufacturing technique that combines 3Y and 5Y oxide-ceramics for the highest level of strength, and esthetics, enabling a smooth progression of shade, translucency, and composition to give superior aesthetics together with high flexure strength (1200 Mpa) and fracture toughness (5 $MPa.m^{1/2}$) unlike multi-layered materials on the market that can have obvious layers of color.

In the present study, alumina particles of grain size (50μm) were selected according to manufacturer recommendations at a distance of 10 mm, for 15 seconds, as it was found in previous studies that 50-μm is enough to improve bond strength with this size of alumina particles without damaging zirconia ceramic specimens.

Sandblasting using particles that are 110 µm or smaller and at pressures under 4 bar can enhance the bi-axial strength and reliability of the material. This is achieved by creating compressive residual stresses, which help to counteract any damage caused by the sandblasting process.

Wolf et al. emphasized the critical factors in sandblasting, including the size, shape, mass of particles, and their kinetic energy upon impact with a ceramic surface.

Therefore, an alternative surface treatment method was selected in the present study aiming to enhance surface topography.

Recently, research has concentrated on the function of CO2, Nd:YAG, and Er:YAG lasers in enhancing the color .hardness and surface roughness of zirconia.

In our study, the zirconia specimen's surface was treated with a CO2 laser with 2 different energy levels which are 3 watt (group 2) and 4 watt (group 3) for 10 seconds for each specimen, the articulating arm of the laser was held perpendicular to the specimen at almost zero distance (focused-continuous mode) moving in lateral directions along the length of the specimen. the Selection of the CO2 laser type was based on past findings which revealed that Zirconia ceramic can fully absorb the CO2 laser beam's energy. Upon absorption, heat induction creates shell-like ruptures on the ceramic surface.

It is crucial to notice that surface topography examination was done in order to determine the effect of different surface treatments on zirconia specimens . Several previous studies used the same methods to detect surface roughness value[8,21,22,23].

The images analysis results could be related to the thermal ablation effect of CO2 laser on surface morphology of zirconia. As increasing in energy level from 3 w to 4 w results in increasing of rupture action known as micro-explosions on the surface of the zirconia specimens occurring by the incident action of laser photons with the zirconia specimens surface which result of increasing in energy level. The 3w laser energy performed superficial scaly irregularities caused by lower energy level in contrast to 4 w group that showed numerous deep and narrow micro-explosions as apparent in AFM images in the form of crystal ice that was prominent in 4 w group than 3 w group [22].

Therefore, the laser outputs applied in the present study were 3 watt and 4 watt, with a minimal irradiation time of 10 seconds, aiming to enhance surface roughness value without deterioration of zirconia specimens, as was reported in the previous studies that as the CO2 energy level increase, irradiation time increase, surface deterioration, and defects increase [22].

The results was also in partial agreement with **Kunt, et al.** [8] who stated that air borne particle abrasion with 50-µm aluminum oxide for 15 seconds showed high surface topography average of Y-TZP in comparison to CO2 laser surface treatments at different energy levels 3 w, and 4 w with continuous wave mode.

The results of the present study are also in partial agreement with **kasreai et al.** [21], who stated that CO2 laser enhances the surface topography of ceramics at output 3w for 10 seconds and showed higher shear bond strength than sandblasting group, the result of this study showed a scaly irregular surface of zirconia surface and micro cracks that attributed to be the reason for showing higher bond strength value than sandblasting group which increase the hardness of specimen.

The present study results were in contrast with **Hemedan et al.** [24] who stated that Fractional CO2 laser surface treatment with different parameters increasing in the crack width with increasing energy level from 10 w to 20 w, this may be due to different parameters of laser used and different irradiation time which decreases the hardness.

The increased hardness value in zirconia irradiated with CO2 at 3W can be explained by high surface roughness. This means that the hardness measurements on rough surfaces may not correlate with the actual hardness of the ceramic material, but instead characterize the shape of the surface. Additionally, the presence of micro-cracks on the irradiated ceramic surfaces significantly contributed to decreasing hardness values.

According to some authors, overheating during CO2 or Nd:YAG laser irradiation might lead to surface and subsurface damage, as well as microcracks. This can cause a decrease in Surface bond strength (adhesive bond strength) compared to an untreated zirconia surface.The integrity of the ceramic surface was observed to be reduced after CO2 laser treatment, potentially impacting the strength and surface hardness of the ceramic structure 25.

Limitations

Although the results of this in vitro study are very promising regarding sandblasting surface treatment, there are some limitations when it comes to fabrication of restoration in the oral cavity as the restoration is subjected to masticatory forces during function also it is subjected to thermal exchanges which affect the hardness on long term service.

CONCLUSIONS

1. Different surface treatment affects the properties of ZirCAD ceramic material.
2. The application of CO2 laser surface treatment resulted in lower hardness of zirconia, while sandblasting surface treatment showed higher hardness.
3. As the CO2 Laser energy level increases, the hardness decreases.

RECOMMENDATION

This study could not propose CO2 laser for zirconia surface treatment instead of sandblasting surface treatment until more investigations are conducted to identify the effect of CO2 laser on the properties of zirconia.

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