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Optical Properties of Zirconia Monolithic Crowns Constructed Using Speed Sintering Cycle

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ABSTRACT

Purpose: This study examined the effect of change in sintering time on the optical properties of monolithic zirconia crowns using ZirCAD Prime. **Materials and methods:** A Sound premolar was scanned using optical oral scanner. The scanned premolar was digitally prepared to receive zirconia restoration using Exocad software following standard preparation guidelines for ceramic restorations. 3D printed resin master die was produced. An impression was made for the 3D printed master die using polyvinylsiloxane impression material then poured using epoxy resin. The procedure was repeated to obtain 16 epoxy resin models. Sixteen crowns were produced by CAD-CAM system from ZirCAD Prime blank shade A2 with 16 mm thickness. Samples were divided into two groups according to sintering time (n=8). Group (A): crowns were sintered using normal sintering cycle for 9h and 50 min. Group (B): crowns were sintered using speed sintering cycle for 2h and 26 min. After sintering the internal surfaces of both groups were abraded with 50 µm Al_2O_3 particles. Optical properties including Translucency Parameter (TP) and change in color (ΔE) of samples were determined using spectrophotometer. Obtained values were statistically analyzed. **Results:** Regarding change of color evaluation mean ΔE values were below 3.0 which is considered “clinically imperceptible”. There was also no significant difference in translucency parameter between both groups. **Conclusion:** ZirCAD Prime speed sintering cycle will have no perceived effect on color and translucency of the final restoration.

KEYWORDS

Zirconia,
CAD-CAM,
Speed Sintering,
Optical Properties.

INTRODUCTION

Zirconia-based restorations have grown rapidly in recent years. Dimensional stability and biocompatible chemical properties,

- Paper extracted from Master Thesis titled “Optical Properties, Fracture Resistance and Microstructure of Zirconia Monolithic Crowns Constructed Using Speed Sintering Cycle”

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mechanical strength and toughness, coupled with modulus of elasticity compatible with oral tissue with promising aesthetic potential was the origin of the interest in using zirconia as a dental ceramic biomaterial [(1)].

One of the obstacles that limited the use of zirconia restorations in the anterior region, is its high opacity. This fact limited the use of zirconia to core/framework construction that should be veneered with an esthetic ceramic. However, chipping of veneering porcelain was a main concern [(2)].

Translucent zirconia was later introduced improving the esthetic qualities of zirconia thus making monolithic zirconia restorations possible. Monolithic crowns produced with only one material can be produced with CAD/CAM systems, with no veneering porcelain [(3)]. Thus, the clinical indication of monolithic zirconia (MZ) expanded due to its superior mechanical and optical properties [(4)].

Over the years, many changes to the traditional white opaque zirconia have been made to enable it to be used as full-contour monolithic restorations with appropriate aesthetics. To increase translucency, the yttria content was increased from 3 mol percent (3Y-TZP) to 4 mol percent (4Y-TZP) and 5 mol percent (5Y-TZP), plus adding polychromatic (multi-layered) zirconia. [(5)].

Another multi-layered technique has recently been launched, one blank with various generations of zirconia in order to achieve the benefits of both traditional and ultra-translucent zirconia by combining high-flexural strength 3Y-TZP in the dentin/body region for increased stability with high-translucency 5Y-TZP in the incisal or occlusal area for improved appearance. This latest zirconia generation, which combines 3Y-TZP and 5Y-TZP in a single blank, is being used for a wide range of clinical indications, from single anterior crowns to full-arch crowns [(6)].

Another disadvantage of zirconia is the prolonged sintering process, which can take up to 12 hours, particularly with the growing popularity of one-visit chairside restorations [(7)]. As a result, speed and high-speed sintering processes were developed to deal with this issue by reducing the overall length of sintering cycles using special types of furnaces, making zirconia the preferred material for one-visit chair-side restorations. [(8)].

Sintering parameters influence the crystalline content directly [(9)], it is expected that variation in sintering time and/or temperature would have a direct effect on different properties of zirconia. Holding time during sintering has been shown to cause the grain to increase and affect the translucency of the material. [(10)]. The longer the sintering time and the higher the temperature, the larger the resulting grain size, which can lead to increase in zirconia creep deformation rate and distortion of the crown [(11)].

Therefore, this study was directed toward investigating the effect of speed sintering on the optical properties of the newly introduced ZirCAD Prime zirconia, which combines 3 Y-TZP with 5 Y-TZP.

MATERIALS AND METHODS

Sample size calculation

A power analysis was designed to have adequate power to apply a two-sided statistical test of the research hypothesis (null hypothesis) that there is no difference between both groups regarding different measured parameters. By adopting an alpha (α) level of 0.05 (5%), a beta (β) level of 0.2 (20%) i.e. power=80%, and an effect size (d) of (1.51) the predicted sample size (n) was a total of (16) samples i.e. (8) samples per group. Sample size calculation was performed using G*Power version 3.1.9.

Construction of master die

To conduct the present study, one anonymous sound maxillary 1st premolar was selected, ultrasonically cleaned, dried and stored at room temperature in 0.1% thymol solution.

Ethical approval was obtained in accordance with guidelines from research ethics committee of faculty of dental medicine Girls' Branch Al Azhar University code (REC-CR-20-09)

The selected premolar was scanned using optical oral scanner (Medit i500). The Medit system is an open system that can export 3D data as an STL (Standard Tessellation Language) file. The scanned premolar was digitally prepared to receive zirconia restoration using Exocad software (Exocad GmbH, Darmstadt, Germany) following standard preparation guidelines for ceramic restorations [12], with1mm occlusal reduction, rounded cusp tips, continuous circumferential 0.5 mm thick chamfer finish line, and 6^o taper of all axial walls. Accordingly, a 3D printed resin master die (Envision Tech LS600 GMBH, Gladbeck, Germany) was produced with 1.5 cm height base.

Duplication of master die:

An impression was made for the 3D printed master die using polyvinylsiloxane impression material Zeta plus (3M ESPE, Seefeld, Germany). After setting, the impression was separated from the master model, and inspected for the presence of tears or defects, which if observed the impression was discarded and retaken. Epoxy resin material (Die epoxy type 8000 system, American dental supply Inc.) was mixed according to the manufacturer's instructions and then poured into the impression on a vibrator to remove any air bubbles, left to set for 24 hours following manufacturers recommendations then checked for any defects after setting. The procedure was repeated to obtain 16 epoxy resin models with base.

Crowns Fabrication:

Sixteen zirconia crowns were fabricated using ZirCAD Prime blank (Ivoclar Vivadent, Schaan,Liechtenstein), shade A2 with 16 mm thickness. Each constructed model was sprayed and secured on the tray for taking the optical impression using Medit Identica T300 (Norton dental products Group, Atlanta) extraoral scanner. The fully anatomical monolithic crown was designed according to the manufacturer's directions and software recommendations (Exocad DentalCAD, Germany) including; a virtual cement space of 50 µm at 0.5 mm short of the margins. Data was sent to the 5-axis milling machine CAM 5-S1 (vhf, Ammerbuch, Germany) to mill the crowns.

Samples' Grouping:

The constructed crowns (n=16) randomly were divided into 2 groups (n=8) according to the sintering cycle followed: Group (A): crowns were sintered using normal sintering cycle for 9h and 50 min including: 1500ºC for 2 hours (heating rate: 10°C/min, holding time: 2.5 hours, and cooling rate: -10 ºC / min). Group (B): crowns were sintered using speed sintering cycle for 2h and 26 min including 1530ºC for 1 hour (heating rate: 60ºC /min and cooling rate: -60ºC / min).

The crowns of each group were glazed using a glazing paste (DD Nature Zr Glaze & Glaze liquid; Dental Direkt) in a ceramic furnace (Ivoclar Vivadent AG).

After sintering the internal surfaces of both groups were abraded with 50 µm Al_2O_3 particles under 2 bar pressure at 10 mm distance for 15 seconds using a special holder to standardize the distance.

Each constructed crown was checked for complete seating and fit on the master die, fig (1).

Figure (1): Zirconia crown seated on 3D printed resin die

Optical Properties Evaluation:

Change of color:

Reflective spectrophotometer (model RM200QC; X-Rite GmbHNeu-Isenburg, Germany) was used to measure the color specimen. The aperture size was 4 mm and the specimens were positioned at the center of the measuring port. A white background (Commission internationale de l'éclairage (CIE) L* = 88.81, a* = –4.98b* = 6.09) was selected and the measurements were made according to the CIE L*a*b* color space relative to the CIE standard illuminant D65, where L* refers to the degree of lightness (0–100), a* to the color coordinate on the red/green axis and b* to the color coordinate on the yellow/blue axis. Three measurements were taken for each specimen and the average was recorded where the spectrophotometer was calibrated before each measurement.

Color change (ΔE) was obtained by using conventionally sintered specimen, group (1), as control. Color change due to speed sintering was calculated using the following equation:

$$\Delta E = [(\Delta L^*)2 + (\Delta a^*)2 + (\Delta b^*)2]^{1/2}$$

where:

ΔE – change in color;

$\Delta L^* = L^*_{\text{speed sintering cycle}} - L^*_{\text{normal sintering cycle}}$;

$\Delta a^* = a^*_{\text{speed sintering cycle}} - a^*_{\text{normal sintering cycle}}$;

$\Delta b^* = b^*_{\text{speed sintering cycle}} - b^*_{\text{normal sintering cycle}}$.

Translucency:

The Translucency Parameter (TP) was used to determine the effect of speed sintering on translucency of zirconia crowns.The color of the specimens was measured using the same spectrophotometer against white (CIE L* = 88.81, a* = –4.98, b* = 6.09) and black (CIE L* = 7.61, a* = 0.45, b* = 2.42) backgrounds relative to the CIE standard illuminant D65. The translucency parameter (TP) values were obtained by calculating the difference in the color of the specimens against black and white backgrounds using the following formula:

$$TP = [(L^*b - L^*w)2 + (a^*b - a^*w)2 + (b^*b - b^*w)^2]^{½}$$

where:

TP – translucency parameter;

L* – degree of lightness;

a* – color coordinate on the red/green axis;

b* – color coordinate on the yellow/blue axis; the subscripts b and w refer to the color coordinates against black and white backgrounds, respectively.

Statistical Analysis

Numerical data was represented as mean and standard deviation (SD) values. Shapiro-Wilk's test was used to test for normality. Homogeneity of variances was tested using Levene's test. Independent t-test was used to analyze intergroup comparison. The significance level was set at $p<0.05$ within all tests. Statistical analysis was performed with R statistical analysis software version 4.0.5 for Windows [13].

RESULTS

Regarding the change of color evaluation occurring as a result of speed sintering procedure. The mean ± standard deviation (SD) value of color change was 2.86± 1.51.

Regarding translucency parameter (TP), descriptive statistics and results of independent t-test for translucency parameter values of both groups are presented in table (1). Results show that there was no significant difference between both groups (p=0.750).). Graphic representation for mean values is presented in fig. (2).

Table (1): *Descriptive statistics for translucency parameter (TP)*

	Long Sintering Group (A)	Speed Sintering Group (B)
Mean	3.12	3.01
Sd	1.49	0.98
Median	3.03	2.91
Min	0.45	1.71
Max	6.84	6.12
Mean Difference [95%Ci]	0.12 [-0.62-0.85]	
T-Value	0.320	
P-Value	0.750	

95%CI= 95% confidence interval

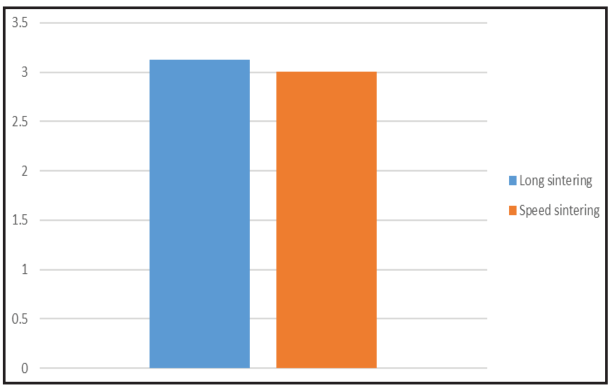

Figure (2): Bar chart showing mean values of translucency parameter (TP)

DISCUSSION

Monolithic zirconia restorations have become greatly popular among dentists as it is associated with decreased amount of tooth reduction and thickness of restorative material when compared to veneered zirconia restoration as well as minimal wear of opposing enamel in contact to polished monolithic zirconia [10].

ZirCAD Prime has been introduced with multi-layered technology that combines zirconia generations in one blank to combine the benefits of different zirconia generations. This combination is based mainly between a 3Y-TZP for higher stability in the dentin/body area and a high translucent 5Y-TZP for better appearance in the incisal or occlusal area [6].

Esthetic ceramic prostheses should match both color and translucency of natural teeth as these factors are the most determining factors that influences esthetic properties of ceramic restorations [10].

Translucency is typically measured in ceramic materials in standardized, flat specimens. However, because important factors such as thickness and surface quality can be standardized, this approach can be more accurate in determining transmittance. Translucency was measured in the current study by defining the translucency parameter (TP), which allows the crowns to be used in their final stage. Clinically, this is more significant than polished discs [14].

Traditional sintering protocols take 4–12 hours to complete, resulting in a significant cost and time investment. Speed sintering has recently gained popularity as a potential alternative.

Some manufacturers suggested the use of high-speed sintering cycles, claiming that no properties would be affected.

However, it is well understood that sintering temperature and dwell time can affect the density and grain size of ceramics, which can have a direct impact on various properties, particularly translucency [7]& [15].

The microstructure of zirconia and its properties could be affected by the difference in the sintering parameters. After the introduction of speed sintering cycles, the extent of this effect has become a spot of interest in the dental field [16].

The crowns of each study group were glazed rather than polished because glazing generates a smoother surface texture than polishing, which reflects greater light than a rough surface, improving lightness values [17].

In the present study all intaglio surfaces of constructed crowns were sandblasted with alumina according to the recommended procedure for adhesive bonding. The metastability (phase transition) of monolithic Y-TZP can be influenced by surface treatments. Grinding and sandblasting of zirconia materials is well known to cause surface phase transformation (tetragonal to monoclinic) and the creation of compressive stresses, both of which can influence the optical characteristics of zirconia. [(18)]. So, in this study surface treatment was done before optical properties tests to simulate the clinical situation.

In order to investigate the effect of speed sintering on optical properties of ZirCAD Prime Translucency Parameter was measured for both groups and it was found that there was no significant difference between the result of long sintering cycle group (A) and speed sintering cycle group (B), table (1). This result implies that applying a short sintering cycle will not affect the translucency of the restoration.

In 2020 [(19)] the influence of shade and sintering temperature on the translucency parameter of multilayer monolithic zirconia was explored, and no significant changes in TP values were detected between 1450 °C and 1600 °C sintering temperatures for the examined thicknesses for shade A2, while TP values for shade A3 were greater at 1600 °C than at 1450 °C.

Higher sintering temperatures caused an increase in grain size, which has a direct effect on the number of grain boundaries; thus, higher sintering temperatures may cause an increase in translucency [(20)]. Increases in a darker chroma's grain boundaries may have a more dramatic effect on TP than increases in a lighter chroma's grain boundaries. This could explain why a sintering temperature of 1600 °C resulted in higher TP values for shade A3 than shade A2 in the previous study [(19)].

However, another study [(8)] contradicted the results of the present study as it reported reduction in translucency parameter following high speed sintering for two different types of zirconia.

This contradiction can be explained by the formation of porosities in the zirconia specimens which prevent the passage of the light therefore translucency will be reduced [(20)].

In the previous study it was found that the higher the sintering temperature, the larger the grain size. Nevertheless, the large grain growth and the presence of porosity were assumed to be due to high sintering temperature and heating rate which led to inadequate time for fusing of the grains [(8)].

Another study made in 2019 [(21)] investigated the effect of speed sintering protocol on three different types of zirconia and it found that conventional sintering resulted in higher translucency than speed sintering for two types of all thicknesses and for the third type with definite thickness.

The results of this study were explained by the effect of the chemical composition of each type on the microstructure. The grain size and the phase content can be affected by Al_2O_3 as a sintering additive and Y_2O_3 as a stabilizer, which in turn affect birefringence and translucency of the zirconia. The zirconia types with less Al_2O_3 had significantly lower translucency when high speed sintering was performed because the speed sintering protocols used high sintering temperatures and short sintering times, which increased particle density in the pressed blank, resulting in reduced pore spaces, phase transformation, and grain formation or growth during sintering. All of this explains why a shorter sintering time or higher temperature rates can result in decreased translucency [(20)].

Regarding the color evaluation, results revealed that change of color (ΔE) between the speed sintering group and the conventional sintering group was 2.86 which is considered clinically imperceptible. Mean ΔE values less than 3.0 were deemed "clinically imperceptible", ΔE values between 3.0 and 5.0 were regarded "clinically acceptable" otherwise ΔE values above 5.0 were regarded "clinically unacceptable" [(22)].

CONCLUSION

Within the limitations of the current study, it could be concluded that ZirCAD Prime speed sintering cycle will have no perceived effect on color and translucency of the final restoration.

Declaration of Conflict of Interest

The authors declare that they have no conflict of interest.

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