

## Original Article

# Effect of sintering temperature on translucency parameter of zirconia blocks

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## ABSTRACT

**Background:** The main drawbacks of zirconia are its high refractive index and opacity. This study aimed to assess the effect of sintering temperature on the translucency of Ivoclar e. max ZirCAD (IEZ), and White Peaks Symphony (WPS) zirconia blocks.

**Materials and Methods:** In this *in vitro* experimental study, 30 IEZ and 30 WPS zirconia blocks measuring 10 mm × 10 mm × 1 mm were prepared and underwent sintering in three subgroups at 1440°C, 1500°C, and 1530°C. The specimens were then photographed against a black and a white background with a standard digital camera. The L\*, a\*, and b\* color parameters were measured using Adobe Photoshop software, and translucency was calculated. Data were analyzed using one-way ANOVA and Tukey's test ( $P < 0.05$ ).

**Results:** In both the IEZ and WPS groups, the maximum and minimum translucency parameters were recorded in 1530°C and 1440°C subgroups, respectively. The difference in the mean translucency was significant among the three subgroups of each zirconia group ( $P < 0.001$ ). The mean translucency of WPS zirconia was significantly higher than that of IEZ zirconia ( $P < 0.01$ ), and maximum difference was noted at 1500°C sintering temperature.

**Conclusion:** Increasing the sintering temperature from 1440°C to 1530°C can significantly increase the translucency of IEZ and WPS zirconia blocks, and can be considered to improve the quality of zirconia restorations.

**Key Words:** Ceramics, refractometry, yttria-stabilized tetragonal zirconia

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## INTRODUCTION

In the past decades, many attempts have been made to improve the quality of dental ceramics to better mimic the esthetic and mechanical properties of natural teeth.<sup>[1,2]</sup> Resultantly, a wide variety of dental ceramics such as feldspathic, leucite, lithium disilicate, fluorapatite glass, zirconia, and mixed

ceramics have been introduced to the market.<sup>[3-5]</sup> Different types of all-ceramic and zirconia restorations are used in dentistry.<sup>[6]</sup> As a general rule, a ceramic restoration should have excellent mechanical and esthetic properties resembling those of natural teeth.<sup>[7-9]</sup> Monolithic zirconia restorations have gained

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increasing popularity in recent years due to their optimal color, causing minimal wear of the opposing teeth, conservative preparation design, and high long-term clinical success rate.<sup>[5,6]</sup>

Translucency is an important parameter that plays a fundamental role in creating a natural tooth color. Translucency refers to the property of passage of light through a material, and can be adjusted by controlling the amount of absorption, reflectance, scattering, and transmission of light.<sup>[10,11]</sup> Low reflectance and high scattering and transmission of light increase translucency. Translucency can be measured by using different equations via different tools. The most commonly used parameter for the calculation of translucency is the color difference of an object with a uniform thickness against a black and a white background.<sup>[12]</sup>

Sintering is a fundamental step in the preparation of prosthetic restorations, which can significantly affect their properties. In the process of zirconia sintering, heat is transferred from the surface to the core to obtain a mature zirconia.<sup>[13]</sup> The sintering temperature is a critical parameter affecting the size and density of zirconia particles. It directly affects the density, porosity, and growth of zirconia particles.<sup>[14,15]</sup> Zirconia, with a relative refractive index of 2.2, has the highest rate of porosities in the core among different ceramic materials. By decreasing these porosities and obtaining a denser material, the translucency of zirconia blocks can be improved, and a more favorable color can be achieved.<sup>[16,17]</sup> Thus, dental clinicians can improve the optical properties of zirconia by changing its crystalline structure via adjusting the sintering conditions.<sup>[18]</sup>

The available studies on the effect of sintering temperature on the translucency of different types of zirconia have reported controversial results. Thus, this study aimed to assess the effect of sintering temperature on color parameters of zirconia blocks. The null hypothesis was that no significant difference would be found in the translucency parameter of different zirconia types, namely, Ivoclar e. max ZirCAD (IEZ), and White Peaks Symphony (WPS) sintered at different temperatures.

## MATERIALS AND METHODS

This *in vitro* experimental study evaluated 30 IEZ (Ivoclar Vivadent, Schaan, Lichtenstein) and 30 WPS (White Peaks Dental De, Germany) zirconia

blocks. The sample size was calculated to be 10 in each subgroup according to a previous study.<sup>[19]</sup> The study was approved by the ethics committee of Hamadan University of Medical Sciences.

IEZ and WPS zirconia specimens measuring 10 mm × 10 mm with 1-mm thickness were milled out of semi-sintered zirconia blocks. Considering 20% shrinkage of zirconia, the specimens were first milled in 12 mm × 12 mm dimensions using a cutting machine (Nemo, Mashhad, Iran). After shrinkage in a furnace, they reached 10 mm × 10 mm dimensions. The specimens in each of the IEZ and WPS groups were randomly divided into three subgroups ( $n = 10$ ) for sintering at 1440, 1500, and 1530°C. After coloring with A3 shade according to the manufacturers' instructions, the specimens in both zirconia groups were first dried in a furnace (Ceramill Therm, Amann Girrbach, Germany) at 1400°C for 30 min, and then underwent sintering at 1440, 1500, or 1530°C (depending on the assigned subgroup) with a temperature rise of 17°C/min for 2 h.

After sintering, the specimens were placed against a black and a white background and photographed by a digital camera (Canon EOS 6D 20.2MP, 2013, USA). Photography was performed under standard conditions. Daylight was obscured, and two light sources illuminated the specimens at 45° angle. The photographs were transferred to Adobe Photoshop software (Adobe Photoshop CS. Berkeley, CA: Peachpit Press, 2018), the background light was eliminated, and the CIE L\* a\*b\* color parameters were measured.<sup>[20,21]</sup> In Photoshop software, the mean L\* can range from 0 to 255, while the L\* parameter in the CIE system can range from 0 to 100. Thus, the L\* parameter was calculated using the formula below:<sup>[22-24]</sup>

$$L^* = L \times 100/255$$

$$\text{Translucency parameter} = (L^*{}^B - L^*{}^W)^2 + (a^*{}^B - a^*{}^W)^2 + (b^*{}^B - b^*{}^W)^2 \quad [0^{22}]$$

where B indicates the color against a black background and W indicates the color against a white background. L\* indicates lightness, a\* indicates redness-greenness, and b\* indicates yellowness-blueness. The translucency parameter could range from 0 to 100. Lower values indicate lower translucency and vice versa.

Data were analyzed using SPSS version 21 (SPSS Inc., IL, USA). The Kolmogorov–Smirnov test was used to analyze the normality of data distribution.

Since the data were normally distributed ( $P = 0.200$ ), the parametric one-way ANOVA was used to compare translucency among the three subgroups of each zirconia group. Pairwise comparisons of the subgroups were carried out using Tukey's test. The two zirconia groups were compared using one-way ANOVA.  $P < 0.05$  was considered statistically significant.

## RESULTS

Table 1 shows the mean translucency of the three subgroups of the two zirconia groups. In both IEZ and WPS groups, the maximum and minimum translucency were noted in 1530°C and 1440°C subgroups, respectively. The difference in the mean translucency was significant among the three subgroups of each zirconia group ( $P = 0.000$ ). Thus, pairwise comparisons of the subgroups within each zirconia group were carried out using Tukey's test. In both zirconia groups, significant differences were noted between every two subgroups such that the mean translucency in 1530°C subgroup was significantly higher than that in 1440°C ( $P = 0.000$ ) and 1500°C ( $P = 0.000$ ) subgroups. The mean translucency in 1500°C subgroup was significantly higher than that in 1440°C subgroup ( $P = 0.000$ ). As shown, in both zirconia groups, increasing the sintering temperature significantly increased the translucency ( $P = 0.000$ ).

Comparison of the two zirconia groups revealed that at all three sintering temperatures, the mean translucency of WPS zirconia was significantly higher than that of IEZ zirconia ( $P < 0.01$ ). The maximum standardized difference between the mean values of the two zirconia groups was observed at 1530°C sintering temperature.

## DISCUSSION

This study assessed the effect of sintering temperatures of 1440°C, 1500°C, and 1530°C on the translucency

of IEZ and WPS zirconia blocks. The results showed that the null hypothesis of the study was rejected since significant differences were noted in the translucency of different zirconia blocks sintered at different temperatures. Several factors such as the oxidation rate of stabilizer, distribution of stabilizer, phase composition, size and distribution of particles, and surface treatment affect the quality of zirconia restorations. Despite the independent nature of each of the above-mentioned parameters, they are mainly influenced by the sintering parameters.<sup>[23]</sup> Zirconia restorations are often sintered at a temperature range of 1350°C–1600°C. Temperatures higher than 1600°C cause excessive growth of particles and increase the porosities. Furthermore, the mechanical and optical properties of zirconia restorations sintered at a temperature lower than 1400°C are not optimal for clinical use.<sup>[25,26]</sup>

In this study, the specimens were photographed against a white background to simulate the clinical setting for posterior teeth and against a black background (for higher light absorption) to simulate the clinical setting for anterior teeth. The  $L^*$ ,  $a^*$ , and  $b^*$  color parameters were measured by Photoshop software due to its high accuracy. The results indicated that increasing the sintering temperature in the tested range significantly increased the translucency of both IEZ and WPS zirconia ceramics. Minimum translucency in both groups was noted following sintering at 1440°C, while maximum translucency was recorded following sintering at 1530°C. In line with our findings, many other studies have reported improved translucency of zirconia with different brands as the result of increase in sintering temperature. For instance, Attachoo and Juntavee<sup>[27]</sup> compared sintering temperatures of 1350°C, 1450°C, and 1550°C and showed that increasing the temperature improved the translucency of zirconia. Sabet *et al.*<sup>[28]</sup> compared 1400°C, 1500°C, and 1600°C sintering temperatures with different sintering times and reported maximum translucency after zirconia sintering at 1600°C with minimum sintering time. Sen *et al.*<sup>[19]</sup> evaluated sintering of Vita YZ HT and Prettau Zirkonzahn zirconia at 1350°C, 1450°C, and 1600°C temperatures and reported that increasing the sintering temperature significantly increased the translucency. Jiang *et al.*<sup>[29]</sup> compared the effects of 1350, 1400, 1450, and 1500°C sintering temperatures on the translucency of zirconia blocks and showed that increasing the sintering temperature significantly

**Table 1: Mean±standard deviation values of translucency parameter of the three subgroups (n=10) of the two zirconia groups**

Zirconia group	1440°C	1500°C	1530°C	P*
WPS	9.25±0.99 <sup>A, a</sup>	11.33±0.68 <sup>B, a</sup>	13.34±0.83 <sup>C, a</sup>	<0.001
IEZ	8.12±0.47 <sup>A, b</sup>	9.32±0.25 <sup>B, b</sup>	10.65±0.48 <sup>C, b</sup>	<0.001
P	0.005	0.0001	0.0001	

\*Groups with different superscript uppercase letters have significant differences in row (Tukey's test), Groups with superscript lower case letters have significant differences in column (Independent t-test). WPS: White Peaks Symphony; IEZ: Ivoclar e.max ZirCAD

increased the density and translucency. Ebeid *et al.*<sup>[30]</sup> compared 1460°C, 1530°C, and 1600°C temperatures and reported a reduction in the porosity of zirconia, and subsequently lower light refraction and higher translucency at higher sintering temperatures. Similar results were also reported by many others.<sup>[25,31]</sup> Despite the conformity of the above-mentioned results with our findings, it should be noted that these results must be interpreted while taking into account some other important parameters such as the color, strength, and resistance of zirconia, which can also be influenced by the sintering conditions. The reason for our findings is that increasing the temperature or duration of sintering increases the size of zirconia particles, and subsequently, the atomic force between them, which leads to a reduction in micro-porosities in the polycrystalline structure of zirconia. The combined effect of shrinkage of porosities between the particles and accumulation of nanocrystalline zirconia particles results in higher homogeneity of the crystalline structure of zirconia. This leads to light transmission with minimal refractive index, and eventual increase in translucency.<sup>[25,29,30,32,33]</sup> In line with this statement, Gómez *et al.*<sup>[34]</sup> showed a reduction in porosity by an increase in temperature such that the relative density increased from 50% to 99%. Furthermore, Sanal and Kilinc<sup>[35]</sup> demonstrated an increase in size of zirconia particles as the temperature increased from 1350°C to 1450°C and then to 1600°C.

Juntavee and Attashu<sup>[36]</sup> demonstrated that translucency of Y-TZP zirconia sintered at 1450 and 1550°C was significantly better than that of zirconia sintered at 1350°C. However, the translucency of zirconia sintered at 1450°C was higher than that at 1550°C. Their results were different from our findings, which may be attributed to the difference in methodology and thickness of specimens. In our study, the specimens had 1-mm thickness and they were all sintered for 2 h, while Juntavee and Attashu<sup>[36]</sup> evaluated specimens with 1.5-mm thickness and variable sintering times. Evidence shows that the thickness of zirconia specimens and duration of sintering affect the zirconia properties.<sup>[37]</sup> Cardoso *et al.*<sup>[38]</sup> found no significant difference in translucency or opacity of zirconia specimens sintered at 1450 and 1600°C; however, light absorption, scattering, and reflectance were significantly different between the two groups. Their results were different from our findings, probably due to the different types of zirconia evaluated in the two studies or the size

and thickness of specimens. The specimens in their study were larger and thicker than those in our study.

Zirconia has three phases of cubic, tetragonal, and monoclinic. The monoclinic phase is stable at temperatures up to 1170°C. At higher temperatures, the monoclinic phase gradually transforms to tetragonal, and then to the cubic phase. The translucency of the cubic phase is higher than in other phases. Thus, some authors believe that tetragonal to cubic phase transformation is another reason for increase in translucency. However, the tetragonal to cubic phase transformation at the conventional sintering temperatures is a matter of controversy.<sup>[30,39,40]</sup> Öztürk and Can<sup>[39]</sup> reported that sintering temperature and duration of storage did not affect phase transformation on the surface of zirconia specimens. Ebeid *et al.*<sup>[30]</sup> also reported that changing the storage time or sintering temperature did not cause phase transformation in monolithic zirconia, although it increased the translucency. In contrast, Inokoshi *et al.*<sup>[40]</sup> evaluated the effect of sintering parameters on phase transformation of three different commercial brands of zirconia and reported an increase in cubic phase on the surface following an increase in sintering temperature and duration of storage of specimens, which led to an increase in translucency. Attachoo and Juntavee<sup>[27]</sup> confirmed the effect of sintering temperature and duration on the translucency of monolithic zirconia. However, they reported that temperatures higher than 1550°C decreased translucency. They attributed this reduction to an increase in small cracks, which have been reported in some other studies as well.<sup>[41,42]</sup> Such small cracks may adversely affect light scattering and consequently the translucency of zirconia blocks.

One limitation of this study was that the zirconia blocks were flat and had no surface complexities; while in the clinical setting, the zirconia crowns have an anatomical shape and complex convex structures. Future studies should be performed on zirconia specimens with a morphology similar to that of tooth morphology to obtain more accurate results. Furthermore, future studies are required to compare the effects of different sintering temperatures on different brands of zirconia and on monolithic versus metal-ceramic restorations.

## CONCLUSION

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

1. Increasing the sintering temperature from 1440°C to 1530°C can significantly increase the translucency of IEZ and WPS zirconia blocks, and can be considered to improve the quality of zirconia restorations
2. The mean translucency of WPS zirconia was significantly higher than that of IEZ zirconia.

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### Conflicts of interest

The authors of this manuscript declare that they have no conflicts of interest, real or perceived, financial or nonfinancial in this article.

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