

Article

The Effect of Sintering Protocols and Resin Cement Shades on the Optical Properties of Monolithic Zirconia Restorations

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Abstract

This study investigates the influence of different sintering protocols and resin cement shades on the optical properties of monolithic zirconia restorations. Zirconia, widely used in dentistry for its superior mechanical strength and esthetic potential, demonstrates phase transformations influenced by stabilizing oxides and processing conditions. While increasing yttria content enhances translucency, it compromises mechanical durability. Factors such as sintering temperature, grain size, porosity, and cement selection further affect translucency parameter, contrast ratio, and opalescence. In this research, 36 zirconia samples were divided into three groups according to sintering procedure performed; conventional, fast, and super-fast sintering. Each was tested with two shades of dual-cure resin cement (yellow and transparent). Optical parameters including translucency parameter (TP), contrast ratio (CR), and opalescence parameter (OP) were measured using a spectrophotometer under controlled conditions. Statistically significant differences in OP values between the conventional sintering protocol and both the rapid and super-fast sintering protocols were found. A statistically significant difference was observed in OP values between the yellow and transparent cement groups. Neither the main effects of the sintering protocol nor the cement type were statistically significant on TP and CR values. However, a statistically significant interaction effect between the sintering protocol and cement type was observed for CR values. The findings highlight that both processing parameters and cement selection interaction play crucial roles in optimizing the TP and CR values of zirconia restorations, enabling improved esthetic outcomes in clinical practice.

Keywords: zirconia; sintering; optical properties; translucency; contrast; opalescence



Academic Editor: Luca Spiridigliozzi

Received: 2 December 2025

Revised: 31 December 2025

Accepted: 7 January 2026

Published: 19 January 2026

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1. Introduction

In dentistry, zirconia ceramics are used in two primary forms: as monolithic restorations or as substructure materials beneath veneering ceramics. When used as a substructure, zirconia forms the foundation of crowns and bridges, supporting an outer layer of veneering ceramic similar to the role metal plays in traditional metal-ceramic restorations [1]. However, unlike metal, zirconia avoids aesthetic drawbacks such as metallic shine-through, soft tissue discoloration, and hypersensitivity reactions. Despite these advantages, a well-known clinical issue is the weak bond between the zirconia core and the veneering layer. This can lead to delamination, fractures, or chipping, often resulting from mismatched

coefficients of thermal expansion between the two materials [2]. To address these challenges, monolithic zirconia restorations made entirely from zirconia without any veneering layer have gained popularity. The development of CAD/CAM technology has further enabled the fabrication of these restorations with improved strength, precision, and esthetics, reducing complications and increasing clinical success [3].

InCoris TZI (Dentsply Sirona Dental Systems GmbH, Bensheim, Germany) is a CAD/CAM-processable 3Y-TZP zirconia material designed for full-contour monolithic posterior restorations, offering high flexural strength (approximately 1000 MPa) and reliable clinical performance under functional loading conditions. Its pre-sintered block structure enables efficient milling and compatibility with rapid sintering protocols, significantly reducing fabrication time in chairside workflows. Long-term clinical data further support its stability, with survival rates reported at 86.9% over five years, confirming its suitability for routine posterior applications. Collectively, these characteristics position InCoris TZI as a robust material option that balances mechanical durability and efficient digital manufacturing [4].

Translucency and color matching are essential for achieving natural-looking dental restorations. As ceramic thickness increases, translucency tends to decrease. While reducing thickness can enhance light transmission, it also compromises the restoration's mechanical strength, posing a trade-off between esthetics and durability [5].

A material's optical behavior can be influenced by multiple factors, including sintering temperature, crystal phase distribution, porosity, coloring techniques, and restoration thickness. Additionally, the choice of luting cement, especially its color and opacity, can significantly alter the final appearance of zirconia-based restorations. Therefore, selecting the appropriate cement involves not only mechanical considerations but also esthetic and optical performance [6].

Three main methods are used to evaluate translucency: direct light transmission, total light transmission, and spectral reflectance. These measurements are typically conducted using spectrophotometers or spectroradiometers. The two most widely accepted metrics for assessing translucency are the TP and the CR [7].

TP is defined as the color difference of a material measured against ideal black and white backgrounds and is widely used to quantify the translucency of dental ceramics [7]. CR is defined as the ratio of light reflected by a material against a black background to that reflected against a white background. Values range from 0 (fully transparent) to 1 (completely opaque), offering a straightforward scale to compare translucency among materials [8,9]. Higher TP values indicate more translucent materials, while higher CR values correspond to increased opacity [10].

Opalescence is an optical phenomenon in which the scattering of shorter wavelengths of visible light results in a bluish-white appearance under reflected light, and an orange/brownish appearance under transmitted light. This behavior, observed in natural enamel and restorative materials, arises from wavelength-dependent light scattering within the material. OP quantifies this phenomenon by comparing CIE $L^*a^*b^*$ color coordinates measured under reflectance and transmittance conditions, with emphasis on differences in the a^* (red–green) and b^* (yellow–blue) axes. Higher OP values indicate a more pronounced opalescent effect [11].

Yttria-stabilized dental zirconia is typically sintered using conventional furnaces at temperatures ranging from 1350 °C to 1400 °C, with holding times of 2–4 h [12,13]. Various sintering methods such as resistive heating, hot pressing, and hot isostatic pressing can be employed. Recently, speed sintering has been introduced as an alternative technique, using higher temperatures (1500–1600 °C) and shorter durations (often under 30 min). This

method is designed to increase efficiency and reduce production time without significantly compromising quality [12].

In recent years, advancements in zirconia processing technology have focused heavily on optimizing sintering conditions to improve the structural integrity, esthetic performance, and clinical longevity of monolithic zirconia restorations. Zirconia sintering protocols—particularly conventional, high-speed, and modified rapid cycles—have been shown to influence grain growth, phase stability, and densification behavior, ultimately determining translucency, contrast ratio, opalescence, and overall optical performance [14,15].

Despite extensive research on zirconia sintering, little is known about how sintering protocol interacts with luting cement shade to influence optical parameters—specifically translucency, contrast ratio, and opalescence—following cementation. Existing studies have evaluated these factors independently, but no previous investigation has examined their combined effect. This gap is clinically relevant because restorative success depends not only on intrinsic material properties but also on the synergy between ceramic structure and cementation conditions. The present *in vitro* study focuses on a single translucent zirconia material (InCoris TZI Sirona) subjected to three clinically relevant sintering protocols (conventional, fast, super-fast) and two commonly used resin cement shades, while simultaneously quantifying translucency, contrast ratio, and opalescence before and after optical bonding. By linking routinely available processing options with multiple optical outcomes that are critical for shade matching, this work aims to provide more clinically oriented guidance for selecting sintering protocols and cement combinations in monolithic zirconia restorations.

2. Materials and Methods

This study examined how different zirconia sintering techniques and resin cement shades influence the final optical properties, specifically translucency, opacity, and contrast of ceramic restorations. InCoris TZI (Dentsply Sirona Dental Systems GmbH, Bensheim, Germany) zirconia block was used for sample fabrication. All samples were standardized into rectangular prisms ($10 \times 10 \times 1$ mm) to maintain consistency across measurements.

A total of 36 zirconia samples were prepared and divided equally into three groups, each subjected to a different sintering protocol:

Group I: Conventional sintering: For conventional sintering, pre-sintered InCoris TZI zirconia blocks were sintered in a zirconia sintering furnace following the manufacturer's recommendations. The specimens were heated at a rate of approximately $8\text{--}10$ °C/min to a final temperature of 1450 °C and held at this temperature for 2 h. After completion of the sintering cycle, the specimens were allowed to cool down gradually inside the furnace under controlled conditions. The total sintering duration, including heating, holding, and cooling stages, was approximately 10–12 h.

Group II: Rapid sintering: For fast sintering, an inFire HTC Speed furnace (Sirona Dental Systems GmbH, Bensheim, Germany) was used. The restorations prepared from pre-sintered zirconium dioxide blocks were placed into the furnace at room temperature. The temperature was initially increased at a heating rate of 99 °C/min to 1100 °C. Subsequently, the heating rate was reduced to 50 °C/min until a final temperature of 1510 °C was reached, and the specimens were held at this temperature for 30 min. After the holding phase, the restorations were cooled at a rate of 99 °C/min down to 800 °C and maintained at this temperature for 5 min before removal from the furnace. The total duration of the fast sintering cycle was approximately 60 min.

Group III: Superfast sintering: For super-fast sintering, an inFire HTC Speed furnace (Sirona Dental Systems GmbH, Bensheim, Germany) was used. Pre-sintered zirconium dioxide ceramic blocks were placed directly into a furnace preheated to 1580 °C and held

at this temperature for 10 min. Immediately after completion of the holding period, the specimens were removed from the furnace. The total duration required for the super-fast sintering procedure was 10 min.

To assess the effect of cement shade, resin cement samples were fabricated (10 × 10 mm, 0.2 mm thick) using two shades of dual-cure resin cement (Multilink Automix, Ivoclar Vivadent AG, Schaan, Liechtenstein): Transparent (T) and yellow (Y).

Each zirconia group underwent a two-step procedure. In the first step, optical bonding was established using the yellow resin cement, and the optical properties were measured. After removal of the yellow cement, the same procedure was repeated using the transparent cement. This approach allowed for a comparative evaluation of the effect of cement shade on optical properties. To simulate optical bonding between zirconia and resin cement, a thin layer of immersion oil with a refractive index of 1.515–1.517 (Merck 104699, Merck KGaA, Darmstadt, Germany) was applied to the resin surface using a brush. Cement specimens were positioned in contact with the unglazed surface of the zirconia, with the glazed surface facing outward. Measurements were performed at room temperature to preserve the optical properties of the immersion medium.

Color coordinates of all samples in each group were recorded on both black and white backgrounds using a digital spectrophotometer (VITA Easyshade Advance 4.0, Vita Zahnfabrik H. Rauter GmbH & Co. KG, Bad Säckingen, Germany) in accordance with ISO 2471:2008 [16]. Three measurements were taken from each specimen, and the mean of these measurements was used to calculate the CR, TP, and OP values for each sample.

The following equation was used to calculate the CR:

$$CR = Y_B / Y_W$$

Y_B : The spectral reflectance obtained over a black background.

Y_W : The spectral reflectance obtained over a white background.

TP, was calculated using the following equation:

$$TP = [(L^*_B - L^*_W)^2 + (a^*_B - a^*_W)^2 + (b^*_B - b^*_W)^2]^{1/2}$$

B = the color coordinates measured over a black background.

W = the color coordinates measured over a white background.

OP, the following equation was used:

$$OP = [(a^*_T - a^*_R)^2 + (b^*_T - b^*_R)^2]^{1/2}$$

T defines the transmitted light.

R defines the light reflected on a black background.

The normality of the continuous measurements in the study was tested using Skewness–Kurtosis tests, and since the measurements were normally distributed, parametric tests were applied. Descriptive statistics for the variables in the study are expressed as mean, standard deviation, number (n), and percentage (%). For the statistical evaluation of the optical properties, including the OP, TP, and CR, the effects of sintering protocol and cement type were analyzed. For each optical parameter, a two-way analysis of variance (ANOVA) was applied to assess the main effects of sintering protocol and cement type, as well as their interaction effects. When statistically significant differences were identified, pairwise comparisons were performed using the Tukey HSD post hoc test. The statistical significance level (α) was set at 5%, and IBM SPSS Statistics for Windows, Version 26.0 (IBM Corp., Armonk, NY, USA) statistical software was used for the analysis. If the *p*-value

obtained from a hypothesis test is below 0.05, it is stated that ‘the relationship/difference found in the comparison is statistically significant ($p < 0.05$).

3. Results and Discussion

Table 1 presents the results of the two-way ANOVA performed for the evaluation of OP values. The findings indicate that both the sintering protocol and cement type exerted statistically significant main effects on OP values ($p < 0.05$). Additionally, a statistically significant interaction was observed between the sintering protocol and cement type ($p < 0.05$).

Table 1. Tests of Between-Subjects Effects OP.

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	1464.66	5	292.93	8.82	0.000
Intercept	12,889.62	1	12,889.62	388.01	0.000
Sintering protocol	454.46	2	227.23	6.84	0.002
Cement	555.19	1	555.19	16.71	0.000
Sintering protocol $\times$ Cement	455.01	2	227.50	6.85	0.002
Error	2192.50	66	33.22		
Total	16,546.78	72			
Corrected Total	3657.16	71			

Table 2 presents the pairwise comparisons of OP values according to the sintering protocols. The results of the Tukey HSD test demonstrated statistically significant differences in OP values between the conventional sintering protocol and both the rapid and super-fast sintering protocols ($p < 0.05$). In contrast, no statistically significant difference was observed between the rapid and super-fast sintering protocols ($p > 0.05$).

Table 2. Multiple Comparisons OP values according to sintering protocols.

	Sintering Protocol (I)	Sintering Protocol (J)	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval (CI) Lower Bound	95% Upper Bound
Tukey HSD	Conventional	Rapid	−5.52	1.97	0.018	−10.23	−0.81
		Super Fast	−5.11	1.97	0.030	−9.82	−0.40
	Rapid	Conventional	5.52	1.97	0.018	0.81	10.23
		Super Fast	0.41	1.97	0.976	−4.30	5.12
	Super Fast	Conventional	5.11	1.97	0.030	0.40	9.82
		Rapid	−0.41	1.97	0.976	−5.12	4.30

Table 3 presents the pairwise comparisons of OP values according to cement type. The results of the Tukey HSD test indicated a statistically significant difference in OP values between the Yellow and Transparent cement groups ($p < 0.05$).

Table 3. Multiple Comparisons OP values according to cement type.

	Cement (I)	Cement (J)	Mean Difference (I-J)	Std. Error	Sig	95% CI Lower Bound	Upper Bound
Tukey HSD	Yellow	Transparent	−5.55	1.57	0.001	−8.68	−2.42
	Transparent	Yellow	5.55	1.57	0.001	2.42	8.68

Table 4 presents the results of the two-way ANOVA performed for TP values. The analysis demonstrated that neither the main effects of the sintering protocol nor the cement type were statistically significant ($p > 0.05$). In addition, the interaction between the

sintering protocol and cement type was not found to be statistically significant for TP values ($p > 0.05$).

Table 4. Tests of Between-Subjects Effects TP.

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	0.44	5	0.09	60	0.699
Intercept	2051.95	1	2051.95	13,860.18	0.000
Sintering protocol	0.17	2	0.08	0.57	0.568
Cement	0.07	1	0.07	0.48	0.489
Sintering protocol $\times$ Cement	0.20	2	0.10	0.69	0.505
Error	9.77	66	0.15		
Total	2062.16	72			
Corrected Total	10.22	71			

Table 5 presents the pairwise comparisons of TP values among the sintering protocols. According to the results of the Tukey HSD test, no statistically significant differences in TP values were observed among the conventional, rapid, and super-fast sintering protocols ($p > 0.05$).

Table 5. Multiple Comparisons TP values among the sintering protocols.

	Sintering Protocol (I)	Sintering Protocol (J)	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval (CI) Lower Bound	95% Upper Bound
Tukey HSD	Conventional	Rapid	0.12	0.11	0.533	−0.15	0.38
		Super Fast	0.07	0.11	0.820	−0.20	0.33
	Rapid	Conventional	−0.12	0.11	0.533	−0.38	0.15
		Super Fast	−0.05	0.11	0.884	−0.32	0.21
	Super Fast	Conventional	−0.07	0.11	0.820	−0.33	0.20
		Rapid	0.05	0.11	0.884	−0.21	0.32

Table 6 presents the pairwise comparisons of TP values according to cement type. The results of the Tukey HSD test indicated that no statistically significant difference was observed in TP values between the Yellow and Transparent cement groups ($p > 0.05$).

Table 6. Multiple Comparisons of TP according to cement type.

	Cement (I)	Cement (J)	Mean Difference (I-J)	Std. Error	Sig	95% CI Lower Bound	Upper Bound
Tukey HSD	Yellow	Transparent	0.06	0.09	0.485	−0.12	0.24
	Transparent	Yellow	−0.06	0.09	0.485	−0.24	0.12

Table 7 presents the results of the two-way ANOVA performed for CR values. The analysis indicated that the main effects of the sintering protocol and cement type on CR values were not statistically significant ($p > 0.05$). However, a statistically significant interaction effect between the sintering protocol and cement type was observed for CR values ($p < 0.05$).

Table 7. Tests of Between-Subjects Effects CR.

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	0.02	5	0.00	1.94	0.100
Intercept	44.24	1	44.24	19,901.06	0.000
Sintering protocol	0.01	2	0.00	1.13	0.331
Cement	0.00	1	0.00	0.01	0.907
Sintering protocol $\times$ Cement	0.02	2	0.01	3.71	0.030
Error	0.15	66	0.00		
Total	44.41	72			
Corrected Total	0.17	71			

Table 8 presents the pairwise comparisons of CR values according to the sintering protocols. The results of the Tukey HSD test showed that no statistically significant differences in CR values were found among the conventional, rapid, and super-fast sintering protocols ($p > 0.05$).

Table 8. Multiple Comparisons CR values according to sintering protocols.

	Sintering Protocol (I)	Sintering Protocol (J)	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval (CI) Lower Bound	95% Upper Bound
Tukey HSD	Conventional	Rapid	0.01	0.01	0.582	−0.02	0.05
		Super Fast	0.02	0.01	0.338	−0.01	0.05
	Rapid	Conventional	−0.01	0.01	0.582	−0.05	0.02
		Super Fast	0.01	0.01	0.907	−0.03	0.04
	Super Fast	Conventional	−0.02	0.01	0.338	−0.05	0.01
		Rapid	−0.01	0.01	0.907	−0.04	0.03

Table 9 presents the pairwise comparisons of CR values according to cement type. The results of the Tukey HSD test demonstrated that there was no statistically significant difference in CR values between the Yellow and Transparent cement groups ($p > 0.05$).

Table 9. Multiple Comparisons CR values according to cement type.

	Cement (I)	Cement (J)	Mean Difference (I-J)	Std. Error	Sig.	95% CI Lower Bound	Upper Bound
Tukey HSD	Yellow	Translucent	0.00	0.01	0.910	−0.02	0.02
	Transparent	Yellow	0.00	0.01	0.910	−0.02	0.02

This study explored how different sintering protocols—conventional, fast, and super-fast—and cement types (yellow and transparent) affect the optical properties of monolithic zirconia. The findings were evaluated in light of existing literature to offer a broader understanding of their clinical implications.

The optical behavior of monolithic zirconia plays a crucial role in the aesthetic success of dental restorations. Properties like TP, OP, and CR are increasingly prioritized not only for clinical performance but also for their ability to replicate the natural appearance of teeth and enhance patient satisfaction [17,18].

Comba et al. and Fonseca et al. reported that the final color and translucency of ceramic restorations are significantly influenced by the type of ceramic material, luting cement, and substrate type [19,20].

Cho et al. [15] indicated that sintering speed is a primary determinant of the TP, independent of zirconia type. Cho et al. [14] reported in another study that material type,

sintering speed, and layer significantly affected the TP), with multiple interactions among these factors. Lawson et al. [21] evaluated three different zirconia materials and reported that two of them became less translucent and weaker using a high-speed sintering program, whereas another was unaffected. In previous research [22], it was demonstrated that sintering protocols significantly influence both the TP and CR. Their study reported the highest TP values with conventional sintering, followed by fast and super-fast protocols. This suggests that extended sintering allows for greater particle agglomeration and reduced porosity via solid-state diffusion, leading to enhanced material density and changes in optical behavior [22]. Kaizer et al. and Jansen et al. reported that the fast-sintering method resulted in the highest translucency values and the finest grain structure [23,24]. Fast-sintered zirconia has been reported to exhibit slightly superior optical properties compared to conventionally sintered materials, and two-step sintering procedures have been shown to be more advantageous than single-step protocols [25–27]. A related investigation evaluated In Coris TZI Sirona zirconia crowns and found that higher sintering temperatures combined with shorter durations improved translucency [23]. Nonaka et al. [28] reported that high-speed sintering reduced the translucency of 5Y-TZP zirconia, attributing this effect primarily to increased residual porosity. However, no statistically significant differences in TP values were observed among the sintering protocols in the present study.

Beyond sintering techniques, cement type also emerged as a key determinant of final esthetic outcomes. The choice of cement influences how light reflects and transmits through the zirconia restoration, underscoring the need to consider both ceramic and cement components when optimizing optical performance [23].

In a previous study [29], it was observed that shorter sintering times led to greater light transmittance. In another study [30], no significant impact of sintering protocols was found on translucency across various specimen thicknesses. Similarly, in a study [31], no significant differences were found in TP and ΔE values between standard and fast sintering protocols. Our data indicated that the effect of sintering protocol on CR values depended on the cement type, as reflected by a significant interaction effect.

In a study [32], researchers reported the influence of cement type by showing that yellow transparent, and opaque cements yielded different optical results. The least color change occurred with yellow cement, while the most noticeable change was observed in titanium abutments paired with transparent cement.

A study [33] reported that white opaque resin cements increased the L^* value, making restorations appear lighter, while other colored cements tended to lower it, resulting in a darker appearance. Their findings also showed that Kerr White cement caused the greatest color difference (ΔE), whereas Panavia Light cement resulted in the least.

A limitation of this study is that immersion oil was used to simulate the refractive index of resin cement. Although this approach allows standardized optical measurements, it does not fully reproduce clinical cementation conditions, and optical results may differ when actual resin cements are used. Another limitation is that only one type of zirconia was used for this study. Further studies including different zirconia types are needed.

4. Conclusions

Statistically significant differences were observed in OP values between the conventional sintering protocol and both the rapid and super-fast sintering protocols. A statistically significant difference was observed in OP values between the Yellow and Transparent cement groups.

Sintering protocol and cement type did not affect TP and CR values. However, a statistically significant interaction effect between the sintering protocol and cement type was observed for CR values.

Author Contributions: Author Contributions: Conceptualization, M.Ç.T., E.T., S.P. and K.E.; methodology, A.D.C. and Ç.S.Ç.; software, A.D.C. and Ç.S.Ç.; validation, M.Ç.T., E.T., S.P. and K.E.; formal analysis, A.D.C. and Ç.S.Ç.; investigation, A.D.C. and Ç.S.Ç.; resources, A.D.C. and Ç.S.Ç.; data curation, A.D.C., Ç.S.Ç., M.Ç.T. and E.T.; writing—original draft preparation, A.D.C. and Ç.S.Ç.; writing—review and editing, M.Ç.T., E.T., S.P. and K.E.; visualization, A.D.C. and Ç.S.Ç.; supervision, M.Ç.T., E.T., S.P. and K.E.; project administration, A.D.C. and Ç.S.Ç.; funding acquisition, A.D.C. and Ç.S.Ç. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Data Availability Statement: The original contributions presented in this study are included in the article. Further inquiries can be directed to the corresponding author.

Conflicts of Interest: The authors declare no conflicts of interest.

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