Comparative Evaluation of the Optical Properties of CAD-CAM Zirconia Materials: An In Vitro Study

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http://doi.org/10.XXXX/j01.xxxxxxx

Received 15 June 2026; accepted 14 October 2026

The aim of this in vitro study was to compare the relative translucency parameter (*RTP*), contrast ratio (*CR*), and opalescence parameter (*OP*) of selected commercial translucent CAD-CAM zirconia materials. Three Computer-Aided Design – Computer-Aided Manufacturing (CAD-CAM) zirconia materials were evaluated: Katana UTML, InCoris TZI C, and Cercon XT. Thirty-six A2-shade specimens with dimensions of 10 × 12 mm and a final thickness of 1.00 ± 0.05 mm were prepared. Color coordinates were measured on standardized black and white backgrounds using a digital spectrophotometer. *RTP* was calculated using the CIEDE2000 formula, *CR* was determined from reflectance values, and *OP* was calculated from differences in a* and b* coordinates. The data were analyzed using one-way analysis of variance followed by the Bonferroni post hoc test. Significant differences were found among the materials for *RTP*, *CR*, and *OP*. Katana UTML showed significantly higher RTP and lower CR values than InCoris TZI C and Cercon XT. However, Katana UTML showed significantly lower OP values. These findings indicate that translucency and opalescence do not necessarily change in parallel. RTP, CR, and OP should therefore be considered together when selecting zirconia materials for esthetic restorations.
Keywords: contrast ratio, dental ceramics, opalescence, translucency, zirconia.

1. INTRODUCTION

The esthetic performance of Computer-Aided Design – Computer-Aided Manufacturing (CAD-CAM) monolithic ceramic restorations depends largely on their ability to reproduce the optical characteristics of natural teeth. Zirconia is widely used in prosthetic dentistry because of its favorable biocompatibility and mechanical properties [1, 2]. However, the high opacity of conventional 3 mol.% yttria-stabilized tetragonal zirconia polycrystal limits its use in esthetically demanding situations.

Zirconia materials with higher yttria (Y_2O_3) contents have been developed to improve translucency. Increasing the Y_2O_3 content promotes the formation of the optically isotropic cubic phase, thereby reducing birefringence and light scattering at grain boundaries [1, 3, 4]. The optical behavior of zirconia is also affected by material thickness, surface texture, chemical composition, microstructure, pigmentation, and sintering protocol [5].

Color perception, translucency, contrast, and opalescence are important parameters in material selection for esthetic restorations. These properties may be evaluated using relative translucency parameter (*RTP*), contrast ratio (*CR*), and opalescence parameter (*OP*) [6, 7]. Although the optical properties of zirconia have been widely investigated, most previous studies have focused on individual materials or specific processing and methodological variables. Uasuwan et al. [4] evaluated *TP*, *CR*, and *OP* simultaneously in monochrome and multilayer 5*Y* zirconia; however, their study primarily examined the effect of different sintering cooling rates and calculated translucency using the conventional CIELAB-based TP. Salas et al. [8] showed that the CIEDE2000 formula provides better agreement between calculated and visually perceived color differences and established perceptibility and acceptability thresholds for CIEDE2000-based translucency differences.

Evidence remains limited on the simultaneous evaluation of CIEDE2000-based *RTP*, *CR*, and *OP* in contemporary commercial CAD-CAM zirconia materials tested at the same shade and thickness under a standardized measurement protocol [8]. Such an evaluation can show whether different translucency indicators rank materials consistently and whether greater translucency is accompanied by greater opalescence. Therefore, this in vitro study compared the *RTP*, *CR*, and *OP* values of selected commercial CAD-CAM zirconia materials and examined whether these parameters showed concordant material-dependent patterns. The null hypothesis was that RTP, CR, and OP would not differ significantly among the materials.

2. EXPERIMENTAL DETAILS

2.1. Sample size calculation

The sample size was determined from previous in vitro dental materials studies and an a priori power analysis performed using G*Power software. With an anticipated effect size of $f = 0.60$, a statistical power of 80 %, and a significance level of $\alpha = 0.05$, the minimum required sample size was 10 specimens per group. Twelve specimens were included in each group.

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2.2. Specimen preparation

Rectangular specimens measuring 10 × 12 mm were digitally designed and milled from A2-shade CAD-CAM zirconia blocks. The specimens were assigned to three groups according to material: Katana UTML, InCoris TZI C, and Cercon XT. For Katana UTML, the specimens were sectioned vertically through the multilayered blank so that each specimen contained the complete layer sequence rather than a single layer. This orientation preserved the multilayer architecture and allowed the combined optical contribution of the layers to be evaluated. The material characteristics are listed in Table 1.

2.3. Sintering and surface standardization

After milling, all specimens were sintered in a zirconia furnace according to the manufacturers' recommendations. The sintering parameters are shown in Table 2. The sintered specimens were ground under water cooling using silicon carbide abrasive papers ranging from #600 to #1500 grit. Final thickness was standardized to 1.00 ± 0.05 mm and verified using a digital caliper. Before the optical measurements, the specimens were ultrasonically cleaned for 10 min. The study design and optical measurement procedure are shown schematically in Fig. 1.

2.4. Optical measurements and calculation of optical parameters

Color measurements were performed using a digital spectrophotometer (VITA Easyshade V; VITA Zahnfabrik, Bad Säckingen, Germany) in Base Shade mode [9]. The instrument uses an integrated white LED light source corresponding to the D65 illuminant, a 2° standard observer, and 45°:0° optical geometry [10]. Each specimen was placed directly on standardized black (L^* = 0.5, a^* = 14.6, b^* = −21.5) and white (L^* = 90.9, a^* = 0.3, b^* = 4.9) backgrounds.

Table 1. Characteristics of the CAD-CAM zirconia materials used in the study

Material	Zirconia type	Chemical composition	Shade/translucency	Manufacturer
InCoris TZI C	Pre-shaded zirconium oxide / 3Y-TZP	ZrO_2; Y_2O_3: 5 wt.%; HfO_2:<3 wt.%; Al_2O_3, SiO_2, and other oxides: < 2 wt.%	A2, high translucency	Dentsply Sirona, Charlotte, North Carolina, USA
Katana UTML	Ultra-translucent multilayered zirconia / 5Y-PSZ	ZrO_2+HfO_2: 87 – 92 wt.%; Y_2O_3: 8 – 11 wt.%; other oxides: 0 – 2 wt.%	A2, ultra-translucent / high translucency	Kuraray Noritake Dental Inc., Japan
Cercon XT	Extra-translucent monochromatic zirconia / 5Y-PSZ	ZrO_2; Y_2O_3: 9 wt.%; HfO_2:<3 wt.%; Al_2O_3, SiO_2, and other oxides: <1 wt.%	A2, extra-translucent zirconia	Dentsply Sirona, Charlotte, North Carolina, USA
Note: Data were compiled from manufacturers' information and relevant literature. Chemical composition percentages are reported by mass (wt%), whereas the 3Y and 5Y classifications refer to nominal molar yttria contents. 3Y-TZP, 3 mol% yttria-stabilized tetragonal zirconia polycrystal; 5Y-PSZ, 5 mol% yttria-partially stabilized zirconia.				

Table 2. Sintering parameters of the zirconia materials

Material	Process	Parameters	Shade/translucency	Manufacturer
InCoris TZI C	Conventional sintering	Heating from room temperature to 880°C, over 40 min (22°C/min) without holding; further heating to 1500°C, over 55 min (11°C/min); holding at 1500°C for 135 min; cooling to 200°C, over 65 min (20°C/min) in the closed furnace.	A2, high translucency	Dentsply Sirona, Charlotte, North Carolina, USA
Katana UTML	Conventional sintering	Total sintering time: 7 h; maximum sintering temperature: 1550 °C; holding time: 120 min; cooling rate: 10 °C/min until room temperature.	A2, ultra-translucent / high translucency	Kuraray Noritake Dental Inc., Japan
Cercon XT	Conventional sintering	Heating from room temperature to 900°C over 40 min; further heating to 1500°C over 55 min; holding at 1500°C for 145 min; cooling in the closed furnace to 200°C.	A2, extra-translucent zirconia	Dentsply Sirona, Charlotte, North Carolina, USA

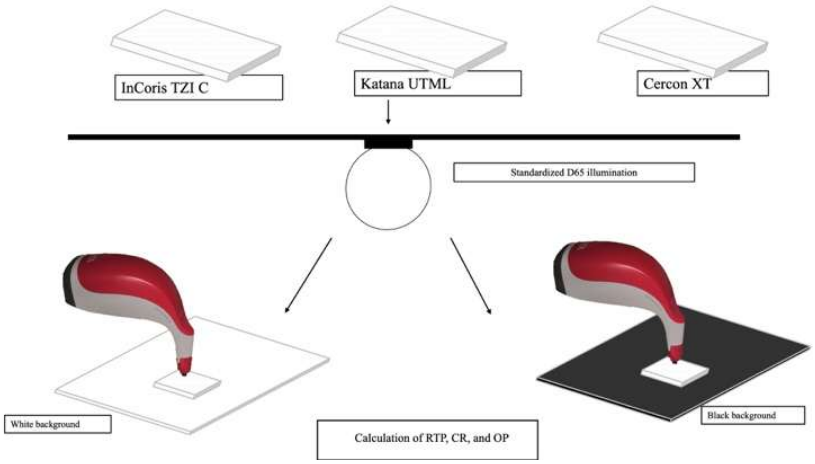


Fig. 1. Schematic representation of the experimental design and optical measurement procedure

The measuring probe was positioned perpendicular to the specimen surface, and measurements were obtained at the center of each specimen. The spectrophotometer was calibrated before each measurement according to the manufacturer's instructions. All measurements were performed by the same investigator in a closed, windowless room under standardized ambient D65 illumination. The three readings were averaged separately for the L^*, a^*, and b^* coordinates on each background. The measuring tip was positioned perpendicular to and in direct contact with the center of the specimen surface. The tip was lifted and repositioned between consecutive readings. A single *RTP*, *CR*, and *OP* value was subsequently calculated for each specimen from the corresponding mean values.

RTP was calculated using the CIEDE2000 color difference formula [8, 11]:

$$RTP_{00} = \sqrt{\left(\frac{\Delta L'}{K_L S_L}\right)^2 + \left(\frac{\Delta C'}{K_C S_C}\right)^2 + \left(\frac{\Delta H'}{K_H S_H}\right)^2 + R_T \left(\frac{\Delta C'}{K_C S_C}\right)\left(\frac{\Delta H'}{K_H S_H}\right)}, \quad (1)$$

where $\Delta L'$, $\Delta C'$, and $\Delta H'$ are the differences in lightness, chroma, and hue between measurements obtained on the black and white backgrounds; S_l, S_c, and S_h are weighting functions; K_l, K_c, and K_h are parametric factors; and R_t is the rotation function.

CR was calculated as follows [12]:

$$CR = \frac{Y_B}{Y_W}, \quad (2)$$

where Y_B and Y_W represent the reflectance values measured on the black and white backgrounds, respectively.

OP was calculated using the following equation [6, 7, 13]:

$$OP = \sqrt{(a^*_B - a^*_W)^2 + (b^*_B - b^*_W)^2}, \quad (3)$$

where *B* represents measurements on the black background, and *W* represents measurements on the white background.

2.5. Statistical analysis

Statistical analyses were performed using SPSS software. The Shapiro-Wilk test was used to assess data distribution, and Levene's test was used to evaluate homogeneity of variance. Differences among the groups were analyzed using one-way analysis of variance (ANOVA), followed by the Bonferroni post hoc test for pairwise comparisons. Statistical significance was set at $p < 0.05$.

3. RESULTS

The mean *RTP*, *CR*, and *OP* values are presented in Table 3 and Fig. 2. One-way ANOVA showed significant differences among the materials for all three optical parameters.

Table 3. *RTP*, *CR*, and *OP* values of the groups

Material	*RTP*	*CR*	*OP*
InCoris TZI C	8.31 ± 0.48[a]	0.70 ± 0.02[a]	5.88 ± 0.46[a]
Katana UTML	10.13 ± 0.98[b]	0.65 ± 0.02[b]	4.23 ± 2.33[b]
Cercon XT	8.07 ± 0.80[a]	0.72 ± 0.03[a]	6.48 ± 1.62[b]

Note: Data are presented as mean ± standard deviation. RTP, relative translucency parameter; CR, contrast ratio; OP, opalescence parameter. Different lowercase superscript letters in the same column indicate significant differences among groups ($p < 0.05$).

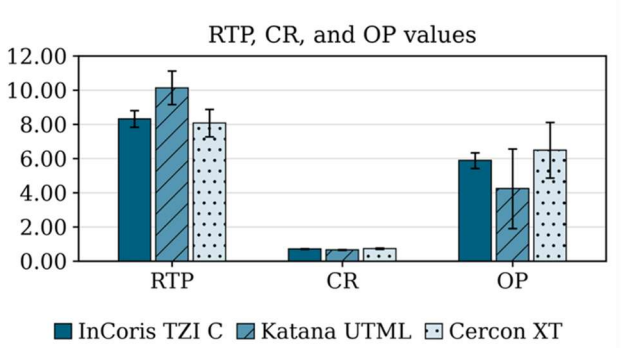


Fig. 2. Mean (± standard deviation) *RTP*, *CR*, and *OP* values of the evaluated CAD-CAM zirconia materials

One-way ANOVA results are presented in Table 4. For RTP, a significant difference was found among the materials ($F(2.33) = 24.699$, $p < 0.001$). The highest value was observed in Katana UTML, whereas the lowest value was observed in Cercon XT. Katana UTML showed significantly higher RTP values than InCoris TZI C and Cercon XT ($p < 0.001$ for both comparisons). No significant difference was found between InCoris TZI C and Cercon XT ($p = 0.738$).

For *CR*, a significant difference was also found among the materials ($F(2.33) = 27.540$, $p < 0.001$). Katana UTML showed the lowest value, whereas Cercon XT showed the highest value. Katana UTML had significantly lower *CR* values than the other two materials ($p < 0.001$ for both comparisons). No significant difference was found between InCoris TZI C and Cercon XT ($p = 0.495$).

Table 4. One-way analysis of variance results for *RTP*, *CR*, and *OP* values

Variable	Source of variation	Sum of squares	df	Mean square	*F*	*p*
RTP	Between groups	30.651	2	15.326	24.699	< 0.001
	Within groups	20.476	33	0.620		
	Total	51.127	35			
CR	Between groups	0.031	2	0.016	27.540	< 0.001
	Within groups	0.019	33	0.001		
	Total	0.050	35			
OP	Between groups	34.428	2	17.214	6.185	0.005
	Within groups	91.851	33	2.783		
	Total	126.28	35			

Note: *RTP* – relative translucency parameter; *CR* – contrast ratio; *OP* – opalescence parameter; *df* – degrees of freedom.

For *OP*, the difference among the materials was statistically significant ($F(2.33) = 6.185$, $p = 0.005$). The lowest value was observed in Katana UTML, whereas the highest value was observed in Cercon XT. Katana UTML showed significantly lower *OP* values than InCoris TZI C ($p = 0.030$) and Cercon XT ($p = 0.006$). No significant difference was found between InCoris TZI C and Cercon XT ($p = 0.801$).

4. DISCUSSION

The optical properties of zirconia materials are clinically important because monolithic restorations are expected to reproduce the appearance of natural dental tissues [1, 14]. In the present study, *RTP*, *CR*, and *OP* differed significantly among the three commercial CAD-CAM zirconia materials. The null hypothesis was therefore rejected for *RTP*, *CR*, and *OP* ($p < 0.001$, $p < 0.001$, $p = 0.005$, respectively).

Katana UTML showed higher *RTP* and lower *CR* values than InCoris TZI C and Cercon XT, indicating a more translucent optical profile. Translucency is related to the amount of light transmitted through a material; as light transmission increases, *RTP* increases, and *CR* decreases [1, 15]. High translucency has been widely reported for zirconia ceramics with higher nominal yttria contents [1, 16]. Inokoshi et al. [17] associated greater yttria content with a larger cubic-phase fraction and increased translucency. They attributed this relationship to the optically isotropic nature of the cubic phase and the resulting reduction in birefringence and light scattering. This mechanism may have contributed to the higher *RTP* and lower *CR* values of Katana UTML. However, phase composition and grain size were not directly characterized in this study. The materials also differed in pigmentation, microstructure, layer architecture, oxide additives, and processing protocols [3, 4, 18, 19]. This explanation should therefore be regarded as a literature-supported interpretation rather than direct mechanistic evidence from the tested specimens.

Recent systematic reviews support this multifactorial interpretation. Yousry et al. [20] found that yttria content influenced zirconia translucency but also reported substantial heterogeneity and differences among materials within the same zirconia generation. They identified additives, microstructure, thickness, phase distribution, and sintering conditions as additional factors affecting translucency. Similarly, the meta-regression by Solá-Ruíz et al. [21] showed that the highest yttria category (> 6.1 % in their analysis) was associated with increased *TP* and reduced *CR*, while alumina content also significantly influenced both parameters. Together, these findings support the interpretation that the higher *RTP* and lower *CR* of Katana UTML were material-dependent rather than attributable solely to its nominal yttria content.

The mean *RTP* differences between Katana UTML and InCoris TZI C ($\Delta RTP_{00} = 1.82$) and between Katana UTML and Cercon XT ($\Delta RTP_{00} = 2.06$) exceeded the CIEDE2000-based 50:50 % perceptibility threshold ($TPT_{00} = 0.62$) but remained below the acceptability threshold ($TAT_{00} = 2.62$) reported by Salas et al. [8]. By contrast, the difference between InCoris TZI C and Cercon XT ($\Delta RTP_{00} = 0.24$) was below the perceptibility threshold. The differences between Katana UTML and the other materials may therefore be visually perceptible while remaining within the reported acceptability threshold. However, these thresholds were established using 1-mm-thick resin composite specimens, and their direct applicability to zirconia should be interpreted cautiously.

The present findings are consistent with those of Elsaka [22], who reported higher translucency and lower *CR* values for a multilayered zirconia than for the other zirconia materials evaluated. Ziyad et al. [23] reported conventional CIELAB-based *TP* values of 14.09 – 14.28 for 1-mm-thick, A2-shade multilayer zirconias, whereas Uasuwan et al. [4] reported a *TP* of 2.76 ± 0.09 for 2-mm-thick Cercon XT after a normal cooling protocol. The *RTP* values in the present study ranged from 8.07 to 10.13. These values cannot be compared directly because the previous studies used the conventional CIELAB-based *TP* formula, whereas the present study used the CIEDE2000-based *RTP* formula. Differences in specimen thickness, instrumentation, measurement conditions, and sintering protocols should also be considered.

Katana UTML showed the lowest *CR*, indicating lower opacity and greater translucency. This result is consistent with the strong inverse relationship between translucency and *CR* reported by Barizon et al. [15]. Ziyad et al. [23] reported *CR* values of 0.689 – 0.710 for 1-mm-thick multilayer zirconias, which were broadly comparable with the range found in the present study (0.65 – 0.72). They reported a *CR* of 0.696 ± 0.039 for Katana STML, whereas Katana UTML showed a value of 0.65 ± 0.02 in the present study. For Cercon XT, Uasuwan et al. [4] reported a higher CR (0.937 ± 0.002) than that obtained in the present study (0.72 ± 0.03). This difference may be partly related to the greater specimen thickness used by Uasuwan et al. (2 mm versus 1 mm), as well as differences in measurement backgrounds, instrumentation, and sintering conditions.

Zirconia materials with higher *RTP* and lower *CR* values may be advantageous for anterior restorations when natural light transmission is desired. However, greater translucency may reduce the ability of a restoration to mask discolored tooth structure, metallic posts, or dark substrates. Cho et al. [24] found that zirconia translucency increased with yttria content and that even Katana UTML did not adequately mask severely discolored dentin. Dai et al. [25] further showed that the masking ability of high-translucency zirconia over dark and metallic substrates depends on restoration thickness and resin cement shade.

Opalescence also contributes to the enamel-like appearance of a restorative material. Katana UTML showed the lowest *OP* in the present study, whereas Cercon XT showed the highest. The lower *OP* of Katana UTML, despite its higher *RTP* and lower *CR*, indicates that translucency and opalescence do not necessarily increase in parallel. Zirconia opalescence may vary with material type, layer position, pigmentation, microstructure, and sintering conditions [4, 7, 18, 26]. Shirani et al. [7] reported material- and region-dependent *OP* values of 5.45 – 8.11 in multilayer zirconia and related the differences among layers mainly to chromatic variables. Juntavee and Attashu [26] found that changes in sintering temperature and holding time significantly affected *OP*, whereas Cho and Seol [18]

observed small material- and layer-dependent changes in opalescence after speed sintering.

Uasuwan et al. [4] reported that slower cooling increased both *TP* and *OP* while decreasing *CR* in a monochromatic 5Y zirconia. Katana UTML, by contrast, showed the highest *RTP* and lowest *CR* but the lowest *OP* in the present study. These contrasting patterns indicate that the relationship between translucency and opalescence depends on the material and processing conditions rather than following a universal pattern.

Ziyad et al. [23] reported *OP* values of 5.07 – 8.31 for multilayer zirconia materials, whereas the values in the present study ranged from 4.23 to 6.48. Their *OP* value for Katana STML was 8.27 ± 0.98, compared with 4.23 ± 2.33 for Katana UTML in the present study. For Cercon XT, Uasuwan et al. [4] reported an *OP* of 2.17 ± 0.11, compared with 6.48 ± 1.62 in the present study. These differences may reflect variation in zirconia generation, layer composition, pigmentation, specimen thickness, sintering protocols, measurement geometry, backgrounds, and spectrophotometer characteristics.

The *OP* values obtained in the present study were considerably lower than the mean value of 22.9 ± 1.9 reported for human enamel by Lee and Yu [27]. Cho et al. [28] similarly reported *OP* values of 1.3 – 7.1 for all-ceramic core, veneer, and layered specimens, all lower than those of natural enamel. Thus, although contemporary zirconia materials have achieved improved translucency, their capacity to reproduce the opalescent appearance of natural enamel remains limited.

The principal contribution of this study is the simultaneous evaluation of *RTP*, *CR*, and *OP* under standardized measurement conditions. *OP* produced a different material ranking from *RTP* and *CR*, showing that these parameters describe complementary aspects of optical behavior. Their combined evaluation may therefore provide a more complete basis for selecting zirconia materials for esthetic restorations.

This study has several limitations. Only three CAD-CAM zirconia materials were evaluated, and all measurements were performed on flat, 1-mm-thick specimens. The actual yttria concentrations, phase fractions, grain sizes, porosity, and pigment or oxide distributions were not independently assessed using X-ray diffraction or microscopic analysis. Material classifications and the proposed microstructural explanations were therefore based on manufacturer information and published evidence. Consequently, the observed differences cannot be attributed solely to nominal yttria content, and the proposed associations should not be interpreted as causal. Future studies should combine direct phase and microstructural characterization with assessments of aging, restoration geometry, substrate color, cement shade, and material thickness.

5. CONCLUSIONS

The optical properties of the evaluated CAD-CAM zirconia materials were material-dependent. Katana UTML exhibited the highest translucency but the lowest opalescence, indicating that these properties do not necessarily change in parallel. Therefore, the relative translucency parameter (*RTP*), contrast ratio (*CR*), and opalescence parameter (*OP*) should be considered together when selecting zirconia materials for esthetic restorations.

Acknowledgments

This study was presented as an oral presentation at the 30th Congress of the Balkan Stomatological Society, held on May 7 – 9, 2026, in Thessaloniki, Greece. The authors declare no conflicts of interest related to this study. The authors received no financial support. This was an in vitro study; no human participants or animals were involved, and ethics committee approval was not required.

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