



TRANSLUCENCY OF DENTAL CERAMICS WITH DIFFERENT THICKNESSES

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Statement of problem. The increased use of esthetic restorations requires an improved understanding of the translucent characteristics of ceramic materials. Ceramic translucency has been considered to be dependent on composition and thickness, but less information is available about the translucent characteristics of these materials, especially at different thicknesses.

Purpose. The purpose of this study was to investigate the relationship between translucency and the thickness of different dental ceramics.

Material and methods. Six disk-shaped specimens of 8 glass ceramics (IPS e.max Press HO, MO, LT, HT, IPS e.max CAD LT, MO, AvanteZ Dentin, and Trans) and 5 specimens of 5 zirconia ceramics (Cercon Base, Zenotec Zr Bridge, Lava Standard, Lava Standard FS3, and Lava Plus High Translucency) were prepared following the manufacturers' instructions and ground to a predetermined thickness with a grinding machine. A spectrophotometer was used to measure the translucency parameters (TP) of the glass ceramics, which ranged from 2.0 to 0.6 mm, and of the zirconia ceramics, which ranged from 1.0 to 0.4 mm. The relationship between the thickness and TP of each material was evaluated using a regression analysis ($\alpha=.05$).

Results. The TP values of the glass ceramics ranged from 2.2 to 25.3 and the zirconia ceramics from 5.5 to 15.1. There was an increase in the TP with a decrease in thickness, but the amount of change was material dependent. An exponential relationship with statistical significance ($P<.05$) between the TP and thickness was found for both glass ceramics and zirconia ceramics.

Conclusions. The translucency of dental ceramics was significantly influenced by both material and thickness. The translucency of all materials increased exponentially as the thickness decreased. All of the zirconia ceramics evaluated in the present study showed some degree of translucency, which was less sensitive to thickness compared to that of the glass ceramics. (J Prosthet Dent 2013;110:14-20)

CLINICAL IMPLICATIONS

In clinical practice, ceramic selection should follow the mechanical and optical requirements of the tooth to be restored. Based on the results of the present study, the effects of both material and thickness on the final optical appearance of ceramic restorations should be considered.

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Ceramic materials have been advocated rather than traditional metal ceramic restorations because of their excellent esthetics and acceptable mechanical properties.¹⁻⁴ Since dentin and enamel have inherent translucency,^{5,6} esthetically matching ceramic restorations with adjacent natural teeth should involve not only shape and texture but also the reproduction of the optical characteristics of natural teeth. The translucency of ceramics has been emphasized as one of the primary factors in controlling the esthetic outcome of ceramic restorations.⁷ In addition, the translucency of ceramics is also closely related to light transmission and the polymerization efficiency of underlying resin-based cements.⁸⁻¹¹

Contrast ratio has been reported for measuring the translucency of restorative resin by Powers et al,¹² which is the ratio of the reflectance from an object resting on a black backing to the reflectance obtained for the same material against a white backing. In 1995, the translucency parameter (TP) was introduced to evaluate the translucency of maxillofacial elastomer.¹³ Johnston and Reisbick¹⁴ used a reflectance model to describe the colors used for determining the TP of esthetic restorative resins. The TP is calculated directly from the color difference for the specimens on the black and white backings. The major factors which affect TP (specimen thickness and the reflectance parameters of the black and white backings) varied only slightly.¹⁴ The translucent parameter was considered to correspond directly to common visual assessments^{13,14} and has been one of the most widely used methods to compare relative translucency of dental materials. The transmission coefficient has also been used for analysis translucency of dental ceramics by calculating the ratio of values of incident and transmitted powers.¹⁰

A range of translucency has been identified for dental ceramic core materials and veneered ceramic systems. Such variability may affect their ability

to match natural teeth.¹⁵⁻¹⁹ Lim et al²⁰ compared the translucency of these 2 types of materials with a spectroradiometer and a spectrophotometer. Differences in the translucency of porcelain with an illuminant was also determined.^{21,22} In these studies, the translucency of dental ceramics was mainly studied at a certain thickness, generally, the thinnest recommended by the manufacturers. In clinical situations, ceramic restorations with various thicknesses are required, depending on the different conditions of the tooth to be restored.^{23,24} Therefore, an accurate knowledge of the relationship between the translucency and thickness of restorative materials is fundamental to improving the esthetic outcome of dental restorations.

The translucency of composite resins has been reported to increase exponentially as the thickness decreases.^{25,26} For glass ceramics, the contrast ratio or transmission coefficient at different thicknesses has been evaluated previously.^{10,27} One study found that the contrast ratio of dental ceramics was linearly related to the thickness,²⁷ but another found an exponential increase of the transmission coefficient of a porcelain with a decrease in thickness.¹⁰ However, no consensus on the correlation between the translucency and thickness of glass ceramics has been achieved. Zirconia is the dental ceramic with the highest mechanical properties²⁸⁻³⁰ and was previously considered to be an opaque material,^{16,19} although zirconia copings have been recently reported to allow some light to pass through.^{31,32} Moreover, activated pressure-assisted densification was reported to improve the translucency of polycrystalline zirconia.³³ However, the authors identified no information in the literature about the relationship between the translucency and thickness of zirconia ceramics.

Therefore, the purpose of the study was to investigate the translucent parameter of representative glass ceramics and zirconia ceramics according to different thicknesses and to analyze the relationship between

translucency and ceramic thickness. The null hypothesis was that the translucency of ceramics was not influenced by ceramic type or thickness.

MATERIAL AND METHODS

The dental ceramics evaluated in the present study are listed in Table I. Eight glass ceramics (4 lithium disilicate glass ceramics [PHO, PMO, PLT, and PHT], 2 leucite-free glass ceramics [AZD and AZT] for heat pressing application, 2 lithium disilicate glass ceramics for CAD/CAM application [CLT and CMO]), and 5 zirconia ceramics (CRB, ZNT, LVS, LVF, and LVP) were tested. Six disk-shaped specimens (13.0 × 2.2 mm) for glass ceramics and 5 disk-shaped specimens (13.0 × 1.1 mm) for zirconia ceramics were prepared following the manufacturers' instructions. The specimens were fixed to a plate index and ground sequentially by using a series of diamond grinding sheets (#100, 320, 600, 1000, and 1500) on a grinding machine (ML-150P; Maruto, Tokyo, Japan). The grinding and polishing procedures were performed on both sides of the specimens to make 2.0-mm thick specimens for the glass ceramics and 1.0-mm thick specimens for the zirconia ceramics. The final thickness was determined with a digital micrometer (MDC-25M; Mitutoyo, Tokyo, Japan) with an accuracy of ±0.01 mm. Before each measurement, the specimens were ultrasonically cleaned in distilled water for 10 minutes and dried with compressed air.

The CIE L*a*b* values of each specimen were measured on a black background ($L^*=7.66$, $a^*=-1.64$, and $b^*=-6.87$) and on a white background ($L^*=91.42$, $a^*=-0.99$, and $b^*=1.31$) with a spectrophotometer (Crystal-eye; Olympus Corp, Tokyo, Japan) calibrated with a calibration plate positioned at a constant distance from the specimen surface. The light source illumination corresponded to average daylight (D65). The translucency parameter (TP) was obtained by calculating the color difference between

TABLE I. Ceramic materials evaluated

Code	Material	Type	Process	Batch	Manufacturer
PHO	IPS e.max Press HO 1	Lithium disilicate glass ceramic	Heat-pressing	M02012	Ivoclar Vivadent Schaan, Liechtenstein
PMO	IPS e.max Press MO1	Lithium disilicate glass ceramic	Heat-pressing	N28321	Ivoclar Vivadent
PLT	IPS e.max Press LT A2	Lithium disilicate glass ceramic	Heat-pressing	N34215	Ivoclar Vivadent
PHT	IPS e.max Press HT A2	Lithium disilicate glass ceramic	Heat-pressing	N38552	Ivoclar Vivadent
CLT	IPS e.max CAD LT A2	Lithium disilicate glass ceramic	CAD/CAM	N12414	Ivoclar Vivadent
CMO	IPS e.max CAD MO2	Lithium disilicate glass ceramic	CAD/CAM	K42686	Ivoclar Vivadent
AZD	AvanteZ Dentin A2	Leucite-free glass ceramic	Heat-pressing	167504	Pentron Ceramic Inc Somerset, NJ
AZT	AvanteZ Trans A2	Leucite-free glass ceramic	Heat-pressing	N30855	Pentron Ceramic Inc
CRB	Cercon Base	Zirconia ceramic	CAD/CAM	18004150	DeguDent GmbH Hanau-Wolfgang, Germany
ZNT	Zenotec Zr Bridge	Zirconia ceramic	CAD/CAM	20101115-26	Wieland Dental+Technic GmbH Pforzheim, Germany
LVS	Lava Standard	Zirconia ceramic	CAD/CAM	#43-2010	3M ESPE AG Seefeld, Germany
LVF	Lava Standard FS3	Zirconia ceramic	CAD/CAM	#381164	3M ESPE AG
LVP	Lava Plus High Translucency	Zirconia ceramic	CAD/CAM	#57-2011	3M ESPE AG

the specimen against the white background and against the black background with the following equation¹³:

$$TP = \sqrt{(L_B^* - L_W^*)^2 + (a_B^* - a_W^*)^2 + (b_B^* - b_W^*)^2}$$

where L^* refers to the brightness, a^* to redness to greenness, and b^* to yellowness to blueness. The subscripts B refers to the color coordinates on the black background and W to those on the white background. A high TP value indicates high translucency and low opacity. Three measurements were made for each specimen on its respective background, and the average value was recorded.

After measuring the translucency at 1 thickness, the specimens were subjected to the grinding and polishing procedure according to the previously described procedure. When the next proposed thickness was achieved, the translucency was measured again. For the glass ceramics, the translucency was determined every 0.2 mm between 2.0 and 1.0 mm and every 0.1 mm from 1.0 to 0.6 mm. The translucency of the zirconia

ceramics was determined every 0.1 mm between 1.0 and 0.4 mm.

The effects of the material and thickness on the TP values of the glass ceramics and zirconia ceramics were analyzed with a 2-way analysis of variance (ANOVA), followed by the Tukey Honestly Significant Difference (HSD) test by using statistical software (SPSS 12.0; SAS, Chicago, Ill; $\alpha = .05$). The relationship between the thickness and TP values of each ceramic was evaluated with a regression analysis of exponential function ($y = a \cdot e^{bx}$; where y was the TP, x was thickness, and a and b were constants).

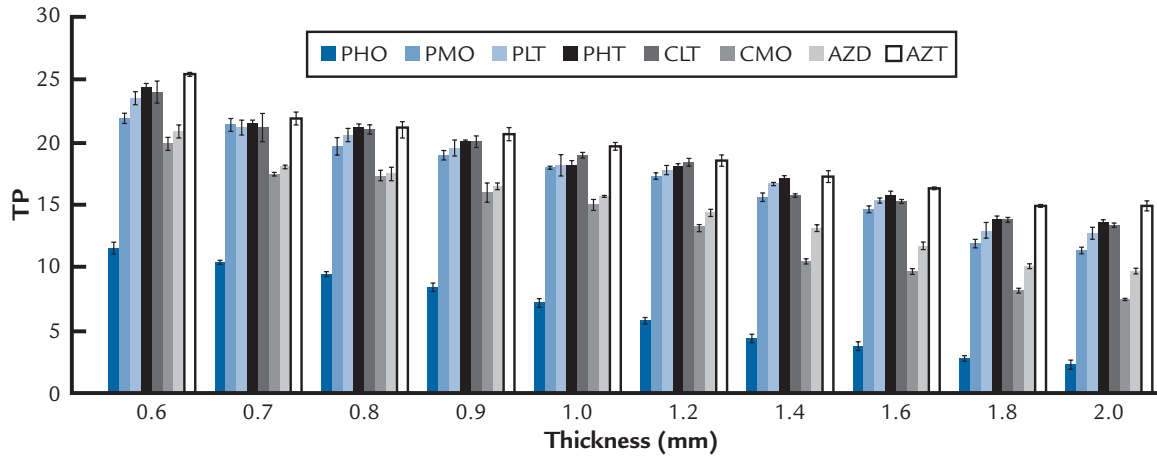
RESULTS

The TP values of the glass ceramics ranged from 2.2 to 25.3, and those of the zirconia ceramics from 5.5 to 15.1 (Figs. 1, 2). There was an increase in the TP with a decrease in thickness, but the amount of change was material dependent. The general ranking of the TP for the glass ceramics was AZT > PHT and CLT > PLT > PMO > AZD > CMO

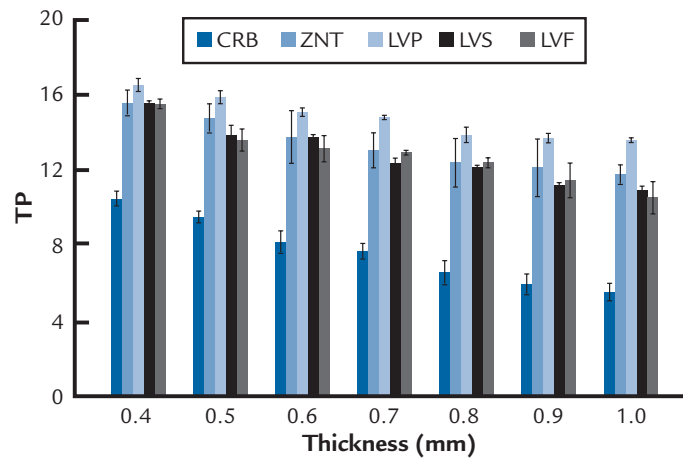
> PHO. For the zirconia ceramics, it was LVP > ZNT > LVS and LVF > CRB.

The results of the 2-way ANOVA for the glass ceramics and zirconia ceramics showed that both main factors (material and thickness) and their interaction were statistically significant ($P < .01$) (Tables II, III). The increase of the TP of the more translucent ceramics due to a decrease in thickness was greater than that of the less translucent ceramics.

Based on the regression analysis of the TP-thickness figures, the correlation between thickness and the TP value was expressed by an exponential function. The calculated regression equations and correlation coefficients (R^2) for each ceramic are summarized in Tables IV and V, in which ceramics are sorted from high translucent to low translucent material. Good correlation coefficients with statistical significance were found for all the materials tested ($R^2 = 0.940$ to 0.997). The more translucent ceramics demonstrated a tendency to have a greater b value both for glass ceramics and zirconia ceramics.



1 TP values of glass ceramics at different thicknesses.



2 TP values of zirconia ceramics at different thicknesses.

TABLE II. Results of 2-way ANOVA of TP values of glass ceramics

Source	df	Sum of Squares	Mean Square	F	P
Material	7	7188	1027	7649	<.001
Thickness	9	5529	614	4576	<.001
Material×Thickness	63	111	1.76	13.1	<.001
Error	400	54	0.13		
Total	480	129313			

TABLE III. Results of 2-way ANOVA of TP values of zirconia ceramics

Source	df	Sum of Squares	Mean Square	F	P
Material	4	998	250	798	<.001
Thickness	6	341	57	182	<.001
Material×Thickness	24	17	0.72	2.3	<.001
Error	140	44	0.31		
Total	175	27627			

TABLE IV. Regression analysis results of TP (y) by thickness (x) of glass ceramics

Code	Regression Equation	R ²	P
AZT	$y=28.6 e^{-0.35x}$	0.950	<.001
PHT	$y=28.7 e^{-0.39x}$	0.961	<.001
CLT	$y=28.9 e^{-0.40x}$	0.976	<.001
PLT	$y=29.0 e^{-0.42x}$	0.973	<.001
PMO	$y=29.3 e^{-0.47x}$	0.978	<.001
AZD	$y=26.8 e^{-0.52x}$	0.986	<.001
CMO	$y=30.1 e^{-0.72x}$	0.992	<.001
PHO	$y=24.0 e^{-1.20x}$	0.997	<.001

R²: correlation coefficient

TABLE V. Regression analysis results of TP (y) by thickness (x) of zirconia ceramics

Code	Regression Equation	R ²	P
LVP	$y=18.7e^{-0.34x}$	0.956	<.001
ZNT	$y=18.5e^{-0.47x}$	0.970	<.001
LVS	$y=19.0e^{-0.57x}$	0.960	<.001
LVF	$y=18.7e^{-0.55x}$	0.940	<.001
CRB	$y=16.2e^{-1.10x}$	0.991	<.001

R²: correlation coefficient

DISCUSSION

The null hypothesis that translucency was not influenced by the type or thickness of ceramics was rejected. Heffernan et al^{16,17} concluded that the range of translucency in ceramics at clinically relevant thicknesses resulted from different crystalline compositions. The results of the present study also confirmed the variations in the translucency derived from the type of ceramics. Generally, the glass ceramics had greater translucency than the zirconia ceramics. Moreover, a significant increase in translucency was also found as a result of the decrease in thickness. The glass ceramics had a range of 2.2 to 25.3 TP values at various thicknesses. The TP value of human dentin with a thickness of 1.0 mm has been determined to be 16.4 and that of human enamel 18.1,⁶ values similar to those for glass ceramics (TP ranged from 14.9 to 19.6), except for PHO. Regarding the zirconia ceramics, the TP at 1.0 mm thickness, which ranged from 5.5 to 13.5, was less than that for human dentin and enamel. These results also confirmed the ability of glass ceramics to provide a better optical match to natural teeth.²

To optimize esthetics, it is important that the translucency of restorative materials is predictable for a given dental restoration. In reports by Kamishima et al and Kim et al,^{25,26}

the translucency of composite resins increased exponentially as the thickness decreased. In the present study, an exponential correlation between translucency and thickness was also established with a high correlation coefficient for both glass ceramics and zirconia ceramics, which agrees with the results of studies on dental composite resins. Analyzing the transmission coefficient of a dental porcelain, Peixoto et al¹⁰ suggested that a linear correlation exists between the Napierian logarithm of the transmission coefficient and the porcelain thickness. When the correlation equation given by these researchers was transformed to the exponential expression, the transmission coefficient of porcelain also changed exponentially as the thickness decreased. Given this interpretation, the results of Peixoto et al¹⁰ were consistent with those in the present study. Antonson and Anusavice²⁷ suggested that the contrast ratio of dental ceramics was linearly related to the thickness. It is possible that this finding was due to the different optical parameters used. Contrast ratio is a ratio of reflectance values, and the TP results that were generated for this research used color differences. In the Antonson and Anusavice study,²⁷ the contrast ratio of the specimens was obtained at thicknesses of 0.7, 1.1, 1.25, and 1.50 mm. In the present study, the TP values of glass ceramics

were measured across a greater range (0.6 to 2.0 mm) of thicknesses. As for zirconia ceramic, due to its high mechanical properties (flexural strength about 900 to 1500 MPa)², usually in clinical practice, zirconia was used with a comparable smaller thickness to fabricate dual-layered ceramic restoration. Therefore, the translucency of zirconia was evaluated from 0.4 to 1.0 mm in the present study.

A regression analysis in the present study resulted in improved accuracy and reliability. It revealed that the more translucent a ceramic was a greater change in TP would be expected as a result of varying thickness (Tables IV, V). This finding was in agreement with the results of Antonson and Anusavice²⁷ in that the esthetics of the least translucent ceramic would not be significantly affected by variations in thickness. In the TP-thickness figures, a greater change in the TP was also observed in the thinner part of the exponential curves, especially for glass ceramics. Therefore, in the clinical situation, a small change in thickness should be considered when a highly translucent ceramic is used to fabricate thin restorations (for example, veneers fabricated with AZT or PHT) because the esthetic outcome of the final restoration would be more sensitive to the thickness.

Zirconia ceramics have been reported to possess the highest me-

chanical properties among dental ceramics.²⁸⁻³⁰ The highly dense microstructure of zirconia ceramics would commonly result in a rapid reduction in translucency, although there is no consensus. Chen et al¹⁹ reported that, with a CR value of 1.0, CRB should be considered opaque. Heffernan et al¹⁶ also indicated that the In-Ceram Zirconia ceramic had a CR value similar to that of metal ceramics. In contrast, Baldissara et al³¹ recently compared the translucency of several zirconia copings and demonstrated that they all allowed light to pass through the material to some degree. Even the least translucent CRB had the 42.1% translucency of a controlled glass ceramic. In the present study, the TP values of 5 zirconia ceramics ranged from 5.5 to 15.1 at thicknesses of 1.0 to 0.4 mm. A TP below 2.0 was considered to be opaque enough to block out a black background.²³ Therefore, all 5 zirconia ceramics evaluated in the present study should be considered as having a certain degree of translucency even at the thickness of 1.0 mm. Moreover, the translucency of the zirconia ceramics also increased exponentially as the thickness decreased. The fact that some amount of light passes through zirconia ceramic is more likely to give the restoration a natural appearance. The least translucent zirconia ceramic in the present study was CRB, which was also found to have the smallest translucency value in the Baldissara et al study.³¹ Significant opacity could be the result of minor dimensional, structural, or chemical differences in the grains and grain boundaries, which yield higher levels of light absorption and scattering.^{31,32} The TP value of LVP was significantly higher than those of any other zirconia ceramics, including the other 2 Lava products (LVS and LVF), which indicates the improved optical properties of this newly developed zirconia ceramic. The translucency difference was assumed to result from the differences in components and the microstructure of these materials, a point that needs further investigation.

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The color of the tooth to be restored is an important consideration in selecting ceramics. In clinical practice, teeth without discoloration are generally better restored with a more translucent ceramic, while teeth with discoloration or metal posts require a more opaque ceramic material. Based on the results of the present study, the interactive effect of material and thickness on the final optical appearance of ceramic restorations should also be considered. The specimens with monolayer form were investigated in the present study, while the ceramic restorations mostly take the form of bilayer structure in clinical practice. To better understand and predict the clinical appearance of the ceramics evaluated in the present study, the translucencies of core-veneering ceramic combinations as a function of thickness should be investigated in further research. Furthermore, repeated firings may also affect the translucency of ceramics. Therefore, further studies on the effects of repeated firing on translucency changes are needed.

CONCLUSIONS

Within the limitations of the present study, the following conclusions were reached:

1. The translucency parameter of dental ceramics was significantly influenced by both material and thickness. The translucency of all materials increased as the thickness decreased, but the amount of change was material dependent.
2. An exponential relationship between the TP and thickness was identified for both glass ceramics and zirconia ceramics. The more translucent a ceramic was, the greater the change demonstrated in the TP as the thickness varied.
3. All of the zirconia ceramics evaluated in the present study showed some degree of translucency, which was less sensitive to thickness than that of the glass ceramics.

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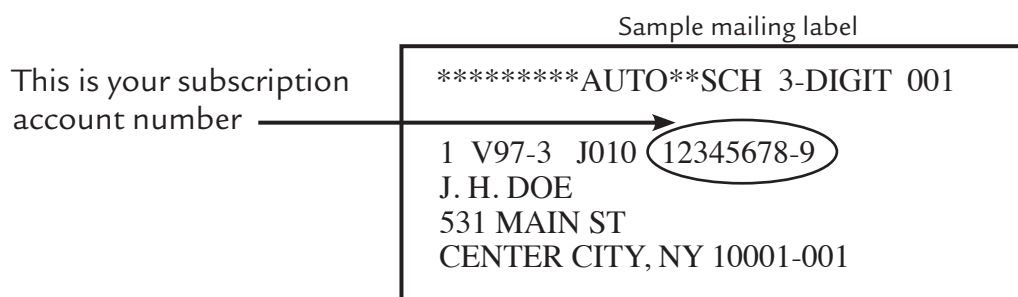
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