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RESEARCH AND EDUCATION

Effect of repeated firing on the translucency of CAD-CAM monolithic glass-ceramics

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ABSTRACT

Statement of problem. The effects of multiple firings on the translucency of newly introduced computer-aided design and computer-aided manufacturing (CAD-CAM) glass-ceramics have not been well evaluated.

Purpose. The purpose of this in vitro study was to assess the changes in the translucency of high-translucency (HT) and low-translucency (LT) lithium disilicate (LDS) and zirconia-reinforced lithium silicate (ZLS) glass-ceramics of 0.6 and 1 mm thickness during crystallization, correction, and glaze firing cycles.

Material and methods. Eighty specimens in 8 groups (n=10) were sectioned and polished to obtain thicknesses of 0.6 and 1 mm. The specimens were then fired in 3 cycles, and the color coordinates were measured by using a spectrophotometer after each cycle. The translucency parameter (TP) and the contrast ratio (CR) were calculated to determine the translucency level. The data were analyzed by using a statistical software program. The TP and CR data after each firing cycle were compared within each group by using repeated-measures ANOVA. Pair-wise comparisons were made by using a multiple paired *t* test. Comparisons between the 2 thicknesses of different materials were made by using the independent *t* test (α=.05).

Results. Repeated firings significantly increased the translucency of 0.6-mm LT-LDS and decreased the translucency of 0.6-mm HT-ZLS (P<.017). No significant changes were noted in the translucency of specimens of 1-mm thickness after repeated firings. Also, 0.6-mm-thick specimens of all materials had significantly higher translucency than 1-mm-thick specimens ($P\leq$.001). The highest translucency was noted in HT-LDS, followed by HT-ZLS.

Conclusions. Repeated firings significantly affected the translucency of LDS and ZLS CAD-CAM glass-ceramics. The translucency increased with decreasing thickness. (J Prosthet Dent 2019;■:■-■)

Patient expectations for natural-looking restorations have increased in recent years. Thus, ceramic restorations have become popular for the fabrication of dental restorations with improved esthetics.[1,2] Factors such as translucency, color, texture, contour, and opalescence are essential for successful restorations.[1-5] Feldspathic porcelain is commonly used to veneer zirconia copings to improve esthetics and has been the topic of previous studies.[6-9] However, chipping is a major problem of veneered restorations.[4] Other problems are related to the presence of an opaque framework and the need for additional tooth reduction.[10] As a result, monolithic ceramics were introduced as an efficient alternative.[11-13]

The advent of computer-aided design and computer-aided manufacturing (CAD-CAM) has revolutionized prosthodontics.[11] This technique has progressed over time to facilitate the rapid fabrication of restorations.[14] CAD-CAM monolithic glass-ceramics were introduced

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Clinical Implications

The translucency of CAD-CAM LDS and ZLS glass-ceramics changes with repeated firings, especially in thin specimens, which can compromise the esthetic outcome of definitive restorations.

for the fabrication of indirect dental restorations in a single visit, increasing patient satisfaction.[2,15,16]

Nevertheless, contour or color correction may be required before delivering a CAD-CAM restoration.[5,14] For these situations, the sintering temperature, time under vacuum, holding time, and heating and cooling rates of the furnace will need to be adjusted to optimize the optical parameters, including translucency.[1,17,18]

Translucency is defined as the ability of a material to allow the passage of light, and a translucent object allows the passage of light with minimal light absorption or reflection.[1] The calculation of the translucency parameter (TP) is a standard method of measuring translucency by considering the entire visible spectrum. A second method is to calculate the contrast ratio (CR), which indicates the reflectance of a specific material with a certain thickness. Therefore, CR measures the translucency indirectly and is useful only for materials with more than 50% transmission.[19] A strong inverse correlation between TP and CR has been reported in the literature.[19]

The effects of factors such as zirconia content,[10] total volume of porosity,[20] surface treatment,[21-23] thermocycling,[21] thickness of the veneer,[24-27] and color stability[27] on the translucency of ceramic restorations have been evaluated. A recent study reported that the type of CAD-CAM glass-ceramic affected its optical properties.[14] A study[20] evaluated the effect of the repeated sintering of LDS-press on the total porosity volume, color, and translucency and concluded that when the number of sintering cycles increased, the porosity volume decreased, and the color change and translucency increased. Such color and translucency changes can be associated with porosity volume.

A reduction in translucency after additional firing of the veneering porcelain or pressed lithium disilicate (LDS) glass-ceramic has been reported.[6,23,28] However, other studies have reported no significant effect of repeated firing on the translucency and color parameters of porcelain veneers.[9,29] To the best of the authors' knowledge, information regarding changes in translucency as the result of the repeated firing of newly introduced CAD-CAM monolithic glass-ceramics is lacking.

The purpose of this in vitro study was to assess the changes in the translucency of high-translucency (HT) and low-translucency (LT) LDS and zirconia-reinforced lithium silicate (ZLS) glass-ceramics with thicknesses of 0.6 mm and 1 mm during crystallization, correction, and glaze firing cycles. The null hypotheses were that no change would be found in the translucency of different types of glass-ceramics after multiple firing cycles and that the translucency of ceramic materials would not be affected by variations in their thickness.

MATERIAL AND METHODS

A total of 80 specimens of 2 CAD-CAM glass-ceramic materials were divided into 8 groups (n=10). The number of specimens in each group has been reported from 5[2,17] to 18[27] in similar studies. The sample size was based on previous studies.[12,14,24] The studied materials were LDS (IPS e.max CAD HT and LT/C 14; Ivoclar Vivadent AG) and ZLS (Suprinity PC HT and T/C 14; VITA Zahnfabrik) glass-ceramics with a thicknesses of 0.6 mm and 1 mm, respectively (Fig. 1).

Precrystallized CAD-CAM blocks (12×14×20 mm) were sectioned in a cutting machine (CNC Cutting Section Machine; Nemo Fanavaran Pars) with a diamond blade under running water. The specimens were rectangular with dimensions of 0.6 ±0.05×12×14 mm and 1 ±0.05×12×14 mm. One surface of each specimen was manually polished by using 600-, 1200-, and 2000-grit silicon carbide abrasive papers.[22] Nonpolished surfaces were marked by a round low-speed bur at 1 corner. The final thickness was adjusted to 0.6 ±0.01 mm and 1 ±0.01 mm and verified with digital calipers (Guilin Guanglu Measuring Instrument Co). The studied thickness values were selected based on the manufacturer's instructions for the minimum thickness of laminate veneers and crowns. All specimens were cleaned in an ultrasonic bath containing distilled water for 15 minutes and were then dried by using absorbent papers.

The specimens were fired 3 times according to the manufacturer's instruction (P500; Ivoclar Vivadent AG). The firings were adjusted for crystallization (sintering), correction, and glaze firings. After each firing cycle, the color of each specimen was measured at 4 predetermined points, 3 times on white and 3 times on black backgrounds by using a reflection spectrophotometer (DeguDent GmbH, Rodenbacher). To ensure reproducible positioning during evaluations, the specimens were placed at the center of gypsum alignment devices with white and black backgrounds. A total of 1440 measurements were made, and the optical parameters of 5760 points were recorded.

The spectrophotometer was calibrated before each measurement, and all measurements were made by 1 investigator (M.j.S.) in the same location and under the same brightness conditions. The optical head was placed at a 90-degree angle to the specimens according to the manufacturer's instructions. The measurements were

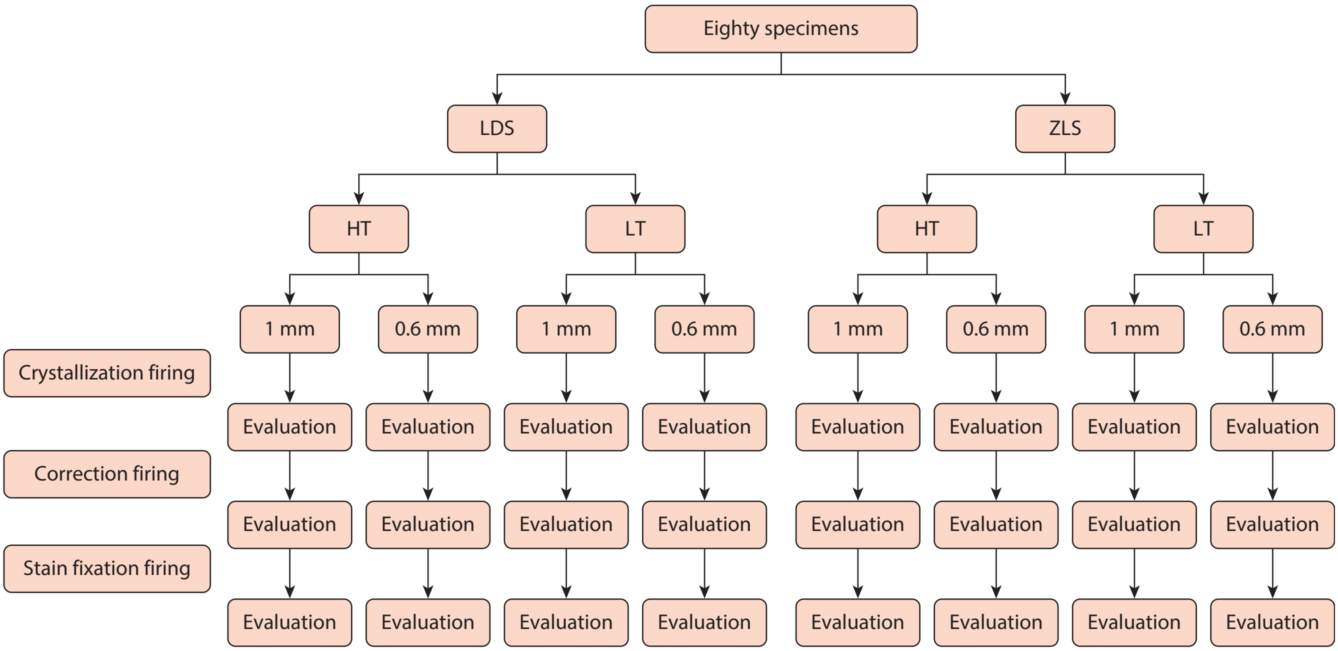

Figure 1. Study design for high-translucency (HT) and low-translucency (LT) lithium disilicate (LDS) and zirconia-reinforced lithium silicate (ZLS) glass ceramics.

made in the visible light spectrum at 410 nm to 680 nm. A 2-degree standard observer with CIE Standard Illuminant D65 and a 45-degree illuminant angle was set to measure the color coordinates. The spectrophotometer used had an 18×14-mm measuring area and a 10-nm optical resolution for each dot.[14,21,27]

The L* (lightness), a* (redness-greenness), and b* (yellowness-blueness) color parameters were recorded for each point. The translucency level of each specimen was then calculated by using both the translucency parameter (TP)[2,12,17,19] and the contrast ratio (CR) in the following equations[2,19,22]

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

$$CR = Y_B/Y_W \quad Y = \left(\left[L^* + 16\right]/116\right)^3 \times 100$$

where $_W$ and $_B$ are color coordinates of the specimens on the white and black backgrounds. Higher TP values represent higher translucency, and the CR range is from 0 (transparent) to 1 (totally opaque).

The data were analyzed by using a statistical software program (SPSS, v16.0; SPSS Inc) (α=.05 for all tests) (β=.2). The mean TP and CR after each firing cycle were compared within each group by using repeated-measures ANOVA. In cases where P<.1, pair-wise comparisons were carried out by using the multiple-paired t test with Bonferroni correction (α=.017). The comparisons between the 2 thicknesses were made by using the independent t test.

RESULTS

Table 1 shows the lightness (L*) values on the white and black backgrounds after the firing cycles. Tables 2 and 3 show the TP and CR of the studied groups and repeated-measure ANOVA results. Figure 2 shows the TP changes of the studied groups after the firing cycles. The highest and lowest translucency were found in HT-LDS with a 0.6-mm thickness (TP=21.75 ±1.38, CR=0.48 ±0.02) and LT-LDS with a 1-mm thickness (TP=13.86 ±0.51, CR=0.67 ±0.01), respectively. No significant difference was found in the TP of the specimens with 1-mm thickness after the firing cycles (Tables 2 and 3). However, intragroup comparisons showed that the translucency of 0.6-mm-thick LT-LDS increased (TP: P=.009, CR: P=.017) while the translucency of 0.6-mm-thick HT-ZLS decreased (TP: P=.001, CR: P=.002) significantly after repeated firings. Furthermore, all the 0.6-mm-thick specimens had significantly higher translucency than the 1-mm-thick specimens (Table 4).

DISCUSSION

The first null hypothesis that repeated firings would not affect the translucency of monolithic glass-ceramics was partially rejected. The repeated firings changed the translucency of 0.6-mm-thick specimens but had no significant effect on 1-mm-thick specimens. Also, the null hypothesis that ceramic thickness would have no significant effect on translucency was rejected. The 0.6-mm-thick specimens had higher translucency than the 1-mm-thick specimens (P=.001).

Table 1. Mean ±standard deviation lightness (L*) values against white and black backgrounds after 3 firing cycles

Studied Groups	White/First	Black/First	White/Second	Black/Second	White/Third	Black/Third
HT-LDS, 1 mm	82.17 ±0.37	65.59 ±0.19	82.06 ±0.35	65.59 ±0.19	81.89 ±0.39	65.41 ±0.46
LT-LDS, 1 mm	78.47 ±0.29	66.77 ±0.41	78.8 ±0.27	67.07 ±0.48	78.65 ±0.32	67.02 ±0.65
HT-ZLS, 1 mm	74.99 ±0.34	62.41 ±0.45	75.18 ±0.24	62.38 ±0.21	75.51 ±0.59	62.98 ±0.34
LT- ZLS, 1 mm	73.6 ±1.2	62.86 ±1.48	73.6 ±1.23	62.9 ±1.09	74.18 ±1.02	63.93 ±1.42
HT-LDS, 0.6 mm	83.41 ±0.3	62.26 ±1.13	83.64 ±0.54	62.52 ±1.19	83.67 ±0.38	62.44 ±1.12
LT-LDS, 0.6 mm	81.16 ±0.86	64.68 ±1.38	81.36 ±0.8	63.97 ±0.92	81.31 ±0.89	63.8 ±0.91
HT-ZLS, 0.6 mm	77.79 ±0.56	59.71 ±0.61	78.31 ±0.54	60.43 ±0.7	78.43 ±0.64	60.94 ±0.63
LT-ZLS, 0.6 mm	76.02 ±0.66	62.04 ±1.17	76.42 ±0.64	62.96 ±0.69	76.69 ±0.61	63.4 ±0.82

HT, high translucency; LDS, IPS e.max lithium disilicate; LT, low translucency; ZLS, Zirconia-reinforced lithium silicate glass ceramics.

Table 2. Mean ±standard deviation of translucency parameter (TP) after 3 firing cycles

Studied Groups	TP1	TP2	TP3	Type III Sum of Squares	Df	Mean Square	F	*P*
HT-LDS, 1 mm	17.33 ±0.45	17.26 ±0.39	17.25 ±0.69	0.041	2	0.02	0.092	.912
LT-LDS, 1 mm	13.86 ±0.51	14.10 ±0.53	14.08 ±0.67	0.341	1.295	0.263	0.459	.561
HT-ZLS, 1 mm	16.59 ±0.36	16.59 ±0.33	16.39 ±0.54	0.26	2	0.13	0.649	.534
LT- ZLS, 1 mm	15.78 ±0.89	15.75 ±1.44	15.09 ±1.32	3.014	2	1.507	1.017	.382
HT-LDS, 0.6 mm	21.64 ±1.35	21.67 ±1.51	21.75 ±1.38	0.068	1.015	0.067	0.025	.880
LT-LDS, 0.6 mm	17.83 ±1.78[a]	18.76 ±1.38[a]	18.94 ±1.46[b]	7.191	1.038	6.93	10.45	.009
HT-ZLS, 0.6 mm	20.98 ±0.69[a]	20.77 ±0.64[ab]	20.41 ±0.71[b]	1.667	2	0.834	10.62	.001
LT-ZLS, 0.6 mm	18.13 ±1.06	17.72 ±0.73	17.45 ±0.96	2.336	2	1.168	2.558	.105

HT, high translucency; LDS, IPS e.max lithium disilicate; LT, low translucency; ZLS, Zirconia-reinforced lithium silicate glass ceramics. Groups with same letter not significantly different (multiple *t* test).

Table 3. Mean ±standard deviation of contrast ratio (CR) of studied groups after 3 firing cycles (repeated-measure ANOVA and multiple *t* test)

Studied Groups	CR1	CR2	CR3	Type III Sum of Squares	Df	Mean Square	F	*P*
HT-LDS, 1 mm	0.57 ±0	0.57 ±0	0.57 ±0.01	-	2	-	0.102	.903
LT-LDS, 1 mm	0.67 ±0.01	0.67 ±0.01	0.67 ±0.01	-	2	-	0054	.948
HT-ZLS, 1 mm	0.64 ±0.01	0.63 ±0.00	0.64 ±0.01	0	2	0	0.994	.389
LT- ZLS, 1 mm	0.68 ±0.02	0.68 ±0.04	0.69 ±0.04	0.001	2	0.001	0.567	.577
HT-LDS, 0.6 mm	0.48 ±0.02	0.48 ±0.02	0.48 ±0.02	-	1.011	-	0.025	.880
LT-LDS, 0.6 mm	0.57 ±0.04[c]	0.55 ±0.03[cd]	0.55 ±0.03[d]	0.003	1.025	0.003	8.38	.017
HT-ZLS, 0.6 mm	0.52 ±0.01[c]	0.53 ±0.01[cd]	0.54 ±0.01[d]	0.001	2	0.001	8.829	.002
LT-ZLS, 0.6 mm	0.61 ±0.03	0.62 ±0.02	0.62 ±0.02	0.002	2	0.001	2.574	.104

HT, high translucency LDS, IPS e.max lithium disilicate; LT, low translucency ZLS, Zirconia-reinforced lithium silicate glass ceramics. Groups with same letter not significantly different (multiple *t* test).

TP and CR have both been used to evaluate material translucency.[19] In this study, both methods were used. One study[19] reported TP values from 16.79 to 18.98 for 1-mm-thick LDS. They also reported TP values of 16.4 and 18.7 for human dentin and enamel of 1-mm thicknesses, respectively.[19] Another study reported the CR values of 0.58 to 0.62 for LDS-CAD.[2] The results of the present study are similar to the results of these studies and to the dentin and enamel of natural teeth.

The optical and translucency properties of dental ceramics are influenced by chemical composition, microstructure, shape and average size of the particles, distribution of the crystalline phase, adaptation of refractive indices of the crystalline phase and matrix, fabrication procedures, and porosity.[19,20] Multiple firings result in color changes because of the alterations in the crystalline structure and surface specifications.[23,28] Repeated sintering causes more compact interlocking of microstructures in LDS crystals.[26]

In the present study, the translucency of 0.6-mm-thick LT-LDS specimens increased significantly after repeated firings. However, the repeated firings decreased the translucency of 0.6-mm-thick HT-ZLS. The effect of repeated firings on the translucency of LDS specimens is consistent with a study on pressed LDS ceramics.[9] These findings can be explained by the crystalline content and crystal size. Smaller crystals and higher crystalline content lead to lower translucency, as noted in LT glass-ceramics compared with HT specimens. Furthermore, heat treatment and repeated firing affect the crystal size.[30]

The zirconia content of ZLS can affect its optical behavior. The studied ZLS has 8% to 12% zirconia, which increased the strength. The results of a study

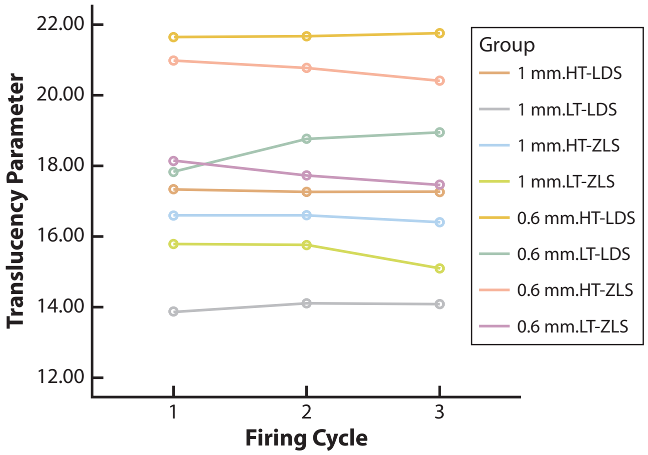

Figure 2. Line graphs of translucency parameter values after 3 firing cycles for high-translucency (HT) and low-translucency (LT) lithium disilicate (LDS) and zirconia-reinforced lithium silicate (ZLS) glass ceramics.

regarding the effect of zirconia content on the translucency of ZLS revealed the negative impact of zirconia content on the translucency level. The 10 wt% zirconia content has the greatest effect on translucency.[10]

The present results regarding the comparison of translucency of LDS and ZLS agreed with those of the other studies.[17,21] An in vitro study on CAD-CAM monolithic glass ceramics showed higher translucency of LDS than of ZLS both before and after thermocycling in coffee.[21]

In the present study, the TP and CR of thin specimens were more translucent than those of thick specimens, and their TPs significantly changed after repeated firings. This finding was consistent with the studies reporting decreasing translucency with an increased ceramic thickness.[9,25] Therefore, repeated firings and increased thickness can adversely affect the esthetics of ceramic restorations. Clinicians should be careful to avoid adjustments and additional firings when providing thinner restorations such as laminate veneers.

As color stability is a necessary requirement for ceramic materials, manual polishing or glazing should be considered.[14] To ensure the optimal esthetics of ceramic restorations, the color scale, light source during colorimetry, optical properties of core materials (thickness, composition, translucency, opalescence, and transmittance), veneering material thickness, color of the remaining tooth structure, presence of post and core, and type of luting agents should be considered. Laboratory factors such as ceramic condensation technique, temperature and number of firing cycles, dentin ceramic thickness, and the glazing cycle should also be considered.[1,2] In selecting appropriate restorative materials, factors such as color, durability in the oral environment, and strength should also be considered.

Table 4. Comparison of 2 thicknesses for translucency parameter (TP) and contrast ratio (CR) for 3 firings (independent *t* test)

Studied Groups	TP1	TP2	TP3	CR1	CR2	CR3
HT-LDS, 1 mm versus 0.6 mm	<.001	<.001	<.001	<.001	<.001	<.001
LT-LDS, 1 mm versus 0.6 mm	<.001	<.001	<.001	<.001	<.001	<.001
HT-ZLS, 1 mm versus 0.6 mm	<.001	<.001	<.001	<.001	<.001	<.001
LT-ZLS, 1 mm versus 0.6 mm	<.001	.001	<.001	<.001	.001	<.001

HT, high translucency; LDS, IPS e.max lithium disilicate; LT, low translucency ZLS, Zirconia-reinforced lithium silicate glass ceramics.

Color and translucency are different optical properties. Translucency can influence the color and final appearance of the restoration[3,13] and is an important factor in providing natural appearance. However, the essential masking property of the material can limit the use of HT materials for patients with dark remaining tooth structure or metal foundation restorations.

Limitations of this study include the plate-shaped specimens and the lack of veneering porcelain and glazing liquid. As the shape of restoration can affect the optical properties, future studies are recommended to evaluate different forms of restorations such as crowns and veneers. Extended glazing results in more perceptible color change and opacity than conventional glazing for LDS and ZLS.[17,22] Also, veneering porcelain can decrease translucency. Future studies are suggested to assess the effect of porcelain veneering and glazing liquid.

CONCLUSIONS

Within the limitations of this in vitro study, the following conclusions were drawn:

1. Repeated firings significantly affected the translucency of 0.6-mm-thick specimens of LT-LDS and HT-ZLS.
2. Decreasing the thickness of CAD-CAM glass-ceramics increased the translucency of ceramic restorations.

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