

RESEARCH AND EDUCATION

In vitro color stainability and relative translucency of
CAD-CAM restorative materials used for laminate veneers and
complete crowns



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ABSTRACT

Statement of problem. Assessing the long-term stainability and durability of restorative materials is an important parameter for determining clinical success and longevity. Information remains limited regarding the color stainability and translucency of the recently introduced ceramic materials for restorative treatment.

Purpose. The purpose of this in vitro study was to compare the effect of cyclic immersion in hot and cold coffee on the color stainability and translucency of 6 computer-aided design and computer-aided manufacturing (CAD-CAM) restorative materials at thicknesses which represent a laminate veneer and a complete crown.

Material and methods. CAD-CAM restorative materials including zirconia-reinforced lithium silicate ceramic (Celtra Duo), lithium disilicate glass-ceramic (IPS e.max CAD), polymerized resin nanoceramic (Lava Ultimate), integrated ceramic and acrylate polymer network material (VITA ENAMIC), zirconia-reinforced lithium silicate (VITA SUPRINITY), and zirconia (VITA YZ HT) were studied in 2 thicknesses for laminate veneer (0.7 mm) and complete crown application (1.3 mm to 1.5 mm). For each specimen, color difference on a gray backing was calculated using a spectroradiometer between its baseline color and after 6000 cycles of coffee thermocycling. The colors of the specimens on the black and white backings were used to calculate the relative translucency parameter from the CIEDE2000 color difference formula. An ANOVA and the Bonferroni-corrected Student *t* tests were used for testing statistical significance ($\alpha=.05$).

Results. No difference was found among the means of color change after coffee thermocycling between any 2 materials for the crown thickness ($P>.999$), and no difference was found among the means of color change between the 2 thickness groups within each material ($P\geq.187$). However, the mean color change of the resin nanoceramic material in laminate veneer application (0.7 mm) was greater than that of every other material in the veneer thickness group ($P<.001$), and the mean color change of the integrated ceramic and acrylate polymer network material was greater than that of the lithium disilicate glass-ceramic material studied at the veneer thickness ($P=.014$). Translucency was found to be lower for complete crown thickness compared with laminate veneer thickness within each combination of material and coffee thermocycling ($P<.001$). The translucency of the lithium disilicate glass-ceramic material studied at the laminate veneer thickness was also found to be higher after coffee thermocycling ($P=.033$). Furthermore, several differences among materials were found for each combination of thickness and coffee.

Conclusions. Color change after coffee thermocycling of the resin nanoceramic material was beyond the acceptability threshold. The lower translucency found for crown thickness compared with veneer thickness was verified. (J Prosthet Dent 2019;122:160-6)

Over the last 25 years, computer-aided design and computer-aided manufacturing (CAD-CAM) has continued to evolve and provide an efficient way of fabricating dental restorations.¹⁻⁴ Several categories of

CAD-CAM restorative materials have demonstrated both predictability and longevity.^{1,4} These materials include esthetic and high-strength ceramics, composite resins for interim and definitive restorations, and newer

Part of this research was funded from a pilot grant awarded from The Ohio State University College of Dentistry. Presented at the American Association of Dental Research Annual Session, Ft. Lauderdale, Florida, March 2018.

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Clinical Implications

The results of this study suggest that when planning a CAD-CAM restoration, material selection is important for color stainability and translucency after coffee consumption particularly for laminate veneers.

nanoceramics that are claimed to offer ease of handling and a glossy surface finish.¹ The clinical outcome of restorations depends on the type of restorative material used.¹ The thickness of the material, color stainability, and translucency need to be considered when evaluating these materials. As the thickness of the ceramic increases, the color difference between the cemented and non-cemented veneer decreases.⁵ Changing porcelain thickness or cement/ceramic shade will affect the final esthetic properties.^{5,6} Mechanical properties, monomer systems, fatigue, and degradation of different materials have also been studied.⁷⁻⁹

The translucency of a material can be of paramount importance when choosing to restore or replace dentition in areas where esthetics are of high importance.¹⁰ In calculating translucency, care must be taken to compare previously generated translucency measurements with newly generated data because details of the thickness and the backings used must be matched or adjustments made to make newly generated data comparable with published values.¹¹ Translucency calculations based on International Commission on Illumination (CIE) colorimetry must include descriptions of the illuminant and the observer used for the calculations; these calculations include luminous transmittance, luminous reflectance, and color.¹¹ These determinants require that a thickness be specified which is dependent on the treatment rendered.

The long-term stainability and durability of restorative materials is an important parameter in determining clinical success and longevity. Although, some information is available on the color stainability and translucency of CAD-CAM restorative materials,¹²⁻¹⁸ information regarding chairside restorative materials, including some recently introduced ceramic materials, remains limited.

Equal exposure of the specimens to the staining solution is important to assess the translucency and color stability of materials accurately. This may be of more importance for resin nanoceramics and integrated ceramic and acrylate polymer network materials. Some studies did not describe the immersion technique used for staining the specimens in adequate detail.^{13,18} In 1 study, the technique used for staining involved placing the specimens in mesh bags and immersing them in the staining solutions.¹⁵ This technique does not appear to

ensure equal exposure of the specimens, and therefore, a technique for staining the specimens to ensure equal exposure was used in the present study.

The purpose of this study was to compare the effect of cyclic immersions in hot and cold coffee staining solution on the color and translucency of 6 CAD-CAM restorative materials at thicknesses representative of a laminate veneer and a complete crown. The null hypotheses were that neither the material nor its thickness would affect color stainability or translucency after coffee thermocycling.

MATERIAL AND METHODS

The study tested 6 CAD-CAM restorative materials (n=5 for each thickness tested) (Table 1). The specimens were prepared by cutting the CAD-CAM blocks with a slow-speed diamond blade (IsoMet Diamond Wafering Blades, series 15 LC, 127×0.4 mm; Buehler Inc) in a slicing machine (VC50 Diamond Saw; Leco Corp). The cut specimens were polished under running water with abrasive papers of 600 to 1200 grit (MicroCut Silicon Carbide grinding papers; Buehler Inc). The thickness of the specimens was measured using a digital micrometer (Digimatic Indicator 0001-2; Mitutoyo Corp), and the specimens were finished and polished according to the manufacturer's instructions as described in Table 2. The prepared specimens were measured again to ensure standardization. Any outliers were replaced with a new specimen of equal dimensions.

The specimens were inserted onto plastic strips (polypropylene sheets 5"×5", 0.02" thickness; Buffalo Dental Mfg Co Inc) to keep them upright while immersed in a coffee solution and to standardize the staining on surfaces to be measured. Small notches corresponding to laminate veneer and complete crown thickness were made on the side of the strips with a high-speed hand piece and a straight fissure bur. The specimens were then inserted in the notches which kept them upright (Fig. 1). A fabric mesh was used to wrap around the plastic strip holding the numbered specimens and secured using a metal wire.

The coffee solution was prepared using a ratio of 15 mL of water and 1 mL of coffee (Black Silk; Folgers Coffee Co). Specimens were inserted in an incubator (BUCHI 461 Water Bath; Fisher Scientific) with hot (55 °C) and cold (5 °C) baths containing the coffee solution for a dwell time of 30 seconds each, a hold time of 2 seconds, and a transfer time of 10 seconds (84-second thermocycle). Fresh coffee was added every 8 hours in the hot and cold tanks. At the completion of the 6000 cycles, the specimens were removed from the mesh bags, cleaned under running water with a tooth brush (Oral B Complete; Proctor and Gamble) and toothpaste (Crest

Table 1. Chairside CAD-CAM materials studied

Material Generic Name	Material Code	Brand Name and Manufacturer/Shade	Thickness by Clinical Application	Thickness* (mm)
Zirconia-reinforced lithium silicate ceramic	CD	Celtra Duo, Dentsply Sirona (Shade A2) Lot #18019284	Laminate veneer	0.7
			Complete crown	1.5
Lithium disilicate glass-ceramic	EM	IPS e.max CAD, Ivoclar Vivadent AG (Shade A2) Lot #V06730	Laminate veneer	0.7
			Complete crown	1.5
Polymerized resin nanoceramic	LU	Lava Ultimate, 3M ESPE (Shade A2) Lot #N450015	Laminate veneer	0.7
Integrated ceramic and acrylate polymer network	VE	VITA ENAMIC, VITA Zahnfabrik (Shade A2) Lot #46680	Laminate veneer	0.7
			Complete crown	1.5
Zirconia-reinforced Lithium silicate ceramic	VS	VITA SUPRINITY, VITA Zahnfabrik (Shade A2)	Laminate veneer	0.7
			Complete crown	1.5
Zirconia	Zir	VITA YZ HT, VITA Zahnfabrik (Stained to Shade A2 VITA Classical) Lot #23920	Complete crown	1.3

CD, zirconia-reinforced lithium silicate ceramic; EM, lithium disilicate glass-ceramic; LU, polymerized resin nanoceramic; VE, integrated ceramic and acrylate polymer network; VS, zirconia-reinforced lithium silicate ceramic; Zir, zirconia. *Based on manufacturer’s recommendation.

Table 2. Finishing and polishing protocols of each material according to manufacturer’s instructions

Material (Generic Names/Codes/Manufacturer)	Sintering/Firing	Finishing/Polishing	Staining/Glazing
Polymerized resin nanoceramic (LU), 3M ESPE	No firing needed	Final polishing with diamond-coated rubber-polishing wheels (coarse/medium), soft bristle brush, muslin rag wheel with Diashine fine soft extraoral polishing paste (3M ESPE)	
Zirconia-reinforced lithium silicate glass-ceramic (VS), VITA Zahnfabrik	Step 1. Cleaned in ultrasonic bath, crystallized in VITA VACUMAT at 840 °C		Step 2. Glazed using VITA AKZENT Plus glaze spray (VITA Zahnfabrik), fired in VITA VACUMAT (VITA Zahnfabrik) at 800 °C
Integrated ceramic and acrylate polymer network (VE), VITA Zahnfabrik	No firing needed	Final polishing achieved with VITA ENAMIC Polishing Set - Clinical (VITA Zahnfabrik)	
Zirconia-reinforced lithium silicate (CD), Dentsply Sirona	Blocks come presintered/fired		Cleaned in ultrasonic bath, Glaze coated on specimens (Dentsply Sirona Universal Glaze) followed by vacuum bake in VITA VACUMAT (starting temperature 500 °C, final temperature 770 °C)
Zirconia (Zir), VITA Zahnfabrik	Step 1. Sintered in Ivoclar Vivadent AG Ceramic furnace (1450 °C)		Step 2. VITA YZ HT shade/staining liquid in VITA Classical A2 applied with brush technique (starting temperature 500 °C, final temperature 760 °C) Step 3. Final glaze with VITA AKZENT Plus glaze spray (starting temperature 400 °C, final temperature 850 °C)
Lithium disilicate glass-ceramic (EM), Ivoclar Vivadent AG	Step 1. Fired in Ivoclar Vivadent AG Ceramic furnace - crystallization temperature (840 °C to 850 °C)		Step 2. IPS e.max CAD Crystall Glaze paste/liquid painted on specimens and fired in Ivoclar Vivadent AG Ceramic furnace – Crystall/Glaze program (820 °C to 840 °C)

Pro Health; Proctor and Gamble) circumferentially 10 times and dried with wipes (Kimwipes; Kimtech Science) to minimize surface stains.

For each specimen, the color was determined on black, gray, and white backings at the baseline and after 6000 cycles of coffee thermocycling, following a previously described protocol.⁶ In brief, the specimens were optically joined to the backing using saturated sucrose solution; a radiance spectrum was obtained from the central 1.1 mm diameter of the specimen at every 2 nm over the visible wavelengths from 380 to 780 nm using the CIE 45-degree, 0-degree geometry¹⁹; the radiance spectrum was converted to absolute reflectance based on a reflectance standard; and the reflectance spectrum was

converted to CIE Lab color coordinates using the CIE D65 illuminant and the CIE Standard Human Observer.¹⁹ Color difference between these 2 times for each specimen on the gray backing was calculated using the CIEDE2000 color difference formula.¹⁹

A 1-way ANOVA was performed to analyze the color difference data in which the main factor was the concatenation of material and thickness. If this model demonstrated statistical significance, the Bonferroni-corrected Student *t* tests ($\alpha=.05$) were used for pairs to resolve the significance of a difference in color change between the thickness groups within each material and the significance of differences in color change between all pairs of materials within each thickness group.

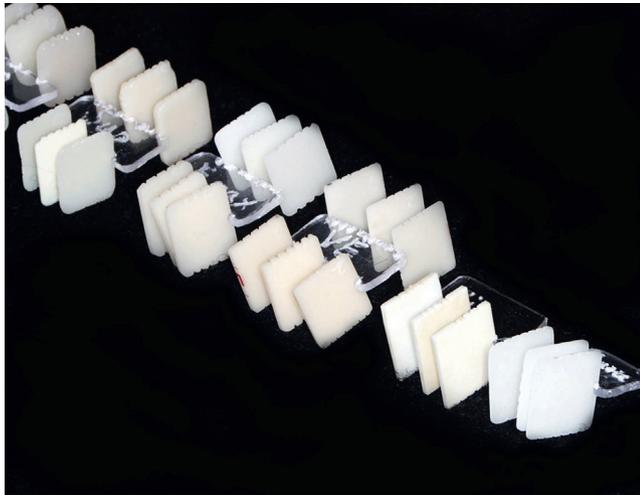


Figure 1. Specimen arrangement on strips cut from polypropylene sheets.

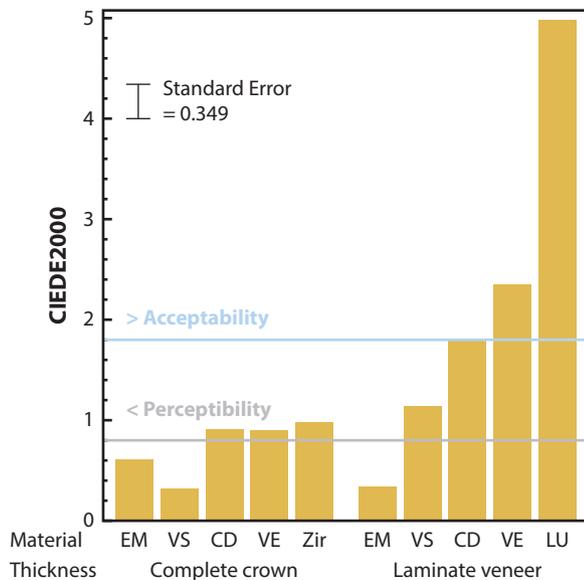


Figure 2. Least square mean color changes after coffee thermocycling. CD, zirconia-reinforced lithium silicate ceramic; EM, lithium disilicate glass-ceramic; LU, polymerized resin nanoceramic; VE, integrated ceramic and acrylate polymer network; VS, zirconia-reinforced lithium silicate ceramic; Zir, zirconia.

The colors of the specimens on the white and black backings were used to calculate the relative translucency parameter (RTP) using the CIEDE2000 color difference formula.¹⁹ A summary of this technique is that RTP was determined as the color difference between the same material and thickness in optical contact with black and white backings, where the color difference between the backings is 84.1 CIEDE2000 color difference units. A repeated measures ANOVA was performed to analyze

Table 3. Summary of repeated measures ANOVA for RTP values

Effect	df of Numerator	df of Denominator	F Ratio	P
Material×thickness*	9	20	326.91	<.001
Coffee thermocycling	1	20	0.12	.736
Material×thickness× coffee thermocycling	9	20	4.16	.004

RTP, relative translucency parameter. *Complete crown/laminate veneer.

the main between-subjects effects of the concatenation of material and thickness and the within-subject effect of coffee thermocycling, with the interaction included. The Bonferroni-corrected Student *t* tests were used to resolve any statistically significant interaction but again limiting the comparisons with those pairs which would have clinical importance. Clinical significance was evaluated using the reported CIEDE2000 50:50% acceptability and perceptibility thresholds. The clinical acceptability threshold was set at 2.25 ΔE_{00} units, and the perceptibility threshold was set at 1.30 ΔE_{00} units.²⁰

RESULTS

The statistical analysis of the color change data revealed that statistical significance was found (*df* of numerator=9, *df* of denominator=20, F ratio=16.09, *P*<.001), and therefore, all possible pairs of different materials within each thickness group and pairs of differing thickness within each material were tested. The least square means of the color change due to coffee thermocycling for all materials and thickness values studied are provided in Figure 2, with the standard error as derived from the ANOVA. No significant difference was found in the means of color change between any 2 materials for the crown thickness (*P*>.999), and no significant difference was found in the means of color change between the 2 thickness groups within each material (*P*≥.187). However, the mean color change of material polymerized resin nanoceramic (LU) was greater than that of every other material in the veneer thickness group (*P*<.001), and the mean color change of material integrated ceramic and acrylate polymer network (VE) was greater than that of material lithium disilicate glass-ceramic (EM) at the veneer thickness (*P*=.014).

The summary of the primary statistical analysis of the RTP data is provided in Table 3. Least square means of RTP for all materials and thickness subgroups studied before and after coffee thermocycling are provided in Figure 3, with the standard error as derived from the repeated measures ANOVA. As seen in Table 3, statistical significance was found in the 2-way interaction (*P*=.004), so pairs tested were between means of RTP for the 2 thermocycling groups within each combination of material and thickness, the 2 thickness groups within each combination of material and coffee thermocycling, and all possible material pairs within each combination of

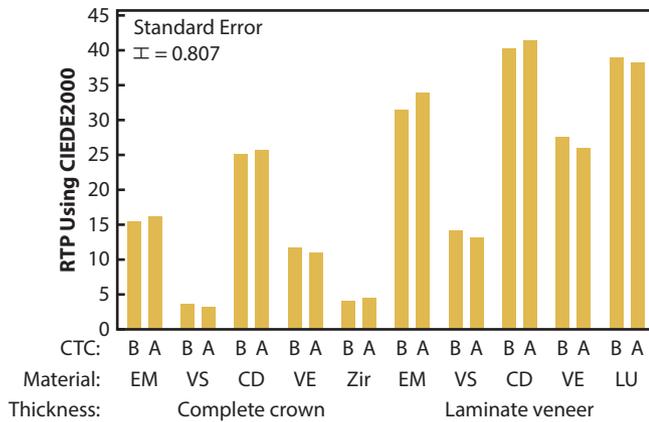


Figure 3. Least square mean RTP values for material and thickness subgroups studied before (B) and after (A) coffee thermocycling (CTC) condition. CD, zirconia-reinforced lithium silicate ceramic; EM, lithium disilicate glass-ceramic; LU, polymerized resin nanoceramic; RTP, relative translucency parameter; VE, integrated ceramic and acrylate polymer network; VS, zirconia-reinforced lithium silicate ceramic; Zir, zirconia.

thickness and coffee thermocycling. Translucency was found to be lower for complete crown thickness compared with laminate veneer thickness within each combination of material and coffee thermocycling ($P \leq .001$). The translucency of material EM at the laminate veneer thickness was also found to be higher after coffee thermocycling ($P = .033$). Furthermore, statistically significant differences for pairs of material are described in Table 4 for each combination of thickness and coffee thermocycling.

DISCUSSION

The first null hypothesis was that neither the material nor its thickness would affect the color change due to coffee thermocycling. No significant difference was found in the means of color change between any 2 materials for the crown thickness, and no significant difference was found in the means of color change between the 2 thickness groups within each material. However, the mean color change of the resin nanoceramic (Lava Ultimate; 3M ESPE) in this study was greater than that of every other material in the veneer thickness group ($P \leq .001$). For the integrated ceramic and acrylate polymer network material (VITA ENAMIC; VITA Zahnfabrik), the mean color change was greater than that of lithium disilicate glass-ceramic (IPS e.max CAD; Ivoclar Vivadent AG) at the veneer thickness ($P = .014$). Among the materials for veneer thickness, color change after coffee exposure resulted in material LU and VE above the clinical acceptability threshold ($2.25 \Delta E_{00}$).²⁰ Color change among the materials for complete crown thickness resulted in all materials to be within the clinical acceptability threshold ($2.25 \Delta E_{00}$).²⁰ Within the laminate veneer thickness group, the type of restorative material was of significance

Table 4. Significant differences between pairs of materials of RTP at each thickness and coffee thermocycling (CTC) condition

Thickness	CTC	Material 1	Material 2	Difference*	P
Complete crown	Before	CD	EM	9.6	<.001
		CD	VE	13.4	<.001
		CD	VS	21.5	<.001
		CD	ZR	21.0	<.001
		EM	VS	11.9	<.001
		EM	ZR	11.4	<.001
		VE	VS	8.1	<.001
		VE	ZR	7.7	<.001
		After	CD	EM	9.5
	CD		VE	14.6	<.001
	CD		VS	22.4	<.001
	CD		ZR	21.1	<.001
	EM		VE	5.1	.008
	EM		VS	12.9	<.001
	EM		ZR	11.6	<.001
	VE		VS	7.9	<.001
	VE		ZR	6.5	<.001
	Laminate veneer	Before	CD	EM	8.8
CD			VE	12.6	<.001
CD			VS	26.1	<.001
EM			LU	-7.5	<.001
EM			VS	17.3	<.001
LU			VE	11.4	<.001
LU			VS	24.9	<.001
VE			VS	13.5	<.001
After			CD	EM	7.5
		CD	VE	15.5	<.001
		CD	VS	28.3	<.001
		EM	LU	-4.3	.046
		EM	VE	7.9	<.001
		EM	VS	20.8	<.001
		LU	VE	12.3	<.001
		LU	VS	25.1	<.001
		VE	VS	12.9	<.001

CD, zirconia-reinforced lithium silicate ceramic; EM, lithium disilicate glass-ceramic; LU, polymerized resin nanoceramic; RTP, relative translucency parameter; VE, integrated ceramic and acrylate polymer network; VS, zirconia-reinforced lithium silicate ceramic; Zir, zirconia. *Mean for material 1 minus mean for material 2.

for color change ($P \leq .014$). Based on these findings, this null hypothesis was rejected as both thickness and material affected the color change after coffee thermocycling. This is consistent with previous studies.^{15,17}

The finding that ceramics are more color stable than composite resin materials when subjected to staining drinks including coffee has been previously reported.^{15,17} Therefore, composite resin material might be best avoided for laminate veneers in areas of high esthetic importance in coffee drinkers. Of the materials tested in this study, the lithium disilicate glass-ceramic (IPS e.max CAD; Ivoclar Vivadent AG) was the most color stable material (below the perceptibility threshold of $1.30 \Delta E_{00}$ units²⁰) and should be suitable for either laminate veneer or complete crown applications where esthetics is a

concern. A previous study¹⁵ also reported the ΔE_{00} values of material EM to be below the perceptibility threshold after coffee thermocycling for 5000 cycles irrespective of the thickness. However, in patients for whom esthetics are not paramount, restorations such as posterior inlays and onlays could be restored with a resin nanoceramic (Lava Ultimate; 3M ESPE) or an integrated ceramic and acrylate polymer network material (VITA ENAMIC; VITA Zahnfabrik). In a comparison between laboratory-processed composite resins versus CAD-CAM composite resin blocks, the material LU was reported to have the lowest color stability.¹⁸ The color difference at which 50% of dentist observers could perceive a color difference (50/50 perceptibility) has been reported to be 2.6 ΔE units.²¹ The color difference at which 50% of participants would remake the restoration because of color mismatch was 5.5 ΔE .²¹

The greater color stainability found in this study with a resin nanoceramic (Lava Ultimate; 3M ESPE) and an integrated ceramic and acrylate polymer network material (VITA ENAMIC; VITA Zahnfabrik) could be related to the material components which has been described previously.^{7-9,15} These materials contain hydrophobic urethane dimethacrylate and hydrophilic triethylene glycol dimethacrylate (TEGDMA); in addition, bisphenol A-glycidyl methacrylate is found in resin nanoceramics.⁷ These elements can increase the susceptibility of the color change seen in these materials, with TEGDMA exhibiting higher water sorption which can lead the hydrophilic colorant to penetrate the resin matrix.⁹ Bisphenol A-glycidyl methacrylate has been reported to cause the highest water sorption compared with urethane dimethacrylate and TEGDMA.⁸ This might be why in this study the resin nanoceramic (Lava Ultimate; 3M ESPE) was less color stable than the integrated ceramic and acrylate polymer network material (VITA ENAMIC; VITA Zahnfabrik), a finding that has been previously reported.¹⁵

The second null hypothesis was that neither the material, its thickness, nor cyclic immersions in hot and cold coffee baths would affect the relative translucency. The relative translucency was found to be lower for complete crown thickness compared with laminate veneer thickness within each combination of thickness and coffee thermocycling ($P \leq .001$). The results suggest that the relative translucency of the restorative materials tested decreased as the thickness increased. Based on these results, the null hypothesis was rejected for all 3 parameters (material, thickness, coffee thermocycling). However, making comparisons with previously generated translucency measurements is problematic because the thickness and the backings used in previous research are inconsistent.¹¹

A limitation of this study was that, as with any in vitro study, corroboration with clinical studies would help in

understanding the clinical behavior of these materials. In addition, as mentioned in a previous study, the use of regular toothpaste for cleaning and incorporation of whitening agents in the dental regimen can lower the risks of permanent staining of teeth.¹⁷ In clinical situations, only one surface of the restoration would be exposed to staining solutions, with the other surface luted to the tooth structure.¹⁴ Therefore, the color change may not be of the magnitude found in in vitro investigations.¹⁴ For future research, comparisons with different shades and the use of different batches of the same material and same shade would help evaluate changes based on such factors. Also of interest would be the influence of tooth interface factors such as luting material thickness, different shades of luting agents, and same shades of different manufacturers on the final color and translucency of the restorative materials in different thicknesses.

CONCLUSIONS

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

1. The mean color change of material LU for veneer thickness was greater than all the other tested materials ($P < .001$).
2. For relative translucency, statistical significance was found in the material and coffee staining interaction ($P = .004$).
3. Translucency was found to be lower for crown thickness compared with veneer thickness within each combination of thickness and coffee thermocycling ($P < .001$).
4. Material selection and thickness are important for color stainability and translucency after coffee staining especially when providing laminate veneers.

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Acknowledgments

The authors thank Dr Xiaoqiu Liu, a visiting professor from Jilin University Heilongjiang, China, and Dr Ibrahim Mostafa, a former research assistant at The Ohio State University College of Dentistry, for their assistance with the project.

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<https://doi.org/10.1016/j.prosdent.2018.09.011>

Noteworthy Abstracts of the Current Literature

Properties of hot-pressed lithium silicate glass-ceramics

Hallmann L, Ulmer P, Gerngross MD, Jetter J, Mintrone M, Lehmann F, Kern M
Dent Mater 2019 May;35:713-29

Objectives. New lithium silicate/disilicate hot-pressed glass-ceramics are introduced into the dental market. It is known that the mechanical properties of this material depend on the microstructure, chemical composition, glass matrix, morphology of crystals, volume ratio crystal/glass, additive, and treatments. This contribution investigates how these factors affect the properties of the new generation of lithium silicate/disilicate hot-pressed glass-ceramics.

Methods. Three lithium silicate/disilicate hot-pressed glass-ceramics were investigated; IPS e.max Press (control group), Initial LiSi Press and Celtra Press. The specimens were prepared according to the manufacturers' instructions. Different methods; DTA, XRD, Raman, optical spectroscopy, SEM were used to characterize the properties of these materials before, after heat and etching treatments. The heat treatments (four firings) were performed according to the manufacturer's instructions (GC company) for veneering (initial LiSi) of LS2 glass-ceramics. The etching was performed according to the manufacturer's instruction. Vita ceramics etch gel (HF 5%) was used as an etching agent. The mechanical properties were investigated according to DIN EN ISO 6872:2015 and ASTM C 1327-08 instructions.

Results. DTA and XRD analysis revealed that the transformation of the lithium silicate (LS) phase to the LS2 phase was completed for IPS e.max and Initial LiSi Press ingots while for Celtra Press ingots it was not. After pressing, the rod-shaped crystals were aligned parallel to the extrusion direction, while the platelet-shaped crystals having an interlocking microstructure were not. The mechanical properties depend on the microstructure, the chemical composition, the crystals morphology, the volume crystal/glass ratio, and the treatments (heat and etching). ZrO₂ did not improved the mechanical properties. Etching with HF gel decreased the flexural strength. After four heat treatments, the biaxial flexural strength, the K_{IC}, the roughness and the optical properties were affected. According to the HT-XRD, IPS e.max Press ingots can be hot pressed up to 900 °C, the initial LiSi Press ingots up to 940 °C and Celtra Press ingots up to 880 °C.

Significance. The properties of LS2 glass-ceramics depend on the chemical composition, the microstructure, the morphology of the crystals, the properties of the residual glass matrix, the volume ratio of crystal/glass, and the treatments (heat and etching).

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