

Double bond conversion of preheated composite resin beneath lithium disilicate standardized occlusal veneers

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The purpose of the study was the investigation of the polymerization of a preheated composite resin beneath lithium disilicate. First, lithium disilicate discs in two shades (HT A2 and HT A4) and three different thicknesses (2, 4, and 6 mm) were bonded on dentine with preheated composite resin that was photo-polymerized for 20 s. The composite resin microhardness, the double bond conversion (DC) and their correlation were estimated. Second, standardized occlusal veneers of two shades and two different thicknesses (4 and 6 mm) were bonded with preheated composite resin and photopolymerized for 60 or 270 s. A microhardness line profiling was performed on the cross-section of each specimen and the correspondence DC was calculated. Shade and thickness of lithium disilicate were found to have a significant impact on micro-hardness and DC of the composite resin. Beneath standardized occlusal veneers DC can reach clinically acceptable level if photopolymerization duration is extended properly.

Keywords: Preheated composite resin, Double bond conversion, Ceramic occlusal veneers cementation, Infrared spectroscopy, Polymerization

INTRODUCTION

Indirect bonded restorations are delivered *via* various adhesive protocols using composite resin luting agents. Apart from dual cure resin cements regular light-polymerized restorative composite resins (CR) have been proposed¹. The use of traditional viscous CR as a means of cementing indirect restorations can be facilitated by preheating but is still a current topic of controversy.

Some of the main advantages of bonding restorations with preheated CR, are the wide range of shades², the color stability², the extended working time³ and superior mechanical properties (wear, hardness and elastic modulus) compared to dual cure cements⁴. Reduced viscosity after preheating the materials ensures the reduction of film thickness⁵. More effective marginal sealing⁶ is also derived from the higher inorganic filler load⁷, which is particularly important for all-ceramic restorations where marginal discrepancy may vary from 41.5 to 96 μm ⁸. Resin bonding of preheated CR to ceramics has been found equal⁹ or superior¹⁰ to using dual cure cements.

Despite the advantages above, the extent of CR polymerization beneath the restoration has not been thoroughly investigated. It is accepted that a minimum double bond conversion or degree of cure (DC) for a CR is 55%¹¹. The DC of resin-based luting agents is affected by the type of the restorative material¹², the shade and the thickness of the restoration^{13,14}. Ceramic translucency is reduced by increasing ceramic thickness¹⁵. Exposure time should be increased when more than 1 mm of restorative ceramic material is used¹⁶. It was proposed that >120 s of irradiation with regular halogen light¹ or 3×90 s (occlusal, buccal and lingual directions) with

high irradiance LED¹⁷ are suitable for the appropriate photopolymerization through thick inlays/onlays. On the other hand, the extension of polymerization duration¹⁸ and the contribution of pre-heating are controversial concerning the DC^{19,20}.

Mechanical properties such as elastic modulus²¹, stiffness and hardness^{22,23}, as well as physicochemical properties such as salivary sorption²⁴, hydrolytic degradation²⁵, and release of residual monomer⁹ are directly related to the DC, affecting clinical parameters, such as restoration survival⁹, bond strength²⁶, and color stability^{9,23}. The DC can be directly quantified with either Infrared^{16,22} or Raman spectroscopy²⁰, or indirectly by measuring hardness^{27,28}. Direct DC quantification, however, appears to be the most accurate^{28,29}. A linear correlation between hardness and DC has been described¹⁸. Although this correlation has not been further investigated for many CR, it is being used widely in polymerization studies. In addition, since there is no precise standardization in the use of preheated CR regarding the thickness and shade of the restoration and proposed duration of polymerization, a more thorough and detailed investigation is required as a guide for the modern clinician.

Hence, the aims of the present study were to determine the double bond conversion and microhardness of a preheated regular CR, light cured through a) lithium disilicate discs, as a function of thickness and shade, and b) standardized lithium disilicate occlusal veneers in *ex-vivo* conditions, as a function of thickness, shade, distance from the margin and duration of photopolymerization.

The first null hypothesis was that there are no differences in the double bond conversion and microhardness of a CR light cured through lithium

disilicate discs, as a function of thickness and shade. The second null hypothesis was that there are no differences in microhardness and double bond conversion beneath standardized occlusal veneers in *ex-vivo* conditions, as a function of thickness, shade, distance from the margin and duration of photopolymerization.

MATERIALS AND METHODS

Information about the materials used in both experiments is listed in Table 1.

First experiment

Lithium disilicate discs (IPS e.max Press, Ivoclar Vivadent, Schaan, Liechtenstein, ϕ 16 mm, $n=30$) were prepared at different thicknesses (2.2, 4.2 and 6.2 mm) and shades HT A2 and HT A4 ($n=5$ for each combination of shade and thickness), by pressing in a ceramic oven (Dekema 654i, Dental-Keramiköfen, Freilassing, Germany) at 940°C. Ceramic discs were flattened by grinding in a grinding/polishing machine (Dap-V, Struers, Balerup, Denmark) with silicon-carbide papers (800 grit) under water cooling. One of the two surfaces was glazed with a transparent glaze (Cerabien ZR, Noritake, Nagoya, Japan) in the ceramic oven (Dekema 624i, Dental-Keramiköfen) at 765°C. The unglazed surfaces were parallelized with the glazed ones and polished in a grinding/polishing machine (EM TXP Target Surfacing System, Leica, Wetzlar, Germany) under water cooling, which also corrected the disc thickness to 2.0, 4.0 and 6.0 \pm 0.1 mm. Polished surfaces were subsequently etched with HF 5% for 20 s, rinsed with water and followed by alcohol rinsing, and hot air drying for 40 s, silanization with a pre-hydrolyzed silane (Silane, Ultradent, South

Jordan, UT, USA) and drying again with hot air. A thin layer of liquid resin (Heliobond, Ivoclar Vivadent) was applied with a brush, gently dried using cold air (5 s).

An ultraviolet-visible spectroscopic direct total transmission analysis was performed within the 350 to 650 nm wavelength range, employing a UV-Vis spectrometer (Lambda 35 UV-Vis spectrometer with 50 mm integrated sphere, PerkinElmer, Waltham, MA, USA). The scanning conditions were as follows: scanning speed 480 nm/min, slit bandwidth 2.00 nm and baseline corrected. From each spectrum, the percentage of light transmittance (%T) corresponding to the absorbance wavelength of the photoinitiator of the polymerization (468 nm) was recorded.

Subsequently, ceramic discs were bonded on cut and polished up to 1000 grit in a grinding/polishing machine (Dap-V, Struers) dentine surfaces, using a spacer of ~0.3 mm with preheated at 55°C for 5 min. in a composite warmer (Ena Heat, Micerium, Genoa, Italy), CR (Herculite XRV, A3, Kerr, Brea, CA, USA) and photopolymerized for 20 s. Dentine specimens were prepared by sound extracted third molars kept in 0.5% sodium azide (Ethics Committee Approval of Athens Dental Board (www.osanet.gr) 453-02/03/2023). LED light-curing unit was used (Radii Plus, SDI, Bayswater, Victoria, Australia), operated in a standard irradiation mode (1,500 mW/cm²) employing a 10 mm diameter tip. Additionally, preheated CR discs ($n=15$) ~0.3 mm thickness, pressed gently and covered with a glass slab, were photo-cured directly on similarly prepared third molars crown dentine, so as to have the same backing reflectance, specifying an accurate distance between light source and surface of CR of 2, 4 and 6 mm ($n=5$ for each distance) respectively performing as reference

Table 1 The materials used in the present study

Product	Composition	Manufacturer
IPS e.max Press HT A2 (LOT: Z0221H) HT A4 (LOT: S28063)	70% by volume lithium disilicate (Li ₂ Si ₂ O ₅) crystallized in a glassy matrix	Ivoclar Vivadent, Schaan, Liechtenstein
Cerabien ZR Clear Glaze, (REF: 104-5861 EU, LOT: EIYSN)	Clear Glaze	Noritake, Nagoya, Japan
Hydrofluoric Acid Solution	5% hydrogen fluoride in water, pH=2	Laboratory prepared solution
Silane (REF-UP 410 LOT: BLM8F)	Methacryloxy-propyl trimethoxysilane CAS No. 7803-62-5 <10%; Isopropyl alcohol >90%	Ultradent Products, South Jordan, UT, USA
Heliobond Light curing bonding agent: (LOT: Z02W68)	Light curing bonding resin: Bisphenol A glycidyl dimethacrylate (Bis-GMA); Triethylene glycol dimethacrylate; stabilizers and catalysts, pH=6.4	Ivoclar Vivadent
Herculite XRV, A3 unidose, LOT: 7240162	Bisphenol A glycidyl dimethacrylate (Bis-GMA); Urethane dimethacrylate (UDMA); Ethoxylated bisphenol A dimethacrylate (Bis-EMA); stabilizers; catalysts and inorganic microhybrid fillers (pyrolytic silica, quartz/glass microparticles)	Kerr, Orange, CA, USA

specimens.

All specimens were incubated in chemically cured resin and were stored for 10 days in 37°C, 100 R.H. Following this period, specimens were sectioned perpendicular to the composite resin film (Fig. 1a) using a microtome (Isomet, Buehler, Lake Bluff, IL, USA). The surfaces were then polished up to 1500 grit.

The hardness of CR of each specimen was estimated (Fig. 1b). A microhardness tester (HMV 2000, Shimadzu, Kyoto, Japan) was used, equipped with Vickers diamond indenter. Measurements were performed under 200 p force for a 15 s loading period. Ten measurements were taken for each specimen and averaged.

Thereupon, the dentine part of specimens was removed (Fig. 1c) by grinding and the CR was polished in the polishing machine at a low speed (~150 rd./min), using water as coolant to avoid specimen heating, up to 1500 grit. Reference specimens were also subjected to the same polishing procedure. The molecular composition of specimen CR was studied with Fourier transform infrared spectroscopy (FTIR), employing an attenuated total reflection (ATR) accessory (Fig. 1d, Golden Gate, Specac, Orpington, UK) with a type III diamond crystal (2×2 mm) and ZnSe lenses, attached to an FTIR spectrometer equipped with a deuterated L-alanine doped triglycine sulphate detector (Spectrum GX, PerkinElmer, Buckinghamshire, UK). CR surfaces were pressed against the refractive crystal with a sapphire anvil and spectra were recorded as follows: 4,000–650 cm^{-1} spectral range, 4 cm^{-1} resolution, 32 scan-coaddition and ~2 μm depth of analysis at 1,000 cm^{-1} . Three spectra were acquired from each specimen. A spectrum from the unset CR was also collected. To calculate the degree of conversion (DC), the variation in peak absorbance areas using the two-frequency technique (aliphatic C=C stretch at 1,637 cm^{-1} against an internal reference frequency: the aromatic C—C stretch at 1,608 cm^{-1}) was utilized. The per-cent degree of conversion was calculated according to the equation:

$$\text{DC} = \left[1 - \frac{\frac{(\text{C}=\text{C}_{\text{specimen}})}{(\text{C}\cdots\text{C}_{\text{specimen}})}}{\frac{(\text{C}=\text{C}_{\text{unset}})}{(\text{C}\cdots\text{C}_{\text{unset}})}} \right] \times 100\%$$

where “specimen” is the CR polymerized through lithium

disilicate or the correspondence reference, and “unset” is the unset CR.

Second experiment

Third molars ($n=40$) were ground and polished up to 1000 grit perpendicular to the tooth axis, until a clear dentine surface (~0.13 mm) was created. As follows, forty occlusal veneers were manufactured in the shape of the section, with axial surfaces parallel to the tooth axis (Fig. 2a). They were HT A2, 4 mm ($n=10$) and 6 mm ($n=10$) thickness, HT A4, 4 mm ($n=10$) and 6 mm ($n=10$) thickness. All the axial and the occlusal surfaces were glazed, and the interface surfaces were prepared for bonding as in the first experiment. Occlusal veneers were bonded on the correspondence dentine surfaces (using a 0.3 mm spacer) with preheated CR. Each group was divided into two subgroups according to the duration of photopolymerization as follows: five that photopolymerized 20 s through the occlusal surface, 20 s from the buccal and 20 from the lingual side (total photopolymerization time: 60 s) and five that photopolymerized 90 s through the occlusal surface, 90 s from the buccal and 90 from the lingual side (total photopolymerization time: 270 s). Specimens were then stored in water at 37°C for 7 days. Afterwards, they were sectioned on the maximum bucco-lingual dimension perpendicular to the interface and the surfaces were polished up to 1500 grit (Fig. 2b). A microhardness line profiling was performed on the CR from the buccal to the lingual side on a step of 1 mm (Fig. 2c). One measurement

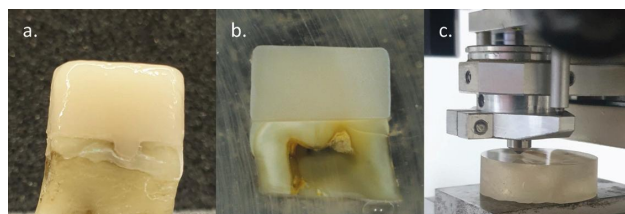


Fig. 2 Second experiment: a: Standardized occlusal veneers were bonded on dentine surfaces, b: incubated specimens were cut and polished on the maximum buccolingual diameter and c: microhardness line profiling of the CR from the buccal to the lingual side was performed for each specimen.

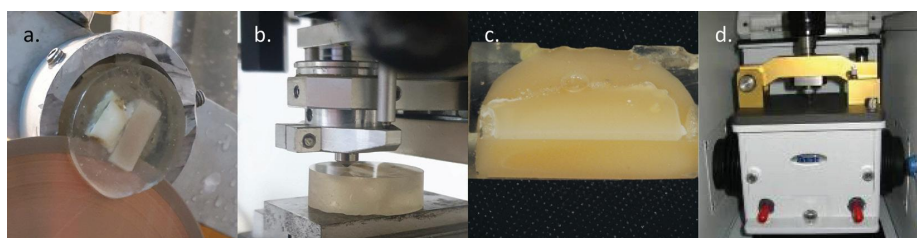


Fig. 1 a: Specimens from the first experiment were sectioned perpendicular to the CR film, b: after polishing, microhardness of CR was estimated, c: Dentine part was removed and d: ATR-FTIR spectra were harvested from the CR.

was taken each time. Five specimens were examined for each combination of shade-thickness-duration of polymerization.

Statistical analysis and data processing

The percentage of light transmittance (T%), of hardness and DC% from the first experiment were subjected to Kolmogorov-Smirnov normal distribution analysis and Levene's test for homogeneity of variance. Hardness and DC% were subsequently further analyzed with two-way ANOVA, followed by Bonferroni *post hoc* tests, with ceramic thickness and shade being the two independent variables. Moreover, a Pearson correlation test was performed, in order to detect the power of correlation between percentage of transmittance and the DC%, percentage of transmittance and hardness, DC% and hardness. Statistical analysis was performed utilizing the SPSS 26 software (IBM Analytics, Armonk, NY, USA) at a 95% confidence level ($\alpha=0.05$).

Specimens were named according to shade (A2 or A4) and thickness, resulting in: A2_2, A2_4, A2_6, A4_2, A4_4 and A4_6. Additionally, reference specimens, polymerized from correspondence distances: REF2, REF4 and REF6.

The equation between VH of the CR and DC% was estimated with the least squares method, to result in a relation form:

$$\text{DC\%} = a + b \cdot (\text{VH}) \quad (1)$$

In the second experiment, in order to achieve a

representative line profiling of hardness from the buccal to the lingual margin, five measurements were averaged, corresponding to one another. According to equation (1) and the results of the averaged VH from the second experiment, the DC% beneath standardized occlusal veneers of 4- and 6-mm thickness and HT A2 and A4 for total polymerization time 60 and 270 s was estimated for every millimeter from the buccal to the lingual side so as to have a line profiling. DC% values that were calculated for the central areas of all specimens (6 or 7 mm from the buccal margin) were subjected to Kolmogorov-Smirnov normal distribution analysis and Levene's test for homogeneity of variance and further analyzed with three-way ANOVA, followed by Bonferroni *post hoc* tests with ceramic thickness, shade and total photopolymerization time as the three independent variables. Moreover, the line profiling of the DC% averaged values for each group of specimens from the buccal margin to the center were approached with a straight line, estimated with the least square method. The slopes of the lines were subjected both to the univariate analysis of variance and to Bonferroni pairwise comparisons.

RESULTS

First experiment

The average presence of light transmittance at 468 nm obtained from the spectroscopic analysis of the ceramic discs and representative spectra are illustrated in Fig. 3. The percentage of light transmittance passed

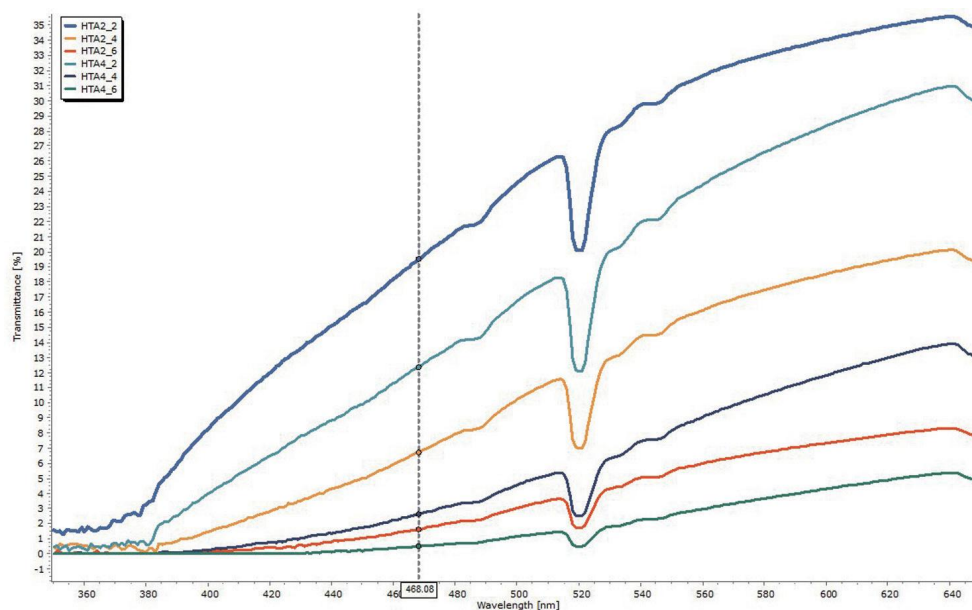


Fig. 3 Total transmittance UV-Vis spectra of ceramic discs, after glazing, polishing, HF etching, silanization and bonding resin application. The transmission at 468 nm (dotted line) for each group is: A2_2: $19.5 \pm 0.5\%$, A4_2: $12.4 \pm 0.5\%$, A2_4: $6.7 \pm 0.4\%$, A4_4: $2.6 \pm 0.4\%$, A2_6: $1.6 \pm 0.2\%$, A4_6: $0.7 \pm 0.2\%$. (350–650 nm wavelength range).

the normality ($p=0.987$) and homoscedasticity test ($p=0.318$). The shade, the thickness of lithium disilicate discs, as well as their interaction, were found to have a significant effect on light transmittance ($p<0.001$). According to *post-hoc* paired comparisons, the transmittance was ranked as follows $A2_2>A4_2>A2_4>A4_4>A2_6>A4_6$.

Both hardness and DC% data distributions passed the normality (DC%: $p=0.943$, Hardness: $p=0.850$) and homoscedasticity (DC%: $p=0.185$, Hardness $p=0.087$) test. The two-way ANOVA indicated that both shade ($p<0.001$) and thickness ($p<0.001$), as well as the interaction of these two factors ($p<0.001$) had a significant effect on hardness and DC%. No statistical difference in hardness and DC% was found among reference CR specimens: $REF2=REF4=REF6$. The results of the hardness measurements are summarized in Table 2.

Characteristic spectra of the CR unset and set (REF2) are presented in Fig. 4. Representative areas of spectra of the unset, reference and all specimens CR, used for the DC% measurements are presented in Fig. 5. The results of the double bond conversion are also

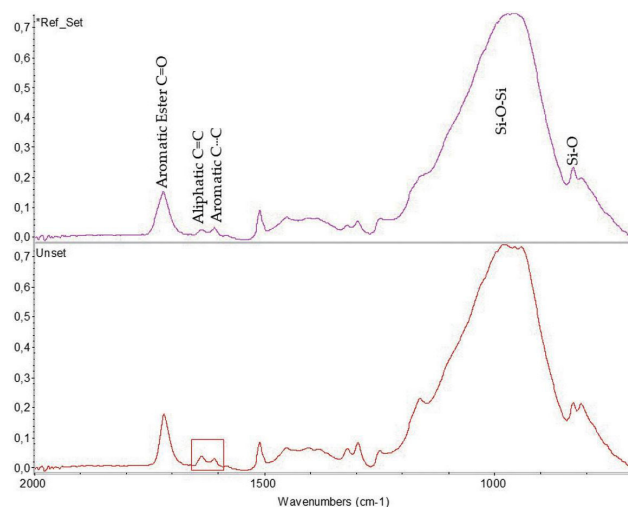


Fig. 4 Representative ATR-FTIR spectra of a reference direct photo-cured (Ref-Set) and Unset CR. The area in the red rectangle indicates the one magnified in Fig. 5, with the peaks that were used for the DC calculation. Absorbance scale, 2,000–700 cm^{-1} .

presented in Table 3.

Pearson correlation coefficients r and p values among the properties tested indicated a strong positive correlation between hardness and DC% ($r=0.947$, $p<0.04$), while weak positive correlation between light transmission and DC% ($r=0.776$, $p<0.070$) as well as light transmission and hardness ($r=0.748$, $p<0.088$).

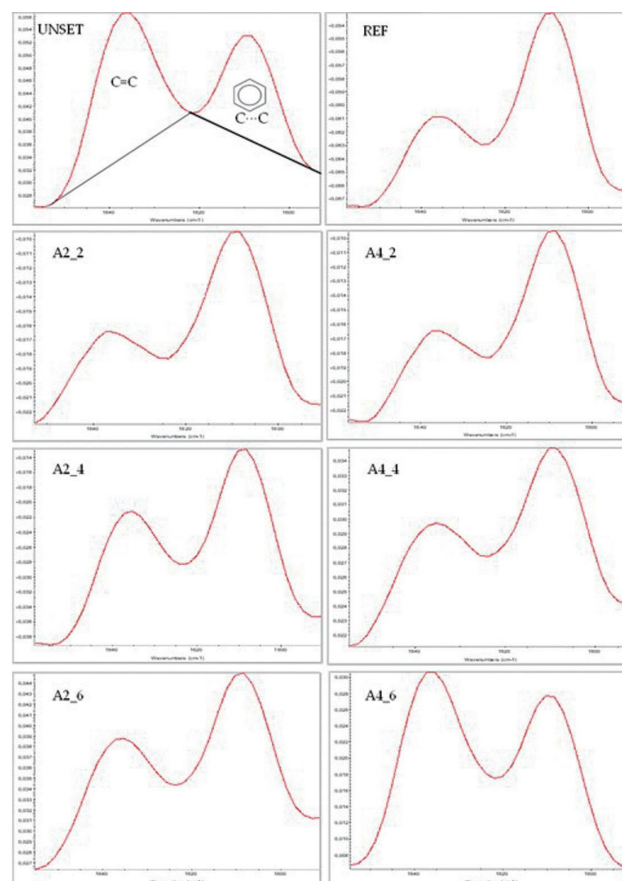


Fig. 5 Expanded ATR-FTIR spectra of the Unset, direct light cured (REF-SET) and beneath ceramic discs light cured CR (A2_2, A2_4, A2_6, A4_2, A4_4 & A4_6). In the unset spectrum, the areas used to calculate the degree of conversion (aliphatic C=C and aromatic C=C) are noted. Absorbance scale, 1,680–1,580 cm^{-1} wavenumber range.

Table 2 Results of the Vickers micro-hardness of CR (means and SDs) polymerized for 20 s, per ceramic shade and thickness

Thickness (mm)		2	4	6
Shade	REF	80.4 (0.9) ^{a,A}	79.8 (0.6) ^{a,A}	79.2 (0.9) ^{a,A}
	HT A2	73.7 (3.7) ^{b,B}	68.2 (8.4) ^{c,C}	44.2 (12.4) ^{d,D}
	HT A4	81.7 (4.1) ^{a,A}	58.2 (7.5) ^{e,E}	14.3 (5.4) ^{f,F}

Same superscript lowercase letters indicate means with no statistically significant differences within the same column and uppercase within the same line ($p>0.05$).

Table 3 Results of the DC% from the first experiment of CR (means and SDs) polymerized for 20 s, per ceramic shade and thickness

		Thickness (mm)		
		2	4	6
REF		69.6 (2.6) ^{a,A}	70.0 (1.3) ^{c,A}	70.1 (1.9) ^{a,A}
Shade	HT A2	58.0 (3.6) ^{b,B}	44.4 (6.7) ^{d,C}	38.6 (2.2) ^{f,D}
	HT A4	50.6 (5.8) ^{b,E}	43.1 (5.9) ^{d,F}	11.8 (2.1) ^{g,G}

Same superscript lowercase letters indicate means with no statistically significant differences within the same column and uppercase within the same line ($p>0.05$).

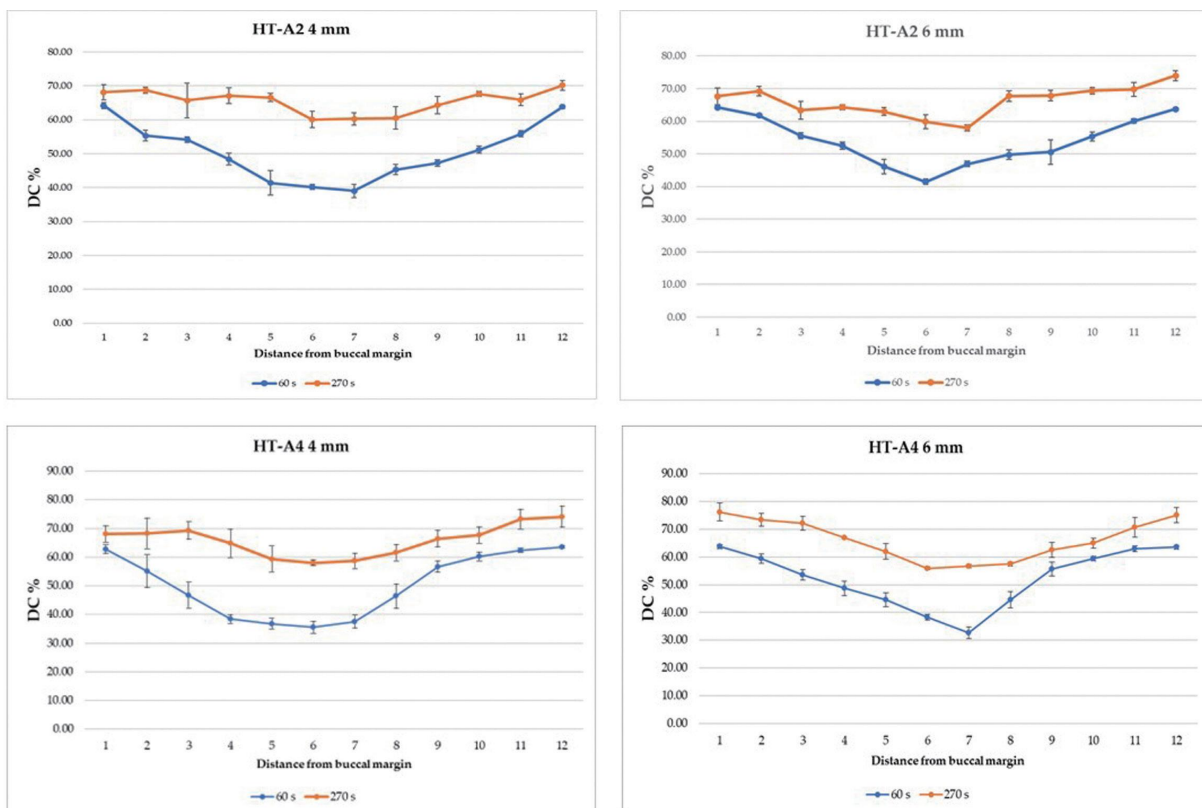


Fig. 6 DC% line profiling beneath the experimental standardized onlays along the CR from the lingual to the buccal side after photopolymerization total 60 s (blue line) and 270 s (orange line)

After least square method calculations, relation of hardness (HV) and DC% for the specific preheated (55°C) CR the following was found:

$$DC\% = 3.4 + 0.68 * (HV) \quad (2)$$

Second experiment

DC% values for the line profiling were calculated from the hardness results of the second experiment and equation 2. The DC% average values calculated for each group of specimens are presented as line profiling for different photopolymerization durations in Fig. 6. The DC% that was calculated for the central area

of the second experiment specimens passed both the normality ($p=0.845$) and homoscedasticity ($p=0.737$) tests. The thickness of the ceramic ($p=0.036$), the shade ($p<0.001$), the total polymerization time ($p<0.001$) and all paired interactions excluding the thickness and total polymerization time ($p=0.076$) had a statistically significant effect on the DC% ($\alpha=0.05$). The results of DC% values of the central areas of the second experiment specimens can be summarized as follows: All central areas polymerized for 60 s were equal and statistically significantly lower compared to the central areas polymerized for 270 s, which were respectively equal. The slopes of the lines profiling the propagation

Table 4 Slopes and standard errors of the line profiling of DC% of polymerized CR, beneath standardized onlays

Shade	Thickness (mm)	Duration of photopolymerization (s)	
		60	270
A2	4	$-4.8 \pm 0.2^{a,A}$	$-1.3 \pm 0.8^{c,B}$
	6	$-4.7 \pm 0.4^{a,A}$	$-1.6 \pm 0.6^{c,B}$
A4	4	$-5.7 \pm 0.4^{b,A}$	$-2.3 \pm 0.7^{c,B}$
	6	$-5.0 \pm 0.5^{a,A}$	$-4.0 \pm 0.3^{d,B}$

Same superscript lowercase letters indicate means with no statistically significant differences within the same column and uppercase within the same line ($p > 0.05$), (Second experiment).

of DC% from the buccal margin to the central area are presented in Table 4.

DISCUSSION

The first null hypothesis can be rejected, as differences in the degree of conversion and the microhardness of CR were detected beneath the discs with different shade and thickness. Both thickness and shades as well as their interaction were found to have a statistically significant effect on the degree of conversion and microhardness of CR. The second null hypothesis can also be rejected, since the double bond conversion beneath standardized occlusal veneers was found to vary according to the distance from the margin to the shade and thickness of the restoration and to the duration of photopolymerization.

The discs used in the first experiment were glazed on the free surface and treated for bonding (Hydrofluoric acid etching, silanization, application of liquid resin) on the flip surface. This experimental condition is the closest to the clinical conditions of bonding an indirect restoration of lithium disilicate. Moreover, the scattering of the light at the surface and the exit from the ceramic disc is significantly reduced. In pilot measurements before the final experiment, the transmission of light through all the discs, and the one after mechanical polishing with silicon-carbide papers (800 grit) were found almost the same, and close to zero even after glazing the free surface. The treatment of the bonding area, including the liquid resin application and sorption in the etched rough ceramic surface significantly increased the translucency, resulting in $19.5 \pm 0.5\%$ for A2_2. Therefore, this is a point of differentiation compared to other research works, in which polymerization of CR through ceramic takes place after the insertion of a mylar strip tape, without liquid resin on the ceramic surface³⁰ and with no total contact of the ceramic surface with the strip. The problem in that practice, apart from the differentiation from the clinical procedure, is the underestimation of the restoration translucency and the insertion of one more material with different refractive index beneath the ceramic, resulting actually in a layering as follows: ceramic–air–film–resin, which is far from the clinical practice. Combining lithium disilicate and liquid resin (Heliobond), materials with a similar

refractive index (~ 1.5)³¹ a smooth surface is achieved, minimizing light scattering. Therefore, measuring the total transmittance of lithium disilicate without any treatment results in an underestimation of the translucency in clinical conditions.

The differentiation in DC% among different specimens in the first experiment, in conjunction with the correspondence microhardness measurements, was the suitable data to investigate the linear correlation for the specific CR. This constitutes valuable information in case of the reverse transformation.

The correlation between microhardness and DC% was utilized in the second experiment to make the DC% line profiling based on the microhardness measurements. In the most of the cases, for the estimation of the DC% beneath ceramic restorations the photopolymerized film of CR, is pressed on the single reflection ATR crystal, harvesting a spectrum approximately in the center of the total area. So, there is not detailed information about the propagation of polymerization beneath all areas of the ceramic. In the present work, a line profiling on the maximum buccolingual diameter took place. Thus, more representative information was obtained. The purpose of this work was not a qualitative assessment of the polymerization through mechanical properties where microhardness is usually used, but a determination of the DC% *via* the specific linear relationship of these two parameters, as described in the first experiment for the specific material.

Several studies have been performed comparing the bond strength, the DC% or the mechanical properties of photo-cured CR, dual cured and/or chemical cured cements. In the present study, only one preheated CR was used. The main purpose of the present study was to have an accurate evidence-based outcome for the best conditions of photopolymerization of preheated resin beneath lithium disilicate indirect restorations.

In the first experiment, DC% and hardness measurements were harvested from each specimen, so paired information was reliable for further investigation of their correlation. The mean values of hardness and DC% of each group were used to detect the linear correlation with the least square method.

In the first experiment results, there was no statistically significant difference among the three

reference groups in terms of DC% or microhardness, in contrast with pre-existing studies in which DC% was unaffected but microhardness of a micro-hybrid CR was found to reduce as the distance from the photopolymerization unit was increasing³², or in which both DC% and microhardness were reduced³³ or even where there was no differentiation only in the first 5 mm^{34,35} of distance from the photopolymerization unit to the CR surface.

The DC% in the present study of the specific CR polymerized through HT A2, 2 mm thickness for 20 s, was found 58%, which is clinically appropriate³⁶. After that, DC% and microhardness of CR polymerized for 20 s beneath ceramics of different thickness and shade, follow the translucency classification, as resulted from the visible spectroscopy and indicated by the positive correlations of light transmittance —DC% and light transmittance— hardness. This observation is according to the principle of optics, as the more translucent the material, the more energy can pass through the material to activate camphorquinone to initiate the polymerization.

The DC% after 60 s of photopolymerization through standardized occlusal veneers, was inadequate (<50%) in the central area of in HT_A2 and HT_A4 both in 4- and 6-mm thickness. Nevertheless, after 270 s of photopolymerization, DC% was found acceptable in all cases and superior to all specimens photopolymerized for 60 s, with statistically significant difference. Moreover, the statistically significant difference in the slope values between 60 s and 270 s photopolymerized specimens, with the latter being less sloped, indicates that the increase of photopolymerization duration results in a more uniform propagation of the polymerization reaction beneath the ceramic. This is in accordance with the assumption that the degree of double bond conversion is related to the total amount of energy that will be offered to the CR during polymerization³⁵. The total amount of energy is equivalent to the duration of photopolymerization³⁷. Both lithium disilicate and CR follow the Beer-Lambert's Law. Moreover, it is well established that the depth of cure in CR, is equivalent to the decimal logarithm of the photopolymerization duration³⁸. Therefore, it is not an excess to consider that a similar relationship to photopolymerization through thick layers of CR or lithium disilicate restorations should exist. Nevertheless, the reduced energy offer, which results in the prolongation of polymerization duration, may also result in some positive effect on CR adaptation to the dentine as well as reduced shrinkage stresses. Since the low initial light intensity provides better adaptation of CR to cavity walls³⁹, the initial photopolymerization through the occlusal surface and as follows from the buccal and the lingual surface may provide better adaptation to prepared dentine. An acceptable DC of preheated CR was achieved beneath 2 mm thickness lithium disilicate discs after 20 s of photopolymerization with a LED unit, as well as beneath 6 mm dark shade (HT A4) standardized occlusal veneers by increasing photopolymerization time up to

270 s. However light exposures above 60 s must be done cautiously as this may lead to a significant increase of the pulp chamber temperature⁴⁰.

CONCLUSIONS

1. Both thickness and shades of high translucent lithium disilicate material have a statistically significant effect on the degree of conversion and microhardness of composite resin.
2. Under the specific conditions and the materials used, preheated photopolymerized composite resin can reach clinically acceptable level of double bond conversion beneath lithium disilicate restorations up to 6 mm thickness by extending properly the photopolymerization time.

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