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Research Article

Evaluation the Color Stability and Masking Ability of Darkened Teeth Treated With Two Kinds of CAD/CAD Veneer after Thermocycling

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Abstract

Objectives: Evaluate color stability and masking ability of darkened substrate restored with two kinds of CAD/CAM veneer materials and the underlying light curing cement (light or neutral) after 1,000,000 thermomechanical cycles. And as a complementary analysis, the residual compression strength of the specimens that survived the thermocycles was carried out.

Materials and methods: 60 indirect veneers (IPS e.max CAD and VITA Enamic) with 0.8 mm were prepared using the milling method and cemented on central incisors replicates, non-darkened (A2) or darkened (C4) with light-curing cement: neutral (N) or light (L) (n=10). Spectrophotometer measurements were performed 48h and 72h after cementation and after thermomechanical cycles (250,000; 500,000; 750,000 and 1,000,000). Color differences were evaluated by CIEDE2000 system (ΔE00). The perceptibility threshold was set at ΔE00 = 1.28

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and clinical acceptability threshold was set at ΔE00 = 2.24. For the survived samples, compression test was performed as a complementary analysis after specimen ageing. Fractographic analysis was employed to observe fracture patterns. Data were analyzed by two-way ANOVA followed by post hoc Tukey test for color test and compression test by Kolmogorov-Smirnov, Shapiro-Wilk and Tukey test (5%).

Results: independent the material and light curing cement used, they were capable to mask the darkened substrate and showed color stability over time, presenting ΔE00 < 0.7. After thermomechanical cycles, lithium disilicate ceramic presented higher residual compression strength and at fractographic analysis demonstrated brittle behavior. Polymer-infiltrated ceramic network presented a plastic deformation and chipping on the veneers' edges.

Conclusion: After 1,000,000 thermomechanical cycles, lithium disilicate ceramic and the polymer-infiltrated ceramic network veneers, processed by CAD/CAM with 0.8 mm and the underlying light curing cement presented color stability and could mask the darkened substrate over time.

Keywords

Ceramics; CAD/CAM; Dental Materials; Color Science; Hybrid Ceramic Blocks

Clinical Significance

Lithium disilicate and polymer-infiltrated ceramic network veneers with 0.8 mm and the light curing cement (neutral or light) presented excellent color stability and was capable to mask the darkened substrate over time. In addition, after thermocycles lithium disilicate exhibited better resistance to compression strength than the polymer-infiltrated ceramic network.

Introduction

The treatment of darkened teeth, particularly anterior teeth, is a relevant topic and are associated with different procedures take into account the severity of discoloration [1-3]. Depending on the severity of dental discoloration, less invasive procedures could be realized as micro abrasion, vital and nonvital bleaching to procedures that require dental wear such as direct and indirect veneers, ceramic crowns and sometimes a combination of them [3,4].

Indirect veneers could reestablish adequate function and the biomechanics of the dentition, mask highly discolored teeth and are considered a conservative technique with tooth preparation varying between 0.3 to 0.9 mm [5,6]. Dental ceramics are the materials of choice

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for this type of restorations due to its excellent optical properties, color stability, high stain resistance, biocompatibility, durability and the material that most mimic the appearance of natural teeth [7-9].

Dentistry has changed significantly with digital technologies associated with advanced dental materials, with improvements related to new ceramics and composite microstructures and CAD/CAM (Computer-aided design/Computer-aided manufacturing) methods [10-12]. Composite materials, called as a polymer-infiltrated ceramic network, in which a porous ceramic block is infiltrated by polymer and processing by CAD/CAM methods have become an alternative to ceramic blocks [11-14]. Polymer-infiltrated ceramic network materials are also easy to mill, can be repaired intraorally, adjustable for occlusion as well as friendly polishing and presented higher fracture strength when compared to ceramic materials [15,16]. Their mechanical and optical properties are influenced by monomer composition as well as filler size or arrangement of the materials their self [17]. All of these factors make polymer-infiltrated ceramic network materials a promising option in digital workflow being indicated for single crowns, inlays, onlays and veneers [11,18].

Dental ceramics are considered a material optically heterogeneous with different degrees of translucency and opacity that can be changed by some characteristics such as thickness, crystal structure, porosities and the ceramic firing temperature [19-25]. The color masking ability of ceramics used for indirect veneers are affected by the thickness of the ceramic, the shade and the thickness of the cement agent used and the color of the prepared tooth [25-28].

Clinical trials are the most reliable way to evaluate dental materials properties, clinical longevity and the esthetic, therefore, laboratory tests can help to predict materials' behavior [29,30]. Few studies have evaluated the interaction of substrate/cement and restorative material. This study was thus conducted to evaluate the color stability and masking ability of darkened substrate over time restored with lithium disilicate or polymer-infiltrated ceramic network veneers with 0.8 mm, processed by CAD/CAM method and the underlying light curing cement (neutral or light) after 1,000,000 thermomechanical cycles. And as a complementary analysis, the residual compression strength of the specimens that survived the thermocycles without any defect was carried out. The research hypotheses were: 1) The color stability and masking ability would be similar for all tested groups after thermomechanical cycles, that aging does not have a significant effect on color difference ($\Delta E00$) value 2) all experimental groups would show similar behavior in residual compression strength after thermomechanical cycles.

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Materials and Methods

This *in-vitro* study involved indirect veneers with 0.8 mm of lithium dissilicate ceramic and a polymer-infiltrated ceramic network manufactured by CAD/CAM method. The veneers were cemented in resin replicas teeth of non-discolored teeth (A2) and discolored teeth (C4). The veneers were cemented with a light curing cement colors neutral or light (Table 1).

Specimens' Preparation

An artificial upper right central incisor positioned in a mannequin was prepared for a veneer. The preparation comprised a 1.0 mm incisal reduction and 0.8 mm axial reduction. The prepared incisor (master model) received an impression with vinyl polysiloxane material (Express; 3M ESPE, St. Paul, MN, USA) to produce stone dies. The stone dies were scanned and 60 dental veneers were manufactured by CAD/CAM (Cerec 3D; Sirona, Bensheim, Hessen, Germany).

The veneers were produced from two different materials: LDC - Lithium Disilicate Ceramic (IPS e.max CAD; Ivoclar-Vivadent, Schaan, Liechtenstein) and VE (CAD/CAM polymer-infiltrated ceramic network, Vita Enamic; Vita Zahnfabrik, Bad Sackingen, Germany). The veneers' color used were: LDC (LT A2) and for VE (2M2-T), both corresponding to A2 translucent blocks. LDC veneers were crystallized in a ceramic furnace and VE veneers were polished; both procedures followed manufacturer instructions. The veneers fitting was checked with a probe. In cases of misfit, the veneer was rejected.

The master model was used to produce 60 composite resin replicas teeth. The master model was included in acrylic resin base. Then, it was impressed with a vinyl polysiloxane material (Express; 3M ESPE, St. Paul, MN, USA) by a metallic device. The mold was filled with composite resin (Z-100; 3M ESPE, St. Paul, MN, USA), with colors according to the experimental group A2 or C4, by the incremental technique. The increments were photoactivated using a Light Emitting Diode (LED) (Radii Cal; SDI, Bayswater, Victoria, Australia) with a power density of 900 mW/cm^2, which was verified before use with a radiometer. The replicas have been carefully removed and inspected. If there were any defect, it was discarded. Then, the replicas were stored in deionized water for 30 days, at 37ºC, allowing resin hygroscopic expansion [31,32]. The water storage enables composite resin to reach modulus of elasticity of 16 GPa, that means very similar to dentin [33,34].

It was determined 6 experimental groups, with 10 specimens in each, as follow Table 1.

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Group (n=10)	Veneer Material / Shade	Light curing Cement Shade	Time / Thermocycling
LDC-N-A2	Lithium disilicate ceramic / IPS e.max CAD / LT A2	Neutral	48h, 72h/ 250,000; 500,000; 750,000 and 1,000,000 thermocycling
LDC-N-C4		Neutral	
LDC-L-C4		Light	
VE-N-A2	Polymer-infiltrated ceramic network/ VITA Enamic / 2M2-T	Neutral	
VE-N-C4		Neutral	
VE-L-C4		Light	

Table 1: Experimental groups.

Previously to cementation, the veneers received internal surface treatment: the polymer-infiltrated ceramic network were airborne-particle abraded with 50-µm Al^2O^3 at 0.15 MPa pressure and the lithium disilicate ceramic were etched with 9% buffered hydrofluoric acid (Porcelain Etch; Ultradent Products, Inc). All materials were ultrasonically cleaned in distilled water for 3 minutes. A ceramic primer (Monobond Plus; Ivoclar Vivadent AG) was applied to all materials for 60 seconds and dried with dry air. The teeth replicas were cleaned with 37% phosphoric acid for 15s, washed and followed by adhesive system application (Adper Scothbond Adhesive - 3M ESPE, St. Paul, MN, USA). The cementation was made with a light curing cement (Variolink Esthetic LC; Ivoclar-Vivadent, Schaan, Liechtenstein) color according to the group (neutral or light). The light curing cement was applied to internal veneers' surfaces, seated by press finger, as described by Lohbauer, et al., 2010 [35]. Excess light curing cement was removed and the photoactivation was performed with a LED (Radii Cal; SDI, Bayswater, Victoria, Australia) with a power density of 900 mW/cm^2.

Digital spectrophotometer Vita Easyshade (Vita-Zanhnfabrik, Bad Säckingen, Germany) was used to evaluate the color measurements at: (1) 48h after cementation (specimens' storage in deionized water) (2) 72h after cementation (specimens' storage in deionized water) (3) after 250,000 thermomechanical cycles (4) after 500,000 thermomechanical cycles (5) after 750,000 thermomechanical cycles and (6) after 1,000,000 thermomechanical cycles with temperatures varying between 5° and 55°C according to International Organization for Standardization (ISO) standard no. 11405:2015 [36], 5Hz and load of 100N in a thermomechanical cycling machine (Biocycle, Biopdi; São Carlos, SP, Brazil). The spectrophotometer was calibrated according to the manufacturer's recommendations before and after the use. During the reading,

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the light of 30 LED lights with ten different color shades were focused on the specimens in a circular way and the color coordinates L* a* b* were registered. For each sample, three measurements were obtained on the medium third of the labial surface of the veneer. The values were tabulated to obtain the groups average.

Color differences were evaluated by CIEDE2000 system ($\Delta E00$) color difference formula [37]. For this study, the perceptibility threshold was set at $\Delta E00 = 1.28$ units and the clinical acceptability threshold was set $\Delta E00 = 2.24$ units [38].

The data were analyzed with 2-way ANOVA followed by the post hoc Tukey test ($\alpha=5\%$).

Compression Test

After thermomechanical cycles, the specimens that survived the cycles (without material fractures and catastrophic failure), were stored at 37°C in a 100% humidity environment (stove) for seven days.

Compression test was performed in a universal testing machine KRATOS (Model K - 2000 MP; Kratos Industrial Equipment, São Paulo, SP, Brazil) at a crosshead speed of 0.75 mm/min. A cylindrical device 10 mm in diameter was applied axially at the incisal edge of each specimen and loaded until fracture. The compression results were recorded and a final report was generated. Data were submitted to the normality test: Kolmogorov-Smirnov and Shapiro-Wilk followed by the T test for independent samples ($p<5\%$).

Fractographic Analysis

After the axial compression test, one fractured specimen of each material was selected for stereomicroscope (SUPRA 40; Carl Zeiss Microimaging, Thornwood, NY, USA) analysis to observe veneer fracture patterns and compare the mechanical behaviors of the veneer materials after aging in thermomechanical cycles [39].

Results

Color Analysis

All groups presented excellent color stability over time (Table 2), since color difference values $\Delta E00$ was < 0.7 and the perceptibility threshold was set at $\Delta E00 = 1.28$ units. Nevertheless,

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significant statistical difference was observed between darkened (C4) and non-darkened (A2) substrates for LDC-N-A2 and LDC-N-C4 ($p=0.001$) groups.

Comparing materials LDC and VE it was found significant statistical difference among several groups: LDC-N-A2 x VE-L-C4 ($p=0.01$), LDC-N-C4 x VE-N-A2 ($p=0.02$) and LDC-N-C4 x VE-N-C4 ($p=0.002$).

The light curing cement colors (neutral x light) influenced $\Delta E00$ values for VE between VE-N-C4 and VE-L-C4 ($p=0.02$) groups.

Compression Test

To perform the compression test, some specimens had already fractured the border of the restoration during thermomechanical cycles (from 60 specimens in the 1,000,000 thermocycles 2 veneers have a catastrophic failure; 32 have little fractures in the incisal border) thus, only 15 specimens of LDC and 11 specimens of VE were analyzed. Next, for the compression test, the color of the substrate and the color of the light curing cement were not considered. For this test, only the material was analyzed. It can be observed that there was a statistically significant difference between the groups ($p<5\%$). The LDC group presented higher strength with an average of 63.67 MPa, while VE presented an average of 38.26 MPa (Table 3) even after 1,000,000 thermomechanical cycles.

Fractographic Analysis

It can be seen that the beginning of the crack occurred almost immediately in the region where the edentator was applied in the compression test point of the fracture growth. A series of micrographs of representative specimens of LDC and VE groups after compression tests are presented in Fig. 1-3.

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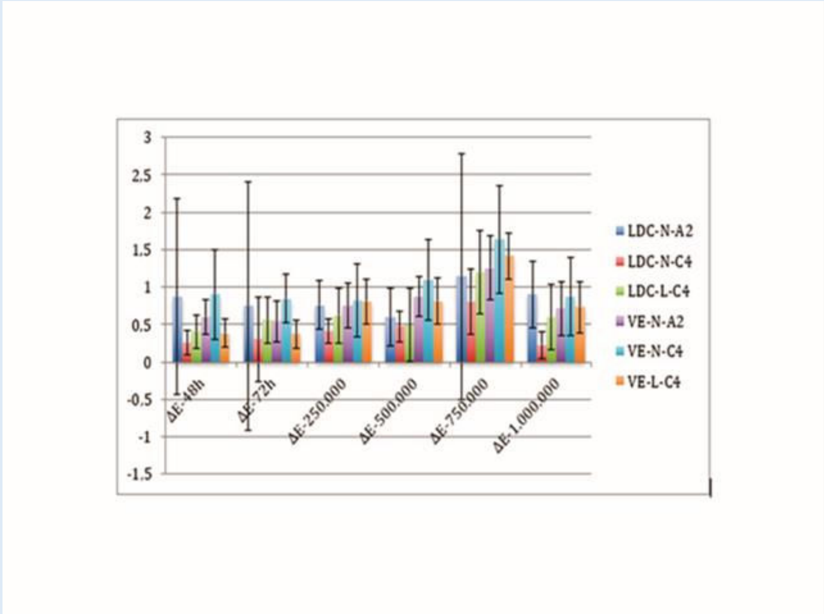

Figure 1: Values of ΔE, Anova-2 repeated measures and Tukey's test.

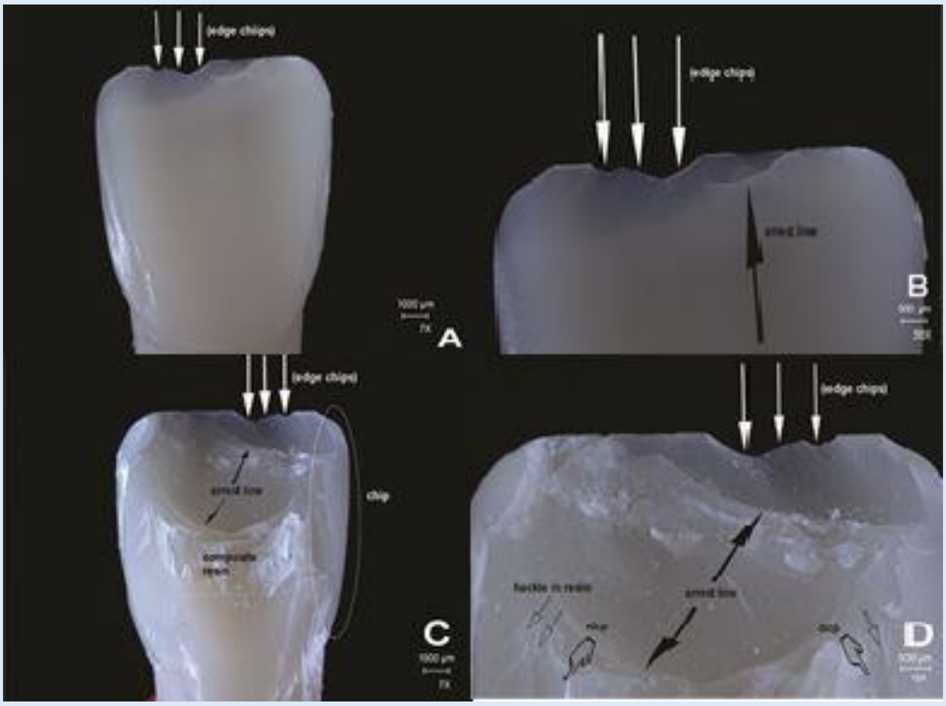

Figure 2: LDC veneer: A. Vestibular view (at 7x) showing the beginning of the failure on the incisal edge. B. The edge chip (at 30x) can be seen and an arrest line. C. Palatal view (at 7x) propagation of failure and a chip in the interproximal distal margin. D. In composite resin, hackles (at 15x) can be seen indicating the Direction of Crack Propagation (DCP) towards the margin.

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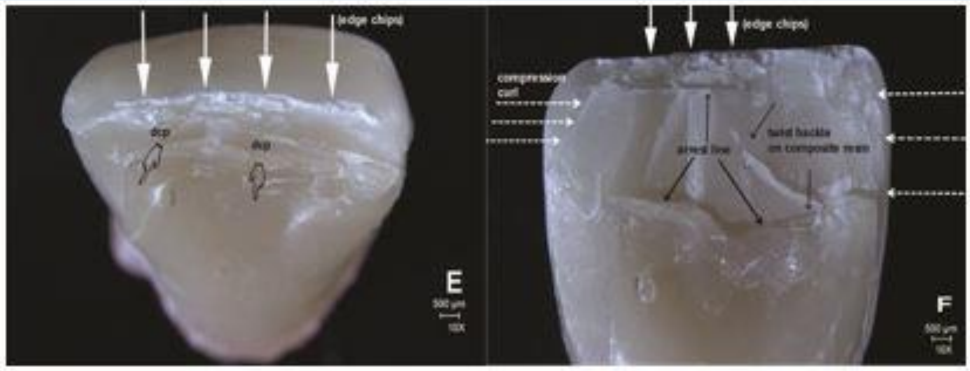

Figure 3: VE veneer: E. Incisal edge view (at 7x) showing edge chips, the DCP and plastic deformation. F. Palatal view (at 10x), showing compression curl towards the margin, arrest lines and twist hackles in the core of the tooth replicate, indicating the direction of crack propagation.

Discussion

The first research hypothesis that the color stability and masking ability would be similar for all tested groups after thermomechanical cycles and that the aging does not have a significant effect on color difference (ΔE00) values was accepted, because the (ΔE00) found were < 0.7, i.e., that is unnoticeable to the observers, providing that booth lithium disilicate or polymer-infiltrated ceramic network veneers with 0.8 mm processed by CAD/CAM method and the underlying light curing cement (neutral or light) was capable to mask the darkened substrate over time [38].

Esthetic dentistry is an area in constantly advancement and dental materials need to match and reproduce the color appearance of the natural teeth [1]. Thus, the use of color difference formula is important to enable better approach between perceptibility and acceptability visual analyses and instrumental color difference values [38]. The employment of CIEDE2000 color difference formula represents better the human perception of color differences (95% agreement with visual findings) and the use of dental shade matching, that comprise spectrophotometers, colorimeters and imaging systems, instruments with daily clinic applicability could reduce errors and inconsistencies of traditional shade matching [1,40].

Color stability of restorations is as important as the mechanical properties, as color changes may limit the longevity and quality of restorations [41,42]. A study evaluating the color stability of materials under thermocycling in coffee solution, a frequently consumed beverage, the authors verified that lithium disilicate color change was not perceptible (ΔE00 < 1.28), while VITA Enamic was perceptible but acceptable (1.28 < ΔE00 < 2.24) and Lava Ultimate (indirect resin composite) and Filtek Supreme (direct resin composite), were unacceptable

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(ΔE00 > 2.24), consider that polymer-infiltrated ceramic network veneers may be an alternative to LDC veneers when stainability by coffee is considered [41].

Polymer-infiltrated ceramic network, that is comprised of two interconnected networks: a dominant ceramic, approximately 70% and a polymeric part, composed of Urethane Dimethacrylate (UDMA) and Triethylene Glycol Dimethacrylate (TEGDMA) crosslinked polymers could have the optical characteristics changing over time because the degradation of the polymeric matrix, the loss of surface gloss with tooth brushing and wear also constitutes an issue to stains deposition in the matrix [11,13,16]. In this study, comparing materials over time it was found difference between LDC-N-A2 x VE-L-C4 ($p=0.01$), LDC-N-C4 x VE-N-A2 ($p=0.02$) and for LDC-N-C4 x VE-N-C4 ($p=0.002$), possibly ceramic materials present better color stability than composite resins [41].

The optical performance of a ceramic restoration is determined by the combination of tooth structure color, ceramic layer thickness and cement color [10]. The light curing cement colors (neutral and light) in this study influenced ΔE00 values only for VE-N-C4 and VE-L-C4 groups, as seen by other studies indicate that the opacity and thickness of cement may contribute to the masking capacity of darkened teeth to restoration thickness. According to Silami, et al., 2016 light curing cements had an influence on the color and luminosity of ceramic restorations, while self-adhesive and dual cements did not influence, a situation also confirmed by Turgut and Bagis, 2011 [43-47]. Therefore, the severity of tooth discoloration, the optical properties of a ceramic veneer system and the underlying light curing cement can influence the final appearance of a ceramic veneer [48].

Laboratory tests of dental materials are necessary to prove their mechanical capability and compatibility to service in the oral cavity and should try to simulate different aspects of the oral cavity to produce failures similar to those seen clinically [49]. In addition, it is valuable to consider that many works' asses the masking ability of dental materials related to materials thickness and cement associated with light and dark background [13,26,41]. However, it is known that the presence of the cement and the substrate influence the final color of the restoration [48,10]. Few laboratory studies have evaluated the interaction of the factors (restorative material/underlying cement/ substrate). Also, materials are tested in the form of cylinders or blocks and the materials are submitted to aging methods in both sides of the specimen [13,49]. Curved conformation of the preparation may influence differently from a flat specimen, being extremely important try to simulate the reality of the dental preparation to assess the masking ability of the materials throughout the time as was performed in this study. This study tried to simulate the material aging (veneer and light curing cement) in the oral cavity conditions through thermomechanical cycles test in a wet environment. The simulation period in this study of 1,000,000 thermocycles are related to about 4 years of use in the oral environment, whereas usually 250,000 cycles represent 1 year in service [49]. Therefore, after

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aging conditions the veneer materials processed by CAD/CAM tested in this study and the light curing cement (neutral or light) had good behavior in masking the darkened substrate and color stability, presenting conditions to be used clinically.

The second research hypothesis, that all groups would show similar behavior in residual compression strength after thermomechanical cycles was rejected. As mastication forces are compressive in nature, it is important to investigate compressive strength as a primary prediction behavior [50]. Few studies persisted in thermomechanical cycles until specimen's failure; studies tend to employ cyclic loading for a specific number of cycles and then submit the specimens to fracture test. This additional test does not exactly represent the fatigue failure of the material, but it provides data for comparing the results through studies [49]. In this study, LDC presented a mean value of 63.67 MPa, while VE showed mean value of 38.26 MPa after 1,000,000 thermomechanical cycles. However, LDC fractographic images showed a brittle behavior and VE presented a plastic deformation. Brittle materials, such as lithium disilicate ceramic, can show higher initial flexural strength and lead to spontaneous fracture [15,31]. Composite, however, shows higher deformation of the material, which reduces the eventual spontaneous fracture probability [51-53] and there is the development of a plastic zone on the crack extensions [54]. With polymer-infiltrated ceramic network, cracking predominantly appears to be through the ceramic matrix with additional fracturing along the polymer-porcelain interface as well as extended polymer deformation ligaments that bridge the crack well behind the crack tip [55]. Moreover, the polymer-infiltrated ceramic network evaluated in this study could have encountered water uptake during thermocycling, which led to deterioration and some microcracks at Scanning Electronic Microscopic (SEM) observation, decreasing the mechanical strength but with failures more clinically reversible [56]. In a study comparing different resin composite blocks, the polymer-infiltrated ceramic network presented better flexural modulus than the dispersed-filler materials, probably because its spatial distribution and continuity of its phases, as well as the matrix/particles interaction contribute to delay effects of water sorption [14].

There is still no universal or ideal materials in restorative dentistry that could be used in all situations, thus, the material choice varies with the clinical situation [16]. On selecting a material to restore an anterior tooth factors as color stability and mechanical behavior dictate the correct indication for each single case. Additionally, indirect composite resin material processed by CAD-CAM systems have become an interesting option because they present intermediate properties between ceramics and direct composites and easy milling and polishing, therefore the balance among these studied factors should be considered [11,12].

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Conclusion

Within the limitations of this study, it can be concluded that lithium disilicate ceramic and polymer-infiltrated ceramic network veneers manufactured by CAD/CAM methods with 0.8 mm and the underlying light-curing cement presented color stability over time and are capable in masking darkened substrate. The residual compression strength after the aging in thermomechanical cycles was higher in lithium disilicate veneers, showing more brittle behavior than the polymer-infiltrated ceramic network that presented chipping and plastic deformation.

Conflict of Interest

There are no conflicts of interest.

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