DOI: https://doi.org/10.17921/2447-8938.2019v21n5p512-517

Optical Properties of a Glass Ceramic and an Indirect Resin Composite: Effects of Polishing and Staining

Propriedades Ópticas de uma Cerâmica Vítrea e uma Resina Composta Indireta: Efeitos do Polimento e Manchamento

Fernando Zurlo Dellazzana[a]; Camila da Silva Rodrigues*[a]; André Mallmann[a]; Letícia Borges Jacques[a]

[a]Federal University of Santa Maria, Stricto Sensu Graduate Program in Dental Sciences, RS, Brazil.
*E-mail: camilasrdg@gmail.com
Recebido em: 14/05/2019; Aprovado em: 31/07/2019

Abstract

Little information is available about the optical behavior of glass ceramics and indirect resin composites. This study aimed to evaluate if an indirect resin composite can present similar behavior of color stability and translucency to a glass ceramic after polishing and aging in staining beverage. Specimens of a dental ceramic (IPS e.max Ceram) and an indirect resin composite (SR Adoro) were made. Half the specimens of each material were polished with disc-shaped tips. Groups were divided according to aging media: distilled water or immersion in red wine for 20 min/day during 30 days. CIE L*a*b* coordinates were measured with a spectrophotometer at baseline and after 30 days of aging. Color change was calculated by CIEDE2000 and translucency was calculated by contrast ratio (CR). Statistical analysis were performed with ANOVA and Tukey tests. Aging in red wine caused perceptible color change in both materials. Polishing only increased color change of indirect composite when aged in red wine. Ceramic groups showed greater opacity than the composite in all measurements. The indirect composite remained more translucent and results showed that it is capable of presenting color stability similar to a ceramic. However, polishing seems to increase its color change.

Keywords: Ceramics. Color. Composite Resins. Dental Polishing.

Resumo

*Pouca informação comparando o comportamento óptico de cerâmicas vítreas e resinas compostas indiretas estão disponíveis na literatura. O objetivo deste estudo foi avaliar se uma resina composta indireta pode apresentar comportamento semelhante a uma cerâmica vítrea em relação à estabilidade de cor e translucidez após polimento e envelhecimento em meio altamente pigmentante. Espécimes de uma cerâmica vítrea (IPS e.max Ceram) e uma resina composta indireta (SR Adoro) foram preparados. Metade dos espécimes de cada material foram polidas com pontas de polimento. Os grupos foram divididos conforme o meio de armazenamento: água destilada ou vinho tinto por 20 min/dia durante 30 dias. As coordenadas CIEL*a*b* foram medidas com espectrofotômetro previamente e após os 30 dias de armazenamento. A alteração de cor foi calculada pela equação CIEDE2000 e a translucidez foi calculada por razão de contraste. A análise estatística foi realizada pelos testes ANOVA e teste de Tukey. O armazenamento em vinho levou a uma alteração de cor perceptível nos dois materiais. O polimento apenas causou alteração de cor na resina composta indireta quando imersa em vinho tinto. A resina composta indireta manteve-se mais translúcida e os resultados mostraram que esse material é capaz de apresentar estabilidade de cor semelhante à cerâmica. No entanto, o polimento parece aumentar sua alteração de cor.*

Palavras-chave: *Cerâmica. Cor. Polimento Dentário. Resinas Compostas.*

1 Introduction

Dental glass ceramics are the indirect restorative materials that best reproduce the optical properties of dental tissues. These materials have excellent potential for light transmission, and due to this behavior, they have increasingly been chosen as a treatment option in situations where esthetic appearance is primordial. Alternatively, it is possible to fabricate highly esthetic restorations with resin composites. Initially developed for direct use and with the main advantage of making it possible to conserve and adhesively reinforce the tooth structure, composites may also be used in indirect restorations. When using resin composites, the indirect approach favors an increase in the degree of conversion of polymers, and results in an improvement of their properties, which leads to better longitudinal clinical performance.[1]

Clinical studies show similar survival rates between indirect resin composites and dental ceramics restorations.[2-4] Other studies have compared resin composites and glass ceramics in evaluating fatigue behavior[5] and roughness[6], and observed similarities between the two materials. However, there are no studies comparing the optical properties of an indirect resin composite and a glass ceramic. It is well known that the contact with staining agents causes color alterations of restorative materials.[7-9] Composites tend to present greater color change due to their organic nature, in which the polymer matrix suffers water sorption;[10] whereas ceramics tend to present greater stability in their optical properties because of their vitreous and inorganic nature.[11]

In clinical practice, adjustments in indirect resin or ceramic restorations (or being veneered with it) are commonly necessary. In addition, polishing the surface of these restorations before cementation is a current tendency, giving restorations a more natural aspect.[12] Akar et al.[13] observed that different surface-finished methods affected color and translucency of ceramic systems. In addition, Motro et al.[14] evaluated the effect of finishing methods on color stability of a glass ceramic after immersion in coffee. The authors observed that all methods caused significant color change and presented ΔE_{ab} mean values between 1.00 and 2.5 in test groups. Arocha et al.[15] evaluated color change of indirect resin composites after contact with staining beverages and presented significant ΔE_{00} mean values (i.e. 5.00) after one week of immersion in coffee. Nevertheless, specimens were not submitted to any polishing procedure, which seems to be a significant factor for color stability of composites.[16]

Within this scope, this study aimed to evaluate if an indirect resin composite is capable of presenting similar behavior of color stability and translucency to a glass ceramic after polishing and aging in a staining beverage. The tested hypotheses were: 1) Composite and ceramic with or without polishing will present similar color and translucency behavior; and 2) polishing will not affect the color stability and translucency of each tested material.

2 Materials and Methods

2.1 Study Design

Factors under evaluation in this in vitro study were: material (glass ceramic, or indirect composite), surface treatment (polished, or non-polished), and aging media (red wine, or distilled water). The commercial brands and material compositions used in this study are described in Table 1. The response variables were: color change (ΔE_{00}) and Contrast Ratio (CR).

Table 1 - Ceramic and indirect Composite materials used in this study.

Material (Shade)	Category	Manufacturer	Composition	Lot Number
IPS e.max Ceram (Dentin A2)	Vitreous nanofluorapatite veneering ceramic	Ivoclar Vivadent AG, Schaan – Liechtenstein	SiO_2. Additional content: Al_2O_3, ZnO_2, Na_2O, K_2O, ZrO, CaO, P_2O_5, fluorides and pigments	R48459
SR Adoro (Dentin A2)	Indirect light polymerizing microhybrid composite/ heat-polymerizing	Ivoclar Vivadent AG, Schaan – Liechtenstein	bis-GMA, TEGDMA, Copolymers of silicon, dioxide and barium crystal, catalyzers, stabilizers, and pigments	R8350

Source: Dados da pesquisa.

2.2 Specimens preparation

A metallic forming matrix for the fabrication of color scales (Porcelain Sampler - Smile Line/St. Imier; Switzerland) was used to build up the 72 specimens, 36 for each tested material. This device was calibrated to the desired dimensions (12 mm in diameter x 2 mm thick) providing all the specimens with the same size, disc-shaped and flat. For the composite (SR Adoro Dentin A2 - Ivoclar Vivadent; Schaan, Liechtenstein) specimen preparations, the restorative material was inserted and accommodated in the forming matrix with the aid of a titanium spatula #11 (Indusbello; Londrina, Brazil). The surface was pre-polymerized with a halogen light source (Quick Curing Light - Ivoclar Vivadent; Schaan, Liechtenstein) for 20 seconds, with an intensity of approximately 600mw/cm². A well-controlled light/heat curing and tempering process was done for further 25 minutes with halogen light, pressure and heat device at a temperature of up to 104ºC (Lumamat 100 Light Furnace - Ivoclar Vivadent; Schaan, Liechtenstein), in accordance with the manufacturer recommendations.

To build up specimens of the glass ceramic, ceramic powder (IPS e.max Ceram Dentin A2/TI 1 - Ivoclar Vivadent; Schaan, Liechtenstein) and modeling liquid (IPS e.max Ceram Build-Up Liquid - Ivoclar Vivadent; Schaan, Liechtenstein) were mixed, compacted, and inserted into the forming matrix with the aid of brushes and spatulas for ceramic. The excess moisture in the ceramic paste was removed with absorbent paper. Specimens were accommodated on the firing support over a refractory pad, and placed in a specific furnace for ceramics (Programat EP 3000 – Ivoclar Vivadent; Schaan, Liechtenstein) at a firing temperature of 750ºC. Specimens were subjected to one firing cycle and then glazed (IPS e.max Ceram Galze Paste - Ivoclar Vivadent; Schaan, Liechtenstein). All procedures followed manufacturer instructions.

After this, half of the specimens of each restorative material were polished on their top surface, performed by the same and previously trained operator. This procedure was carried out using disc-shaped tips with diamond particles for ceramic restoration polishing system (OptraFine® Ceramic Polishing System - Ivoclar Vivadent; Schaan, Liechtenstein). Each specimen was polished for 30 seconds at a low speed with gentle circular movements under constant cooling with water spray. After every 3 polished specimens, tips were changed and the specimen washed under running water for 30 seconds and then dried with gauze. Each ceramic and composite resin specimen were marked on their lateral side with a double-faced diamond disc (Hyperflex 911H - Komet Brasil; Santo André, SP, Brazil) at low speed, according to the lines of the target window of spectrophotometer. This procedure allowed successive color coordinate measurements to always be made on the same surface and position of the specimen. A digital caliper (Absolute Digimatic - Mitutoyo;

Tokyo, Japan) was used to measure the thickness in various points of the specimen, thus assuring uniform thickness of each sample being standardized at 2 mm. Specimens that varied more than 0.05 mm were discarded.

Specimens of each restorative material were randomly divided into 4 groups (n = 9) immediately after fabrication, according to the surface treatment (polished or non-polished) and aging media red wine (pH 3.51, 13.5% in volume of alcohol - Gato Negro; San Pedro, Chile – Lot number: M1H9L2117) or distilled water as control group (Laboratórios B. Braun S.A.; São Gonçalo, Brazil – Lot number: 13123321B1).

2.3 Aging procedures

Specimens aged in red wine were immersed in 3 ml of the beverage for 20 minutes daily during 30 days. After contact with red wine, specimens were washed in running water for 30 seconds, dried with gauze and kept in distilled water at 37ºC until the next immersion. Red wine was chosen as aging media because it has been used in previous studies.[8,17] As it is an acidic, alcoholic, and rich in staining agents medium, it could somewhat represent the association of degradation, erosion, and pigment sorption. Specimens aged in distilled water were kept in hermetically-sealed amber glass bottles, filled with 3ml of water and stored at 37ºC during the study time. The distilled water was renewed every 3 days for both distilled water groups.

2.4 Color change and opacity percentage evaluation

CIE $L^*a^*b^*$ measurements were performed at three time points: after specimen fabrication (baseline), after 7 days, and after 30 days of aging. CIE $L^*a^*b^*$ coordinates were measured with the spectrophotometer SP60 (X-Rite; Grand Rapid, MI, USA) in reflectance mode using illuminant D65, specular component excluded (SPEX), observer angle of 10º, and CIE L^* a^* b^* system (Comission International L´Eclairage). In this system, L* is the luminosity axis with values varying from zero (black) to one hundred (white), and a^* and b^* are the color coordinates on green-red axis and in blue-yellow axis, respectively. During the entire test, the spectrophotometer remained plugged in a voltage stabilizer to prevent variations in light intensity. Before the readings began, the appliance was calibrated according to the manufacturer recommendations using a white and black standard device that accompanied the equipment. Two backgrounds were used to carry out the readings: a white (L^* = 93.07, a^* = -1.28, b^* = 5.25) and black (L^* = 27.94, a^* = -0.01, b^* = 0.03) munsell-like neutral value scale sheet backgrounds (BYKO – CHART; Gardner – USA – Lot number: 3606204). A coupling substance [glycerin P.A. ACS (glycerol $C_3H_8O_3$ - VETEC Química Fina Ltda; Rio de Janeiro, RJ, Brazil – Lot number: 1201761)] with a refraction index of around 1.48 was used to minimize light dispersion between the specimen and the sheet background. This sequence was performed three times for each specimen and the median of the readings was used in the analysis.

Color change (ΔE_{00}) was calculated through the $L^*a^*b^*$ values measured of white background, using CIEDE2000 formula (Equation 1):

$$\Delta E_{00} = \left[\left(\frac{\Delta L'}{K_L S_L}\right)^2 + \left(\frac{\Delta C'}{K_C S_C}\right)^2 + \left(\frac{\Delta H'}{K_H S_H}\right)^2 + R_T\left(\frac{\Delta C'}{K_C S_C}\right)\left(\frac{\Delta H'}{K_H S_H}\right)\right]^{\frac{1}{2}} \quad (1)$$

Where ΔL, ΔC, and ΔH are the differences in lightness, chroma, and hue for a pair of samples, and R_T is a function (the so-called rotation function) that accounts for the interaction between chroma and hue differences in the blue region. Weighting functions, S_L, S_C, and S_H adjust the total color difference for varying the location of the color difference pair in L', a', b' coordinates, and the parametric factors k_L, k_C, and k_H are correction terms for deviation from reference experimental conditions. In the present study, these parametric factors of CIEDE2000 color difference formula were set to 1.

Values described by Paravina et al.[18] were considered as clinical thresholds which defined perceptibility and acceptability thresholds through ΔE_{00} as 0.8 and 1.8, respectively.

L^* coordinate values obtained over the white and the black backgrounds were used to calculate specimen translucency through the Contrast Ratio (CR) (Equations 2 and 3). Clinical thresholds described by Liu et al.[19] were considered, in which a CR difference (ΔCR) greater than 0.06 can be perceived.

$$RC = Y_b/Y_w \quad (2)$$

$$Y = [(L^* + 16)/116]^3 \ x\ 100 \quad (3)$$

Where Y_b is the reflectance over the black backgrounds, and Y_w is the reflectance over the white backgrounds. In all calculations, 0 is considered a transparent object and 1 is an opaque object.

2.5 Statistical Analysis

Data were analyzed with the statistical program Statistica version 7.0 (Statsoft South America, Brasília, Brazil). Data had normality (Shapiro-wilk test) and homoscedasticy (Levene test) tested. Results of color change (ΔE_{00}) were submitted to two-way analysis of variance (ANOVA), and contrast ratio (CR) were submitted to two-way repeated measures ANOVA. Both tests were carried out separately for groups immersed in water and red wine. The analyzed factors were surface treatment and material. All pairwise multiple comparison procedures were conducted using the Tukey Test. Significance level was set at 5%.

3 Results and Discussion

Means and standard deviation of ΔE_{00} values are described in Table 2. Factor material was not significant (P = 0.45), and neither was the surface treatment (P = 0.19) when specimens were submitted to distilled water. In addition, no group reached the clinical perceptibility threshold (ΔE_{00} > 0.8). There was no interaction between experimental group and time (P = 0.19) factors. On the other hand, when specimens had contact with red wine, the material factor was statistically significant (P

= 0.04), as well as the surface treatment factor (P = 0.01). Furthermore, significant interaction between the analyzed factors was observed (P = 0.009), which indicates that each material color change depends on each surface treatment being present. All groups showed clinically unacceptable color change (ΔE_{00} > 0.8), and the greater ΔE_{00} values were observed in polished composite specimens.

Table 2 - Means (standard deviation) of ΔE_{00} values of groups aged in distilled water and red wine.

Aging media	Material	Treatment	ΔE_{00*}
Water	Ceramic	Non-polished	0.24 (0.05)[a]
		Polished	0.53 (0.04)[a]
	Composite	Non-polished	0.47 (0.08)[a]
		Polished	0.47 (0.06)[a]
Red wine	Ceramic	Non-polished	2.33 (0.12)[b]
		Polished	2.39 (0.94)[b]
	Composite	Non-polished	2.12 (0.39)[b]
		Polished	4.07 (1.35)[a]

*Different letters in the same column indicate significant differences (P<0.05) among experimental groups aged in distilled water or red wine, respectively. Two-way ANOVA for both water and red wine, and Tukey test for the red wine groups.
Source: Research data.

Means and standard deviation of contrast ratio (CR) values are described in Table 3. Factor material (P < 0.001) showed statistically significance influence on translucency. However, no significant difference was observed between surface treatments (P = 0.09), nor in the analyzed factors interaction (P = 0.12). No group presented statistically significant difference between the two translucency measurements (baseline versus 30 days). Regarding red wine data analyses, the factors experimental material (P = 0.00) and surface treatment (P = 0.01) showed statistically significance differences, as well as the interaction between the two factors (P = 0.00). All groups had stable CR values in both measurements. At baseline, ceramic groups showed greater opacity than the composite groups. This behavior was maintained after contact with red wine, except that the polished composite had lower CR than the non-polished composite group. Clinically, no water or red wine group reached 0.06 difference between CR at baseline or after 30 days.

Table 3. Means (standard deviation) of contrast ratio (CR) values of all experimental conditions and the differences between the two measurements.

Aging Media	Material	Treatment	Baseline*	30 days*	ΔCR
Water	Ceramic	Non-polished	0.87 (0.03)[A,a]	0.88 (0.03)[A,a]	0.01
		Polished	0.91 (0.04)[A,a]	0.90 (0.03)[A,a]	0.01
	Composite	Non-polished	0.78 (0.03)[A,b]	0.82 (0.03)[A,b]	0.04
		Polished	0.78 (0.02)[A,b]	0.81 (0.03)[A,b]	0.03
Red wine	Ceramic	Non-polished	0.90 (0.05)[A,1]	0.89 (0.04)[A,1]	0.01
		Polished	0.89 (0.03)[A,1]	0.91 (0.02)[A,1]	0.02
	Composite	Non-polished	0.78 (0.02)[A,2]	0.80 (0.03)[A,2]	0.02
		Polished	0.72 (0.02)[A,2]	0.72 (0.05)[A,3]	0.00

*Different uppercase letters in the same row indicate significant differences (P<0.05) between times. Different lowercase letters and different numbers in the same column indicate significant differences (P<0.05) among experimental groups aged in distilled water or red wine, respectively. Two-way RM ANOVA for both water and red wine, and Tukey test for the red wine groups.
Source: Research data.

The results showed that only daily contact with red wine led the ceramic and the composite to clinically perceptible color change. The polished composite group reached ΔE_{00} values 92% greater than the non-polished group after 30 days aging in red wine, whereas ceramic groups and non-polished composite had similar color stability behavior. Ceramic presented greater opacity than composite in all study points. Therefore, the first hypothesis was rejected since significant color and translucency differences between ceramic and composite were observed. In addition, the second hypothesis was partially rejected since polishing only affected the color and translucency behavior of resin composite.

Previous studies also showed greater color alteration of glass ceramic[7] and indirect resin composite[9] after contact with staining beverages. Polishing did not affect color stability of the ceramic, indicating that this finishing method did not cause surface alteration capable of increasing pigment retention. These findings are different from those of Atay et al.[20] in which polished ceramic specimens reached greater ΔE_{ab} values than glazed groups after contact with staining beverages. On the other hand, polishing caused greater color change on the indirect composite groups compared to the non-polished group, indicating that this procedure may cause surface alteration on this material, which improves pigment retention. Vrochari et al.[6] evaluated roughness of two different glass ceramics and an indirect composite after surface treatments such as polishing. The authors observed better performance of the ceramics than the composite.

Despite being a polymer that is well known for suffering water sorption,[10] the indirect composite used in this study presented similar color stability to the ceramic when not polished. Arocha et al.[15] used the same indirect composite we used in this study (SR Adoro), among other materials. When immersed in red wine, ΔE_{00} reached 18.34 in one month. However, in aforementioned investigation the staining beverage contact was continuous, whereas the specimens in the present study were immersed in red wine 20 minutes a day, leading to lower values (ΔE_{00} = 2.12) and was similar to the ceramic color alteration. Color stability of direct and indirect resin composites and a glass ceramic after contact with staining agents was investigated in a previous study,[21] in which porcelain showed lower color alteration. However, the tested materials were different from those used in this study in commercial brand and composition, thereby leading the materials to different behavior. Indirect resin composites are generally regarded to have better color stability than direct composites due to the higher conversion degree.[22] Moreover, the dental industry is always developing new material compositions, so the improvement in dental material properties is expected.

In this paper, we opted to use the contrast ratio (CR) method, which has strong correlation to the translucency parameter method.[23] As expected, the results showed that the ceramic material had greater opacity than the composite, even though both presented the same shade. This fact may also be observed clinically, since the difference in CR values (ΔCR) of any ceramic and composite groups are equal to or greater than 0.06. It is documented in scientific literature that the translucency of restorative materials depends on absorption and scattering,[24,25] which is influenced by the matrix, filler particles, and its distribution. Despite having both ceramic and composite (an amorphous composition), their compounds are widely different. Thus, they present different light interaction, and consequently different optical properties such as translucency.

The translucency of the ceramic used in the present study was not affected by the polishing procedure. Otherwise, Akar et al.[13] observed that surface finishing methods increased roughness and decreased translucency of lithium disilicate specimens. It is well known that lithium disilicate ceramics have better mechanical properties than porcelains due to their greater amount of crystalline content.[12] However, specimens in the aforementioned study had 1.5 mm thickness, and the tested finishing methods involved more steps, which may have decreased thickness and roughness more than our method affected the porcelain we used. Thus, divergent results were noted. Awad et al.[26] evaluated the effect of thickness and roughness on several resin composites. They found that thickness was the greatest influencing factor on translucency. Analysis of groups aged in red wine showed more translucency on the polished composite group. Even though a single trained operator carried out the present study procedures, it is not as accurate as using an automatic device, which is a study limitation. The fact that the statistical analysis pointed out significant CR difference between composite groups only for those aged in red wine was probably caused by operator bias. Therefore, the groups polished for a longer time or under greater pressure may have had their thickness decreased, and consequently they became less opaque.

The staining protocol adopted in this study consisted of immersion in red wine for 20 min a day. This protocol is plausible since people can easily keep their restorations in contact with staining beverages for this amount of time in one day. Nevertheless, people usually brush their teeth at least once a day, and this factor was not included in this research, which means that clinically the ΔE_{00} values should be lower. Despite the limitations of an *in vitro* study, the results of present study indicate that indirect composite seems to have similar performance to a glass ceramic regarding color stability, as long as the clinician is cautious in polishing it. Moreover, considering the clinical literature available and the presented results, indirect composite material seems to be a safe alternative in cases where a more translucent material is needed.

4 Conclusion

Contact with staining agents lead the ceramic and the composite to unacceptable color change. Polishing does not affect the ceramic color stability, nor its opacity percentage. Moreover, indirect composite is more translucent and it is capable of presenting color stability similar to a ceramic, but polishing it seems to increase color change.

Acknowledgements

The authors would like to acknowledge the support of Ivoclar Vivadent for the donation of the materials for this work. Nevertheless, the authors do not have any financial interest in the companies whose materials are included in this article.

References

1. Shokry TE, Shen C, Elhosary MM, Elkhodary AM. Effect of core and veneer thicknesses on the color parameters of two all-ceramic systems. J Prosthet Dent. 2006;95(2):124-9. doi: 10.1016/j.prosdent.2005.12.001

2. Gresnigt MM, Kalk W, Ozcan M. Randomized clinical trial of indirect resin composite and ceramic veneers: up to 3-year follow-up. J Adhes Dent. 2013;15(2):181-90. doi: 10.3290/j.jad.a28883

3. Thordrup M, Isidor F, Hörsted-Bindslev P. A prospective clinical study of indirect and direct composite and ceramic inlays: ten-year results. Quintessence Int. 2006;37(2):139-44

4. Kaytan B, Onal B, Pamir T, Tezel H. Clinical evaluation of indirect resin composite and ceramic onlays over a 24-month period. Gen Dent. 2005;53(5):329-34.

5. Belli R, Geinzer E, Muschweck A, Petschelt A, Lohbauer U. Mechanical fatigue degradation of ceramics versus resin composites for dental restorations. Dent Mater. 2014;30(4):424-32. doi: 10.1016/j.dental.2014.01.003

6. Vrochari AD, Petropoulou A, Chronopoulos V, Polydorou O, Massey W, Hellwig E. Evaluation of surface roughness of ceramic and resin composite material used for conservative

indirect restorations, after repolishing by intraoral means. J Prosthodont. 2017;26(4):296-301. doi: 10.1111/jopr.12390

7. Gawriolek M, Sikorska E, Ferreira LFV, Costa AI, Khmelinskii I, Krawczyk A. Color and luminescence stability of selected dental materials in vitro. J Prosthodont. 2012;21(2):112-22. doi: 10.1111/j.1532-849X.2011.00808.x

8. Lago M, Mozzaquatro LR, Rodrigues C, Kaizer MR, Mallmann A, Jacques LB. Influence of bleaching agents on color and translucency of aged resin composites. J Esthet Restor Dent. 2017;29(5):368-377. doi: 10.1111/jerd.12261

9. Dos Santos DM, De Paula AM, Bonatto LR, Da Silva EV, Vechiato Filho AJ, Moreno A, et al. Influence of colorant solutions in properties of indirect resin composites. Am J Dent. 2015;28(4):219-23

10. Anusavice KJ. Phillips, Materiais Dentários. 11th ed, Rio de Janeiro: Elsevier, 2005; 764.

11. Ruyter IE, Nilner K, Möller B. Color stability of dental composite resin materials for crown and bridge veneers. Dent Mater. 1987;3(5):246-51.

12. Kelly JR. Dental Ceramics: What is this stuff anyway? J Am Dent Assoc. 2008;139 Suppl:4S-7S.

13. Akar GC, Pekkan G, Çal E, Eskitaşçıoğlu G, Özcan M. Effects of surface-finishing protocols on the roughness, color change, and translucency of different ceramic systems. J Prosthet Dent. 2014;112(2):314-21. doi: 10.1016/j.prosdent.2013.09.033

14. Motro PF1, Kursoglu P, Kazazoglu E. Effects of different surface treatments on stainability of ceramics. J Prosthet Dent. 2012; 108(4): 231-7. doi: 10.1016/S0022-3913(12)60168-1.

15. Arocha MA, Basilio J, Llopis J, Di Bella E, Roig M, Ardu S, Mayoral JR. Colour stainability of indirect CAD–CAM processed composites vs. conventionally laboratory processed composites after immersion in staining solutions. J Dent. 2014;42(7):831-8. doi: 10.1016/j.jdent.2014.04.002

16. Alawjali SS1, Lui JL. Effect of one-step polishing system on the color stability of nanocomposites. J Dent. 2013;41 Suppl 3:e53-61. doi: 10.1016/j.jdent.2012.10.008

17. Rodrigues CS, Nora BD, Mallmann A, May LG, Jacques LB. Repolishing Resin Composites After Bleaching Treatments: Effects on Color Stability and Smoothness. Oper Dent. 2019;44(1):54-64. doi: 10.2341/17-107-L.

18. Paravina RD, Ghinea R, Herrera LJ, Bona AD, Igiel C, Linninger M, et al. Color difference thresholds in dentistry. J Esthet Restor Dent. 2015;27(1 Suppl):S1-9. doi: 10.1111/jerd.12149

19. Liu MC, Aquilino SA, Lund PS, Vargas MA, Diaz-Arnold AM, Gratton DG, et al. Human perception of dental porcelain translucency correlated to spectrophotometric measurements. J Prosthodont. 2014;19(3):187-93. doi: 10.1111/j.1532-849X.2009.00542.x

20. Atay A, Karayazgan B, Ozkan Y, Akyil MS. Effect of colored beverages on the color stability of feldspathic porcelain subjected to various surface treatments. Quintessence International. 2009;40(7):e41-8.

21. Samra AP, Pereira SK, Delgado LC, Borges CP. Color stability evaluation of aesthetic restorative materials. Braz Oral Res. 2008;22(3):205-10.

22. Lee YK, Yu B, Lim HN, Lim JI. Difference in the color stability of direct and indirect resin composites. J Appl Oral Sci. 2011;19(2):154-60.

23. Della Bona A, Nogueira AD, Pecho OE. Optical properties of CAD-CAM ceramic systems. J Dent. 2014;42(9):1202-9. doi: 10.1016/j.jdent.2014.07.005

24. Shortall AC, Palin WM, Burtscher P. Refractive index mismatch and monomer reactivity influence composite curing depth. J Dent Res. 2008;87(1):84-8. doi: 10.1177/154405910808700115

25. Yu B, Ahn JS, Lim JI, Lee YK. Influence of TiO_2 nanoparticles on the optical properties of resin composites. Dent Mater. 2009;25(9):1142-7. doi: 10.1016/j.dental.2009.03.012

26. Awad D, Stawarczyk B, Liebermann A, Ilie N. Translucency of esthetic dental restorative CAD/CAM materials and composite resins with respect to thickness and surface roughness. J Prosthet Dent. 2015;113(6):534-40. doi: 10.1016/j.prosdent.2014.12.003