Original Article / Özgün Araştırma

Effects of Polishing on Color Stability and Surface Roughness of CAD-CAM Ceramics

Polisajın CAD-CAM Seramiklerin Renk Stabilitesi ve Yüzey Pürüzlülüğüne Etkileri

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Abstract

Objective: The purpose of this study is to determine the effects of polishing techniques on color stability and surface roughness of lithium disilicate glass ceramic (LDC) and zirconia-reinforced lithium silicate ceramic (ZLS).

Materials and Methods: Two hundred forty disks of LDC and ZLS were prepared. Glazing with the ceramics' own glazing procedure, a series of sof-lex polishing discs and abrasive stones were used as the different polishing groups. Color differences (ΔE*) was evaluated by spectrophotometer, initial and after 48 hours of immersion in various solutions (n=10). Surface roughness (Ra) was evaluated by profilometer (n=10). Data were analyzed by Two-Way ANOVA, and Mann-Whitney U test.

Results: No significant difference in ΔE* values was observed between the sof-lex groups and abrasive stone groups (p>0.05) on LDC. ΔE* values were significantly different with glazed, and abrasive stone groups than sof-lex groups (p<0.05) on ZLS. Within the staining solutions for LDC specimens decreasing ΔE* values were observed in coffee to coke, and then tea and water. However, within the staining solutions for ZLS specimens the highest ΔE* values were observed in coffee, and then equal ΔE* values in coke and tea and the lowest ΔE* values were observed in water. Within the CAD-CAM ceramic materials ΔE* values of ZLS specimens were higher than LDC specimens (p<0.05). Both of ZLS and LDC specimens, the lowest Ra values were observed in glazing groups, which were not statistically different from each other (p>0.05). The highest Ra value in ZLS was observed in group sof-lex. No significant difference was observed among group abrasive stone and sof-lex in LDC specimens (p>0.05).

Conclusion: The amount of staining in the polished ZLS samples was more than the LDC samples. The coffee was determined as the most colorant solution. Abrasive stone may be used instead of sof-lex for polishing of LDC specimens.

Keywords
Color stability, surface roughness, polishing, CAD-CAM ceramic

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Renk stabilitesi, yüzey pürüzlülüğü, polisaj, CAD-CAM seramikleri

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Öz

Amaç: Bu çalışmanın amacı, polisaj tekniklerinin lityum disilikat cam seramik (LDC) ve zirkonya ile güçlendirilmiş lityum silikat seramiklerin (ZLS) renk stabilitesi ve yüzey pürüzlülüğüne etkilerini belirlemektir.

Gereç ve Yöntemler: LDC ve ZLS'den 240 disk hazırlanmıştır. Farklı polisaj grupları olarak seramiklerin kendi glaze prosedürü, sof-lex polisaj diskleri ve aşındırıcı taşlar kullanılmıştır. Renk farklılıkları (ΔE*), 48 saat çeşitli solüsyonlarda bekletilme öncesinde ve sonra spektrofotometre ile değerlendirilmiştir (n=10). Yüzey

pürüzlülüğü (Ra) profilometre ile değerlendirilmiştir (n=10). Veriler çift-yönlü ANOVA ve Mann-Whitney U testi ile analiz edilmiştir.
Bulgular: LDC için sof-lex grupları ve aşındırıcı taş gruplarının ΔE* değerleri arasında anlamlı fark bulunmamıştır (p>0,05). ZLS için gleyz ve aşındırıcı taş gruplarının ΔE* değerleri sof-lex gruplarından anlamlı fark göstermiştir (p<0,05). Boyayıcı solüsyonlar arasında LDC örnekler için kahveden kola, çay ve suya doğru azalan ΔE* değerleri gözlenmiştir. Bununla birlikte boyayıcı solüsyonlar arasında ZLS örnekler için en yüksek ΔE* değerleri kahvede, ardından eşit ΔE* değerleri kola ve çayda ve en düşük ΔE* değerleri ise suda gözlenmiştir. CAD-CAM seramik materyalleri arasında ise ZLS örneklerin ΔE* değerleri LDC örneklerden daha fazladır (p<0,05). ZLS ve LDC örneklerin her ikisi için de en düşük Ra değerleri gleyz gruplarında gözlenmiş olup istatistiksel olarak birbirinden farklı değildir (p>0,05). ZLS için en yüksek Ra değeri sof-lex grubunda gözlenmiştir. LDC örnekler için aşındırıcı taş ve sof-lex grupları arasında önemli fark gözlenmemiştir (p>0,05).
Sonuç: Polisaj yapılmış ZLS örneklerdeki boyanma miktarı LDC örneklerden fazla bulunmuştur. Kahve en boyayıcı solüsyon olarak tespit edilmiştir. LDC örneklerin polisajında aşındırıcı taş, sof-lex yerine kullanılabilir.

Introduction

High-performance restorative materials are able to obtain with industrially produced CAD-CAM blocks. Besides excellent esthetic properties with good polishing characteristic and high refiring stability industrially produced and secondary milled materials are more homogeneity in comparison with hand-built materials. Today, industrially produced CAD-CAM materials are recognized as high reliable materials. IPS e.max CAD (Ivoclar, Vivadent, Liechtenstein) is the lithium disilicate glass ceramic (LDC) block which has been designed for CAD-CAM technique and is indicated veneers to twelve-unit bridges with its high strength. Also, high translucent blocks especially are used with ceramic inlay and onlay restorations exhibit a chameleon effect in oral environment. Vita suprinity (Vita Zahnfabrik, Germany) glass ceramic is the first zirconia-reinforced lithium silicate ceramic (ZLS) which is fortified with zirconia (approximately 10% by weight) to provide superior durability. Moreover ZLS was adopted glass ceramic properties aesthetically.

The surface texture of dental restorative material is very important because of longevity and aesthetics. When the surface texture is irregular, many negative effects occur of such as loss of esthetic qualities, wear of the occlusal surface of tooth on the opposite arch, decrease of strength of restoration material (1-5). Smooth surfaces do not mean perfect aesthetically but can be mean that more suitable biologically. Moreover, both of the wear of the tooth on the opposite arch can be minimum level and longevity of restoration can be prolonged (1,2,6,7).

Glaze surfaces may deformate during contour adjustments of the restoration's surfaces. Due to clinical adjustments of the ceramic restoration, some aesthetic problems may occur with patients' visual perception. Intraoral finishing and polishing sets can be used alternatively that have sufficient properties to obtain clinically acceptable surface roughness (6,7).

Furthermore, staining of the ceramic restorations with colorant inside the frequently consumed drinks requires extra efforts from the clinicians. Several studies are avaliable on the efficiency of various polishing techniques instead of glazing about color stability (2-4).

The aim of this *in vitro* study was to investigate the effects of staining solutions and different polishing techniques on color stability and surface roughness of CAD-CAM ceramics. The null hypotheses of the study were that various staining solutions and polishing techniques would be not correlated with the stainability and surface roughness of CAD-CAM ceramics.

Materials and Methods

LDC and ZLS materials used in the study are listed in Table 1. Specimens were obtained with cutting of the high translucent-CAD/CAM blocks with 1.2-mm-thick, and 14-mm-diameter specimens at low speed (150 rpm) in a precision saw machine (Micracut 201, Bursa, Turkey). A2-color were chosen for all of the specimens in accordance with the scale of Vitapan Classical shade guide (Vita Zahnfabrik, Germany).

Twelve groups consisting of 10 specimens were created for both LDC and ZLS (totally 240) as listed in Table 2. Distilled water served as the control group in groups I1a, I2a, I3a, S1a, S2a and S3a. The LDC and ZLS specimens were roughened on both sides with a fine diamond instrument (Dega Medical Instrument, Wanchai Hong Kong) for smoothing out the surface structure created by the CAD/CAM procedure before glazing. Staining and glazing were made with IPS e.max CAD Stains (Ivoclar, Vivadent, Liechtenstein), IPS e.max CAD Glaze Paste and Liquid

(Ivoclar, Vivadent, Liechtenstein) in one step to the manufacturer's recommendations in LDC groups I1a, I1b, I1c, I1d. ZLS specimens were made stains and glaze firing with Vita Akzent Plus effect stains (Vita Zahnfabrik, Germany) and Vita Akzent Plus powder materials (Vita Zahnfabrik, Germany) following the manufacturer's recommendations in S1a, S1b, S1c and S1d. The specimens in the I2a, I2b, I2c, I2d, S2a, S2b, S2c and S2d groups were polished with a series of 12.7-mm-diameter sof-lex polishing discs (3M Espe, MN, USA) on an hand piece set at a speed of 10.000 rpm for coarse and medium discs, and 30.000 rpm for fine and superfine discs, according to the manufacturers' instructions. The specimens were polished with a low-speed hand piece at 10.000 rpm with an abrasive stone (Dura Green Stones; Shofu Inc, Kyoto, Japan) and with coarse silicon carbide polisher (Ceramaster Coarse; Shofu Inc, Kyoto, Japan), and silicon carbide polisher (Ceramaster; Shofu Inc, Kyoto, Japan) in the groups I3a, I3b, I3c, I3d, S3a, S3b, S3c and S3d. Both sides of the specimens were polished with a low-speed rotating hand piece (Kavo Ewl 4990; KaVo Dental Gmbh, Germany). Allpolishing process were conducted by the same investigator.

All the specimens were ultrasonically cleaned in deionized water (Pro-Sonic 600; Sultan Healthcare, NJ, USA) for ten minutes and then dried with compressed air. Also thickness of the specimens were controlled with a digital caliper (Absolute Digimatic, Mitutoyo, Japan).

Mean surface roughness (Ra) of the specimens were analyzed by a tactile profilometer (Taylor Hobson Surtronic 25, Leicester, UK) initially and after polishing with a 0,25 mm cut-off value. The constant measuring speed of 0.5 mm/sec was used to determine an average roughness profile (Ra) in µm. The profilometer calibrated before measurements of each group (n=10). All surface roughness records were made at the sample center.. For each specimen, three measurements were made and the mean was obtained as the parameter Ra. When the Ra value falls, the surface becomes smoother.

Baseline color measurements were performed with a clinical spectrophotometer (Vita Easy Shade Advance, Vita Zahnfabrik, Germany) using CIE L*a*b* and recorded before exposure to the staining solution. All measurements were performed onto the white, black and neutral gray surfaces under

Table 1. Materials tested

Material	Code	Composition	Translucency/shade	Lot no.	Manufacturer
IPS e.max CAD	LDC	Lithium disilicate glass ceramic	HT/A2	S50172	Ivoclar Vivadent
Suprinity	ZLS	Zirconia reinforced lithium disilicate ceramic	HT/A2	45000	Vita Zahnfabrik

LDC: Lithium disilicate glass ceramic, ZLS: Zirconia-reinforced lithium silicate ceramic

Table 2. Materials, surface finishing and groups

Materials	Surface finishing and groups			
LDC IPS e-max CAD (I)	Glaze+water I1a	Glaze+coke I1b	Glaze+tea I1c	Glaze+coffee I1d
	Sof-lex+water I2a	Sof-lex+coke I2b	Sof-lex+tea I2c	Sof-lex+coffee I2d
	Abrasive stone+water I3a	Abrasive stone+coke I3b	Abrasive stone+tea I3c	Abrasive stone+coffee I3d
ZLS Suprinity (S)	Glaze+water S1a	Glaze+coke S1b	Glaze+tea S1c	Glaze+coffee S1d
	Sof-lex+water S2a	Sof-lex+coke S2b	Sof-lex+tea S2c	Sof-lex+coffee S2d
	Abrasive stone+water S3a	Abrasive stone+coke S3b	Abrasive stone+tea S3c	Abrasive stone+coffee S3d

LDC: Lithium disilicate glass ceramic, ZLS: Zirconia-reinforced lithium silicate ceramic standard illuminant D65. Measurements were repeated 3 times for each specimen and the mean values of the L*, a*, and b* data were calculated. According to the CIE L*a*b* color differences (ΔE*) formula, L* demonstrates lightness, a* demonstrates the chromaticity coordinate for red-green, and b* demonstrates the chromaticity coordinate for yellow-blue (6).

After baseline color measurements were made the specimens were stored in various solutions. The tea solution 2g-tea bag (Lipton, Unilever, Turkey) with adding into 200 mL boiling water was prepared. And the coffee solution was prepared with 3.6g-coffee (Nescafe Classic; Nestle, Bursa, Turkey) was dissolved in 300 mL of boiling distilled water. After 10 min of stirring, the solution was filtered through a filter paper. Among coffee drinkers, the average consumption of coffee is 3.2 cups per day. When the average time for consumption of one cup of a drink is thinking is 15 min, the 48 hours storage time simulated consumption over a two-month period (2,7). The solution was stirred every 8±1 hours. Distilled water served as control group. Cola solution was represented by a can of 330-mL coke (The Coca-Cola Company, Turkey). All specimens were stored at 37 °C for 48 hours in 100 mililiters of solution. After the storage time the specimens were rinsed with distilled water for 5 min, and dried.

At this point, color measurements were performed with spectrophotometer in the same manner described for baseline readings. The calculation of the color differences ΔE* between the two color measurements (after 48-hour storage and baseline) were made using the following formula.

$$\Delta E^*=[(\Lambda_1^*-\Lambda_2^*)^2+(\alpha_1^*-\alpha_2^*)^2+(\beta_1^*-\beta_2^*)^2]^{½}$$

In this study, average color acceptability threshold of ceramics were accepted as ΔE*=2.7 (8).

Statistical Analysis

A statistical analysis was performed with SPSS 20.0 System (SPSS Inc., Chicago IL, USA) for Windows. ΔE* data were analyzed by Two-Way ANOVA, and Mann-Whitney U test. Ra data were analyzed by Two-Way ANOVA. The relationship between the polishing techniques and color stability was evaluated with the Pearson rank correlation test. The level of significance was set at 5% ($p<0.05$).

Results

The Two-Way ANOVA test results and the means and standard deviations of ΔE* values are shown in Table 3. No significant difference in ΔE* values was observed between the groups I1a, I2a, I3a, S1A, S2a and S3a, which distilled water served as control group ($p>0.05$). Also no significant difference in ΔE* values was observed between the sof-lex groups (I2a, I2b, I2c, I2d) and abrasive stone groups (I3a, I3b, I3c, I3d) ($p>0.05$) on LDC. But these two polishing groups were significantly different with glazed groups (I1a, I1b, I1C, I1d) ($p<0.05$) on LDC. ΔE* values were significantly different with glazed (S1a, S1b, S1C, S1d), and shofu

Table 3. Mean and standard deviation of ΔE* values and differences between groups

		Distilled water	Coke	Tea	Coffee
LDC IPS e-max CAD (I)	Glaze (n=10)	0.027±0.004 A,x,p	0.65±0.16 B,x,p	1.01±0.07 C,x,p	1.60±0.15 D,x,p
	Sof-lex (n=10)	0.035±0.006 A,x,p	1.27±0.14 B,x,q	1.43±0.20 C,x,q	2.48±0.29 D,x,q
	Abrasive stone (n=10)	0.030±0.006 A,x,p	1.19±0.16 B,x,q	1.35±0.12 C,x,q	2.28±0.27 D,x,q
ZLS Suprinity (S)	Glaze (n=10)	0.030±0.008 A,x,p	1.19±0.11 B,y,p	1.16±0.12 B,y,p	1.98±0.22 C,y,p
	Sof-lex (n=10)	0.035±0.004 A,x,p	1.61±0.22 B,y,q	1.73±0.21 B,y,q	2.96±0.28 C,y,q
	Abrasive stone (n=10)	0.030±0.007 A,x,p	1.45±0.28 B,y,p,q	1.57±0.25 B,y,p,q	2.63±0.26 C,y,p,q

Different latters indicate statistically significant difference between groups ($p<0.05$), *A,B,C,D intra-group comparisons, **x,y between-group comparisons column, ***p,q,z column-group comparisons, LDC: Lithium disilicate glass ceramic, ZLS: Zirconia-reinforced lithium silicate ceramic

Table 4. Mean and standard deviation of Ra values and differences between groups

	Glazing	Abrasive stone	Sof-lex
LDC	0.39±0.09 A,x	0.81±0.21 B,y	0.79±0.14 B,y
ZLS	0.30±0.14 A,y	0.85±0.25 C,y	1.07±0.32 B,x

Different laters indicate statistically significant difference between groups ($p<0.05$), *A,B,C intra-group comparisons, **x,y between-group comparisons column, LDC: Lithium disilicate glass ceramic, ZLS: Zirconia-reinforced lithium silicate ceramic

groups (S3a, S3b, S3c, S3d) than sof-lex groups (S2a, S2b, S2c, S2d) ($p<0.05$) on ZLS.

Within the staining solutions, decreasing ΔE* values were observed in coffee to coke, and then tea and water for LDC specimens. However within the staining solutions for ZLS specimens the highest ΔE* values were observed in coffee, and then equal ΔE* values in coke and tea and the lowest ΔE* values were observed in water. Also, ΔE* values of ZLS specimens were higher than ΔE* values of LDC materials ($p<0.05$).

The Two-Way ANOVA test results and the means and standard deviations of Ra values are shown in Table 4. Comparing the Ra values of ZLS and LDC ceramics at baseline, no statistically significant differences were found among all groups ($p>0.05$). Both of LDC and ZLS specimens, the lowest Ra values were observed in glazing groups, which were not statistically from each other ($p>0.05$). The highest Ra value in ZLS was observed in group abrasive stone (1.07±0.32). No significant difference was observed among group abrasive stone (0.81±0.21) and sof-lex (0.79±0.14) in LDC specimens ($p>0.05$). For ZLS specimens the group abrasive stone (0.85±0.25) differed significantly from the group sof-lex (1.07±0.32) ($p<0.05$).

The result of Pearson correlation analysis, the coefficient of correlation between Ra and ΔE values was found to be statistically significant ($p<0.01$, $r^2=0.74$), indicating that these two variables were correlated, in a portion of 74%, with each other. For both ceramic types, smoother surfaces showed more color stability than rough surfaces.

Discussion

According to the results of the study, the null hypotheses that staining solutions and polishing techniques are not correlated with the stainability and surface roughness of CAD-CAM ceramics were rejected.

Extra laboratory procedures have to be applied for additional firings thus these procedures are time-consuming. And additional firings can cause color changes and porcelain devitrification. For these reasons, mechanical finishing methods have been recommended instead of reglazing (5,9-11). Clinicians can obtain good aesthetic and acceptable surface smoothness if mechanical finishing methods are applied in the direction of the manufacturer's proposal (12,13). In the investigations it has been detected that silicon carbide points obtain better surface roughness than polishing paste and disks (2,14).

Many studies have reported that several chairside polishing systems recommended for ceramic restorations have created smooth surfaces as glazing (1,5,13). However, type of surface treatment was a significant factor in color stability (3,4,9). Because the different ceramic materials, and polishing systems are now available, which polishing system yields the smoothest surface on a prefered ceramic material should have been determined.

In the present study, it was concluded that polishing with abrasive stone created smooth surfaces as well as glazing on zirconia-reinforced lithium disilicate ceramic.

Some of the *in vitro* studies have shown that surface of ceramic restoration which applies glazing ensures adequate surface smoothness (1,5,9), and however there are studies which have demonstrated mechanical surface finishing methods such as rubber abrasives and rotary instruments shown acceptable surface smoothness (1,5,13).

Johnston and Kao (15) reported average color acceptability threshold of ceramics is ΔE*=3.7. A large number of ΔE* value is considered to be the reference value which varies ΔE*=2 to 4 in the different studies based on dental ceramics (3,8,16,17). O'Brien (16), limited ΔE* values between 0 and more than 3.5 (ΔE*=0, perfect; ΔE*=0.5 to 1, is accepted excellent; ΔE*=1 to 2, is accepted good; ΔE*=2 to 3.5, is accepted clinically acceptable; and ΔE*>3.5, is accepted inconsistent). Also, color perception is related to multiple factors such as illuminant conditions, difference in perception of color, selected material's properties, and measurement differences of color matching (17).

Clinical evaluation degrees of color differences have classified by some of the authors. Goldstein and Schmitt (18) proposed that experienced clinicians or technicans can detect when ΔE* values more than 0.4. On the other hand, another study states that color differences of dental restoration can be acceptable when ΔE* value was less than 2.6 (19).

In this study, average threshould value of color difference was accepted ΔE*=2.7 like previous studies (8). Also, there is a contentious about the accepted ΔE* limit as a threshould until the present day. In the study, only ΔE* values of the ZLS specimens' polished with sof-lex and stored in coffee were over the accepted threshold of 2.7 (Group S2d, ΔE*=2.96).

In a previous study (20), evaluated the effects of tea, coffee, and cola on the color of composite resins and porcelain, it was reported that staining of porcelain was not noticeable (ΔE*=1.2 to 1.4). In another study (21), glazed ceramic material's staining after immersion in coffee was found less than composite resin.

Coffee was used as a staining solution that followed by tea, and coke in the most color studies (3,4,7,8). In our study, within the staining solutions the highest ΔE* values were observed in coffee for LDC and ZLS specimens.

Some of the authors have used tea, coffee and coke to evaluate discoloration of dental restorative materials (2,3,20,21). In this study, four different staining solutions were used to evaluate color changes (3,7).

In the present study, LDC has shown lower ΔE* values than ZLS in all staining solution groups. The fact remains that coffee solution groups have shown higher ΔE* values than tea and coke (22).

As the color stability became better the surface roughness is decreased. In the present study, no significant difference was observed with Ra parameter among group abrasive stone and sof-lex in LDC specimens. It was also determined that correlated with the results of ΔE* values of abrasive stone and sof-lex groups of LDC specimens. Also ΔE* and Ra values of abrasive stone and sof-lex groups of LDC were determined that correlated with each other.

Most of the investigators have studied to get better surface smoothness and so they have investigated a lot of various finishing methods on ceramic surfaces. But there is no consensus about how to get greater surface via finishing method among investigators (23).

Usually, some of the factors such as grain size, crystalline mold, pigment types, size of crystalline and distribution of porosity can affect the translucency of dental ceramics. The most studied chemical structure among dental ceramics is LDC.

ZLS ceramics are produced with three different translucency. Also it was thought that color of oral tissues may absorb by high translucent ZLS blocks with chameleon effect. But presinterised zirconia-reinforced glass ceramic ZLS contain lithium metasilicate (Li_2SiO_3) crystals. Contraction of the material during the transformation of lithium metasilicate (Li_2SiO_3) crystals to lithium disilicate crystals may be responsible of the lower color stability of ZLS ceramics than lithium disilicate ceramics.

Although there are many materials that can be tested, IPS e.max CAD and Vita Suprinity have been choosen because clinicians preferred. On the other hand, little knowledge can be found about IPS e.max CAD and there was no information about Vita Suprinity.

In the present there is little knowledge about the efficiency of polishing materials and polishing techniques of CAD/CAM ceramics. Also further investigations should necessary to evaluate the color stability and surface roughness of different types of CAD/CAM ceramics.

Study Limitations

The main limitation of the present study is that the study is carried out *in vitro*. Another limitation is that only three of various chairside polishing techniques were applied. Although the coffee was found to be the most colorant drink in previous studies (3,4,7,8), only four different solutions were used in the present study. In addition, Atomic Force Microscopy or Scanning Electron Microscopy analyzes of samples may be performed to support surface roughness measurements with profilometer.

Conclusion

1. Within the CAD-CAM ceramic materials ΔE* values of ZLS were higher than LDC materials.

2. The coffee was determined as the most colorant solution.

3. Polishing with abrasive stone and sof-lex creates a similar polished surface on the surface of LDC material.

Ethics

Ethics Committee Approval: Human subjects, human material, or human data, have not been used in this research article. So, the Declaration of Helsinki, and an ethics committee consent have not been referring provided.

Informed Consent: Human subjects, human material, or human data, have not been used in this research article. So, any informed constent have not been referring provided.

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Authorship Contributions

Surgical and Medical Practices: I.S., Concept: I.S., Y.H., Design: I.S., Y.H., Data Collection or Processing: I.S., Analysis or Interpretation: I.S., Y.H., Literature Search: Y.H., I.S., Writing: I.S.

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References

1. Goldstein GR, Barnhard BR, Penugonda B. Profilometer, SEM, and visual assessment of porcelain polishing methods. J Prosthet Dent 1991; 65: 627-34.
2. Sarikaya I, Guler AU. Effects of different surface treatments on the color stability of various dental porcelains. J Dent Sci 2011; 6: 65-71.
3. 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 Int 2009; 40: e41-8.
4. Kursoglu P, Karagoz Motro PF, Kazazoglu E. Correlation of surface texture with the stainability of ceramics. J Prosthet Dent 2014; 112: 306-13.
5. Raimondo RL Jr, Richardson JT, Wiedner B. Polished versus autoglazed dental porcelain. J Prosthet Dent 1990; 64: 553-7.
6. Commission Internationale de l'Eclairage (CIE). CIE technical report: colorimetry. [CIE Pub No.15.3]. 2004.
7. Guler AU, Kurt S, Kulunk T. Effects of various finishing procedures on the staining of provisional restorative materials. J Prosthet Dent 2005; 93: 453-8.
8. 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) doi: 10.1111/jerd.12149. Epub 2015 Apr 17.
9. Ragain JC Jr, Johnston WMMinimum color differences for discriminating mismatch between composite and tooth color.9. Patterson CJ, McLundie AC, Stirrups DR, Taylor WG. Efficacy of a porcelain refinishing system in restoring surface finish after grinding with fine and extra-fine diamond burs. J Prosthet Dent 1992; 68: 402-6.
10. Fuzzi M, Zaccheroni Z, Vallania G. Scanning electron microscopy and profilometer evaluation of glazed and polished dental porcelain. Int J Prosthodont 1996; 9: 452-8.
11. Jefferies SR. Abrasive finishing and polishing in restorative dentistry: a state-of-the-art review. Dent Clin North Am 2007; 51: 379-97.
12. Klausner LH, Cartwright CB, Charbeneau GT. Polished versus autoglazed porcelain surfaces. J Prosthet Dent 1982; 47: 157-62.
13. al-Wahadni A, Martin DM. Glazing and finishing dental porcelain: a literature review. J Can Dent Assoc 1998; 64: 580-3.
14. Sarac D, Sarac YS, Yuzbasioglu E, Bal S. The effects of porcelain polishing systems on the color and surface texture of feldspathic porcelain. J Prosthet Dent 2006; 96: 122-8.
15. Johnston WM, Kao EC. Assessment of appearance match by visual observation and clinical colorimetry. J Dent Res 1989; 68: 819-22.
16. O'Brien WJ. Dental Materials and Their Selection. 3rd ed. Chicago: Quintessence; 2008; 24-36.
17. Ishikawa-Nagai S, Yoshida A, Sakai M, Kristiansen J, Da Silva JD. Clinical evaluation of perceptibility of color differences between natural teeth and all-ceramic crowns. J Dent 2009; 37 (Suppl 1): e57-63.
18. Goldstein GR, Schmitt GW. Repeatability of a specially designed intraoral colorimeter. J Prosthet Dent 1993; 69: 616-9.
19. Douglas RD, Steinhauer TJ, Wee AG. Intraoral determination of the tolerance of dentists for perceptibility and acceptability of shade mismatch. J Prosthet Dent 2007; 97: 200-8.
20. Gupta R, Parkash H, Shah N, Jain V. A spectrophotometric evaluation of color changes of various tooth colored veneering materials after exposure to commonly consumed beverages. J Indian Prosthodont Soc 2005; 5: 72-8.
21. Samra AP, Pereira SK, Delgado LC, Borges CP. Color stability evaluation of aesthetic restorative materials. Braz Oral Res 2008; 22: 205-10.
22. Acar O, Yilmaz B, Altintas SH, Chandrasekaran I, Johnston WM. Color stainability of CAD/CAM and nanocomposite resin materials. J Prosthet Dent 2016; 115: 71-5.
23. Al Ben Ali A, Kang K, Finkelman MD, Zandparsa R, Hirayama H. The effect of variations in translucency and background on color differences in CAD/CAM lithium disilicate glass ceramics. J Prosthodont 2014; 23: 213-20.