Original Article

Evaluation of the Color Stability of Three Resin-Ceramic Materials Using a Spectrophotometer and a Digital Photography Software

Abstract

Background: Computer-aided design/computer-aided manufacturing (CAD/CAM) resin ceramics allow easier milling than glass ceramics but are suspected to be more stainable. Although Photoshop® is widely used for picture analysis, its potential for shade selection has not been properly assessed. **Aim:** Purpose primary: To evaluate the color stability of three CAD/CAM resin ceramics and Lithium Disilicate. Secondary: to compare the color evaluation between a spectrophotometer (Vita Easyshade compact) and Photoshop software. **Materials and Methods:** Three CAD/CAM resin ceramic materials ($n = 10$) and a fourth group of lithium disilicate were used. Half of each group were thermocycled (5°C and 55°C; 3000 cycles). All samples were immersed in colored beverages (coffee, tea and red wine) for 30 days. Values were obtained by spectrophotometry and photographs analyzed using Photoshop software. The parameters measured were CIEL*a*b, and the color difference (ΔE) was analyzed. A mixed model test was used to compare the results through time and materials ($\alpha = 0.05$). The comparison between the spectrophotometer and Photoshop results was performed using the bivariate Pearson's correlation test. **Results:** Lithium disilicate glass ceramic exhibited less color change ($\Delta E = 14$) than resin ceramics ($15.7 < \Delta E < 18.7$). The least change was noted with GC Cerasmart ($\Delta E = 15.7$) followed by Vita Enamic ($\Delta E = 17^*$) and Brilliant Crios ($\Delta E = 18.7^*$). Spectrophotometer and Photoshop values showed low correlations. **Conclusions:** Resin ceramics may suffer from color change in clinical use. Photoshop is technique sensitive; pictures are easily affected by the light conditions and camera settings.

Keywords: *Lithium disilicate, photoshop, resin ceramic, spectrophotometer, stainability*

Nicolas Naffah,
Hani Ounsi[1,2],
Mutlu Ozcan[3],
Ziad Salameh

Departments of Prosthodontics and [1]Endodontics, Faculty of Dental Medicine, Lebanese University, Beirut, Lebanon, [2]Faculty of Dental Medicine, Siena University, Siena, Italy, [3]University of Zurich, Division of Dental Biomaterials, Clinic of Reconstructive Dentistry, Center of Dental Medicine, Zurich, Switzerland

Introduction

Computer-aided design/computer-aided manufacturing (CAD/CAM) technology has made giant steps in dentistry.[1,2] Precision and aesthetic outcome are now digitally guided to facilitate impression, design and manufacturing[3] allowing single-visit treatments. The introduction of monolithic CAD/CAM blocks/discs has allowed more predictable shade matching since final shade outcome is no longer related to lab technician skills or to the various other factors that influence the final color of traditional dental porcelain restorations.[4]

Combining translucency and excellent physical properties, lithium disilicate glass ceramic (LDGC) is considered to be the reference for prosthetic rehabilitation using monolithic restorative materials.[5,6] However, in its metasilicate state, this material consists of 40% of crystals and it is time (and bur) consuming during milling.[7] Furthermore, crystallization and glazing of LDGC in a ceramic oven for 20–25 min is mandatory to achieve full strength and proper shade, thus limiting its advantage for chairside single appointment procedures.[8] LDGC hardness can also result in wear of opposing teeth,[9,10] and in case of chipping, the mechanical results following repair are questionable.[11-13]

Several materials with improved physical characteristics have been developed. A composite resin block (Paradigm MZ100, 3M ESPE, St. Paul, MN, USA) was the first marketed CAD-CAM block product containing 85% zirconia-silica fillers by weight in a BIS-GMA and TEG-DMA polymer matrix.[7] Later, a polymer-infiltrated ceramic-network (PICN) (Enamic, Vita ZahnFabrik, BAD Säckingen, Germany) was introduced, followed by resin-based materials charged with dispersed ceramic nanoparticles that were termed

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How to cite this article: Naffah N, Ounsi H, Ozcan M, Salameh Z. Evaluation of the color stability of three resin-ceramic materials using a spectrophotometer and a digital photography software. Contemp Clin Dent 2024;15:44-50.

Submitted : 27-Aug-2018
Revised : 15-Nov-2018
Accepted : 26-Nov-2018
Published : 23-Mar-2024

Address for correspondence:
Dr. Nicolas Naffah,
Lebanese University, School of Dental Medicine, Hadath, Lebanon.
E-mail: drnicolas@live.com

Access this article online
Website:
https://journals.lww.com/cocd
DOI: 10.4103/ccd.ccd_656_18
Quick Response Code:

resin nanoceramics (RNC) (Lava Ultimate, 3M ESPE; Cerasmart, GC; and Brilliant Crios, Coltène). Since resin ceramic materials are highly charged with ceramic particles (70%–85% by weight), hydrofluoric acid etching and silane coupling is possible.[14-16] In addition, due to their organic network and nano-sized charge, resin ceramics cause lower shock transmission and less wear to opposing teeth,[17,18] favoring their use in implant-supported restorations.[19] In a recent investigation, Awada and Nathanson[17] demonstrated that milling resin ceramics yields a smoother surface and better margin integrity than glass ceramics. Argyrou *et al*. additionally illustrated that resin ceramics are subject to less frequent edge chipping,[20] and Doghan showed that resin ceramics were more resistant to fracture than feldspathic ceramic.[21]

The aesthetic requirements of dental materials used for restorations include color stability. Previous research has demonstrated greater color changes following chromogenic food and beverage intake in resin-based restorations than in glazed ceramics.[22-24] PICN and RNC materials are mechanically polished and/or use a photopolymerized glaze, and as such do not have the surface strength of glazed ceramics to resist wear and color stain.[25,26]

Clinically, shade selection for dental restorations is traditionally performed using shade guides. Digital spectrophotometers have recently been advocated in light of increasing research demonstrating the superior accuracy of digital shade selection over the classic shade guide.[3,27-30] Additionally, recent research efforts have geared towards assessing the applicability of utilizing digital cameras in conjunction with proprietary digital imaging software for color measurement due to their widespread use by practitioners to communicate with colleagues and lab technicians.[31-33] Although promising, research on this method is still in its infancy and requires validation through extensive research.

The primary aim of this study was to evaluate the color changes of two CAD/CAM RNC and one CAD/CAM PICN by immersion in colored beverages using a spectrophotometer (Vita Easyshade® compact) and a digital photography software (Photoshop). A secondary aim was to compare the accuracy of the assessment of color change between the two methods of color change assessment. The null hypotheses were that:[1] there would be no differences between groups in artificial staining when they are immersed in the same colored beverage, and[2] that there are no differences between the accuracy of the assessment of color change using Photoshop® and Vita Easyshade® for the stained materials.

Color evaluation is usually done using "L*a*b" numerical parameters issued by the Commission Internationale de l'Éclairage;[34-37] (L) represents lightness and varies between 0 and 100, (a) a value of green and red balance in 256 steps and varies between (–128) and (+127), and (b) a value of blue and yellow having the same range as (a). For color change measurement, (ΔE) expresses the color shift of these 3 parameters according to the following formula: $\Delta E = (\Delta L^2 + \Delta a^2 + \Delta b^2)^{½}$. Some authors like Acar *et al.*[38] and Ghinea *et al.*[39] prefer the CIEDE 2000 formula for subtle color changes (Commission internationale de l'Eclairage delta E formula corrected in year 2000), this formula deals with color difference through corrected parameters (L = Lightness, C = Chroma and H = Hue).

Materials and Methods

Preparation of specimens

Four different materials were selected and divided into 4 groups of 10 each [Table 1]. The resin ceramic blocks were cut 3 mm above the metal holder to prevent any translucency showing the metal holder. Specimens were arranged in rows and labeled according to the material [Figure 1]. They were then polished using 600–1000 wet silicon carbide abrasive papers (Imperial Wetordry, 3M, Saint Paul, USA).

LDGC blocks were separated from their metal holders and crystallized in a ceramic furnace (Programat P310, Ivoclar, Vivadent, Schaan, Liechtenstein) following the manufacturer's recommendation, then partially embedded in self-cured resin (Novacryl, Tricodent LTD, Victoria Rd, Burgess Hill, England) for labeling and staining [Figure 1]. The surface was polished with 600–1000 wet silicon carbide abrasive papers to make the stainability condition similar to that of resin ceramic since the glazed LDGC surface is smoother[40] and thus harder to stain.[24] The polished LDGC blocks were then arranged in two rows for labeling and color recording.

Table 1: Computer aided design/computer-aided manufacturing materials used

Group	Blocks used	Manufacturer	Composition		Lot number
1	Cerasmart	GC, Japan	Resin nanoceramic	Composite resin material (Bis UDMA, DMA) 71 weight % silica and barium glass	1504271
2	Enamic	Vita, Germany	PICN	Feldspar ceramic 86 weight % Methacrylate polymer 14 weight %	37380
3	Brilliant Crios	Coltene, Switzerland	Resin nanoceramic	Crosslinked metacrylates 29.3 weight % Amorphous silica 70.7 weight %	G99755
4	E.max	Ivoclarvivadent Liechtenstein	LDGC	70 volume % lithium disilicate and glass ceramic	U50480

PICN: Polymer-infiltrated ceramic-network; LDGC: Lithium disilicate glass ceramic; DMA: Dimethacrylate; UDMA: Urethane dimethacrylate

Following initial baseline color recording, half of the samples from each group (*n* = 5) were thermocycled (aged) for 3000 cycles between 5°C and 55°C (computer-controlled custom-made thermocycler) with an immersion time of 30 s in each water bath and a transfer time of 10 s.

Staining procedures

All samples were subjected to artificial staining after the initial color assessment by immersion in an incubator at 37°C for 30 days. The incubator contained 3 separate reservoirs of 500 ml each, the first containing 500 ml red wine (Clos St-Thomas, Ksara, Lebanon), the second containing coffee (3 tablespoons of Nescafé Red MUG in 500 ml water) and the third containing tea (Lipton tea classic, 3 predosed bags in 500 ml water). The samples were immersed for a period of 8 h in each container and were rinsed for 15 s with abundant running water before being transferred into the next container. The solutions were renewed each day, and all specimens were brushed daily under running water using a soft toothbrush.

Figure 1: The blocks are arranged in rows for labeling and color record

Color recording

All samples were color scanned to measure the (L* a*b) values. As issued by the Commission Internationale de l'Éclairage.[34-37]

For each specimen, color was evaluated using both spectrophotometry and digital photography at baseline (prestaining and postaging if applicable) and at days 1, 2, 7, 14, and 30. For digital color assessment, all samples were subjected to color recording:

Color recording 1: All samples were color scanned prior to staining using a spectrophotometer (Vita Easyshade Compact, Vita ZahnFabrik, BAD Säckingen, Germany) to measure (L*a*b) values.

Color recording 2: All samples were also photographed. The mounted set up for still photography included 4 daylight 5W LED spots (Go Ocean, China, 5500°K) in a 40 cm × 40 cm light chamber to obtain an even illumination.[41] The light source was set at 45°angle to prevent reflection to the camera lens [Figure 2]. A digital single lens reflex camera (Nikon D3200, Nikon Corp, Japan and a macro lens, Model A001NII, Tamron AF 70–200 mm f/2.8 Di LD IF, TAMRON, Japan) was mounted on a tripod and set on manual mode (200 ASA, F/32, white balance set at "fluorescent"). The intensity of light was measured using a light-meter (L358, Sekonic, Tokyo, Japan) and with the given distance (25 cm); the light-meter indicated (EV = 10.8) and 1/5 s for shutter speed. The pictures were saved in JPEG uncompressed format (4608 × 3072 pixels), and transferred to a photography software (Photoshop CS6, ADOBE systems incorporated, USA), (L*a*b) parameters were measured with a selected spot of 3 × 3 pixels.

Statistical analysis

Normality of data distribution was confirmed using the Kolmogorov–Smirnov test.

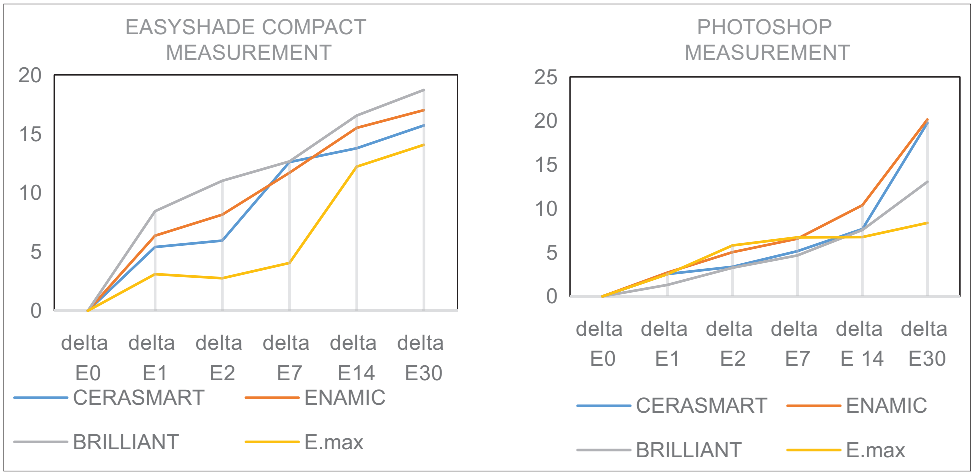

Figure 2: ∆E change of the four groups through time (0 to 30 days) measured by Vita Easyshade compact and Photoshop

A mixed model analysis of variance was used to assess the effects of material, time and aging (thermocycling). Since color change was measured at five-step intervals for groups and aging process, there were between-groups and within-groups effects which have to be analyzed.

Pearson's product-moment correlations were used to compare Photoshop measurements with Easyshade values. The IBM® SPSS® statistics version 18.0 statistical package was used to carry out all statistical analyses. Statistical significance was set at 0.05.

Results

All ΔE values were high ($14 < \Delta E < 20$) after 30 days of immersion in the three consecutive colored beverages and brushing with water only [Table 2 and Figure 2].

Based on Spectrophotometer assessment, Group 4 showed the least color change at day one with significant differences compared to Groups 2 and 3 ($P < 0.05$). Group 3 (Brilliant) was the most affected. At day 2, a significant difference was noticed between Group 4 and the other three groups ($P < 0.01$) with less important differences between Group 1 and 2 ($P > 0.01$). At day 7, Group 4 showed significant differences when compared with the three others ($P < 0.01$), whereas the three other groups displayed similar values to each other. At day 14, Group 4 showed significant differences when compared with Groups 2 and 3 ($P < 0.01$) whereas the difference with Group 1 was not significant. At day 30, among the four materials, Group 4 showed the least color change and showed significant difference with Groups 2 and 3 ($P < 0.01$) while the color shift with Group 1 was not significant.

There was a statistically significant difference across the 5 time points ($P < 0.001$), and significant differences between types of material ($P < 0.01$). The interaction effect between time and type of material was also significant ($P < 0.01$). The interaction between thermocycling and time or type did not show any significant difference (time * aging: $P = 0.353$) and (time * type*aging: $P = 0.488$). Thermocycling had no significant effect on staining in any group.

The comparison between Easyshade and Photoshop measurements showed a difference between groups and within groups. There was a weak correlation between the two methods of measurement except at day 30 where the correlation increased ($P = 0.002$) but was still at a low level ($r = 0.48$; $P = 0.002$) [Table 3].

Discussion

The artificial aging used in this experiment (thermocycling/color staining) simulates a clinical use of 2.5 years (30 months), as it has been described that 24 h of staining *in vitro* corresponds to approximately 1 month *in vivo*,[22,38,42,43] therefore the immersion period would simulate approximately 30 months. The 3000 thermic cycles (5°C–55°C) are also equivalent to the same period.[44,45]

The fact that no toothpaste was used during the daily brushing is due to the abrasion ability of the toothpaste that might have altered the surface and modify the color change intensity,[46] this routine reduces the ability to transfer our results to the clinical outcome but abrasive brushing is a factor that is related to wear/staining and should be assessed separately in future studies.

The first null hypothesis was rejected since all specimens exhibited important color changes at 30 days. The changes affected mainly ΔL and Δa values with less important changes in Δb values. This finding could be explained by the kind of beverages used being more saturated with black and red (wine, coffee, and tea) than blue or yellow. The second null hypothesis was also rejected, as Photoshop evaluation of color was not comparable with that of the spectrophotometer.

Resin ceramics are more sensitive to staining agents than glass ceramics as was confirmed by Lawson and Burgess, and Karaokutan *et al*.[43,47] In this study, Cerasmart exhibited less stain than Enamic, which contradicts previously published results[38] where the samples were only thermocycled in coffee and the formula used for color analysis was CIEDE2000. A recent study showed that red wine stains more than coffee and tea for all composites and CAD/CAM resin ceramics.[48] The low PH of red wine (3 < PH < 4) may justify the high values of color changes reported. More recent studies demonstrate that resin ceramic color change is greatly affected by polishing quality.[49,50] RNC are easier to polish because they are less charged than PICN and this can lead to a better color stability. However, this explanation does not justify the high staining of Brilliant Crios. Other factors that may interfere with color outcome include surface hardness,[51] and Kurtulmus *et al*. found that

Table 2: Color change monitoring through time and between groups

Photoshop					Material	Easyshade compact				
ΔE1	ΔE2	ΔE7	ΔE14	ΔE30		ΔE1	ΔE2	ΔE7	ΔE14	ΔE30
2.55	3.37	5.14	7.68	19.75	Cerasmart	5.41	5.94*	12.61*	13.78	15.71
2.71	5.03	6.56	10.38	20.13	Enamic	6.37*	8.15*	11.71*	15.50*	17.01*
1.31	3.25	4.65	7.55	13.05	Brilliant	8.44*	11.02*	12.66*	16.56*	18.72*
2.52	5.79	6.71	6.76	8.36	E.max	3.11	2.95	4.05	12.22	14.07

*Significant difference with LDGC. LDGC: Lithium disilicate glass ceramic

Table 3: Comparison of Easyshade compact to the photoshop method (bivariate Pearson's correlation)

Spectrophotometer	Photoshop	Pearson *r*	*P*
ΔES01	ΔPhE01	−0.172	0.287
ΔES02	ΔPhE02	−0.286	0.074
ΔES07	ΔPhE07	−0.339	0.032
ΔES14	ΔPhE14	0.113	0.489
ΔES30	ΔPhE30	0.479	0.002*

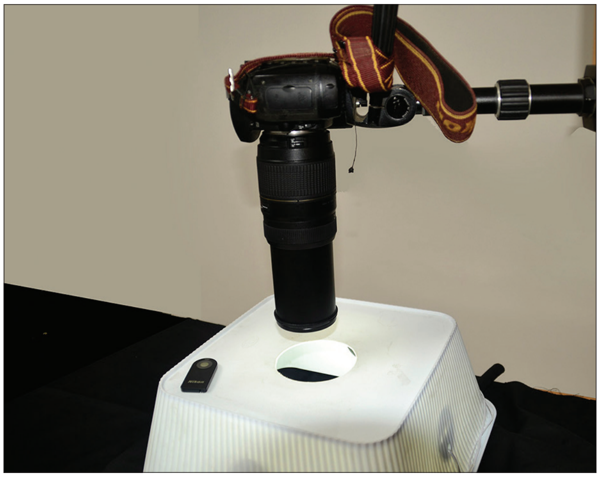

Figure 3: Self-made still photography setup for color evaluation

optics as well as physical properties are affected by surface treatment of resin ceramics.[52]

Mainjot *et al*. incriminates degradation of the resin matrix at the surface as a cause of color change in resin-based ceramic.[7] Also, Sideridou and Karabela showed that all resins absorb water (and water-based colorants) at different levels,[53] and Belli highlighted the presence of hydrophilic triethylene glycol dimethacrylate (TEG-DMA) and (BIS-EMA) in all resin-based materials.[54] This explains the lower surface integrity of resin-based ceramics as compared to glass ceramics. CAD/CAM materials are highly cured (heat and pressure) with little or no free radicals and no photoinitiators,[7] this finding explains that the staining is related to surface alteration and not porosity, however, a recent paper showed that CAD/CAM resin ceramics may be polished or even office bleached to remove stains.[55] Vita Easyshade and Photoshop showed major differences in ΔE values, which may be justified by the different way each system works. In a previous study[33] comparing Photoshop and a spectrophotometer where the sample was a standard shade guide measured in a single step; the agreement between the two methods of measurement was very high, although the authors did report higher reliability for spectrophotometry. Other studies emphasize that digital photographs are influenced by light and camera setting[31,32] and recommend method verification and calibration of the algorithm function of custom white balance in different digital cameras.[38] Similarly, a recent study showed that the difference between a spectrophotometer and a digital camera can be significant and the color reproduction can lead to color errors beyond acceptance.[56]

Several previously published studies[57-59] fail to mention crucial details regarding the digital camera settings used such as the flash setting (through the lens metering "TTL" or manual). It is important to mention that the TTL function of the flash will adjust the flash power to get a correct exposure and average brightness in all pictures. The second missing detail was whether the camera was set at spot metering or (evaluative) matrix metering. When the camera is in spot metering or center-weighted mode, the lightness is measured at the center of the picture while the surrounding area is neglected (in case of photographing a tooth, the gum is neglected). If the camera is set in matrix mode, the whole frame lightness is taken into consideration (in case of oral photography, the gum brightness may interfere with the illumination of the tooth by the TTL macro flash). These two details affect the brightness (ΔL) while setting the camera's white balance to auto (auto white balance) will affect the color (Δa and Δb).

Photoshop has a spot for color analysis of (3 × 3 pixels) and can be adjusted to a maximum of (15 × 15 pixels) but it remains very narrow compared to the 5 mm diameter tip of Easyshade.

In the light-box used in our study, the electric vehicle (EV) (light power) was calculated to be = 10.8, while the Easyshade showed that it works at EV = 13.5 (measured by the same light-meter). This overexposure condition of Easyshade is helpful for light penetration through the surface of tooth/ceramic but does not comply with general conditions of photography.

The low-angle illumination used in still photography is needed to eliminate any direct light reflection to the lens [Figure 3]. This is very different from the perpendicular sub-surface illumination of Easyshade where 2 consecutive illuminations of about 0.5 s each are emitted (first the outer row of fibers approximately 5 mm in diameter illuminate, then the inner row of approximately 3 mm) [Figure 4]. By the dual consecutive lighting, Easyshade results in some penetration of light and reflection from a deeper layer than just the surface that may be helpful to the lab technician. In fact, Easyshade gives two side results for each measurement, the first for deeper layers (as for dentin) and the second for a shallower depth (as for enamel).

The above-mentioned divergences explain the different results between the two systems. It is useful to mention that taking a picture containing the patient's teeth and shade guide elements at the same time with a black or graeyy background remains a useful hint for the lab technician since the shade guide and the patient's teeth are being photographed under the same conditions.

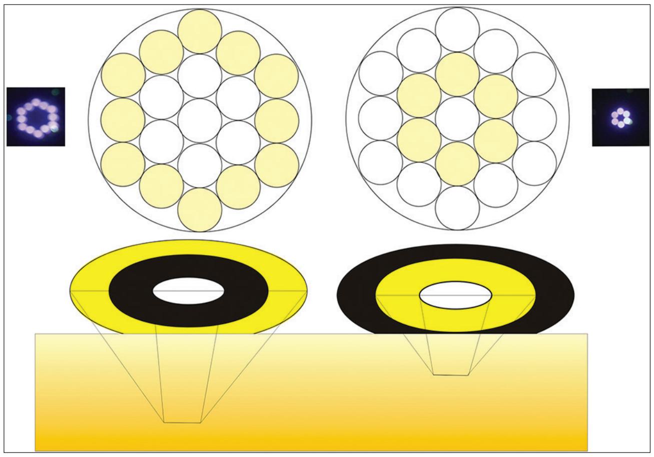

Figure 4: Two consecutive steps of Easyshade illumination

Conclusions

Within the limitations of this *in vitro* study, the following conclusions can be drawn:

- Cerasmart exhibits less color change than Enamic, and Brilliant Crios is the most susceptible to staining
- E. max shows better color stability than RNC's and hybrid ceramic materials
- Staining values (ΔE change) are more affected by time and material than thermocycling in all assessed materials. Thermocycling has no significant effect on staining in the assessed ceramics
- Photoshop and digital photography show poor precision in intra-oral color measurement and produce results that do not concur with their spectrophotometer counterparts.

Financial support and sponsorship

This is a self-funded study.

Conflicts of interest

There are no conflicts of interest.

References

1. Rekow ED, Silva NR, Coelho PG, Zhang Y, Guess P, Thompson VP, *et al.* Performance of dental ceramics: Challenges for improvements. J Dent Res 2011;90:937-52.
2. Syrek A, Reich G, Ranftl D, Klein C, Cerny B, Brodesser J, *et al.* Clinical evaluation of all-ceramic crowns fabricated from intraoral digital impressions based on the principle of active wavefront sampling. J Dent 2010;38:553-9.
3. Kröger E, Matz S, Dekiff M, Tran BL, Figgener L, Dirksen D, *et al. In vitro* comparison of instrumental and visual tooth shade determination under different illuminants. J Prosthet Dent 2015;114:848-55.
4. Vichi A, Louca C, Corciolani G, Ferrari M. Color related to ceramic and zirconia restorations: A review. Dent Mater 2011;27:97-108.
5. Gehrt M, Wolfart S, Rafai N, Reich S, Edelhoff D. Clinical results of lithium-disilicate crowns after up to 9 years of service. Clin Oral Investig 2013;17:275-84.
6. van den Breemer CR, Vinkenborg C, van Pelt H, Edelhoff D, Cune MS. The clinical performance of monolithic lithium disilicate posterior restorations after 5, 10, and 15 years: A retrospective case series. Int J Prosthodont 2017;30:62-5.
7. Mainjot AK, Dupont NM, Oudkerk JC, Dewael TY, Sadoun MJ. From artisanal to CAD-CAM blocks: State of the art of indirect composites. J Dent Res 2016;95:487-95.
8. Li RW, Chow TW, Matinlinna JP. Ceramic dental biomaterials and CAD/CAM technology: State of the art. J Prosthodont Res 2014;58:208-16.
9. Lee A, Swain M, He L, Lyons K. Wear behavior of human enamel against lithium disilicate glass ceramic and type III gold. J Prosthet Dent 2014;112:1399-405.
10. Saiki O, Koizumi H, Akazawa N, Kodaira A, Okamura K, Matsumura H, *et al.* Wear characteristics of polished and glazed lithium disilicate ceramics opposed to three ceramic materials. J Oral Sci 2016;58:117-23.
11. Leibrock A, Degenhart M, Behr M, Rosentritt M, Handel G. *In vitro* study of the effect of thermo- and load-cycling on the bond strength of porcelain repair systems. J Oral Rehabil 1999;26:130-7.
12. Kumbuloglu O, User A, Toksavul S, Vallittu PK. Intra-oral adhesive systems for ceramic repairs: A comparison. Acta Odontol Scand 2003;61:268-72.
13. Gourav R, Ariga P, Jain AR, Philip JM. Effect of four different surface treatments on shear bond strength of three porcelain repair systems: An *in vitro* study. J Conserv Dent 2013;16:208-12.
14. Carvalho AO, Bruzi G, Giannini M, Magne P. Fatigue resistance of CAD/CAM complete crowns with a simplified cementation process. J Prosthet Dent 2014;111:310-7.
15. Park JH, Choi YS. Microtensile bond strength and micromorphologic analysis of surface-treated resin nanoceramics. J Adv Prosthodont 2016;8:275-84.
16. Kömürcüoğlu MB, Sağırkaya E, Tulga A. Influence of different surface treatments on bond strength of novel CAD/CAM restorative materials to resin cement. J Adv Prosthodont 2017;9:439-46.
17. Awada A, Nathanson D. Mechanical properties of resin-ceramic CAD/CAM restorative materials. J Prosthet Dent 2015;114:587-93.
18. Gunge H, Ogino Y, Kihara M, Tsukiyama Y, Koyano K. Retrospective clinical evaluation of posterior monolithic zirconia restorations after 1 to 3.5 years of clinical service. J Oral Sci 2018;60:154-8.
19. Rohr N, Coldea A, Zitzmann NU, Fischer J. Loading capacity of zirconia implant supported hybrid ceramic crowns. Dent Mater 2015;31:e279-88.
20. Argyrou R, Thompson GA, Cho SH, Berzins DW. Edge chipping resistance and flexural strength of polymer infiltrated ceramic network and resin nanoceramic restorative materials. J Prosthet Dent 2016;116:397-403.
21. Dogan DO, Gorler O, Mutaf B, Ozcan M, Eyuboglu GB, Ulgey M, *et al.* Fracture resistance of molar crowns fabricated with monolithic all-ceramic CAD/CAM materials cemented on titanium abutments: An *in vitro* study. J Prosthodont 2017;26:309-14.
22. Arocha MA, Basilio J, Llopis J, Di Bella E, Roig M, Ardu S, *et al.* Colour stainability of indirect CAD-CAM processed composites vs. conventionally laboratory processed composites after immersion in staining solutions. J Dent 2014;42:831-8.
23. Mahshid Mohammadibassir, Mohammad Bagher Rezvani, Hossein Golzari, Elham Moravej Salehi, Mohammad Amin Fahimi, Mohammad Javad Kharazi Fard. Effect of Two Polishing Systems on Surface Roughness, Topography, and Flexural Strength of a Monolithic Lithium

Disilicate Ceramic. J Prosthodont. 2019;28:e172-e180.

24. 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;112:314-21.
25. Lawson NC, Bansal R, Burgess JO. Wear, strength, modulus and hardness of CAD/CAM restorative materials. Dent Mater 2016;32:e275-83.
26. Alharbi A, Ardu S, Bortolotto T, Krejci I. Stain susceptibility of composite and ceramic CAD/CAM blocks versus direct resin composites with different resinous matrices. Odontology 2017;105:162-9.
27. Nedelcu R, Olsson P, Nyström I, Rydén J, Thor A. Accuracy and precision of 3 intraoral scanners and accuracy of conventional impressions: A novel *in vivo* analysis method. J Dent 2018;69:110-8.
28. Dozic A, Kharbanda AK, Kamell H, Brand HS. European dental students' opinions about visual and digital tooth colour determination systems. J Dent 2011;39 Suppl 3:e23-8.
29. Pecho OE, Pérez MM, Ghinea R, Della Bona A. Lightness, chroma and hue differences on visual shade matching. Dent Mater 2016;32:1362-73.
30. Mehl A, Bosch G, Fischer C, Ender A. *In vivo* tooth-color measurement with a new 3D intraoral scanning system in comparison to conventional digital and visual color determination methods. Int J Comput Dent 2017;20:343-61.
31. Jarad FD, Russell MD, Moss BW. The use of digital imaging for colour matching and communication in restorative dentistry. Br Dent J 2005;199:43-9.
32. Tung OH, Lai YL, Ho YC, Chou IC, Lee SY. Development of digital shade guides for color assessment using a digital camera with ring flashes. Clin Oral Investig 2011;15:49-56.
33. Farah RI. Agreement between digital image analysis and clinical spectrophotometer in CIEL*C*h° coordinate differences and total color difference (ΔE) measurements of dental ceramic shade tabs. Int J Esthet Dent 2016;11:234-45.
34. Hassel AJ, Doz P, Nitschke I, Rammelsberg P. Comparing L*a*b* color coordinates for natural teeth shades and corresponding shade tabs using a spectrophotometer. Int J Prosthodont 2009;22:72-4.
35. Ioannidis K, Beltes P, Lambrianidis T, Kapagiannidis D, Karagiannis V. Crown discoloration induced by endodontic sealers: Spectrophotometric measurement of commission international de I'eclairage's L*, a*, b* chromatic parameters. Oper Dent 2013;38:E1-12.
36. Knösel M, Attin R, Becker K, Attin T. A randomized CIE L*a*b* evaluation of external bleaching therapy effects on fluorotic enamel stains. Quintessence Int 2008;39:391-9.
37. Krasniqi TP, Lila-Krasniqi Z, Ajeti N, Shala K, Bicaj T, Dula L, *et al.* Differences of tooth colorimetric parameters L*a*b* depended on age. Open Access Maced J Med Sci 2017;5:777-80.
38. 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.
39. Ghinea R, Pérez MM, Herrera LJ, Rivas MJ, Yebra A, Paravina RD. Color difference thresholds in dental ceramics. J Dent 2010;38 Suppl 2:e57-64.
40. Mota EG, Smidt LN, Fracasso LM, Burnett LH Jr., Spohr AM. The effect of milling and postmilling procedures on the surface roughness of CAD/CAM materials. J Esthet Restor Dent 2017;29:450-8.
41. Wee AG, Meyer A, Wu W, Wichman CS. Lighting conditions used during visual shade matching in private dental offices. J Prosthet Dent 2016;115:469-74.
42. Özarslan MM, Büyükkaplan UŞ, Barutcigil Ç, Arslan M, Türker N, Barutcigil K, *et al.* Effects of different surface finishing procedures on the change in surface roughness and color of a polymer infiltrated ceramic network material. J Adv Prosthodont 2016;8:16-20.
43. Lawson NC, Burgess JO. Gloss and stain resistance of ceramic-polymer CAD/CAM restorative blocks. J Esthet Restor Dent 2016;28 Suppl 1:S40-5.
44. Yuan JC, Barão VA, Wee AG, Alfaro MF, Afshari FS, Sukotjo C, *et al.* Effect of brushing and thermocycling on the shade and surface roughness of CAD-CAM ceramic restorations. J Prosthet Dent 2018;119:1000-6.
45. Ehlers V, Kampf G, Stender E, Willershausen B, Ernst CP. Effect of thermocycling with or without 1 year of water storage on retentive strengths of luting cements for zirconia crowns. J Prosthet Dent 2015;113:609-15.
46. Ganss C, Möllers M, Schlueter N. Do abrasives play a role in toothpaste efficacy against erosion/abrasion? Caries Res 2017;51:52-7.
47. Karaokutan I, Yilmaz Savas T, Aykent F, Ozdere E. Color stability of CAD/CAM fabricated inlays after accelerated artificial aging. J Prosthodont 2016;25:472-7.
48. Quek SH, Yap AU, Rosa V, Tan KB, Teoh KH. Effect of staining beverages on color and translucency of CAD/CAM composites. J Esthet Restor Dent 2018;30:E9-17.
49. Sagsoz O, Demirci T, Demirci G, Sagsoz NP, Yildiz M. The effects of different polishing techniques on the staining resistance of CAD/CAM resin-ceramics. J Adv Prosthodont 2016;8:417-22.
50. Sarıkaya I, Yerliyurt K, Hayran Y. Effect of surface finishing on the colour stability and translucency of dental ceramics. BMC Oral Health 2018;18:40.
51. Sagsoz O, Yildiz M, Hojjat Ghahramanzadeh AS, Alsaran A. *In vitro* fracture strength and hardness of different computer-aided design/computer-aided manufacturing inlays. Niger J Clin Pract 2018;21:380-7.
52. Kurtulmus-Yilmaz S, Cengiz E, Ongun S, Karakaya I. The effect of surface treatments on the mechanical and optical behaviors of CAD/CAM restorative materials. J Prosthodont 2019;28:e496-e503.
53. Sideridou ID, Karabela MM. Sorption of water, ethanol or ethanol/water solutions by light-cured dental dimethacrylate resins. Dent Mater 2011;27:1003-10.
54. Belli R, Geinzer E, Muschweck A, Petschelt A, Lohbauer U. Mechanical fatigue degradation of ceramics versus resin composites for dental restorations. Dent Mater 2014;30:424-32.
55. Alharbi A, Ardu S, Bortolotto T, Krejci I. In-office bleaching efficacy on stain removal from CAD/CAM and direct resin composite materials. J Esthet Restor Dent 2018;30:51-8.
56. Lakhanpal S, Neelima MS. Accuracy of three shade-matching devices in replicating the shade of metal ceramic restorations: An *in vitro* study. J Contemp Dent Pract 2016;17:1003-8.
57. Yamanel K, Caglar A, Özcan M, Gulsah K, Bagis B. Assessment of color parameters of composite resin shade guides using digital imaging versus colorimeter. J Esthet Restor Dent 2010;22:379-88.
58. Tam WK, Lee HJ. Dental shade matching using a digital camera. J Dent 2012;40 Suppl 2:e3-10.
59. Signori C, Collares K, Cumerlato CB, Correa MB, Opdam NJ, Cenci MS, *et al.* Validation of assessment of intraoral digital photography for evaluation of dental restorations in clinical research. J Dent 2018;71:54-60.