



# Color matching of full ceramic versus metal-ceramic crowns - a spectrophotometric study

Delia Cristina Greță<sup>1</sup>, Cristina Gasparik<sup>1</sup>, Horațiu Alexandru Colosi<sup>2</sup>, Diana Dudea<sup>1</sup>

1) Department of Prosthetic Dentistry and Dental Materials, Faculty of Dental Medicine, Iuliu Hatieganu University of Medicine and Pharmacy, Cluj-Napoca, Romania

2) Department of Medical Education, Division of Medical Informatics and Biostatistics, Faculty of Medicine, Iuliu Hatieganu University of Medicine and Pharmacy, Cluj-Napoca, Romania

## Abstract

**Background and aims.** To verify the color match of metal-ceramic and full ceramic crowns, using instrumental methods.

**Methods.** A number of 153 teeth (anterior and posterior teeth), in 62 patients, were restored with metal ceramic (MC, n=119), pressed-ceramic (PC, n=28), and zirconia-ceramic (ZC, n=6) full coverage crowns. The shade of a reference natural tooth was recorded instrumentally with a dental spectrophotometer (Vitaeasyshade Advance 4.0) in “single tooth measurement”, which provided the base color in Vita Classic (VC) and Vita 3D Master shades (3D).

For verifying the outcome of the restoration “verify restoration” mode was used, and  $\Delta E$  values were recorded for both VC and 3D Master shade guides. Moreover, matching symbols were also recorded (\*\*\*=good, \*\*=fair, \*=poor). Descriptive statistics was performed and data were analyzed (One-sample z-Test,  $\alpha=0.05$ ) for comparison with visual thresholds in dentistry (Perceptibility Threshold – PT=1.2 and Acceptability Threshold – AT=2.7).

**Results.** The data did not follow a normal distribution (Kolmogorov-Smirnov test,  $p<0.05$ ). Recorded color difference was significantly higher than PT and AT, for all types of restorations, regardless of the coding system ( $p<0.05$ ). For MC crowns in 2.52% (4.20% for 3D) of the cases the color difference was smaller than PT, in 19.32% (the same for 3D) of cases was between PT and AT, and in 78.15% (76.47% for 3D) of cases was higher than the AT. For PC crowns in 3.57% (0% for 3D) of the cases the color difference was smaller than PT, in 25% (32.14% for 3D) of cases was between PT and AT, and in 71.42% (67.85% for 3D) of cases was higher than the AT. In the case of ZC crowns none of the restorations had color difference smaller than PT, but in 16.66% of cases was between PT and AT, and in 83.33% of cases was higher than the AT, for both VC and 3D.

**Conclusion.** Within the limitations of the study, a better color match was achieved in the case of pressed ceramic crowns, made of lithium disilicate. In most of the situations the color difference between the restoration and the reference tooth exceeded the perceptibility thresholds, but the matching was recorded as “fair” by the spectrophotometer.

**Keywords:** metal-ceramic crowns, full ceramic crowns, dental spectrophotometer, color matching, color parameters

## Background and aims

In modern dentistry, patients' expectations as well as clinicians' standards regarding esthetic treatments increased over the past years. In the case of composite fillings or ceramic restorations, a major concern is directed towards shade matching [1–3]. Due to their highly esthetic properties, dental ceramics have been extensively used in restorative dentistry, leading to researches oriented

towards the development of new classes and representative materials, as well as new techniques aimed to improving properties of the existing ceramics [4–10].

In order to achieve clinical validation, it is essential to analyze the clinical performance of restorative materials. Metal-ceramic crowns were considered as the golden standard, combining mechanical resistance with esthetics [11–13]. However, nowadays,

DOI: 10.15386/mpf-1330

Manuscript received: 01.04.2019  
Received in revised form: 26.06.2019  
Accepted: 09.07.2019

Address for correspondence:  
gasparik.cristina@umfcluj.ro

This work is licensed under a Creative Commons Attribution-NonCommercial-NoDerivatives 4.0 International License

full ceramic crowns are becoming most often the solutions of choice for protection and/or replacement of altered dental structures, especially in anterior dental areas due to their advantages over metal-ceramic restorations: improved esthetics because of their increased translucency and light transmission [14,15], minimal tooth reduction [14,16], low thermal conductivity [17], less periodontal damage because of the supragingival placement of margins [18–20] and less susceptibility to metal allergies [14].

Extensive *in vivo* studies have been performed to investigate different types of ceramic restorations using criteria such as: tissue health [21], marginal integrity [22], secondary caries [14], proximal contacts [14], anatomic contour [23], occlusion [23], surface texture [23], cracks/chips (fractures) [24], color match [25], tooth sensitivity [24], and wear [23].

A major criterion to evaluate the esthetic appearance of ceramic restorations is their color matching with adjacent teeth.

The methods for selecting tooth shade can be classified in two categories: visual and instrumental measurements. Clinicians often use both methods, in order to eliminate errors associated with each technique. Studies showed that instrumental measurements using a dental spectrophotometer may provide the most precise and accurate shade-matching outcomes [26–28].

Dental spectrophotometers, are often used by dental professionals in order to evaluate basic color parameters of natural teeth (“single tooth mode” or “tooth areas mode”), but they also allow to verify that a ceramic restoration’s shade is an acceptable match to a particular shade (“verify restoration mode”).

Color matching is expressed as a difference in color, calculated by a formula which includes the color coordinates ( $L^*$ -lightness,  $a^*$ color on the red-green axis,  $b^*$ color on the yellow-blue axis\*) of the two units (teeth, restorations); in order to evaluate if it would be perceptible or clinically acceptable, the color difference is compared with the thresholds of color perceptibility and color acceptability in dentistry [29].

Few studies investigated exclusively the clinical performance related to color matching of ceramic and

metal-ceramic restorations using only spectrophotometric evaluation [30,31].

The aim of this study was to compare, through spectrophotometric evaluation the color matching performance of metal-ceramic versus full-ceramic crowns, fabricated by different technologies and materials: ceramics layered to a metal core, ceramics layered to a heat-pressed ceramic core, and ceramics layered to a milled zirconia core.

The null hypotheses of this study were: 1. Color matching between metal-ceramic or full-ceramic crowns (heat-pressed or zirconia ceramics) and reference natural teeth is below the perceptibility threshold; 2. There was no difference in color matching between metal-ceramic and full-ceramic crowns, against the respective reference natural teeth.

## Methods

### Participants and instrumental measurements

A total of 153 teeth (anterior and posterior teeth) in 62 patients (Table I) were restored with full coverage crowns: metal-ceramic crowns (MC, n=119), lithium disilicate heat-pressed ceramic crowns (PC, n=28), and zirconia core layered with ceramics crowns (ZC, n=6). The design and materials used in the study are presented in Table II. All full coverage crowns included in the study were fabricated in the same dental laboratory.

**Table I.** Demographic characteristics of subjects.

Total	Gender		Age Groups	
	Female	Male	23-40 years	41-64 years
62	37 (59.67%)	25 (40.32%)	34 (54.83%)	28 (45.16%)

The optical properties of the restoration resulted from data measured by the dentist. Reference teeth were considered both the contralateral vital tooth and the adjacent teeth, in order to provide optimal color matching. Color parameters for reference teeth were evaluated using visual shade guides (Vita Classic and Vita 3D Master) and a dental spectrophotometer (Vitaeasyshade Advance 4.0). In addition, the spectrophotometer was used to measure the central area of the reference tooth, in “single tooth mode”.

**Table II.** Distribution and description of investigated types of ceramic restorations.

	No	Type of restoration	Core of the restoration	Type of ceramic
				Layering technique (Creation Ceramic – Willi Geller)
Total 153	119 (77.77%)	Metal-ceramic <b>MC</b>	Sintered/cast dental alloy (CoCr)	
	28 (18.30%)	Lithium disilicate pressed ceramic <b>PC</b>	Pressed ceramic (IPS e.max Press core, lithium disilicate glass-ceramic – Ivoclar Vivadent)	Layering technique (IPS e.max Ceram – Ivoclar Vivadent)
	6 (3.92%)	Zirconia core layered with ceramic system <b>ZC</b>	Milled core (Katana Zirconia Block – Kuraray Noritake)	Layering technique (Creation Ceramic – Willi Geller)

Participation in the study was on voluntary basis and each participant signed an informed consent form. The study was approved by the Ethics Committee of the Iuliu Hatieganu University of Medicine and Pharmacy Cluj-Napoca, Romania.

The ceramic restorations were visually evaluated for color matching, both by the dentist and by the patients, before cementation. Patients acknowledged that the ceramic crowns were clinically acceptable, therefore the dentist finalized the dental treatment by cementation of the restorations using adhesive luting composite resin. For full ceramic crowns, try-in pastes were used prior to cementation.

One week after cementation, patients were examined by an experienced dentist (DCG) who instrumentally measured the color both of the restorations and of the reference teeth.

The shade of a reference natural tooth was recorded with a dental spectrophotometer (VITA Easyshade Advance 4.0, Vita Zahnfabrik) in "single tooth measurement" mode, which provided the color in VITA Classical (VC) and 3D Master (3D) codifications. To verify the outcome of the ceramic restorations, the "verify restoration" mode was used, which involved verifying the matching between the color introduced as reference (of the reference tooth) and the color of the restoration; furthermore, color differences ( $\Delta E^*ab$ ) were registered for both VC and 3D Master shade systems.

Symbols which expressed the degree to which the restoration matched the target shade were also recorded (\*\*\*=good, \*\*=fair, \*=adjust). Three stars ("good") means that the global color of the restoration has little to no color difference from the reference shade with which it has been compared. Two stars ("fair") means that the base color of the restoration may have a noticeable but still acceptable difference from the target shade, and one star ("adjust") means that the base color of the restoration has a noticeable

difference from the target shade.

Following the manufacturer's instructions, the base color was evaluated on the middle third of the buccal surface of the teeth and of ceramic restorations, an area that best illustrates tooth shade [32,33]. Three measurements were determined for each tooth/ ceramic restoration and an average was calculated. In order to avoid variations of the spectrophotometers' probe angulation and to measure similar tooth areas, custom-made acrylic jigs were used for all color measurements (Figure 1). The acrylic jigs were fabricated to fit either the anterior or the posterior teeth.

Differences in value ( $\Delta L^*$ ), chroma ( $\Delta C^*$ ) and hue ( $\Delta h^\circ$ ), between reference tooth and ceramic restoration were also recorded with the spectrophotometer.

The dental office where the instrumental recordings were performed had specific artificial illuminants (ceiling fluorescent tube lightning OSRAM LumiluxDeluxe 36W/965 5500K).

Color difference thresholds have been used for interpreting the outcomes: CIELAB 50:50% perceptibility threshold (PT=1.2) and 50:50% acceptability threshold (AT=2.7) were used to interpret the magnitude of color differences ( $\Delta E^*ab$ ) [29,34].

#### Statistical analysis

Descriptive statistics and normality test (Kolmogorov-Smirnov test) were performed and color differences (One-sample z-Test) were compared with visual thresholds in Dentistry (Perceptibility Threshold – PT=1.2, Acceptability Threshold – AT=2.7). Color differences ( $\Delta E^*$  values) calculated between reference teeth and restorations (metal-ceramic, pressed-ceramic and zirconia) were analyzed using the Kruskal Wallis test. A statistical significance threshold of  $\alpha=0.05$  has been chosen for all analyses. Statistical analyses were performed using StatPlus:mac v.6, AnalystSoft Inc., and SPSS Statistic v.23 for MacIntosh, IBM.



a



b

**Figure 1 a and b.** Instrumental measurement using a custom-made acrylic jig.

## Results

The data did not follow a normal distribution (Kolmogorov-Smirnov test,  $p<0.05$ ), therefore non-parametric tests were used for further analyses.

Color difference ( $\Delta E^*ab$ ) values between the reference teeth and the restorations were significantly higher than PT and AT, for all types of restorations, regardless of the codification (One-sample z-test,  $p<0.05$ ).

The distribution of the values for color differences between the crowns and the teeth used as reference, in

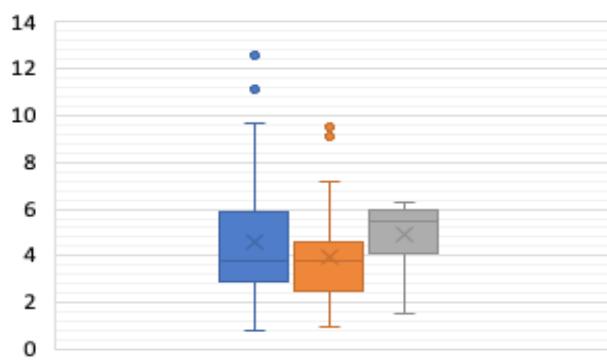
relation with the PT and AT are presented in Table III.

Results for color difference  $\Delta E^*ab$  between the three types of investigated ceramic crowns and the teeth considered as reference, in Vita Classic and Vita 3D Master codifications are included in Figure 2 a, b. The results of the Kruskal-Wallis test showed no significant differences in  $\Delta E^*$  values between the three types of crowns, regardless of the codification (Chi-square=2.343, df=2, p=0.310 for Vita Classical, and Chi-square=6.059, df=2, p=0.051 for 3D Master).

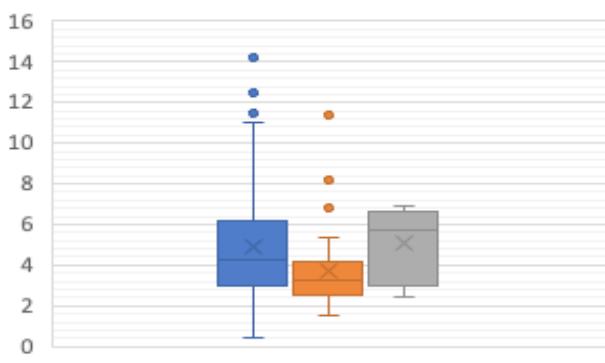
**Table III.** Distribution of color difference according to “PT” and “AT” indicated by spectrophotometer (in Percentages).

	Thresholds	n (VC)	% (VC)	n (3D Master)	% (3D Master)
MC	<1.2	3	2.52%	5	4.20%
	1.2-2.7	23	19.32%	23	19.32%
	>2.7	93	78.15%	91	76.47%
PC	<1.2	1	3.57%	0	-
	1.2-2.7	7	25%	9	32.14%
	>2.7	20	71.42%	19	67.85%
ZC	<1.2	0	-	0	-
	1.2-2.7	1	16.66%	1	16.66%
	>2.7	5	83.33%	5	83.33%
<b>Total</b>		153		153	

MC=metal-ceramic, PC=pressed ceramic, ZC=zirconia ceramic, VC= Vitaclassic system, 3D Master=3D Master system, PT=perceptibility threshold, AT=acceptability threshold.



a Vita Classic System



b Vita 3D Master System

**Figure 2 a,b** illustrate the distribution of  $\Delta E$  between the three types of investigated ceramic crowns according to Vita Classical and Vita 3D Master Systems.

Table IV illustrates the color match between the ceramic restorations and the teeth used as reference, based on the symbol (\*) evaluation system of the spectrophotometer. Best color match was achieved by lithium disilicate pressed ceramic crowns (PC) corresponding for VC system (53.57%) and for 3DMaster system (50%). However, in most situations matching symbol was recorded as “fair” by the spectrophotometer,

regardless of the type of restoration (Table IV).

“Verify restoration” mode of VitaEasyshade Advance 4.0 offers information regarding color differences in value ( $\Delta L^*$ ), chroma ( $\Delta C^*$ ) and hue ( $\Delta h^\circ$ ), both in VC and 3DMaster system between the desired color (used as reference) and the actual color of restoration. Results are illustrated in Table V and Table VI.

**Table IV.** Distribution of “color match” symbol indicated by spectrophotometer among different types of ceramic crowns.

	Matching symbol	n (VC)	% (VC)	n (3DMaster)	% (3DMaster)
MC	***	29	24.36%	29	24.36%
	**	47	39.49%	48	40.33%
	*	43	36.13%	42	35.29%
PC	***	7	25%	10	35.71%
	**	15	53.57%	14	50%
	*	6	21.42%	4	14.28%
ZC	***	1	16.66%	1	16.66%
	**	1	16.66%	1	16.66%
	*	4	66.66%	4	66.66%
<b>Total</b>		153		153	

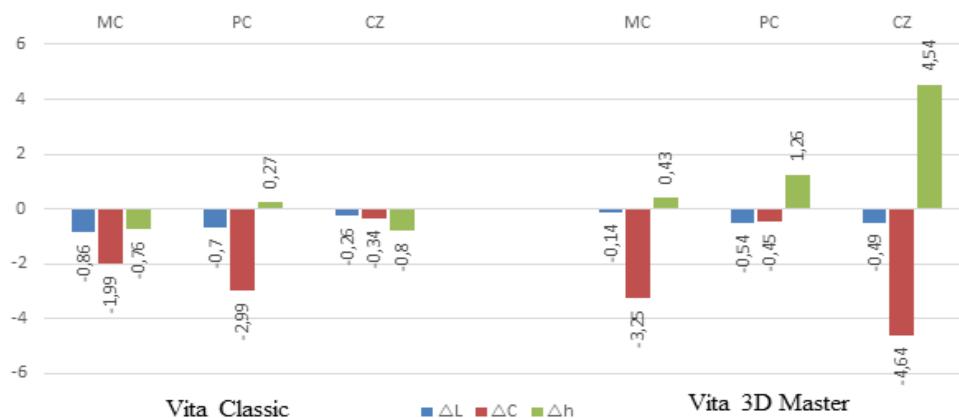
MC=metal-ceramic, PC=pressed ceramic, ZC=zirconia ceramic, VC= Vita Classic Shade Guide System, 3D=Vita3D Master Shade Guide Systems

**Table V.** Values of color difference  $\Delta L^*$ ,  $\Delta C^*$ ,  $\Delta h^\circ$  in Vita Classic System.

Matching symbol	* “adjust”			** “fair”			*** “good”			
	Type of restoration	MC	PC	ZC	MC	PC	ZC	MC	PC	ZC
$\Delta L^*$	mean	-1.93	-3.84	-3.82	-0.52	-2.14	3.00	-0.27	-0.62	1.30
$\Delta C^*$	mean	-3.98	3.83	-2.82	-1.73	-0.07	-3.50	-0.24	-0.92	0.20
$\Delta h^\circ$	mean	0.91	2.55	4.88	-1.19	-0.48	5.30	-2.40	-1.79	-2.40

**Table VI.** Values of color difference  $\Delta L^*$ ,  $\Delta C^*$ ,  $\Delta h^\circ$  in 3D Master System.

Matching symbol	* “adjust”			** “fair”			*** “good”			
	Type of restoration	MC	PC	ZC	MC	PC	ZC	MC	PC	ZC
$\Delta L^*$	mean	-0.25	-0.20	-3.12	0.01	-1.14	2.50	-0.04	-0.94	1.70
$\Delta C^*$	mean	-6.38	-5.60	-3.93	-1.53	1.17	2.00	-0.29	-1.66	-1.50
$\Delta h^\circ$	mean	1.74	3.58	5.30	-0.57	0.48	0.40	-0.42	1.38	3.00



**Figure 3.** Distribution of mean values of  $\Delta L$ ,  $\Delta C$  and  $\Delta h$  among the investigated ceramic restorations.

Moreover, the recording of  $\Delta L^*$ ,  $\Delta C^*$  and  $\Delta h^\circ$  by Vita Easyshade spectrophotometer in “verify restoration mode” allows to acknowledge which color parameter is modified from the reference and in what sense. Trends in which color parameters  $L^*$ ,  $C^*$  and  $h$  are changed, in comparison to the reference, for the investigated ceramic restorations are presented in Figure 3.

On average, lightness of all restorations was decreased in comparison with the reference, regardless of the codification system taken into account. Metal-ceramic crowns displayed the most important lack of correspondence between the lightness of restorations and the lightness of reference teeth with a mean value of  $\Delta L^* = -0.86$ . On average, Chroma of the restorations was reduced too, in comparison with reference, especially for Zirconia-ceramic crowns (mean value  $\Delta C^* = -4.64$ ).

Both increased and decreased  $h^\circ$  (hue) was recorded, in comparison with reference teeth. Zirconia-ceramic restorations exhibited the highest value of color difference  $\Delta h^\circ$  (mean value of 4.54) (Figure 3).

## Discussion

This research assessed the clinical performance of three types of full ceramic crowns, based on their optical characteristics evaluated with instrumental methods. A clinically acceptable ceramic full crown, requires particular attention in terms of color matching with adjacent teeth. Visual color matching in dentistry is subjective. Instrumental measurement of tooth color provides objective, quantified data to match natural teeth [27,28,35,36].

The first null hypothesis was rejected, since most of the color differences recorded for each type of crown were above perceptibility and acceptability thresholds. However, the second null hypothesis could not be rejected, because the recorded color differences were not significantly different between the three types of crowns. Yet the best instrumental color matching was recorded for lithium

disilicate pressed-ceramic crowns (PC). In 53.57% PC when Vita Classic and in 50% PC when 3D Master was used, the spectrophotometer indicated as matching symbol “fair” (noticeable but acceptable difference from reference tooth). 25% in VC and 35.71% in 3D Master of PC crowns displayed “good”, meaning no color difference from target shade. The lowest degree of color match was recorded for zirconia-ceramic crowns (ZC), 66.66% displayed “adjust” by spectrophotometer, (noticeable difference from reference shade) (Table IV).

Though the restorations were clinically accepted by patients, color difference recorded by the spectrophotometer exceeded the acceptability threshold ( $AT=2.7$ ), suggesting noticeable color mismatch between ceramic restorations and reference teeth. In 25% (VC) and 32.14% (3D Master) of PC Crowns, the recorded color difference ranged between PT (1.2) and AT (2.7), indicating that PC crown were the most acceptable among the types of ceramic crowns investigated in this study. Over 19% of MC crowns (both VC and 3D Master) were between PT and AT, whilst only 16.66% of ZC crowns were considered acceptable (Table III). These results were in agreement with the study of Peng M et al., published in 2014, which indicated that the color difference against the reference, measured spectrophotometrically, was significantly lower for metal ceramic restorations in comparison to zirconia-based crowns. In that study, the authors aimed to compare two types of ceramic restorations (metal-ceramic and zirconia-ceramic crowns), lithium disilicate pressed ceramic restorations were not included in their research.

Another aim of Peng et al.’s study was to investigate whether instrumental methods alone, could provide reliable data regarding color matching. Similar studies concluded that instrumental measurements using a spectrophotometer may provide the most precise and accurate shade-matching results, but further research is necessary to validate this claim [26–28].

The results obtained in our study might have been influenced by some limitations. The global color data of reference teeth, recorded before fabrication of the ceramic crowns was evaluated using both visual (with VitaClassic and Vita 3D Master Shadeguides) and spectrophotometric methods, whilst the final color match of the ceramic crowns was assessed using only instrumental methods.

One of the most difficult assignments of a prosthodontist is shade taking. The reference tooth most often considered by dental practitioners is the contralateral or a neighboring tooth, but often other teeth are also evaluated in order to obtain a clinically acceptable shade. Teeth have chromatic particularities, depending on the group they belong to [33,36,38]. A limit of our study was that only one tooth was selected as a reference for the final color match (when possible from the same group).

The clinical precision of Vita Easyshade spectrophotometers has already been validated by several researches [26–28]. However, instrumental devices like Vita Easyshade may encounter problems while measuring curved surfaces, as the measuring probe tip is flat. Edge-loss errors are common, due to the fact that the probe tip of the instrument cannot be in direct contact with the buccal surfaces of the natural tooth or the ceramic surface [32,33]. In addition, positioning errors of the probe tip cannot be excluded, leading to reduced L\* values recorded for these types of ceramic crowns (Tables V and VI).

Variations of color parameters  $\Delta L^*$ ,  $\Delta C^*$  and  $\Delta h^*$  among the investigated ceramic crowns was observed. Significantly reduced L\* (lightness) values were recorded predominately in case of MC restorations. These findings may be explained by the material used for the core of the restorations (sintered/cast dental alloy Co-Cr) which is darker than the core of full ceramics and therefore absorbs more light. Furthermore, metal cores are completely opaque and light penetration is practically impossible, leading thus to a less vivid appearance than in the case of full ceramic restorations.

Our findings were in agreement with other studies [10,30]. Lithium disilicate pressed-ceramic crowns had decreased chroma (Tables V and VI), which can be explained by the increased translucency of this material. PC crowns permit a better light transmission than MC crowns and zirconia-ceramic crowns (ZC) [39–42].

## Conclusion

Within the limitations of the study, the best color match with the reference teeth was achieved for lithium disilicate pressed-ceramic crowns, followed by metal-ceramic and zirconia core layered with ceramic system crowns. However, the results were not significantly different. In most situations the color difference between the ceramic restoration and the reference tooth, exceeded the perceptibility threshold, but the matching was recorded

as “fair” by the spectrophotometer. Vita Easyshade Advance provides useful information regarding the nature and magnitude of the conflicting color parameters ( $\Delta L$ ,  $\Delta C$ ,  $\Delta h$ ), but, in order to verify the final color matching of a restoration, both visual and instrumental methods should be used.

## Acknowledgment

This study was supported by the Research Project (PCD 7690/52).

## References

- Ruan DP, Wu CY, Zhang DH. Application of digital photography in color matching of porcelain restoration in special color teeth. *Shanghai Kou Qiang Yi Xue*. 2010;19:19-22.
- Lam WYH, Hsung RTC, Cheng LYY, Pow EHN. Mapping intraoral photographs on virtual teeth model. *J Dent*. 2018;79:107-110.
- Sampaio CS, Atria PJ, Hirata R, Jorquera G. Variability of color matching with different digital photography techniques and a grey reference card. *J Prosthet Dent*. 2019;121:333-339.
- Rasouli R, Barhoum A, Uludag H. A review of nanostructured surfaces and materials for dental implants: surface coating, patterning and functionalization for improved performance. *Biomater Sci*. 2018;6:1312-1338.
- Camposilvan E, Leone R, Gremillard L, Sorrentino R, Zarone F, Ferrari M, et al. Aging resistance, mechanical properties and translucency of different yttria-stabilized zirconia ceramics for monolithic dental crown applications. *Dent Mater*. 2018;34:879-890.
- Samran A, Al-Ammari A, El Bahra S, Halboub E, Wille S, Kern M. Bond strength durability of self-adhesive resin cements to zirconia ceramic: An in vitro study. *J Prosthet Dent*. 2019;121:477-484.
- Kwon SJ, Lawson NC, McLaren EE, Nejat AH, Burgess JO. Comparison of mechanical properties of translucent zirconia and lithium disilicate. *J Prosthet Dent*. 2018;120:132-137.
- Alao AR, Stoll R, Song XF, Abbott JR, Zhang Y, Abduo J, et al. Fracture, roughness and phase transformation in CAD/CAM milling and subsequent surface treatments of lithium metasilicate/disilicate glass-ceramics. *J Mech Behav Biomed Mater*. 2017;74:251-260.
- Kružic JJ, Arsecularatne JA, Tanaka CB, Hoffman MJ, Cesar PF. Recent advances in understanding the fatigue and wear behavior of dental composites and ceramics. *J Mech Behav Biomed Mater*. 2018;88:504-533.
- Baldissara P, Wandscher VF, Marchionatti AME, Parisi C, Monaco C, Ciocca L. Translucency of IPS e.max and cubic zirconia monolithic crowns. *J Prosthet Dent*. 2018;120:269-275.
- Pjetursson BE, Valente NA, Strasdinger M, Zwahlen M, Liu S, Sailer I. A systematic review of the survival and complication rates of zirconia-ceramic and metal-ceramic single crowns. *Clin Oral Implants Res*. 2018;29 Suppl 16:199-214.

12. Al Hamad KQ, Al Quran FA, AlJalam SA, Baba NZ. Comparison of the accuracy of fit of metal, zirconia and lithium disilicate crowns made from different manufacturing techniques. *J Prosthodont.* 2019;28:497-503.
13. Monaco C, Rosentritt M, Llukacej A, Baldissara P, Scotti R. Marginal adaptation, gap width, and fracture strength of teeth restored with different all-ceramic vs metal ceramic crown systems: an in vitro study. *Eur J Prosthodont Restor Dent.* 2016;24:130-137.
14. Esquivel-Upshaw J, Rose W, Oliveira E, Yang M, Clark AE, et al. Randomized, controlled clinical trial of bilayer ceramic and metal-ceramic crown performance. *J Prosthodont.* 2013;22:166-173.
15. Raigrodski AJ, Chiche GJ. The safety and efficacy of anterior ceramic fixed partial dentures: a review of the literature. *J Prosthet Dent.* 2001;86:520-525.
16. Sorensen JA. The IPS Empress 2 system: defining the possibilities. *Quintessence Dent Technol.* 1999;22:153-163.
17. Rosenstiel SL, Land MF, Fujimoto J. Contemporary Fixed Prosthodontics. 5<sup>th</sup> ed.. St. Louis, Missouri: Mosby Elsevier; 2016:264-277, 674-693.
18. Sorensen JA, Cruz M, Mito WT, Raffeiner O, Meredith HR, Fosher HP. A clinical investigation on three-unit fixed partial dentures fabricated with a lithium disilicate glass-ceramic. *Pract Periodontics Aesthet Dent.* 1999;11:95-106; quiz 108.
19. Gargiulo AW, Wentz FM, Orban B. Dimensions and relationships of the dentogingival junction in humans. *J Periodontol.* 1961;32:261-267.
20. Silness J. Periodontal conditions in patients treated with dental bridges. 3. The relationship between the location of the crown margin and the periodontal condition. *J Periodontal Res.* 1970;5:225-229.
21. Nicolaisen MH, Bahrami G, Schropp L, Isidor F. Functional and esthetic comparison of metal-ceramic and all-ceramic posterior three-unit fixed dental prostheses. *Int J Prosthodont.* 2016;29:473-481.
22. Halici SE, Hekimoğlu C, Ersoy O. Marginal fit of all-ceramic crowns before and after cementation: an in vitro study. *Int J Periodontics Restorative Dent.* 2018;38:e41-e48.
23. Goyal MK, Goyal S, Hegde V, Balkrishana D, Narayana AI. Recreating an esthetically and functionally acceptable dentition: a multidisciplinary approach. *Int J Periodontics Restorative Dent.* 2013;33:527-532.
24. Kosyfaki P, del Pilar Pinilla Martín M, Strub JR. Relationship between crowns and the periodontium: a literature update. *Quintessence Int.* 2010;41:109-126.
25. Vichi A, Fazi G, Carrabba M, Corciolani G, Louca C, Ferrari M. Spectrophotometric evaluation of color match of three different porcelain systems for all-ceramic zirconia-based restorations. *Am J Dent.* 2012;25:191-194.
26. Chen H, Huang J, Dong X, Qian J, He J, Qu X, et al. A systematic review of visual and instrumental measurements for tooth shade matching. *Quintessence Int.* 2012;43:649-659.
27. Lehmann K, Devigus A, Wentaschek S, Igiel C, Scheller H, Paravina R. Comparison of visual shade matching and electronic color measurement device. *Int J Esthet Dent.* 2017;12:396-404.
28. Okubo SR, Kanawati A, Richards MW, Childress S. Evaluation of visual and instrument shade matching. *J Prosthet Dent.* 1998;80:642-648.
29. Paravina RD, Ghinea R, Herrera LJ, Bona AD, Igiel C, Linniger M, et al. Color difference thresholds in dentistry. *J Esthet Restor Dent.* 2015;27 Suppl 1:S1-S9.
30. Peng M, Fei W, Hosseini M, Gotfredsen K. Crown color match of implant-supported zirconia and porcelain-fused-to-metal restorations: a spectrophotometric comparison. *Hua Xi Kou Qiang Yi Xue Za Zhi.* 2014;32:62-65.
31. Chen Y, Liu H, Meng Y, Chao Y, Liu C. The study of the colorimetric characteristics of the cobalt-chrome alloys abutments covered by four different all-ceramic crowns by using dental spectrophotometer. *Hua Xi Kou Qiang Yi Xue Za Zhi.* 2015;33:226-229.
32. Gómez-Polo C, Gómez-Polo M, Martínez Vázquez de Parga JA, Celemín Viñuela A. Study of the most frequent natural tooth colors in the Spanish population using spectrophotometry. *J Adv Prosthodont.* 2015;7:413-422.
33. Pop-Ciutrla IS, Colosi HA, Dudea D, Badea ME. Spectrophotometric color evaluation of permanent incisors, canines and molars. A cross-sectional clinical study. *Clujul Med.* 2015;88:537-544.
34. 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-e64.
35. Dancy WK, Yaman P, Dennison JB, O'Brien WJ, Razzoog ME. Color measurements as quality criteria for clinical shade matching of porcelain crowns. *J Esthet Restor Dent.* 2003;15:114-121; discussion 122.
36. Pecho OE, Pérez MM, Ghinea R, Della Bona A. Lightness, chroma and hue differences on visual shade matching. *Dent Mater.* 2016;32:1362-1373.
37. Pop-Ciutrla IS, Ghinea R, Colosi HA, Dudea D. Dentin translucency and color evaluation in human incisors, canines, and molars. *J Prosthet Dent.* 2016;115:475-481.
38. Pop-Ciutrla IS, Ghinea R, Perez Gomez MDM, Colosi HA, Dudea D, Badea ME. Dentine scattering, absorption, transmittance and light reflectivity in human incisors, canines and molars. *J Dent.* 2015;43:1116-1124.
39. Kanat-Ertürk B. Color stability of CAD/CAM ceramics prepared with different surface finishing procedures. *J Prosthodont.* 2019 Jan 14. doi: 10.1111/jopr.13019. [Epub ahead of print]
40. Kelly JR. Dental ceramics: current thinking and trends. *Dent Clin North Am.* 2004;48: 513-530.
41. Shahmiri R, Standard OC, Hart JN, Sorrell CC. Optical properties of zirconia ceramics for esthetic dental restorations: A systematic review. *J Prosthet Dent.* 2018;119:36-46.
42. Willard A, Gabriel Chu TM. The science and application of IPS e.Max dental ceramic. *Kaohsiung J Med Sci.* 2018;34:238-242.