

Cement opacity and color as influencing factors on the final shade of metal-free ceramic restorations.

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INTRODUCTION

The desire to mimic the optical properties of natural teeth with ceramic systems has always been a major challenge for modern dentistry.¹ For PFM restorations, the presence of a metallic substructure, which is a total barrier to the transmission of light, creates unfavorable chromatic properties due to the increased light reflectivity.^{2,3} Many all-ceramic systems have been developed over the past forty years to overcome the esthetic deficiencies of PFM,⁴ and more recently CAD/CAM technology has facilitated the use of newer materials.

The translucency of metal-free materials is an important esthetic advantage⁵ but adds a higher level of complexity to the shade matching process,⁶ and the limited color availability of machinable CAD/CAM blocks or disks is an important limitation in the color matching process.

The final color of all-ceramic restorations is not merely a shade selection process, but rather the combined result of several factors, including the degree of translucency, the thickness of the restoration, the surface characteristics such as gloss and roughness, the color and the opacity of the luting agents.⁷

It is well documented that white opaque cements are indicated with stained or metallic abutments, to mask the color of the substrates.⁸ Furthermore, it is well known that the shade of a feldspathic ceramic restoration is more readily influenced than that of a zirconia restoration, due to the different translucency of the ceramic structure.⁹ Similarly, the color after cementation of thin veneers can be more easily influenced by the color of the resin cement, compared with thicker crowns made with the same material, where the effect of the color of the cement is lower.¹⁰ Recently the influence of cement has been reported as one of the factors able to influence the shade of zirconia based restoration due to their increased translucency.^{11,12} Although the observation that translucency is influenced by the wall thickness has been reported for feldspathic ceramic^{13,14}, and recently for lithium disilicate^{15,16} and zirconia¹⁷, limited clinical guides are available¹⁸ and no studies correlating color and opacity of cement and ceramic are present in the literature.

For this reason, the influence of color and opacity of luting cements on the final shade of ceramic restorations of different thickness, and consequently variable translucency, was investigated in this study.

The formulated null-hypotheses were:

i: After the cementation procedure, the color of resin cement does not influence the final shade of different thicknesses of feldspathic restorations.

ii: No linear correlation exists between the influence of cement and the optical properties (color and translucency) of cement and ceramic.

MATERIALS AND METHODS

Five resin cement colors were tested in combination with four different translucencies of CAD/CAM feldspathic ceramic, using different specimen thicknesses, on a composite substrate used as a dentin color reference, for a total of 20 combinations (n=3).

Sixty disks (15 mm diameter x 2 mm thickness) of Herculite XRV Ultra Dentine #A2 (Kerr Italia s.r.l., Scafati SA, Italy; #34019) were used as substrates. A calibrated mold was employed to control the diameter and thickness of the disks. A glass plate was pressed on the mold to eliminate the excess of material and then polymerization was performed by a halogen lamp (VIP Bisco, Schaumburg, IL, USA). Composite disks were removed from the mold, finished and polished in a grinder/polisher machine (EXTEC® Labpol 8, Extec Corp. Enfield, CT, USA) with #600, #1000 and #1200 silica-carbide paper (South Bay Technology, Inc., San Clemente, CA, USA).

VITA Mark II #2M2 (Vita Zahnfabrik, Bad Sackingen, Germany; #19050) CAD/CAM ceramic blocks were perpendicularly cut with a water-cooled low speed diamond saw (Isomet, Buehler, Lake Bluff, IL, USA). Flat 14 mm x 12 mm specimens of variable thicknesses of 0.5, 1.0, 1.5 and 2.0 mm, were cut. A special support maintained the block insertion pin perpendicular to the saw during cutting, to ensure a consistent thickness of specimen. To simulate clinical conditions, in which the external surface of the restoration is finished and polished while the intaglio surface is treated for cementation, one side of the specimens was glazed with VITA Akzent Glaze Spray (Vita Zahnfabrik, Bad Sackingen, Germany) and fired in a VITA Vacumat 4000T (Vita Zahnfabrik, Bad Sackingen, Germany), following the manufacturer's instructions.

The color evaluations were performed with a spectrophotometer (OceanOptics PSD1000) equipped with a 10.0 mm opening integrating sphere (OceanOptics ISP-REF). The spectrophotometer was connected to a computer running color measurement software (OOILab 1.0, Ocean Optics, FL, USA). D65 illumination and a 10° standard observation angle were selected. Measurements were taken using the CIELAB color coordinate system against a neutral gray background (Kodak, Rochester NY, USA). The output of the spectrophotometer was set over 10 scans

To identify the color differences before and after cementation, the initial color of the complex ceramic and composite substrate was assessed before cementation. Glycerin was used instead of cement to avoid light scattering during color measurement.¹⁹ After initial measurement, the specimens were cleared of the glycerin in an ultrasonic bath and then submitted to the cementation procedure. The glaze free surface was submitted to the etching procedure with 4.9% hydrofluoric acid (VITA ceramics etch, Vita Zahnfabrik, Bad Sackingen, Germany) for 20 seconds.

The clear, white, yellow, brown and white opaque shades of the self-adhesive resin cement Maxcem Elite™ (Kerr Italia s.r.l., Scafati SA, Italy; #34062) were selected.

To simulate the clinical bonding procedure²⁰ and ensure a constant cement thickness, a 100 µm spacer was placed on top of the substrate disk (Figure 1) and a standardized seating force of 40 g/mm² was applied over the ceramic specimen and the composite substrate disk. The application of this seating pressure on a 15mm diameter composite disk is equivalent to a force of about 70 N, which can be considered a medium seating force²¹ and a moderate biting force^{22,23}. The specimens were maintained under pressure for 10 minutes, allowing the cement to self-cure. Three specimens were prepared for each cement color and each ceramic thickness combination.

Spectrophotometric color measurements were performed with the same setup previously described. To calculate the differences in color before and after cementation (ΔE_f), the CIEDE2000 formula was applied.

$$\Delta E_{00} = \sqrt{\left(\frac{\Delta L'}{K_L S_L}\right)^2 + \left(\frac{\Delta C'}{K_C S_C}\right)^2 + \left(\frac{\Delta H'}{K_H S_H}\right)^2 + R_T \left(\frac{\Delta C'}{K_C S_C}\right) \left(\frac{\Delta H'}{K_H S_H}\right)}$$
 where $\Delta L'$, $\Delta C'$, and $\Delta H'$ are the differences in lightness, chroma, and hue for a pair of samples in CIEDE2000, and R_T is a function that accounts for the interaction between chroma and hue differences in the blue region. Weighting functions, S_L , S_C , S_H adjust the total color difference for variation in the location of the color difference pair in L' , a' , b' coordinates and the parametric factors, K_L , K_C , K_H , are correction terms for experimental conditions. In the present study, the parametric factors of the CIEDE2000 color difference formula were set to 1.²⁴⁻²⁶

For the cement and ceramic color and opacity assessments 1.0±0.1 mm thick disk specimens were produced for each of the cement shades in the same way as described before for the composite substrate. One extra 1 mm thick ceramic specimen was prepared for color evaluation. Spectrophotometric color evaluation was performed against a 50% gray standard background. CIELAB values were recorded, and the color coordinates were assessed over 10 scans. The differences in color between the ceramic specimens and the cement disks (ΔE_{cc}) were calculated applying the CIEDE2000 formula to evaluate the magnitude of the color differences and to correlate them with the influence of the cement on ceramic color, after cementation (ΔE_f).

The relative translucency of the five cement colors (1mm thick disks) and the ceramic specimens for all the tested thicknesses, were analyzed by measuring the translucency parameter (TP). The TP was calculated using the following CIELAB color difference equation:

$TP_{ab} = \sqrt{(\Delta L_b^* - \Delta L_w^*)^2 + (\Delta a_b^* - \Delta a_w^*)^2 + (\Delta b_b^* - \Delta b_w^*)^2}$ where the subscripts “b” and “w” refer to color coordinates over black (CIELAB 0,0,0 – 3% reflectivity) and white (CIELAB 100,0,0 – 90% reflectivity) backgrounds (Kodak Gray Scale Q-14, Rochester NY, USA).

Calculated data were reported in Table 1. The differences in translucency between the 4 tested ceramic thicknesses and the cement specimens, were calculated using the formula $\Delta TP = TP_{cer} - TP_{cem}$. The mean ΔTP was calculated for each ceramic thickness and was compared to the ΔE_f , to evaluate the role of both ceramic and cement translucency, on the color of the restoration after cementation. The ΔE_f values were statistically analyzed for the variables Cement Shade and Ceramic Thickness by applying the Two-Way ANOVA followed by the Tukey Test for post-hoc comparison ($p < 0.05$). The acceptability (AT) and perceptibility (PT) thresholds were set respectively at ΔE_{00} 1.8 and 0.8^{25,26} and the color mismatch was classified as indicated by Paravina *et al.*²⁷

Multiple correlation analyses between ΔE_{cc} and ΔE_f were performed, pooled data were divided into groups based on the 4 levels of mean ΔTP between the tested cements and their specific ceramic thickness (Group 1 to 4 respectively -10.45, -6.34, -2.86 and 7.15 ΔTP).

The whole data were again divided into 5 groups based on the level of ΔE_{cc} (Group 1 to 5 respectively 6.53, 10.16, 10.20, 11.03 and 15.31 ΔE_{cc}) for the correlation between ΔTP and ΔE_f . The level of linear correlation was determined by evaluating Pearson's correlation values "r²".

RESULTS

The mean values for ΔE_f , the statistical significance for the variables Cement color and Ceramic thickness and the classification in terms of color differences were reported in Table 2.

A statistically significant influence on final color was found between 0.5 mm, 1.0 mm and 1.5 mm thick specimens. No significant differences were found between the 1.5 mm and 2.0 mm thicknesses. The white opaque cement showed the greatest influence on color compared to all the other tested shades of resin cements. A significant influence was reported also for the Brown shade while no statistically significant influence was found for the clear, white and yellow cement colors.

The 0.5 mm thick ceramic specimens were influenced for all the cement colors with respect to the AT threshold. Varying color changes were observed within the tested combinations.

The data expressing the strength of the correlation between the influence of cement on cementation and factors influencing the shade are summarized in Table 3. Considering the influence of the difference in color between the ceramic and the cement (ΔE_f Vs. ΔE_{cc} , Figure 2), a strong linear correlation was found only with a positive ΔTP ($\Delta TP=7.15$). Evaluation of the influence of the different translucencies between cement and ceramic and the influence of the final shade after cementation (ΔE_f Vs. ΔTP , Figure 3), demonstrated a strong linear correlation ($r_2 > 0.6$) only when the ΔE_{cc} was greater than 11.

DISCUSSION

The results revealed differences in the color of the specimen after cementation.

Since the differences were statistically significant, the first null-hypothesis was rejected.

The correlation analysis showed strong correlations for positive ΔTP and ΔEcc greater than 11, therefore the second null-hypothesis was partially rejected.

The wide range of translucencies and colors that can be achieved with the materials tested in the present study, were measured to quantify factors that are usually described as categorical variables. Hence, statistical analysis allowed a more scientific description to be applied to the influence of the resin cement on the final color of metal-free restorations.

Based on the results of the present study, no significant color changes were introduced into the final restoration by the cement when its color was close to that of the restoration and the translucency was higher than the restoration. Conversely, when the opacity of the cement was higher than that of the restoration, significant color changes were measured. Contrary to the current manufacturer held view that several marketed resin cement shades are required, it is reasonable to observe that a variety of shaded very translucent cements could be unnecessary for the majority of the delivered ceramic restorations. Opaque and shaded cements, not only in the white shade, could be helpful for the clinician in certain situations, such as where dichromic abutments are used or when minor color corrections are required.

The translucency of metal-free restorations significantly improved their esthetics.²⁸ A wide range of translucencies was reported for ceramic materials and this is a pivotal factor for luting procedures²⁹⁻³² and thereby for the optical performance of the final restoration, for both translucency and color.³³⁻

35

Chang *et al.*¹⁹ found that the color of the cement substrate could influence the final color of the CAD/CAM lithium disilicate crown. Similar conclusions were drawn by Turgut & Bagis³⁶ for heat pressed lithium disilicate veneers. Alghazzawi *et al.*⁹ reported how in a spectrophotometric analysis

of feldspathic, lithium disilicate and zirconia veneers, the influence of the cement was present for feldspathic and lithium disilicate and absent for the zirconia veneers, due to their intrinsic opacity.

In an *in vitro* test on Leucite-reinforced glass ceramic, Karaagaclioglu & Yilmaz³⁷ reported the influence of the cement color when the thickness of the veneers was less than 0.8 mm. For most of the published papers, the analyzed variables were: i) the ceramic thickness,^{10,38-41} ii) the ceramic structure^{9,42,43} and iii) the cement shade.⁴⁴⁻⁴⁶

An evident problem of this area of interest is that the cement shade is usually named after the generic hue (e.g. White, Yellow, Brown) or is based on the VITA classical shade guide. For some brands, a translucency index was added (e.g. HT, LT, Opaque). This classification has been criticized as differences were reported between the same shades of different cement brands.⁴⁷ Thus, shade definitions can be considered material-dependent and not universal. This resulted in material dependent results because similar nominal shades like (e.g. clear or yellow) could have a different influence on the final restoration, thereby not addressing the goal of esthetic indirect restorations in terms of color matching.

The same criticism could be used when thickness and ceramic structure were indicated as categorical variables. Ceramic translucency is influenced by the thickness and by the structure of the ceramic and plays an important role on influencing the final color of metal-free restorations.⁴⁸

The presence of an opaque layer of cement beneath a translucent ceramic restoration is usually described in the literature as having the function of masking a discolored abutment or titanium implant abutment and its influence on the final color of metal-free restorations is limited.^{8,49-51} This opaque layer of cement can influence the light transmitted through the restoration, reflecting most of its spectral composition. In the present study only a tooth colored background was applied in combination the only opaque cement color available. This limitation of the study suggests the needing of further investigations to confirm the possible deduction derived from the correlation analysis.

By the use of shaded opaque resin cements, clinicians can correct the appearance of all types of cemented ceramic restorations, by using a cement opaquer. This is a difficult aspect in clinical

situations where the exact translucency of every single part of the restoration can not be measured. However, from the results of the present *in vitro* study, in order to influence the final color of a restoration, a cement opaquer is needed. Therefore, in order to correctly influence the final color of the restoration, a more extensive range of opaque resin cements colors should be available. This will require further investigation, in order to provide clinicians with more detailed information, relating to any color modification of the final metal-free restoration. The unavailability of a greater variety of shades and opacities of the resin cement was the main limiting factor for this *in vitro* study. Likewise, *in vivo* clinical studies using try-in pastes and a clinical spectrophotometer, would be helpful to support the *in vitro* the results of this study.

CONCLUSION

Based on the results and within the limitations of the present study, it can be concluded that:

- The final shade of ceramic restorations can be significantly influenced using resin cements, by virtue of their cement optical properties.
- The final shade of a ceramic restoration is highly influenced by the translucency and the color of the complex ceramic cement. Translucent resin cements showed a low influence on the color of the final restoration and their different shades seem to be ineffective and unnecessary. Conversely, shaded resin cement opaquer could be useful to influence the color of the restoration in cases where there is a color mismatch within the desired shade.

REFERENCES

1. Li, Q, Yu H, Wang YN. Spectrophotometric evaluation of the optical influence of core build-up composites on all-ceramic materials. *Dent Mater.*, 2009; 25:158-165.
2. McLean JW. The science and art of dental ceramics: aesthetics of dental porcelains. Monograph III. New Orleans: Louisiana State University School of Dentistry; 1976. p. 1-41.
3. Carossa S, Lombardo S, Pera P, et al. Influence of posts and cores on light transmission through different all-ceramic crowns: spectrophotometric and clinical evaluation. *Int J Prosthodont.*, 2001; 14:9–14.
4. Holloway JA. The effect of core translucency on the aesthetics of all-ceramic restorations. *Pract Periodontics Aesth Dent.*, 1997; 9:567-574.
5. McLean JW. New dental ceramics and esthetics. *J Esthet Dent.*, 1995; 7:141-9.
6. Chan J, Da Silva JD, Sakai M, et al. The optical effect of composite luting cement on all ceramic crowns. *J Dent.*, 2009; 37:937-43.
7. Garber DA, Goldstein RE, Feinman RA. *Porcelain Laminate Veneers*. Chicago: Quintessence., 1998: 91
8. Dede DÖ, Armaganci A, Ceylan G, et al. Influence of abutment material and luting cements color on the final color of all ceramics. *Acta Odontol Scand.*, 2013; 71:1570-8.

9. Alghazzawi TF, Lemons J, Liu P, et al. Evaluation of the optical properties of CAD-CAM generated yttria-stabilized zirconia and glass-ceramic laminate veneers. *J Prosthet Dent.*, 2012; 107:300-8.
10. Omar H, Atta O, El-Mowafy O, Khan SA. Effect of CAD-CAM porcelain veneers thickness on their cemented color. *J Dent.*, 2010; 38 Suppl 2:e95-9.
11. Tabatabaian F. Color Aspect of Monolithic Zirconia Restorations: A Review of the Literature. *J Prosthodont.*, 2019; 28:276-87.
12. Tabatabaian F, Jafari A, Namdari M, Mahshid M. Influence of coping and veneer thickness on the color of zirconia-based restorations on different implant abutment backgrounds. *J Prosthet Dent.*, 2019; 121:327-32.
13. Antonson SA, Anusavice KJ. Contrast ratio of veneering and core ceramics as a function of thickness. *Int J Prosthodont.*, 2001; 14:316-20.
14. Wang F, Takahashi H, Iwasaki N. Translucency of dental ceramics with different thicknesses. *J Prosthet Dent.*, 2013; 110:14-20.
15. Czigola A, Abram E, Kovacs ZI, et al. Effects of substrate, ceramic thickness, translucency, and cement shade on the color of CAD/CAM lithium-disilicate crowns. *J Esthet Restor Dent.*, 2019; 31:457-64.

16. Dede DÖ, Sahin O, Özdemir OS, et al. Influence of the color of composite resin foundation and luting cement on the final color of lithium disilicate ceramic systems. *J Prosthet Dent.*, 2017; 117:138-43.
17. Dede DÖ, Armağanci A, Ceylan G, et al. Influence of implant abutment material on the color of different ceramic crown systems. *J Prosthet Dent.*, 2016; 116:764-69.
18. Tabatabaian F. Color in Zirconia-Based Restorations and Related Factors: A Literature Review. *J Prosthodont.*, 2018; 27:201-11.
19. Chang J, Da Silva JD, Sakai M, et al. The optical effect of composite luting cement on all ceramic crowns. *J Dent.*, 2009; 37:937-43.
20. Goracci C, Cury AH, Cantoro A, et al. Microtensile bond strength and interfacial properties of self-etching and self-adhesive resin cements used to lute composite onlays under different seating forces. *J Adhes Dent.*, 2006; 8:327-35.
21. Wilson PR. The effect of oscillation, low seating force and dentine surface treatment on pulpward pressure transmission during crown cementation: a laboratory study. *J Oral Rehab.*, 2003; 30:957-63.
22. Fernandes CP, Glantz PO, Svensson SA, Bergmark A. A novel sensor for bite force determinations. *Dent Mater.*, 2003; 19:118-26.

23. Tortopidis D, Lyons MF, Baxendale RH, Gilmour WH. The variability of biting force measurement between sessions, in different position within the dental arch. *J Oral Rehabil.*, 1998; 25:681-686.
24. Luo MR, Cui G, Rigg B. The development of the CIE2000 colour difference formula: CIEDE2000. *Color Res Appl.*, 2001; 26:340–50.
25. Ghinea R, Pérez MM, Herrera LJ, et al. Color difference thresholds in dental ceramics. *J Dent.*, 2010; 38 Suppl 2:e57-64.
26. Perez M del M, Ghinea R, Herrera LJ, et al. Dental ceramics: a CIEDE2000 acceptability thresholds for lightness, chroma and hue differences. *J Dent.*, 2011; 39 Suppl 3:e37-44.
27. Paravina RD, Pérez MM, Ghinea R. Acceptability and perceptibility thresholds in dentistry: A comprehensive review of clinical and research applications. *J Esthet Restor Dent.*, 2019; 31:103-112.
28. Kelly JR, Nishimura I, Campbell SD. Ceramics in dentistry: historical roots and current perspectives. *J Prosthet Dent.*, 1996; 75:18-32.
29. Rosenstiel SF, Porter SS, Johnston WM. Colour measurements of all ceramic crown systems. *J Oral Rehabil.*, 1989; 16:491-501.
30. Soares CJ, da Silva NR, Fonseca RB. Influence of the feldspathic ceramic thickness and shade on the microhardness of dual resin cement. *Oper Dent.*, 2006; 31:384-9.

31. Turp V, Sen D, Poyrazoglu E, et al. Influence of zirconia base and shade difference on polymerization efficiency of dual-cure resin cement. *J Prosthodont.*, 2011; 20:361-5.
32. Kilinc E, Antonson SA, Hardigan PC, Kesercioglu A. The effect of ceramic restoration shade and thickness on the polymerization of light- and dual-cure resin cements. *Oper Dent.*, 2011; 36:661-9.
33. Vichi A, Carrabba M, Paravina R, Ferrari M. Translucency of Ceramic Materials for CEREC CAD/CAM System. *J Esthet Restor Dent.*, 2014; 26:224-31.
34. Heffernan MJ, Aquilino SA, Diaz-Arnold AM, et al. Relative translucency of six all-ceramic systems. Part I: core materials. *J Prosthet Dent.*, 2002; 88:4-9.
35. Heffernan MJ, Aquilino SA, Diaz-Arnold AM, et al. Relative translucency of six all-ceramic systems. Part II: core and veneer materials. *J Prosthet Dent.*, 2002; 88:10-5.
36. Turgut S, Bagis B. Colour stability of laminate veneers: an in vitro study. *J Dent.*, 2011; 39 Suppl 3:e57-64.
37. Karaagaclioglu L, Yilmaz B. Influence of cement shade and water storage on the final color of leucite-reinforced ceramics. *Oper Dent.*, 2008; 33:386-91.
38. Koutayas SO, Kakaboura A, Hussein A, Strub JR. Colorimetric evaluation of the influence of five different restorative materials on the color of veneered densely sintered alumina. *J Esthet Restor Dent.*, 2003; 15:353-60.

39. Chaiyabutr Y, Kois JC, Lebeau D, Nunokawa G. Effect of abutment tooth color, cement color, and ceramic thickness on the resulting optical color of a CAD/CAM glass-ceramic lithium disilicate-reinforced crown. *J Prosthet Dent.*, 2011; 105:83-90.
40. Xing W, Jiang T, Ma X, et al. Evaluation of the esthetic effect of resin cements and try-in pastes on ceromer veneers. *J Dent.*, 2010; 38 Suppl 2:e87-94.
41. Kucukesmen HC, Usumez A, Ozturk N, Eroglu E. Change of shade by light polymerization in a resin cement polymerized beneath a ceramic restoration. *J Dent.*, 2008; 36:219-23.
42. Alqahtani MQ, Aljuraiss RM, Alshaafi MM. The effects of different shades of resin luting cement on the color of ceramic veneers. *Dent Mater J.*, 2012; 31:354-61.
43. Salameh Z, Tehini G, Ziadeh N, et al. Influence of ceramic color and translucency on shade match of CAD/CAM porcelain veneers. *Int J Esthet Dent.*, 2014; 9:90-7.
44. Yoshida A, Miller L, Da Silva JD, Ishikawa-Nagai S. Spectrophotometric analysis of tooth color reproduction on anterior all-ceramic crowns: Part 2: color reproduction and its transfer from in vitro to in vivo. *J Esthet Restor Dent.*, 2010; 22:53-63.
54. Azer SS, Ayash GM, Johnston WM, et al. Effect of esthetic core shades on the final color of IPS Empress all-ceramic crowns. *J Prosthet Dent.*, 2006; 96:397-401.
46. Terzioğlu H, Yilmaz B, Yurdukoru B. The effect of different shades of specific luting agents and IPS empress ceramic thickness on overall color. *Int J Periodontics Restorative Dent.*, 2009; 29:499-505.

47. Turgut S, Bagis B. Effect of resin cement and ceramic thickness on final color of laminate veneers: an in vitro study. *J Prosthet Dent.*, 2013; 109:179-86.
48. Turgut S, Bagis B, Ayaz EA. Achieving the desired colour in discoloured teeth, using leucite-based cad-cam laminate systems. *J Dent.*, 2014; 42:68-74.
49. Okuda WH. Using a modified subopaquing technique to treat highly discolored dentition. *J Am Dent Assoc.*, 2000; 131:945-50.
50. Mizrahi B. The anterior all-ceramic crown: a rationale for the choice of ceramic and cement. *Br Dent J.*, 2008; 205:251-5.
51. Dozic A, Tsagkari M, Khashayar G, Aboushelib M. Color management of porcelain veneers: influence of dentin and resin cement colors. *Quintessence Int.*, 2010; 41:567-73.

Table 1
Mean TP values of ceramic samples and cements.

Ceramic	TP	Cement (1.0 mm thick)	TP
0.5 mm	30.32	clear	30.66
1.0 mm	20.32	white	24.70
1.5 mm	16.83	yellow	24.51
2.0 mm	12.73	brown	27.21
		white opaque	8.79

Table 2

Color variation analysis and statistical significance (p=0.05). Upper case letters indicate statistically significant differences between factors thickness and cement color (p=0.05). Lower case letters indicate statistically significant differences inside the groups for the cement shade and underlined lower case letters indicate statistically significant differences inside the groups for the ceramic thickness(p=0.05). Interpretation of color differences according to Paravina *et al.*²¹ (2019): 1: Excellent Match, 2: Acceptable Match, 3: Moderately unacceptable match, 4: Clearly unacceptable match, 5: Extremely unacceptable match.

Thickness	0.5 mm ^A			1.0 mm ^B			1.5 mm ^C			2.0 mm ^C		
	Shade	mean	(SD)	Inter.	mean	(SD)	Inter.	mean	(SD)	Inter.	mean	(SD)
Clear ^C	2.39 ^{c,a}	(0.33)	3	1.81 ^{bc,a}	(0.78)	3	0.91 ^{b,b}	(0.45)	2	0.69 ^{b,b}	(0.54)	1
White ^C	2.22 ^{c,a}	(0.68)	3	1.80 ^{bc,a}	(1.00)	2	0.98 ^{b,b}	(0.51)	2	1.06 ^{b,b}	(0.22)	2
Yellow ^C	2.38 ^{c,a}	(0.72)	3	1.20 ^{c,b}	(0.45)	2	1.03 ^{b,b}	(0.66)	2	0.93 ^{b,b}	(0.15)	2
Brown ^B	3.85 ^{b,a}	(0.44)	4	2.03 ^{bc,b}	(0.39)	3	1.49 ^{ab,b,c}	(0.51)	2	1.14 ^{b,c}	(0.49)	2
White Op ^A	5.53 ^{a,a}	(0.46)	5	3.03 ^{a,b}	(0.21)	3	2.06 ^{a,c}	(0.13)	3	1.76 ^{a,c}	(0.26)	2
Mean	3.27	0.52		1.97	0.32		1.29	0.19		1.12	0.17	

Table 3

Pearson's test results.

* indicates a linear correlation between the two tested variables.

Correlation Analysis					
ΔE_f Vs. ΔE_{cc}			ΔE_f Vs. ΔTP		
ΔTP Groups	r2	Sign.	ΔE_{cc} Groups	r2	Sign.
-10.45	0.30	P<0.001	6.53	0.32	p<0.001
-6.34	0.29	p<0.001	10,16	0.53	p<0.001
-2.86	0.43	p<0.001	10,20	0.53	p<0.001
7.15*	0.63	p<0.001	11.03*	0.76	p<0.001
			15.31*	0.92	p<0.001

Figure 1
Setup for cementation and color evaluation.

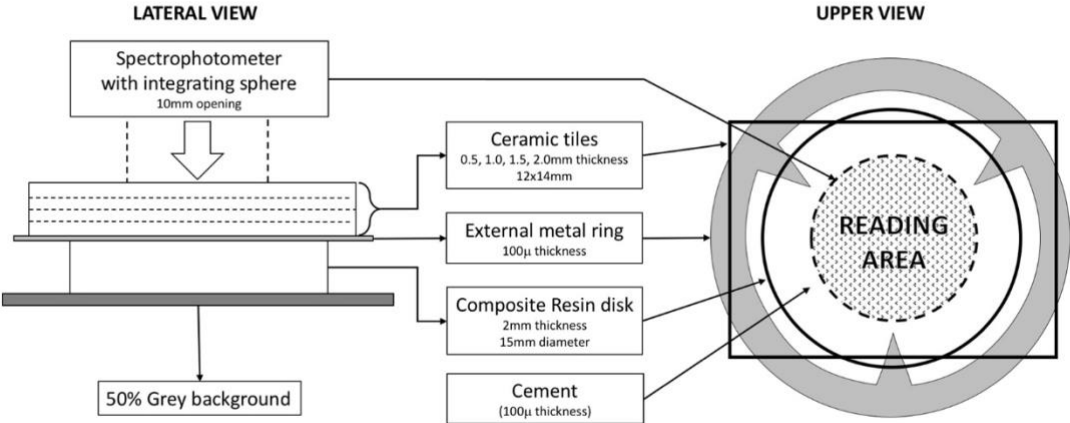


Figure 2

Correlation Analyses between groups of ΔE_f and ΔE_{cc} , classified for different level of ΔTP . A strong linear correlation was reported only with a positive ΔTP ($r_2=0.63$).

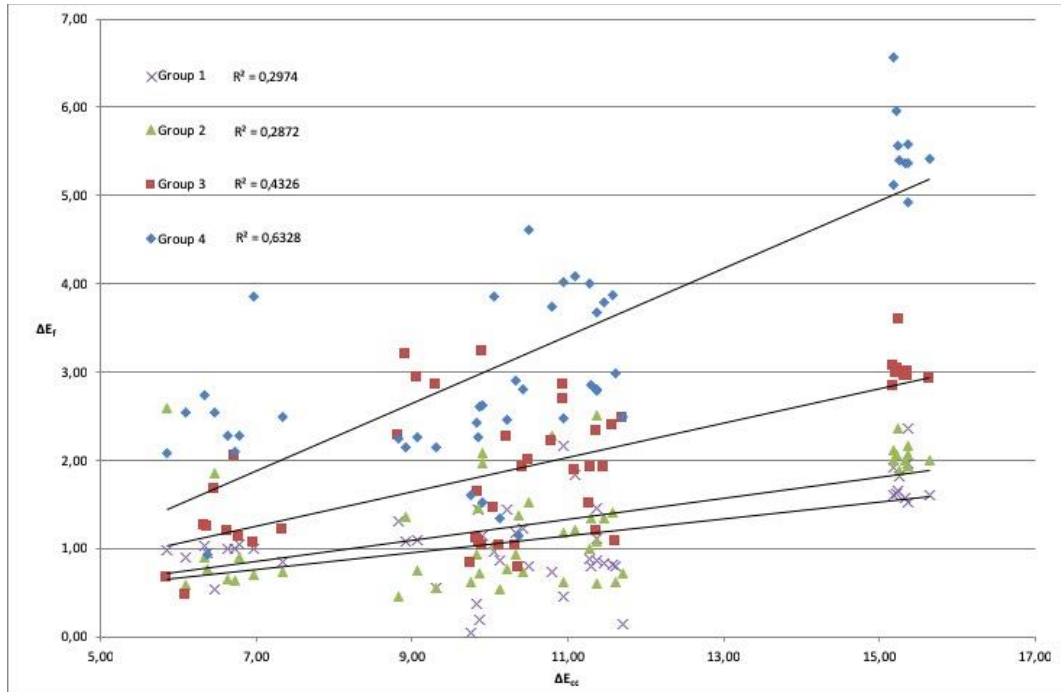


Figure 3

Correlation analyses between groups of ΔE_f and ΔTP , classified for different levels of ΔE_{cc} . The analyses reported that a positive correlation between the two variables became strong when the ΔE_{cc} was higher than 11 ($r_2 > 0.76$).

