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In Vitro Effect of Thickness of Veneering Ceramic on Color Parameters of Zirconia All-Ceramic Restorations

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ABSTRACT

*Statement of the Problem: Controversy exists regarding the effect of porcelain thickness on color of restoration. Purpose: This study sought to assess the effect of thickness of the veneering ceramic on color parameters of zirconia all-ceramic restorations. Materials and Method: This in vitro experimental study was conducted on 30 discs measuring 10mm in diameter and 0.5mm in thickness fabricated of A3 shade of ZIRCAD zirconia using computer-aided design/computer aided manufacturing (CAD/CAD) system. Discs were divided into three groups (n=10). Disc-shaped metal molds measuring 10mm in diameter and 1, 1.5 and 2mm in height were used to fabricate IPS e.max veneering ceramic in 1, 1.5 and 2mm thicknesses. After applying porcelain and firing, the color parameters (CIE L*a*b*) were measured using a spectrophotometer in three phases of zirconia core, dentin porcelain and glazing. Color difference (ΔE) was compared among the three groups. Data were analyzed using ANOVA and Tukey's test. Results: By an increase in the veneering ceramic thickness from 0.5 to 1.5mm, ΔE changed from 10.78 to 13.45 units. The highest ΔE was noted in presence of 1.5mm thickness of dentin porcelain. A significant difference was noted in ΔE among the three groups (p= 0.000); ΔE in presence of 1.5mm thickness of the veneering porcelain was significantly higher than that in the other two groups (p< 0.05). Conclusion: Significant improvement in color occurs by an increase in thickness of the veneering ceramic, and 1.5mm thickness of veneering ceramic is favorable for use in the clinical setting.*

Key words: Zirconium Oxide, Computer-Aided Design, Color

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INTRODUCTION

Due to an increase in esthetic demands of patients as well as some health and environmental concerns with regard to the use of metal restorations, porcelain fused to metal restorations are increasingly replaced with non-metal, all-ceramic restorations [1,2]. Optimal biocompatibility [3], color stability, excellent esthetics [4,5], high wear resistance, low thermal conductivity, no risk of causing metal allergy [6] and decrease in plaque accumulation are among the main advantages of all-ceramic restorations [7-9]. Use of all-ceramic restorations has greatly increased in the recent years owing to more esthetic demands of patients and high success rate of these restorations. Perfect simulation of natural teeth and optimal color stability play important roles in high success rate of all-ceramic restorations from the patients' perspective [10-14]. Due to absence of a metal framework, these restorations can better simulate natural teeth in terms of color parameters [11,12]. However, color properties of natural teeth are highly complex and it is difficult to obtain ideal color match with prosthetic restorations [15].

To obtain the desired color, ceramic restorations are fabricated of different layers with variable opacities, colors and thicknesses [16-18]. In most all-ceramic systems, a strong ceramic core is covered by a weak layer of veneering porcelain [19]. When light is irradiated on a ceramic restoration, the fractions of light absorbed, reflected or passed through the restoration determine the color parameters of the respective restoration; these fractions depend on the chemical composition of material, content of crystals and their dimensions [20,21]. Evidence shows that increase in crystalline content of ceramic for the purpose of increasing the strength has often resulted in higher opacity and less esthetics [22,23]. Thus, it is important to determine the ideal thickness of ceramic that yields optimal color parameters.

The results of previous studies on the effect of porcelain thickness on final color of restorations have been controversial [24,25]. A previous study showed that porcelain thickness had no significant effect on color of restorations [24] while another study reported that even a slight change in porcelain thickness significantly affected the color of restoration [25]. Considering the existing controversy in this respect and the significance of this topic, this study aimed to assess the effect of thickness of the veneering ceramic on color parameters of all-ceramic restorations.

MATERIALS AND METHODS

This in vitro, experimental study was conducted on 30 A3 shade of ZIRCAD zirconia discs (Ivoclar Vivadent, Schaan, Liechtenstein) measuring 10mm in diameter and 0.5mm in thickness fabricated by the CAD/CAM system. These discs were fabricated to simulate restoration core in the clinical setting [26-28]. The discs were then completely veneered with 0.5, 1 and 1.5mm thickness of lithium disilicate glass ceramic fabricated using a standard mold [28,29]. Sample size was calculated to be 30 samples (n=10 for each thickness of the veneering porcelain to be tested) based on similar previous studies [26,30].

Color parameters of all disc-shaped samples were measured based on the CIE L*a*b* system using a spectrophotometer (VITA Easy Shade; VITA Zahn Fabrik, Bad Sackingen, Germany). Disc-shaped metal molds measuring 10mm in diameter and 1, 1.5 and 2mm in height were used to fabricate IPS e.max Press veneering ceramics (Ivoclar Vivadent, Schaan, Liechtenstein) to cover the zirconia cores [29,31-33]. After fabrication of zirconia discs, they were placed at the bottom of each mold and porcelain was applied on top of them as recommended by the manufacturer. Porcelain was fired four times according to the manufacturer's instructions. All phases were performed by the same operator. After porcelain application and standard firing, excess material was removed by silicon carbide paper discs [29,31,32]. The CIE L*a*b* color parameters of each sample were measured using a spectrophotometer (VITA Easy Shade; VITA ZahnFabrik, Bad Sackingen, Germany). The operator was blinded to the thickness of veneering porcelain applied [24,26,27,30,34]. Total color difference (ΔE) was calculated using the formula below:

E*ab=[(ΔL*)2+(Δa*)2+(Δb*)2]1/2Δ

L* indicates degree of lightness, a* indicates degree of redness or greenness and b* indicates degree of blueness or yellowness [35].

The obtained ΔE values in the three groups were compared with each other and with the ΔE of A3 Vita shade as reference. All samples were then glazed and CIE L*a*b* color parameters were measured again by a spectrophotometer (VITA Easy Shade; VITA ZahnFabrik, Bad Sackingen, Germany).

Since the obtained data had normal distribution, ANOVA was applied for statistical analysis. Tukey's test was used for pairwise comparisons of the groups. Statistical analyses were carried out using SPSS version 22 (SPSS Inc., IL, USA) at $P<0.05$ level of significance.

RESULTS

Table 1 summarizes descriptive statistics of ΔE in the three groups (three thicknesses of ceramic). By an increase in thickness of the veneering porcelain from 0.5mm to 1.5mm, the mean ΔE changed from 10.78 to 13.45 units. The highest ΔE was noted in presence of 1.5mm thickness of dentin porcelain.

One-way ANOVA was applied to compare ΔE before veneering (zirconia core phase) and after veneering (dentin porcelain phase) and showed a significant difference in this regard (P=0.000). Tukey's HSD test was then applied, which showed that ΔE in presence of 1.5mm thickness of the veneering porcelain was significantly higher than that in the other two groups (P<0.05). However, no significant differences were noted between groups with 0.5mm and 1mm thickness of dentin porcelain (P=0.428).

Descriptive statistics of L*, a* and b* color parameters in presence of the three thicknesses of the veneering ceramic are presented in Tables 2-4, respectively.

By an increase in dentin porcelain thickness from 0.5mm to 1.5mm, the mean ΔL decreased, the mean Δa increased and the mean Δb decreased. One-way ANOVA was applied to assess the changes in these parameters after veneering (compared to before), which showed that the changes in all three parameters after veneering (compared to before) were statistically significant (p< 0.05). Tukey's HSD test showed that changes in all three color parameters (Δa, Δb and ΔL) were significantly greater in presence of 1.5mm thickness of dentin porcelain compared to the other two groups (p< 0.05). However, no significant differences existed in change of these parameters between the remaining two groups (0.5mm and 1mm thickness of dentin porcelain, p> 0.05).

After glazing, ΔL decreased, Δa increased and Δb decreased; but according to one-way ANOVA, these changes were not statistically significant (p> 0.05, Tables 2-4).

Figure 1 shows the error bar and 95% confidence interval of the mean color difference in presence of the three thicknesses of the veneering porcelain.

Table 1: The mean and standard deviation of color difference (ΔE) in the three groups (three thicknesses of veneering ceramic).

Thickness/ Phase	Zirconia core-dentin porcelain		Dentin porcelain glazing		Zirconia core-glazing	
	Mean± SD	CV	Mean± SD	CV	Mean± SD	CV
0.5mm	10.789±1.366	12.7	6.202±1.586	25.6	9.214±1.763	19.1
1mm	11.506±0.774	6.7	7.667±0.873	11.4	10.142±1.704	16.8
1.5mm	13.455±1.541	11.5	8.276±1.356	16.4	10.133±1.876	18.5
P value	P<0.05 P=0.000		P<0.05 P=0.004		P>0.05 P=0.421	

CV: Coefficient of variation; SD: Standard deviation

Table 2: The mean and standard deviation of ΔL in the three phases for the three thicknesses of the veneering ceramic

Thickness/ Phase	Zirconia core-dentin porcelain		Dentin porcelain-glazing		Zirconia core-glazing	
	Mean± SD	CV	Mean± SD	CV	Mean± SD	CV
0.5mm	4.014±2.017	50.2	2.861±1.557	54.4	6.875±2.146	31.2
1mm	5.694±1.539	27	3.216±1.759	54.7	8.910±2.023	19.8
1.5mm	6.533±1.55	23.7	1.984±0.85	42.8	8.101±2.115	23.8
P value	P<0.05 P=0.009		P>0.05 P=0.164		P>0.05 P=0.069	

CV: Coefficient of variation; SD: Standard deviation

Table 3: The mean and standard deviation of Δa in the three phases for the three thicknesses of the veneering ceramic

Thickness/ Phase	Zirconia core-dentin porcelain		Dentin porcelain-glazing		Zirconia core-glazing	
	Mean± SD	CV	Mean± SD	CV	Mean± SD	CV
0.5mm	3.256±0.705	21.7	0.918±0.679	74.1	4.174±0.852	20.4
1mm	2.752±0.764	27.8	0.943±0.419	44.5	3.695±0.631	17.1
1.5mm	2.360±0.809	34.3	1.450±0.568	39.2	3.810±0.832	21.8
P value	P<0.05 P=0.045		P>0.05 P=0.078		P>0.05 P=0.370	

Table 4: The mean and standard deviation of Δb in the three phases for the three thicknesses of the veneering ceramic

Thickness/ Phase	Zirconia core-dentin porcelain		Dentin porcelain-glazing		Zirconia core-glazing	
	Mean± SD	CV	Mean± SD	CV	Mean± SD	CV
0.5mm	9.236±1.477	16	5.191±1.551	29.9	4.045±1.434	35.5
1mm	9.470±0.820	8.7	6.646±1.122	16.9	2.824±1.199	42.5
1.5mm	11.363±1.842	16.2	7.827±1.456	18.6	3.468±1.484	42
P value	P<0.05 P=0.005		P<0.05 P=0.001		P>0.05 P=0.158	

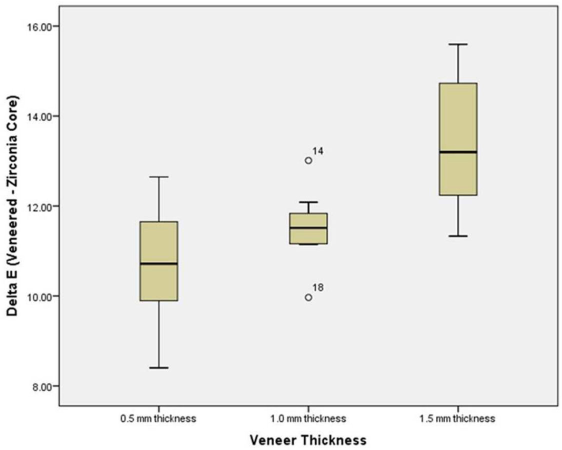

Figure 1: Error bar and 95% confidence interval of the mean color difference for the three thicknesses of the veneering porcelain

DISCUSSION

At present, smile esthetics is as important as optimal function of teeth for patients [36]. Thus, this in vitro study assessed the effect of different thicknesses of the veneering porcelain on color parameters of all-ceramic zirconia restorations. The methodology of our study was similar to that of Ozturk et al [26]. A review study showed that most ceramic systems are comprised of 0.5 to 1mm of core ceramic and 1 to 1.5mm of veneering porcelain [23]. In our study, disc-shaped core ceramics were fabricated in 0.5mm thickness by the CAD/CAM system. Dozic et al. [21] reported that 0.5 to 0.75mm of core material is sufficient to mask the underlying color and its effect on the final color of restoration. Thus, the selected disc thickness was adequate in our study and the underlying color factor in the clinical setting cannot change the results. Evidence shows that the thickness of core, the veneering porcelain and combination of ceramic layers affect the final color of restorations [21,30,37-38]. The thicker the dentin porcelain, the smaller would be the effect of zirconia core on light reflection, and a larger fraction of light is reflected by dentin porcelain layer. It means that dentin porcelain thickness can significantly affect the color parameters of all-ceramic restorations [28]. In the current study, ΔE increased by an increase in thickness of the veneering porcelain. In other words, by an increase in thickness of the veneering ceramic, the samples became more translucent; this finding was in line with the results of previous studies [21,26-27,38-39]. Heffernan et al. [23,40] evaluated the effect of core thickness alone and in combination with the veneering ceramic on overall translucency of samples and indicated that increasing the thickness of the veneering ceramic increased the ΔE value and resulted in restorations with higher translucency.

In the current study, increasing the dentin porcelain thickness decreased the L* value, which was in line with the results of previous studies [24,26,30,41-42]. Since the L* value indicates lightness, its reduction following an increase in the veneering porcelain thickness decreases the lightness of restorations [26,30]. The reduction in lightness of samples following an increase in dentin porcelain thickness is due to the fact that a larger fraction of light is scattered or absorbed by the restoration surface. It means that a smaller fraction of light is reflected by the restoration surface and thus, restoration appears darker and shows a reduction in L* parameter [39]. In the current study, an increase in dentin porcelain thickness increased the a* and decreased the b* color parameters, which translates to more red (due to increase in a*) and more blue (due to reduction in b*) restorations in presence of a thick layer of dentin porcelain.

It has been reported that minimum color difference (ΔE) perceptible to the naked eye is one CIE unit, and color difference between 1-2 CIE units is perceived by most observers [43]. Based on the results of the current study, ΔE values in all thicknesses of the veneering porcelain tested changed by more than 2 units. Son et al. [30] reported color difference higher than the perceivable threshold (1-2 CIE units), which was in agreement with our findings and highlights the effect of dentin porcelain thickness on final color of all-ceramic restorations. Our results showed that 1.5mm thickness of dentin porcelain caused the highest color difference (yielded the highest ΔE value) while no significant color difference was noted in presence of 0.5 and 1mm thicknesses. Sinmazisik et al. [24] and Son et al. [30] reported that 0.5mm thickness of dentin porcelain did not cause a perceivable color difference. Moreover, they showed that thicknesses over 1.5mm did not significantly affect ΔE either, which was in accordance with our results. The results of a study by Begum et al, [44] also supported the above-mentioned findings.

Some other studies have discussed that surface gloss, texture and roughness also affect the color of all-ceramic restorations [45-47]. Kim et al. [48] demonstrated that the color of porcelain and particularly the L* value were correlated with surface topography of restorations. Although glazed surfaces in their study appeared whiter, the L* value was found to be significantly lower than that of polished surfaces, which indicted darkness of restorations. In another study, Yuzugullu et al. [49] evaluated the surface properties and color of porcelain after polishing and concluded that surface modifications significantly affected the roughness of restoration surface but had no significant impact on its color. Similarly, in the current study glazing had no significant effect on color parameters of samples.

It is believed by some that type of ceramic system used can also affect the color parameters of restorations. Antonson and Anusavice [37] assessed the effect of ceramic thickness on contrast of all-ceramic dental restorations and concluded that this factor was significantly correlated with the type of ceramic tested. In the current study, IPS e.max Press ceramic was used, which contains lithium disilicate crystals to strengthen the matrix [50]. This ceramic has lower crystalline content and is more translucent that other ceramic systems available in the market. In other words, it mainly allows passage of light instead of reflecting it [23]. Based on the above-mentioned findings and the results of Son et al, 30, increasing the thickness of IPS e.max Press ceramic greatly impacts on color difference and results in higher ΔE values, which is also in agreement with our findings.

It should be noted that our study had an in vitro design; thus, generalization of the results to the clinical setting must be done with caution. Future studies are required on the effect of type of ceramic system, shade, frequency of firing and type of luting cement as well as the interaction effect of these factors on final color parameters of all-ceramic restorations.

CONCLUSION

Within the limitations of this in vitro study, it may be concluded that increasing the thickness of the veneering ceramic causes a significant color difference and improves the color parameters of all-ceramic restorations. Also, 1.5mm thickness of the veneering porcelain yields optimal color parameters for use in the clinical setting.

REFERENCES

1. Okutan M, Heydecke G, Butz F, Strub JR. Fracture load and marginal fit of shrinkage-free ZrSiO4 all-ceramic crowns after chewing simulation. J Oral Rehabil 2006;33:827-832.
2. Zahran M, El-Mowafy O, Tam L, Watson PA, Finer Y. Fracture strength and fatigue resistance of all-ceramic molar crowns manufactured with CAD/CAM technology. J Prosthodont 2008;17:370-377.
3. Sjögren G, Sletten G, Dahl JE. Cytotoxicity of dental alloys, metals, and ceramics assessed by millipore filter, agar overlay, and MTT tests. J Prosthet Dent 2000;84:229-236.
4. Bachhav VC, Aras MA. Zirconia-based fixed partial dentures: a clinical review. Quintessence Int 2011;42:173-182.
5. Vagkopoulou T, Koutayas SO, Koidis P, Strub JR. Zirconia in dentistry. Part 1. Discovering the nature of an upcoming bioceramic. Eur J Esthet Dent 2009;4:130-151.
6. Gokcen-Rohlig B, Saruhanoglu A, Cifter ED, Evlioglu G. Applicability of zirconia dental prostheses for metal allergy patients. Int J Prosthodont 2010; 23:562-565.
7. Von Steyern P, Ebbesson S, Holmgren J, Haag P, Nilner K. Fracture strength of two oxide ceramic crown systems after cyclic pre-loading and thermocycling. J Oral Rehab 2006;33:682-689.
8. Tinschert J, Natt G, Mautsch W, Augthun M, Spiekermann H. Fracture resistance of lithium disilicate-, alumina-, and zirconia-based three-unit fixed partial dentures: a

laboratory study. Int J Prosthodont 2001;14:231-238.
9. Raigrodski AJ, Chiche GJ. Five year evaluation of posterior all-ceramic three-unit (in-ceram) FPDs. J Esthet Restor Dent 2002;14:317-318.
10. Lee YK, Yu B, Lee SH, Cho MS, Lee CY, Lim HN. Shade compatibility of esthetic restorative materials–a review. Dent Mater 2010;26:1119-1126.
11. Spear F, Holloway J. Which all-ceramic system is optimal for anterior esthetics? J Am Dent Assoc 2008;139:S19-24.
12. Herrguth M, Wichmann M, Reich S. The esthetics of all-ceramic veneered and monolithic CAD/CAM crowns. J Oral Rehabil 2005;32:747-752.
13. Conrad HJ, Seong WJ, Pesun IJ. Current ceramic materials and systems with clinical recommendations: a systematic review. J Prosthet Dent 2007;98:389-404.
14. Kelly JR, Benetti P. Ceramic materials in dentistry: historical evolution and current practice. Aust Dent J 2011;56(suppl 1): 84-96.
15. Vichi A, Louca C, Corciolani G, Ferrari M. Color related to ceramic and zirconia restorations: a review. Dent Mater 2011;27:97-108.
16. Khashayar G, Bain PA, Salari S, Dozic A, Kleverlaan C, Feilzer A. Perceptibility and acceptability thresholds for colour differences in dentistry. J Dent 2014;42:637-644.
17. Seghi RR, Johnston WM, O'Brien WJ. Spectrophotometric analysis of color differences between porcelain systems. J Prosthet Dent 1986;56:35-40.
18. Judd DB, Wyszecki G. Color in business, science, and industry. 3rd ed., New York, John Wiley & Sons; 1975:105-122.
19. Subbarao EC. Zirconia - an overview. In Heuer AH, Hobbs LW, editors. Science and technology of zirconia, vol. 3. Westerville: The American Ceramic Society; 1981:1-24.
20. Isgrò G, Pallav P, van der Zel JM, Feilzer AJ. The influence of the veneering porcelain and different surface treatments on the biaxial flexural strength of a heat-pressed ceramic. J Prosthet Dent 2003;90:465-473.
21. Dozic A, Kleverlaan CJ, Meegdes M, van der Zel J, Feilzer AJ. The influence of porcelain layer thickness on the final shade of ceramic restorations. J Prosthet Dent 2003;90:563-570.
22. Mclean JW. New dental ceramics and esthetics. J Esthet Dent 1995;7:141-149.
23. Heffernan MJ, Aquilino SA, Diaz-Arnold AM, Haselton DR, Stanford CM, Vargas MA. Relative translucency of six all-ceramic systems. Part I: core materials. J Prosthet Dent 2002;88:4-9.
24. Sinmazisik G, Demirbas B, Tarcin B. Influence of dentin and core porcelain thickness on the color of fully sintered zirconia ceramic restorations. J Prosthet Dent 2014;111:142-149.
25. Niu E, Agustin M, Douglas RD. Color match of machinable lithium disilicate ceramics: Effects of cement color and thickness. J Prosthet Dent 2014;111:42-50.
26. Ozturk O, Uludag B, Usumez A, Sahin V, Celik G. The effect of ceramic thickness and number of firings on the color of two all-ceramic systems. J Prosthet Dent 2008;100:99-106.
27. Bachhav VC, Aras MA. The effect of ceramic thickness and number of firings on the color of a zirconium oxide based all ceramic system fabricated using CAD/CAM technology. J Adv Prosthodont 2011;3:57-62.
28. Uludag B, Usumez A, Sahin V, Eser K, Ercoban E. The effect of ceramic thickness and number of firings on the color of ceramic systems: an in vitro study. J Prosthet Dent 2011;97:25-31.
29. Kürklü D, Azer SS, Yilmaz B, Johnston WM. Porcelain thickness and cement shade effects on the colour and translucency of porcelain veneering materials. J Dent 2013;41:1043-1050.
30. Son HJ, Kim WC, Jun SH, Kim YS, Ju SW, Ahn JS. Influence of dentin porcelain thickness on layered all-ceramic restoration color. J Dent 2010;38 Suppl 2:e71-77.
31. Seghi RR, Hewlett ER, Kim J. Visual and instrumental colorimetric assessments of small color differences on translucent dental porcelain. J Dent Res 1989;68:1760-1764.
32. Barath VS, Faber FJ, Westland S, Niedermeier W. Spectrophotometric analysis of all-ceramic materials and their interaction with luting agents and different backgrounds. Adv Dent Res 2003;17:55-60.
33. Jacobs SH, Goodacre CJ, Moore BK, Dykema RW. Effect of ceramic thickness and type of metal ceramic alloy on color. J Prosthet Dent 1987;57:138-145.
34. Lee YK, Cha HS, Yu B. Illuminating light-dependent color shifts in core and veneer

layers of dental all-ceramics. J Biomed Opt 2014;19:95002.
35. CIE (Commission Internationale de l'Eclairage). Colorimetry-technical report. CIE pub. no.15, 2nd ed., Vienna, Austria: Bureau Central de la CIE; 1986:35–6(corrected reprint 1996).
36. Jarad FD, Griffiths CE, Jaffri M, Adeyemi AA, Youngson CC. The effect of bleaching, varying the shade or thickness of composite veneers on final colour: an in vitro study. J Dent 2008;36:554-559.
37. Antonson SA, Anusavice KJ. Contrast ratio of veneering and core ceramics as a function of thickness. Int J Prosthodont 2001;14:316-320.
38. Shokry TE, Shen C, Elhosary MM, Elkhodary AM. Effect of core and veneer thicknesses on the color parameters of two all-ceramic systems. J Prosthet Dent 2006;95:124-129.
39. Douglas RD, Przybylska M. Predicting porcelain thickness required for dental shade matches. J Prosthet Dent 1999;82:143-149.
40. Heffernan MJ, Aquilino SA, Diaz-Arnold AM, Haselton DR, Stanford CM, Vargas MA. Relative translucency of six all-ceramic systems. Part II: core and veneer materials. J Prosthet Dent 2002;88:10-15.
41. O'Brien WJ, Fan PL, Groh CL. Color differences coefficients of body-opaque double layers. Int J Prosthodont 1994;7:56-61.
42. Terada Y, Maeyama S, Hirayasu R. The influence of different thicknesses of dentin porcelain on the color reflected from thin opaque porcelain fused to metal. Int J Prosthodont 1989;2:352-356.
43. Berger-schunn A. Practical color measurement: A primer for the beginners, a reminder for the expert. New York, Wiley,1994:55-56.
44. Begum Z, Chheda P, Shruthi CS, Sonika R. Effect of Ceramic Thickness and Luting Agent Shade on the Color Masking Ability of Laminate Veneers. J Indian Prosthodont Soc 2014;14(Suppl 1):46-50.
45. Obregon A, Goodkind RJ, Schwabacher WB. Effects of opaque and porcelain surface texture on the color of ceramometal restorations. J Prosthet Dent 1981;46:330-340.
46. Sarac D, Sarac YS, Yuzbasioglu E, Bal S. The effects of porcelain polishing systems on the color and surface texture of feldspathic porcelain. J Prosthet Dent 2006;96:122-128.
47. Tuncdemir AR, Dilber E, Kara H, Ozturk A. The Effects of Porcelain Polishing Techniques on the Color and Surface Texture of Different Porcelain Systems. Mater Sci Appl 2012; 3.05: 294.
48. Kim IJ, Lee YK, Lim BS, Kim CW. Effect of surface topography on the color of dental porcelain. J Mater Sci Mater Med 2003;14:405-409.
49. Yuzugullu B, Celik C, Erkut S, Ozcelik TB. The effects of extraoral porcelain polishing sequences on surface roughness and color of feldspathic porcelain. Int J Prosthodont 2009;22:472-475.
50. Lee YK, Cha HS, Ahn JS. Layered color of all-ceramic core and veneer ceramics. J Prosthet Dent 2007;97:279-286.