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Shade Matching Assisted by Digital Photography and Computer Software

Lars Schropp, DDS, PhD

Associate Professor, Department of Prosthetic Dentistry, University of Aarhus, Denmark

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Correspondence
Lars Schropp, University of Aarhus–Department of Prosthetic Dentistry, Vennelyst Boulevard, 9 Aarhus C 8000, Denmark. E-mail: lschropp@odont.au.dk

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Abstract

Purpose: To evaluate the efficacy of digital photographs and graphic computer software for color matching compared to conventional visual matching.
Materials and Methods: The shade of a tab from a shade guide (Vita 3D-Master Guide) placed in a phantom head was matched to a second guide of the same type by nine observers. This was done for twelve selected shade tabs (tests). The shade-matching procedure was performed visually in a simulated clinic environment and with digital photographs, and the time spent for both procedures was recorded. An alternative arrangement of the shade tabs was used in the digital photographs. In addition, a graphic software program was used for color analysis. Hue, chroma, and lightness values of the test tab and all tabs of the second guide were derived from the digital photographs. According to the CIE L*C*h* color system, the color differences between the test tab and tabs of the second guide were calculated. The shade guide tab that deviated least from the test tab was determined to be the match. Shade matching performance by means of graphic software was compared with the two visual methods and tested by Chi-square tests ($\alpha = 0.05$).
Results: Eight of twelve test tabs (67%) were matched correctly by the computer software method. This was significantly better ($p < 0.02$) than the performance of the visual shade matching methods conducted in the simulated clinic (32% correct match) and with photographs (28% correct match). No correlation between time consumption for the visual shade matching methods and frequency of correct match was observed.
Conclusions: Shade matching assisted by digital photographs and computer software was significantly more reliable than by conventional visual methods.

Several parameters influence whether the esthetic outcome of prosthodontic treatment is acceptable. A key factor is fabrication of a restoration whose color and shape is harmonious with the rest of the dentition. To duplicate the color of a natural tooth, three procedures are required: determination of the tooth shade clinically, communication of the shade to a dental laboratory technician (if shade taking is performed by the dentist), and shade reproduction in dental porcelain. These are all challenging tasks.[1-5] One study[1] evaluating the total color replication process concluded that reliable fabrication of a properly matched restoration to existing porcelain restorations cannot be ensured regardless of the shade assessment method used. Lagouvardos et al[2] also demonstrated difficulty in shade matching of shade tabs and teeth.

Traditionally, shade selection has been performed visually with the aid of a shade guide. Various guides exist to facilitate the matching process. Studies have shown that some shade-matching systems are superior to others[6-8] and that new designs of guides and alternative shade tab arrangements may yield better results;[9,10] however, regardless of the type of shade guide system used, visual shade determination is associated with a high degree of subjectivity. The ability to perceive color differences varies from person to person,[11] and experience in shade matching may also be of importance. Furthermore, the performance may be affected by eye fatigue.[12] The light source used when determining the shade has an impact on the appearance (metamerism) and could be a source of error as well.[11] Therefore, a demand for methods that can analyze tooth shade objectively has emerged.[13] This could result in greater reliability and thereby diminish the need for prosthesis color corrections.

Digital imaging has potential for use in dental shade determination.[14,15] This is obvious in situations where the tooth color, including a description of effects, such as enamel hypoplasia or decalcification, and translucency must be communicated between the clinician and the laboratory technician. Furthermore,

Table 1 Correct match of 12 test tabs determined by 9 observers. Each test tab was matched against 6 alternative shade tabs on computer screen

	Test tabs											
	2M2	2R2 1/2	3L2 1/2	3M2	3R2 1/2	4L2 1/2	4M1	4R2 1/2	2M1	5M1	4R1 1/2	2L1 1/2
WE	5/9	4/9	8/9	6/9	8/9	7/9	9/9	3/9	8/9	5/9	6/9	7/9
OE	2/9	2/9	7/9	6/9	5/9	4/9	8/9	3/9	9/9	9/9	9/9	8/9
UE	4/9	5/9	9/9	7/9	4/9	0/9	3/9	3/9	7/9	8/9	7/9	7/9

WE, well-exposed photograph; OE, overexposed photograph; UE, underexposed photograph.

digitized images can be transmitted electronically, which along with the widespread use of the Internet, makes this option advantageous.

Instrumental color determination has been introduced recently. In previous investigations the use of colorimeters or spectrophotometers has been shown to be efficient;[16-18] however, these devices are rather expensive, which may restrict their extension to dental practices. Therefore, development of a simple shade selection system with high reliability that is usable in dental practice would be beneficial.

The purpose of this clinical study was to evaluate digital imaging combined with an alternative shade guide arrangement, as well as the use of graphic computer software for shade matching in comparison to conventional visual matching. The null hypothesis was that no difference existed between visual shade matching performed clinically or with digital photographs, and shade matching assisted by computer software.

Materials and methods

Twelve tabs from a shade guide (Vita 3D-Master Guide, Vident, Brea, CA) were selected for shade determination. The test tabs are presented in Table 1. A power analysis was performed to determine adequate sample size. The study was divided into four parts. First, each shade tab was visually matched to five alternative shade tabs on digital photographs presented on a computer monitor by nine observers. Three flash settings were compared. Second, the observers visually matched the shade tabs by the use of a second shade guide in a simulated clinic environment. Third, the observers matched the shade tabs by the use of the second shade guide, now with an alternative arrangement of the shade tabs, on a computer monitor. Fourth, the shade tabs were matched by the use of a graphic computer program.

In Part 1, the influence of flash settings on shade matching performance when using digital photographs was evaluated. Shade matching of the test tabs was executed visually on a computer screen by nine observers (eight women, one man): four dentists, four dental laboratory technicians, and one first-year dental student. All observers stated that they were unaware of having abnormal color vision but were not tested.

For each of the test tabs, the matching shade tab (the one with the same color code) plus five alternative shade tabs were selected from a second Vita 3D-Master Guide. The alternative shades chosen were similar in shade to that of the test tab but did not match according to the guide. The test tab and the matching shade tab were placed side by side on a neutral light gray background (lightness = 207, chroma = 12, hue = 57), and a photograph was made using a digital single lens reflex camera (Canon EOS 20D, Canon USA Inc, Lake Success, NY) with a ring flash (Macro Ring Lite MR-14EX, Canon). The camera/flash settings were: macro lens AF 100 mm, aperture F22, shutter speed 1/125 s, ISO 200, Automated White Balance. The distance from object to lens was 25 cm. Likewise, photographs were made with the test tab placed beside each of the alternative shade tabs. Three settings for the flash were used (manual flash mode: 1/4, 1/32, and 1/8 flash output of full power), resulting in overexposed (OE), underexposed (UE), and well-exposed (WE) images, respectively. Using graphic software [Paint Shop Pro (PSP), Version 9.0; Corel Corp, Ottawa, Canada] the six WE digital images were merged to one file and arranged in three rows and two columns (Fig 1) and similarly for the OE and UE images. By viewing the image arrangement on a 17-inch LCD display (ViewSonic VG700b, ViewSonic Corp, Walnut, CA), the observers were asked to select the image they found containing the two shade tabs with identical color codes, and the image chosen and time spent for the assessment were recorded. Overall, 36 image arrangements were evaluated (12 test tabs, 3 flash settings). The monitor was calibrated before each color-matching procedure by the use of the monitor software (auto image adjust).

All test tabs as well as the tabs of the second shade guide used in the study were tested using a spectrophotometer (Vita Easyshade Spectrophotometer, Vident). The spectrophotometer measurement corresponded with the color code of the guide for all specimens.

In Part 2, at the same session, the observers' ability to visually match each of the 12 test tabs using a Vita 3D-Master Guide with 26 shade tabs was evaluated. The arrangement of the shade tabs is displayed in Figure 2. A phantom head (not commercially available) based on a Columbia dentoform model (S562, Columbia Dentoform Corp, Long Island City, NY) was used. The test tab was placed in the phantom head (Fig 3), and the original identification code from the guide was masked by a label with an "anonymous" sample code. Shade taking was performed in a dental clinic with standardized daylight lamps (Elipse U3 EL-4,000° K, D-TEC AB, Östra Hamnen, Sweden). The use of supplemental light from an operatory lamp (Kavolux 1410, Kavo Dental GmbH, Biberach, Germany) with a color temperature of 4,800° K (color corrected to approximate to daylight) was permitted if preferred by the observer. The observer was asked to match the color of each tab by the use of the guide, and the shade chosen and the time spent for the procedure were recorded. The same dental clinic was used for all shade-matching procedures, and the observers were

Figure 1 Test tab placed beside six alternative shade tabs. Tabs in lower right-hand corner match.

Figure 2 The tab arrangement of the Vita 3D-Master Guide.

Figure 3 Test tab placed in phantom head for conventional visual shade matching in simulated clinic.

Figure 4 Digital photograph with alternative arrangement of shade tabs from shade guide for shade matching on computer screen.

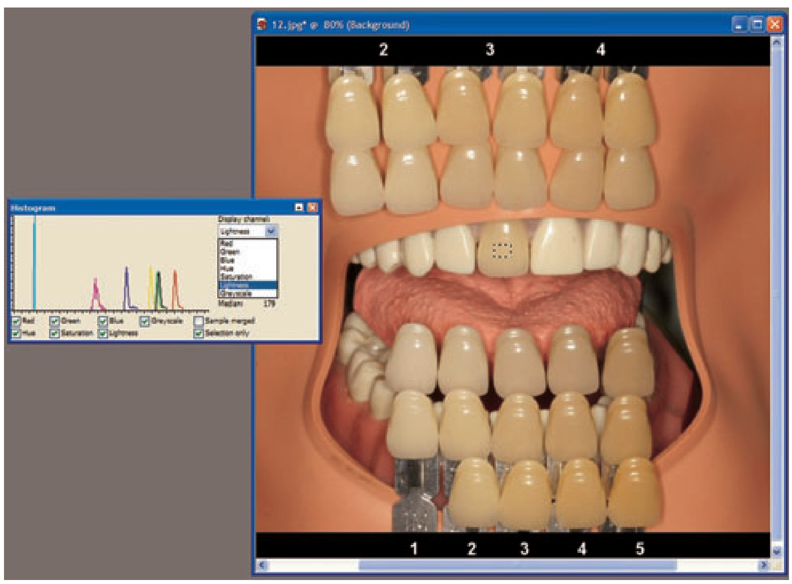

Figure 5 Lightness, chroma, and hue values were derived from selected area of test tab and shade tabs from the second guide using a graphic computer program.

positioned alike in the clinic in relation to light source and phantom head.

According to the manufacturer of the shade guide, shade determination should be conducted in three steps: (1) selection of lightness level (value groups 1 to 5), (2) selection of saturation (chroma groups 1 to 3 based on the middle hue group (M), and (3) selection of hue (L, M, or R). Five of the nine observers stated they knew how to use the guide; however, this was not verified, and none of the observers were instructed in proper use of the guide.

In Part 3, approximately 2 months after the first session, shade matching of the twelve test tabs was performed by the observers combining the use of the shade guide and digital photography. An alternative grouping of the shade tabs was made and arranged above and below the test tab placed in the phantom head (Fig 4). The middle hue group (M) of all five lightness groups were arranged at the bottom, with the lightest tabs on the left, the darkest on the right, and the tabs with the lowest saturation (chroma) situated nearest to the test tab. Correspondingly, the R and L hue groups of lightness groups 2 to 4 were arranged at the top. A digital photograph of the phantom head was made for all twelve test tabs with the same camera and settings as described above. The observers evaluated the images one at a time on the same computer screen being used in the first session, and were this time instructed in shade matching. First, the observer was asked to decide which lightness group (1 to 5) the test tab belonged to. Second, the observer selected the chroma. Third, in the situation of having chosen a shade in lightness groups 2 to 4, the observer was asked to evaluate the R and L hues of the same value group before the final determination. The shade selected and the amount of time spent for the procedure were recorded.

In Part 4 of the study, a method for quantitative shade matching by the use of graphic software was evaluated. The images of the phantom head with test tab and shade tabs of the Vita 3D-Master Guide used for the visual shade selection were analyzed using PSP graphic software. The graphic software has the ability to analyze the image in terms of lightness (L), chroma (C), and hue (h) values. The internationally recognized CIE L*C*h* color system[19] uses these color values to objectively describe a color. An area of the test tab was selected manually by the mouse pointer, and mean values of L, C, and h for the area were derived by PSP (Fig 5). The selection was approximately one-tenth the size of the shade tab and was situated in the middle part of the tab. The zoom function of the program was used to ease selecting an area containing a uniform color, and areas with reflections from the light flash were avoided. L, C, and h values for the 26 shade tabs from the guide were likewise recorded. By using the formula $\Delta E = \sqrt{\Delta L^2 + \Delta C^2 + \Delta h^2}$ from the CIE L*C*h* color system, the color differences between the test tab and the 26 shade tabs were calculated. The shade guide tab, which deviated least from the test tab (smallest value of ΔE) was determined to be the match. The recordings in PSP were blinded, as the dentist who performed the color analyses did not know the color code of the test tab. Recordings of hue, saturation, and lightness were repeated with an interval of 4 weeks for six test tabs and thirty shade guide tabs selected from the twelve images.

Chi-square tests were used for comparison of shade matching performed in the simulated clinic and by the use of photographs. Likewise, shade-matching performance by means of graphic software was compared with the two visual methods by Chi-square tests. Correlation between time consumption and frequency of correct match for visual shade matching in the simulated clinic and with digital photographs was tested by means of Spearman's rho test. Reproducibility of the color analysis performed with the graphic software was tested by the Wilcoxon signed rank test for paired data. An alpha level of 0.05 was used for all statistical testing.

Results

The observers were on average able to match the test tab to six alternative shade tabs correctly on a computer screen in 66% of the situations (range 22 to 29 matches of 36). Matches for the underexposed (59%) photographs were slightly lower than for the overexposed (67%) and well-exposed (70%) photographs. The results for the twelve test tabs are displayed in Table 1. Data did not show tendencies for lighter shades or darker shades of the guide (high or low lightness) to be easier to match. The observers spent on average 33 seconds on the shade matching procedure per test tab (range 29 to 35 seconds for the different professional groups). A significant correlation between match and time was found ($p = 0.01$), in that a better match was found among observers who spent more time for the procedure.

The nine observers were on average able to determine the correct shade tab in 32% of the situations when the shade guide in the simulated clinical scenario was used for conventional visual shade taking (range 0 to 9 of 12 tabs). The percentages of correct shade determination were 31% for the dental technicians and 35% for the dentists. Seven observers matched less than half of the 12 test tabs correctly. As shown in Table 2, four of the test tabs were matched by one or none of the observers. The observers matched the correct lightness of the test tab in 44% of the situations. A darker shade (1 or 2 values) was chosen in 54% of the situations. The matching procedure took, on average, 97 seconds per test tab (dental technicians: 77 seconds, dentists: 102 seconds). No correlation between time and match was found ($p = 0.3$).

The nine observers were, on average, able to determine the correct shade tab in 28% of the situations when digital photographs with an alternative arrangement of the shade tabs were evaluated on a computer screen (range 2 to 5 of 12 tabs). The results are presented in Table 2. This was not significantly different from the conventional matching method ($p = 0.51$). The percentages of correct match for the technicians (31%) corresponded to those achieved by the conventional shade-taking procedure in the simulated clinic environment. The dentists performed worse (25% correct matches) than with the conventional method (35%); however, the difference was not significant ($p = 0.27$). On average for all observers, the correct lightness of the test tab was recognized in 55% of the situations, which was not significantly different from the results of the conventional procedure ($p = 0.13$). A darker shade (1 or 2 values) was chosen in the remaining situations except for one. The matching procedure took on average 45 seconds per test tab (technicians:

Table 2 Correct match of 12 test tabs determined by 9 observers using shade guide in simulated clinic and digital photographs with alternative arrangement of guide, and correct match (√) by graphic software program (GSP)

	Test tabs											
	2M2	2R2½	3L2½	3M2	3R2½	4L2½	4M1	4R2½	2M1	5M1	4R1½	2L1½
Clinic												
CS	0/9	0/9	1/9	1/9	2/9	2/9	6/9	2/9	6/9	7/9	5/9	3/9
CL	0/9	1/9	1/9	1/9	4/9	4/9	7/9	3/9	6/9	8/9	7/9	6/9
Photos												
CS	1/9	0/9	0/9	1/9	3/9	1/9	7/9	1/9	2/9	9/9	4/9	1/9
CL	4/9	0/9	3/9	7/9	4/9	2/9	8/9	3/9	6/9	9/9	8/9	5/9
GSP												
CS		√	√			√	√	√	√	√	√	
CL	√	√	√		√	√	√	√	√	√	√	√

CS, correct shade tab; CL, correct lightness.

37 seconds, dentists: 43 seconds). No significant correlation between time and match was detected ($p = 0.08$).

By using a graphic software program for shade selection, 8 of 12 shade tabs (67%) were correctly matched (Table 2). In three of the four situations of incorrect match, the program suggested a shade with correct lightness and chroma, while only the hue differed from the true one. In the last situation, the program suggested the shade 2M3 instead of 3M2. The reproducibility of the hue, saturation, and lightness recordings was statistically significant ($p > 0.35$). The shade-matching capabilities of the computer program were significantly better than those of the observers when visual shade taking was performed in the simulated clinic or by the use of digital photographs ($p < 0.02$).

Discussion

Data of the present study support rejection of the null hypothesis that no difference exists between visual shade matching performed in a simulated clinic environment or with digital photographs and shade matching assisted by computer software.

A reliable shade selection method is a prerequisite for obtaining a predictable esthetic outcome of a prosthetic restoration. Previous studies have demonstrated that conventional visual shade determination, irrespective of the type of shade guide used, is a challenging task.[2–4] Preliminarily (Part 1), this study investigated the significance of the quality of digital photographs when using these for matching shade tabs from a dental shade guide. The percentage of correct matches was lower on underexposed photographs than with well- or overexposed photographs, and it is suggested that optimal images concerning exposure should be provided for shade taking.

The Vita 3D-Master Guide was used for visual shade matching in this study, because it is commonly used among clinicians and associated with a high intrarater repeatability[8] and success in achieving acceptable color match.[6,7] Since shade guides may vary between batches, all shade tabs were measured with a spectrophotometer to ensure that the shade corresponded to the color code.

The results of this study showed that the performance of conventional visual shade matching and shade matching executed with digital photographs presented on a computer screen was comparable. In a previous study, Jarad et al[14] found a significantly better matching performance when evaluating on a computer monitor (61%) than with a visual matching method simulated in a phantom head (43%). Visual matching of twelve shade tabs was difficult for most dental professionals for both methods, while a smaller interobserver variance was seen for the latter method. On average, only one-third of the tabs were matched correctly, while the lightness level of the shade was determined correctly in approximately 50% of the situations. It was striking that the observers were highly inclined to choose a shade tab that was too dark. Other studies have matched shade tabs under in vitro conditions. Two studies demonstrated correct matches of approximately 45% of the shade tabs using Vita Lumin shade guides,[4,14] while Geary and Kinirons[5] found a matching performance of 64%. However, the latter study was conducted on the laboratory bench and may not be comparable with the simulated clinic environment. There is no reason to believe that color determination of a natural tooth should be easier, since the color of a tooth is often far more complex than that of a shade tab. The present sample population sizes were too small to evaluate whether the type of dental profession has an impact on shade-taking skills, and studies with a larger population are needed to provide evidence in this respect.

It has been stated that short rests should be allowed during the color-matching procedure to prevent eye fatigue.[12] This may increase the time spent for shade selection. The present results disclose a correlation between time consumption and success of match in Part 1, but no correlation when matching shades in the simulated clinic (Part 2) or on the computer monitor (Part 3).

Half the observers in this study were not familiar with the use of the shade guide, and no instructions were given. Furthermore, the phase sessions for the groups were not alternated. Experience in shade matching gained during the sessions may be expected (particularly for the individuals who were not familiar with the shade guide) and could have skewed the results. All observers stated that they were not aware of having abnormal color vision, but this was not tested. These facts may be considered study limitations.

One advantage of using digital photographs is that they can be transmitted electronically to the dental laboratory technician for color selection. In addition to determination of the basic tooth shade, the technician will also have a better chance to assess the tooth regarding form, surface texture, translucency, and the presence of various effects, such as hypoplastic or decalcified areas. These parameters might be difficult to communicate efficiently between dentist and laboratory technician verbally or by means of conventional laboratory prescriptions. It should be noted that the same digital image will not appear to be the same color on different computer monitors. Therefore, one or more shade tabs with known color codes must be present on the photograph together with the tooth to be matched, or, alternatively, calibration between the clinician and laboratory monitors must be made. Provision of the digital photographs will obviously take some time; however, the data revealed that the observers spent 1 minute less per test tab for the bare shade matching procedure on the computer screen than in the simulated clinic. In a patient situation, it was determined that making of the photograph including the alternate arrangement of the shade guide took less than 1 minute more than making a photograph without a shade guide.

An alternative arrangement of the shade tabs in this part of the study was suggested. One of the differences between the conventional visual method and the matching procedure on the computer screen is that the observer in the former method is able to take the tabs out of the shade guide, whereas the position of the tabs is fixed in the latter method. Arranging the middle hue group (M) of all five lightness groups together was considered to facilitate shade selection on the screen; however, it is not possible to determine whether this alternative arrangement had an influence on the results.

Realizing the limited reliability associated with visual shade matching, a method for shade selection applying computer software was proposed in this study. It was demonstrated that this method was superior to visual shade matching. By means of quantitative color measuring, two-thirds of the test tabs were matched correctly, and the correct lightness of the tab was recognized in more than 90% of the cases. Selecting the measuring area of the shade tabs manually (free-hand) may be a source of error; however, the good reproducibility of the recordings in this study corresponded to the findings of a previous study,[13] which revealed a high accuracy of a similar graphic program for color analysis. It should be emphasized that precaution must be taken in extrapolating data of this study to a clinical scenario. Matching one shade tab to another is not the same as matching to a natural tooth. Difference in translucency and varying shades in different parts of the tooth could complicate matters. Furthermore, the appearance of translucency may differ due to the fact that the tooth to be matched is in the mouth, and the shade tabs are outside the mouth, which may hinder the use of a graphic program.

The use of graphic software for quantitative color determination may be an alternative to colorimeters and spectrophotometers. The method is relatively inexpensive, as digital cameras and computers are generally available in dental practices and laboratories.

In spite of the limitations associated with this study, the author suggests that color analysis of digital photographs has the potential to be used for shade matching in dentistry. Future clinical studies are needed to verify application of the computer software method for shade matching to natural teeth in the clinical situation and whether it has an influence on the esthetic result of prosthetic treatments.

Conclusion

The present study demonstrated a statistically better performance by the graphic computer program than with visual shade taking performed in the simulated clinic or by the use of digital photographs. Furthermore, no statistical difference was found between visual shade matching performed in the simulated clinic scenario and by viewing digital photographs.

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References

1. Wee AG, Monaghan P, Johnston WM: Variation in color between intended matched shade and fabricated shade of dental porcelain. J Prosthet Dent 2002;87:657-666
2. Lagouvardos PE, Diamanti H, Polyzois G: Effect of individual shades on reliability and validity of observers in colour matching. Eur J Prosthodont Restor Dent 2004;12:51-56
3. Klemetti E, Matela AM, Haag P, et al: Shade selection performed by novice dental professionals and colorimeter. J Oral Rehabil 2006;33:31-35
4. Okubo SR, Kanawati A, Richards MW, et al: Evaluation of visual and instrument shade matching. J Prosthet Dent 1998;80: 642-648
5. Geary JL, Kinirons MJ: Use of a common shade guide to test the perception of differences in the shades and value by members of the dental team. Prim Dent Care 1999;6:107-110
6. Hassel AJ, Koke U, Schmitter M, et al: Clinical effect of different shade guide systems on the tooth shades of ceramic-veneered restorations. Int J Prosthodont 2005;18:422-426
7. Wee AG, Kang EY, Jere D, et al: Clinical color match of porcelain visual shade-matching systems. J Esthet Restor Dent 2005;17:351-357
8. Hammad IA: Intrarater repeatability of shade selections with two shade guides. J Prosthet Dent 2003;89:50-53
9. Paravina RD: Evaluation of a newly developed visual shade-matching apparatus. Int J Prosthodont 2002;15:528-534
10. Analoui M, Papkosta E, Cochran M, et al: Designing visually optimal shade guides. J Prosthet Dent 2004;92:371-376
11. Fondriest J: Shade matching in restorative dentistry: the science and strategies. Int J Periodontics Restorative Dent 2003;23: 467-479
12. Miller LL: Shade selection. J Esthet Dent 1994;6:47-60
13. Cal E, Sonugelen M, Guneri P, et al: Application of a digital technique in evaluating the reliability of shade guides. J Oral Rehabil 2004;31:483-491
14. Jarad FD, Russell MD, Moss BW: The use of digital imaging for colour matching and communication in restorative dentistry. Br Dent J 2005;199:43-49

15. Wee AG, Lindsey DT, Kuo S, et al: Color accuracy of commercial digital cameras for use in dentistry. Dent Mater 2006;22:553-559
16. Ishikawa-Nagai S, Ishibashi K, Tsuruta O, et al: Reproducibility of tooth color gradation using a computer color-matching technique applied to ceramic restorations. J Prosthet Dent 2005;93:129-137
17. Paul SJ, Peter A, Rodoni L, et al: Conventional visual vs spectrophotometric shade taking for porcelain-fused-to-metal crowns: a clinical comparison. Int J Periodontics Restorative Dent 2004;24:222-231
18. Dancy WK, Yaman P, Dennison JB, et al: Color measurements as quality criteria for clinical shade matching of porcelain crowns. J Esthet Restor Dent 2003;15:114-121
19. CIE Publication No. 15.2. CIE Colorimetry (ed 2). Paris, Bureau Central de la CIE, 1986