Critical Appraisal

COLOR IN DENTISTRY: IMPROVING THE ODDS OF CORRECT SHADE SELECTION

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This Critical Appraisal focuses on how well dental shade guides correspond to the color range and distribution of natural teeth. In other words, we will discuss "chances" of shade guides to match shades of human teeth and demonstrate alternatives.

COVERAGE ERROR OF THREE CONCEPTUALLY DIFFERENT SHADE GUIDE SYSTEMS TO VITAL UNRESTORED DENTITION

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ABSTRACT

Statement of the Problem: It remains unclear which shade guide system is most representative of the shades found in the human dentition.

Purpose: The aims of this study were to determine and to compare the coverage errors (CEs) of three different shades in a selected population (five age groups: 18–29, 30–39, 40–49, 50–59, and 60–85 years old).

Materials and Methods: The CEs of the following shade guide systems were evaluated to determine which shade guide system is most effective in producing the best visual shade match: (1) Vita Lumin (Vita Zahnfabrik, Bad Säckingen, Germany), (2) Chromascop (Ivoclar Vivadent, Schaan, Liechtenstein), (3) Vitapan 3D-Master (Vita Zahnfabrik), and (4) a combination of the three shade guide systems. The spectral reflectance values of the central one-ninth (1-mm diameter) of each shade tab (without a backing) were measured by using a spectroradiometer and an external light source at wavelengths from 380 to 780 nm at 2-nm intervals. All spectral reflectance measurements were made by using 0-degree observer and 45-degree illumination and were converted to Commission Internationale de l'Eclairage, Vienna, Austria values. The color parameters of 359 anterior teeth were measured with the same protocol. The CEs for each of the 359 anterior teeth for each shade guide

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system, and with all three shade guide systems, were determined and averaged. Repeated measures analysis of variance was used to evaluate the mean minimum CEs within-subject (shade guide system) and between-subject (age) difference as well as the interaction between these variables. Post hoc multiple comparisons were performed by using the Tukey–Kramer test.

Results: A significant difference was found between the mean minimum CEs of the three shade guide systems and their combination but not between age groups. The interaction of shade guide systems and age was significant. The mean minimum CEs for the Vita Lumin (5.39 ΔE) and Chromascop (5.28 ΔE) shade guide systems were not significantly different from each other. However, the combination of all three shade guide systems (3.69 ΔE) and Vitapan 3D-Master (3.93 ΔE) was significantly different from the Vita Lumin and Chromascop shade guide systems. The rankings of the shade guide systems within each age group were similar between the age groups.

Conclusions: The Vitapan 3D-Master shade guide system resulted in lower CEs than the Vita Lumin or Chromascop shade guide systems. CEs for the Vitapan 3D-Master shade guide system did not differ significantly from the CEs when all three shade guide systems were combined.

COMMENTARY

Shade guides are tools for visual color matching in dentistry. Dental color standards are supposed to be schematic representations of tooth color and consist of a certain number of shade tabs. Although several instruments for intraoral color measurement are available, visual color matching method by means of shade guides is by far the predominant method. The term "coverage error" (CE) was introduced in 1991 to describe the mean color difference between each evaluated natural tooth and the best matching tab from a particular shade guide.

CEs reported in this study (5.4 for Vita Lumin, 5.3 for Chromascop, and 3.9 for Vitapan 3D-Master) are larger than those reported in 1991, when the CE was 3.0 for both Vita Lumin and Bioform (Dentsply Prosthetics, York, PA, USA) shade guides. A 2004 study also reported smaller CE values: 3.1, 3.3, and 2.7 for Vita Lumin, Trubyte Bioform, and Vitapan 3D-Master, respectively.

Based on one of the figures in the paper presented in this abstract, the a* values (green–red coordinate) of all evaluated shade guides were lower than the corresponding a* values of natural teeth. The highest a* values in three shade guides were recorded for C4 of Vita Lumin (2.6), 540 of Chromascop (7.6), and 5M3 of Vitapan 3D-Master (7.0). At the same time, extreme green–red coordinate values for natural teeth were up to a* ≈ 12. The maximum color difference of ΔE* ≈ 27 for each shade guide was likely influenced by the a* coordinate discrepancy. These findings are very interesting and agree with the clinical observation that shade guides lack redder shades. What is not in accordance with the literature and clinical practice is that the best matches for almost 50% of natural teeth were shades C3, C4, D2, and D3, with C3, C4, and D3 being more frequent than any of A-group shades.

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IN VIVO SPECTRORADIOMETRIC EVALUATION OF COLOR MATCHING ERRORS AMONG FIVE SHADE GUIDES

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ABSTRACT

Purpose: The purpose of this study was to evaluate the color errors of visual shade selection by five different shade guides.

Materials and Methods: The maxillary left central incisors of 60 subjects were visually evaluated by two groups of prosthodontists having different levels of clinical experience. The shade selection results were recorded, and the most frequently selected tab was determined as the resultant shade for each tooth. If totally different opinions were obtained, consensus was forced to determine the resultant shade among the observers. The Commission Internationale de l'Eclairage L*a*b* (CIELAB) coordinates of each tooth and shade tab were measured by using a spectroradiometer. The CEs of each shade guide and color difference (ΔE) between a tooth and the selected shade tab were calculated. Two-way ANOVA and Tukey's post hoc analysis were used to evaluate the differences of CE and ΔE values between shade guides and level of clinical experience.

Results: CEs and ΔEs in all of the five shade guide systems were all beyond the clinical threshold of 3.3 units. Consensus provided better color matching than the single-decision group for the Vitapan 3D-Master and Vintage Halo NCC (Shofu, Menlo Park, CA, USA) shade guides. Significant differences were found for ΔEs by shade guide system and clinical experience.

Conclusions: None of the shade guide systems achieved clinically compatible shade matching. However, the Vitapan 3D-Master had the lowest CEs and ΔEs. Consensus could be helpful in enhancing the esthetic results by using the Vitapan 3D-Master and Shofu NCC (Shofu, Menlo Park, CA, USA) shade guides.

COMMENTARY

In addition to providing the instrumental findings on the CEs of different shade guides (as in the first paper presented in this Critical Appraisal), this study considered visual (subjective) CE and the influence of consensus and years in practice on the quality of shade matching.

The visual CEs were calculated by using the same approach as in the instrumental (objective) method. The only difference is that the best-matching tabs were selected visually. Therefore, the selected tabs were not necessarily the ones with the smallest color difference compared with natural teeth. The increases in visual CEs (with consensus) compared with instrumentally obtained values were 5.7, 10.3, 13.4, 22.3, and 24.1% for Vitapan 3D-Master and Vita Lumin (Vita Zahnfabrik, Bad Sackingen, Germany), Vintage Halo and Vintage Halo NCC (Shofu, Menlo Park, CA, USA), and Chromascop, respectively. Obviously, a smaller discrepancy between the visual and instrumental CEs is more favorable and might originate from the tab arrangement, which directly influences the user friendliness of the shade-matching procedure.

It appears that the visual CE, reported for the first time in this article, deserves full attention because the line between the *objective* and the *subjective* is very thin in color science and in psychophysics. Color measurement instruments are considered to be objective but only if their readings are in accordance with visual (subjective) findings.

If we put errors in visual shade matching aside for a second, what if the best match instrumentally is really not the best match visually? Visual thresholds for lightness (*L*, achromatic, black to white, value), chroma (*C*, color strength, pale to strong), and hue (*h*, color name) differences are not the same, whereas the ΔE* value per se tells us nothing about the origin of color difference. In other words, the ΔE* provides information on the magnitude but not the direction of color differences.

Therefore, a ΔE* = 3 that predominantly originates from the hue difference might visually appear more pronounced than the ΔE* = 4 that predominantly originates from the difference in lightness. The instruments do not have awareness of that. They will give us numbers for color differences and differences in lightness, chroma and hue but will not tell us which color difference from our examples really appears larger visually. One example to illustrate that simply following the numbers can be misleading is a comparison of the A1 and B1 Vita shades. Although A1 actually has a higher value, the vast majority of dental professionals consider that B1 (which is less chromatic) is the lighter shade and is the first tab of the so-called value orientation of the Vita shade guide.

Whereas the decrease in visual CEs with consensus for some shade guides might be clinically relevant, the number of observers in this study probably diminishes the significance of findings on the influence of years in practice on shade-matching quality.

Standardization of color-matching method and conditions, together with monitoring color temperature and illuminance, would add more significance to this otherwise very nice contribution.

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OPTIMIZATION OF TOOTH COLOR AND SHADE GUIDE DESIGN

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ABSTRACT

Purpose: One critical prerequisite for dental shade guides is to match the color range and distribution of human teeth. The aims of this study were to design computer models for dental shade guides and to compare them with an existing shade guide. A targeted CIELAB (ΔE*) CE for a newly developed shade guide was ΔE* < 2, with a corresponding CIEDE2000 (ΔE') value.*

Materials and Methods: A total of 1064 teeth were evaluated in vivo by using an intraoral spectrophotometer. Shade guide models were designed by using different methods for representation of the data set, hierarchical clustering, and nonlinear constrained optimization. CE was calculated for both CIELAB and CIEDE2000 values. Recorded values were compared with CE of the Vitapan Classical (Vita Zahnfabrik) shade guide. Wilcoxon signed-rank test for paired samples and linear regression was used in the statistical analysis.

*CIELAB and CIEDE2000 are color difference formulae of the CIE system.

Results: CE of the Vitapan Classical was 4.1, ranging from 0.5 to 11.5 ΔE^*. Group A shades had the best match for human teeth (43.9%) followed by Groups C (24.1%), B (20.4%), and D (11.7%) shades, respectively. CIELAB CEs of the newly designed 24-tab shade guide using clustering and optimization were 2.05 and 1.96, respectively. Corresponding CIEDE2000 CE values were 1.43 and 1.40, respectively. A significant difference between results obtained by using clustering and optimization was determined. CIELAB color differences were greater but highly correlated as compared with their CIEDE2000 counterparts ($\Delta E' = 0.64 \times \Delta E^* + 0.13$, $r > 0.99$). This means that ΔE^* values can be successfully calculated based on a known $\Delta E'$ value and vice versa.

Discussion: This study demonstrated that, compared with existing shade guides, future shade guides can provide either (1) similar coverage of tooth color with fewer tabs, thus simplifying the shade-matching procedure, or (2) better coverage of tooth color with a similar number of tabs. Either approach could improve the chances of satisfactory matches and, consequently, could provide better esthetics.

Conclusions: Both clustering and optimization enabled better representation of tooth color than an existing dental shade guide. Optimization outperformed clustering and is therefore recommended as a method of choice for representation of tooth color and design of dental shade guides.

COMMENTARY

The aim of the studies presented in the previous two abstracts was to determine CE of various dental shade guides. Results were not quite satisfactory for some of the evaluated products.

The objective of this in vivo study was to compare CEs of an existing shade guide with computer models for dental shade guides. Four sets of 30 model shade guides (containing 1, 2, 3 . . . , and 30 tabs) were designed by using two methods for representation of the data set (clustering and optimization) and two color difference formulae (CIELAB and CIEDE2000) based on color coordinates of 1064 natural teeth. The CIELAB CE of Vitapan Classical to natural teeth ($\Delta E^*_{COV} = 4.1$) was matched with the corresponding five-tab optimized model. The 12-tab model matched the 50:50% acceptability threshold of $\Delta E^* = 2.7$, and the 24-tab model had $\Delta E^*_{COV} < 2.0$. Corresponding CIEDE2000 CEs for 5, 12, and 24-tab optimized shade guide models were 2.7, 1.9, and 1.4, respectively. The 26-tab model, derived from an in vitro study of 150 extracted teeth with the use of hierarchical clustering only, exhibited the same CE as the 24-tab model in this study of 1064 teeth in vivo with the use of both clustering and optimization.

It is interesting that the Vitapan Classical exhibited almost the identical CE to permanent teeth ($\Delta E^*_{COV} = 4.1$) and primary teeth ($\Delta E^*_{COV} = 4.2$), as recorded in two independent studies and data sets. However, the color difference between mean L*a*b* values for primary and permanent teeth was 8.2, with the former being lighter, redder, and less chromatic. Because of the narrower ranges of lightness, chroma, and hue, the computer modeling worked even better with primary teeth; CIELAB CE of Vitapan Classical was matched with corresponding two-tab optimized model.

Several issues should be mentioned relative to the computer models of dental shade guides:

1. The color differences between natural teeth and best-matching tabs were obtained from the measuring device database
2. The models were ideal for given data sets, and it would be reasonable to expect higher CE when applying them to independent data sets. When the models

from one study of primary teeth were applied to the data set from another study, the CE value increase was 5 to 18%.

3. Color formulation and reproduction of physical shade tabs are complicated by the fact that teeth are small, curved, polychromatic, translucent, and multilayered
4. The creation of a shade guide with logical and user-friendly tab arrangement out of the physical tabs manufactured based on computer models could be challenging.

Computer-designed shade guides could enable a better esthetic outcome, and this topic certainly requires additional research. Until they appear on the market, it will be beneficial to learn how to use the existing products to their best advantage.

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THE BOTTOM LINE

The most critical prerequisite for dental shade guides is to match the color range and distribution of natural teeth. They also should be logically arranged and user friendly so that dentists and technicians with limited or no knowledge in color science can successfully match shades. However, additional education, including information on appropriate shade-matching method and conditions, and color training are always a plus and should be a permanent task for dental educators.

Although the absolute numbers reported as coverage errors (CEs) of available shade guides are different, largely to variety of color measurement instruments and techniques (contact or noncontact type), the bottom line is fairly clear: Vitapan Classical (Lumin Vacuum) and Trubyte Bioform have the biggest CE, and Vitapan 3D-Master has the smallest CE (i.e., it matches natural teeth the best). CEs of other shade guides are in-between these boundaries—Chromascop and Vintage Halo are closer to Classical, whereas Vintage Halo NCC is closer to the 3D-Master.

CE is a very convenient and simple method for evaluation of how well dental shade guides match the color of human teeth—the smaller the CE, the better the shade guide and the better the chances of selecting an appropriate match. The CE should be interpreted through the comparison with the 50:50% acceptability threshold—the color difference that is acceptable for 50% of observers (the remaining 50% of observers would replace or correct color of the restoration; *see the previous Critical Appraisal by this author*).

Generally, a good shade guide would have the CE at or below the 50:50% acceptability threshold. Getting closer to the 50:50% perceptibility threshold would probably make a shade guide less practical, as it would need to have a huge number of tabs. The number of tabs in the custom-designed shade guide models depends on the targeted CE. Fewer tabs and higher CE might be sufficient for direct restorative materials because of color shifting due to blending effect and physical translucency. Fewer tabs might also be needed for primary teeth because of their narrow color range. On the other hand, more tabs and lower CE might be needed to achieve the same esthetic outcome with fixed or removable prosthodontic restorations.

Current shade guide designs employ two basic conceptions: empiric (Vitapan Classical and shade guides keyed to it) and scientific (3D-Master), with the latter method being clearly superior. Within the scientific method, there are two main approaches. The existing one is mechanical, with the shade tabs relatively uniformly distributed within the tooth color space (as in 3D-Master). The second one is computer generated, custom-tailored, and based on realistic tooth color distribution (which is not uniform). If the first approach is the current state of the art, the second one appears to be very promising as a next step in evolution of dental shade guides. The study presented in the third abstract demonstrated that, compared with existing products, future dental color standards can provide either similar CE with fewer tabs (thus simplifying shade-matching procedure) or smaller CE with a similar number of tabs. This is a win–win scenario that might lead to better shade matching results, enhanced esthetics, and, ultimately, improved patient satisfaction.