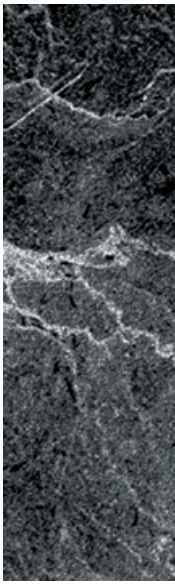

Critical Appraisal

COLOR IN DENTISTRY: MATCH ME, MATCH ME NOT

Author

Rade D. Paravina, DDS, MS, PhD*

Associate Editor

Edward J. Swift Jr., DMD, MS

This Critical Appraisal focuses on defining color match in dentistry through determination of perceptibility and acceptability visual thresholds. Differences between in vitro and clinical conditions, monochromatic and polychromatic materials, and old and new Commission Internationale de l'Eclairage (International Commission on Illumination; CIE) formulas will be considered. Color difference thresholds can serve as a quality control tool and as guidelines for selection of dental materials and evaluation of their clinical performance.

INTRAORAL DETERMINATION OF THE TOLERANCE OF DENTISTS FOR PERCEPTIBILITY AND ACCEPTABILITY OF SHADE MISMATCH

R.D. Douglas, T.J. Steinhauer, A.G. Wee
Journal of Prosthetic Dentistry 2007 (97:200–8)

ABSTRACT

Statement of the Problem: There is little agreement in the dental literature as to how much color difference constitutes an acceptable shade mismatch or how much color difference is perceptible to observers. Most studies attempting to determine perceptibility and acceptability of tolerances for shade mismatches have been conducted under in vitro conditions that are not applicable to clinical scenarios.

Purpose: The goal of this study was to determine valid acceptability and perceptibility tolerances for shade mismatch in an actual clinical scenario using spectroradiometric instrumentation.

Materials and Methods: A test denture was fabricated that allowed 10 maxillary left central incisors of varying shade mismatch with the right central incisor to be interchanged within the denture base. A spectroradiometer was used to determine the CIELAB coordinates and color differences (ΔE) between the right central incisor and the interchangeable left central incisor denture teeth. The interchangeable denture teeth ranged uniformly from 1 ΔE unit (visually undetectable) to >10 ΔE units (an obvious shade mismatch). The test denture with each of the interchangeable teeth was modeled by a subject to 28 dentists in a clinical setting. For each of the interchangeable teeth, dentist

*Assistant professor, Department of Restorative Dentistry and Biomaterials, University of Texas Dental Branch at Houston, Houston, TX 77030-3402

DOI 10.1111/j.1708-8240.2009.00246.x

observers were asked if they could see a difference between the central incisors and, if so, whether the difference was acceptable. A Probit regression analysis was used to predict acceptability and perceptibility tolerances with 95% confidence limits.

Results: The predicted color difference at which 50% of the dentist observers could perceive a color difference (50/50 perceptibility) was 2.6 ΔE units. The predicted color difference at which 50% of these observers would remake the restoration because of color mismatch (clinically unacceptable color match) was 5.5 ΔE. Acceptability and perceptibility color tolerances at the 50/50 level were significantly different.

Conclusions: Tolerances for perceptibility were significantly lower than tolerances for acceptability for shade mismatch between two adjacent denture teeth in a clinical setting.

COMMENTARY

Study design is critical when visual judgments are involved. Many design aspects of this study were well planned, and the article is a nice contribution to our understanding of perceptibility and acceptability thresholds.

However, there are several concerns. The first is related to differences in areas compared visually (whole teeth) and instrumentally (1 mm in diameter, at the middle of labial surface). Averaging the color of the small measured area in the latter method obviously did not take the overall tooth color transitions into account. Even if we assume that the color of the middle third is an adequate representation of the tooth color as reported in some publications, this approach is probably more appropriate for instrumental color measurements than for the psychophysical process of color perception and interpretation. Second, overhead light with possible shadowing by the patient's nose, uncontrolled illuminance, and a "freestyle" shade matching method (which likely resulted in variability of viewing geometries and shade matching distances) did not enhance the control and repeatability of the experiment. Together with the differences in evaluated tooth areas, these factors likely contributed to the higher values of perceptibility and acceptability thresholds as compared with some other dentistry and nondentistry studies.

Although routine clinical shade matching is rarely controlled, clinical research, especially when dealing with color difference thresholds and aiming to set standards for the profession, must be carefully controlled. It would be helpful to perform the identical experiment under controlled in vitro and in vivo conditions and determine whether there are discrepancies in color difference judgments.

SUGGESTED READING

Kuehni FG, Marcus RT. An experiment in visual scaling of small color differences. Color Res Appl 1979;4:83–91.

Bergen SF. Color in esthetics. N Y State Dent J 1985;51:470–1.

Ruyter IE, Nilner K, Moller B. Color stability of dental composite resin materials for crown and bridge veneers. Dent Mater 1987;3:246–51.

Douglas RD, Brewer JD. Acceptability of shade differences in metal ceramic crowns. J Prosthet Dent 1998;79:254–60.

Ragain JC, Johnston WM. Color acceptance of direct dental restorative materials by human observers. Color Res Appl 2000;25:278–85.

USE OF A PORCELAIN COLOR DISCRIMINATION TEST TO EVALUATE COLOR DIFFERENCE FORMULAS

A.G. Wee, D.T. Lindsey, K.M. Shroyer, W.M. Johnston
Journal of Prosthetic Dentistry 2007 (98:101–9)

ABSTRACT

Statement of the Problem: Limited studies have indicated that an alternative small color difference formula would be more appropriate for use in dentistry.

Purpose: The purposes of this study were to determine which color difference formula provides a superior degree of fit for judgments of perceptibility and acceptability and to determine whether different groups of evaluators have different levels of perceptibility and acceptability for each color difference formula.

Materials and Methods: Each observer from four groups (four dentists, four dental assistants, four technicians, and four patients) made independent observations of perceptibility and acceptability on pairs of opaque porcelain disks (14-mm diameter × 3-mm thickness). Color differences of the pairs were calculated using $\Delta E^*(ab)$, ΔE $(CMC)_{(l:c)}$, and ΔE (2000) color difference formulas. The observer judgments were regressed to each color difference independently for perceptibility and acceptability. The area under the receiver operator curves was calculated and ranked, and the optimal factor for the Color Measurement Committee (CMC; Society of Dyers and Colorists, Great Britain) color difference formula was chosen. A repeated measures maximum likelihood analysis of variance (ANOVA) was applied to determine the statistical significance of fit between the observer groups and the various color difference formulas for both perceptibility and acceptability.

Results: A difference in the degree of fit of the judgments of color differences was found for the three formulas and the two judgment types studied, with no significant interaction. There was a lower degree of fit for the $\Delta E^*(ab)$ formula than for ΔE $(CMC)_{(2:3)}$ and ΔE (2000) formulas. No significant difference was found in the mean judgment levels between the observer groups studied, nor with any interaction.

Conclusions: The ΔE (2000) and ΔE $(CMC)_{(2:3)}$ color difference formulas provide a better fit to the calculated color differences, therefore providing better indicators of human perceptibility and acceptability of color differences between tooth colors.

COMMENTARY

Luo and colleagues tested four reliable color discrimination data sets and found that the CIEDE2000 formula outperformed CMC and CIE94 by a large margin. The superior performance of CIEDE2000 as compared with CIELAB was also reported in several dentistry-related studies. However, we are not aware of another publication that reported on the performance of three color difference formulas (CIELAB, CIEDE2000, and $CMC_{[2:3]}$)† in quantifying perceptibility and acceptability thresholds in dentistry. The study was performed under in vitro conditions, using pairs of monochromatic (opaque ceramics), tooth-shaped specimens (visible part), and a background that mimicked the color of gingival tissue.

It appears that the narrow color range of natural teeth justifies the absence of multiple centers (anchors) in this study. Instead,

†CIELAB (CIE76), CIE94, and CIEDE2000 are color difference formulas of the CIE system; $CMC_{(l:c)}$ is a modification of CIE76 formula developed by the CMC of the Society of Dyers and Colorists. Its two parameters, lightness (l) and chroma (c), allow the users to weight the difference based on the ratio of l to c (such as $CMC_{[2:3]}$, see earlier discussion).

there was one anchor pair (standard color difference pair) with a negligible color difference. The maximum CIELAB color difference as compared with the anchor specimen was 5.2, which is less than the 50 : 50% acceptability threshold reported by Douglas and colleagues. (See previous structured abstract in this Critical Appraisal.)

According to studies on visual judgments, the repeatability of a single observer and the reproducibility between observers are alarmingly poor, and it has been recommended to include at least 20 observers in order to achieve reasonable agreement (Berns). Therefore, results from a total of 16 observers in this study can be considered sufficient, whereas the results by group (only four observers in each) are probably less relevant.

The finding that the CIEDE2000 and $CMC_{(2:3)}$ formulas provided better fit to the calculated color differences and were better indicators of perceptibility and acceptability thresholds as compared with CIELAB is very relevant. It is also nice that the dentistry-related findings in this study were in accordance with the color science literature.

Although this study was designed and executed well, the authors failed to report the color difference thresholds obtained using the various formulas. The good news, however, is that some threshold values can be extrapolated from the article. Based on one of the figures in this article, CIEDE2000 perceptibility and acceptability thresholds were approximately 1.2 and 1.6, respectively. Based on another of the figures and the literature, this might correspond to CIELAB values of approximately 1.5 to 1.8 and 4.0, respectively.

The finding by Barrett and colleagues that there was no difference in the matching of flat disks compared with the matching of shade tabs brings certain clinical relevance to the above-mentioned thresholds (with caution related to approximation on CIELAB thresholds). In addition to the in vitro/in vivo comparison suggested at the end of the first commentary, it appears that a monochromatic/polychromatic comparison in clinical settings might shed more light on this area.

SUGGESTED READING

Berns RS. Billmayer and Saltzman's principles of color technology. 3rd ed. New York: Wiley; 2000.

Luo MR, Cui G, Rigg B. The development of the CIE 2000 colour-difference formula: CIEDE2000. Color Res Appl 2001;26:340–50.

Barrett AA, Grimaudo NJ, Anusavice KJ, Yang MC. Influence of tab and disk design on shade matching of dental porcelain. J Prosthet Dent 2002;88:591–7.

ASTM International Standards on Color and Appearance Measurement. 7th ed. Conshohocken, PA: ASTM; 2004.

Lindsey DT, Wee AG. Perceptibility and acceptability of CIELAB color differences in computer-simulated teeth. J Dent 2007;35:593–9.

COLOR DIFFERENCE THRESHOLDS OF MAXILLOFACIAL SKIN REPLICATIONS

R.D. Paravina, G. Majkic, M.M. Perez, S. Kiat-Amnuay
Journal of Prosthodontics (in press)

ABSTRACT

Statement of the Problem: Restoration of esthetics is an important need for patients who wear facial prostheses, which emphasizes the rationale for the evaluation of properties and mechanisms that might contribute to the fulfillment of this need.

Purpose: The purpose of this study was to determine the perceptibility and acceptability thresholds for color differences of light and dark skin-colored maxillofacial elastomers.

Materials and Methods: A total of 15 pairs of light specimens (mimicking white, Asian, and Hispanic skin), and 15 pairs of

dark specimens (mimicking African-American skin) were made using skin-colored maxillofacial silicon elastomers, combined with opacifiers and pigments. Color match/mismatch and acceptable/unacceptable mismatch of each pair of specimens were visually evaluated by 45 evaluators under controlled conditions of a viewing booth. Color differences were calculated using CIELAB and CIEDE2000 formulas. After calculating the model parameters, receiver operating characteristics (ROC) curves and area under the ROC curve (AUC) were analyzed. Repeated measures ANOVA and Tukey's HSD test were used in statistical analysis.

Results: CIELAB/CIEDE2000 perceptibility and acceptability thresholds for light specimens were 1.1/0.7 and 3.0/2.1, respectively. Corresponding values for dark specimens were 1.6/1.2 and 4.4/3.1. Differences in primary specimen color and type of threshold were found to be significant. Only the primary specimen color effect was found significant in AUC comparisons.

Conclusions: Within the limitations of this study, both main effects of threshold type (perceptibility and acceptability) and primary color (light and dark) on 50: 50% color difference thresholds of colored maxillofacial elastomers were found significant for both color difference formulas used (CIELAB and CIEDE2000). In addition, significant interaction between the two main effects was found, indicating a stronger effect of skin type on acceptability than on perceptibility thresholds. Primary specimen color (light versus dark) was found to be the only significant main effect on the AUC of ROC curves constructed from logistic regression.

Clinical Implications: Color difference thresholds of maxillofacial skin replications can serve as guidelines and as a quality control tool for maxillofacial prostheses, thus contributing to patients' need for improved esthetics of these prostheses.

COMMENTARY

The skin is the body's largest organ, so it is not surprising that the restoration of skin esthetics is reported to be the highest priority for patients who wear facial prostheses. Although facial prostheses are by far less frequent than direct and indirect dental restorations, the severity of clinical indications (patients who lose parts of their face because of cancer, trauma, or birth defects) require full attention of the dental community.

Ethnicity-wise, people of African, Asian, and Hispanic origin are less affected than Caucasians, but investigation of color and other properties of their skin deserves the same attention. This is why visual judgments in this study were performed on light and dark specimens, made using the typical formulations for fabrication of facial prostheses for patients of different ethnicities in the clinical setting. There were two "calibration pairs" with negligible color difference, one for each light and dark specimens. Color differences between specimen pairs in both groups were balanced. Mean color differences (ranges) between light specimens were 2.8 (0.1–5.7) and 1.9 (0.1–3.9) for CIELAB and CIEDE2000, respectively. Corresponding values for dark specimens were 2.8 (0.7–5.9) and 2.0 (0.4–4.0), respectively.

The number of observers was adequate and color matching conditions were carefully controlled. Visual comparisons were performed in the viewing booth using a local D50 illuminant (overhead lights were turned off), with an illuminance (light intensity) of approximately 1,000 lux. Specimens were observed in edge-contact along their length, using 0/45° optical geometry. Larger sizes increase visual precision: 25-mm × 50-mm × 3-mm specimens combined with the observation distance of 30 cm enabled a visual angle of subtense of 10°. This also corresponded to the CIE

1964 standard observer used for the instrumental assessment.

According to literature, color difference thresholds of human skin were evaluated only on silicone hand and digit prostheses (Leow and colleagues). For light skin, they reported perceptibility and acceptability thresholds of $\Delta E^* = 0.8$ and $\Delta E^* = 1.8$, respectively. Corresponding values for dark skin were $\Delta E^* = 1.3$ and $\Delta E^* = 2.6$.

It is true that color stability of facial prostheses is presently a huge concern. However, this does not diminish the need for a scientific evaluation of skin color that is unaffected by the choice of materials. Future research should address the limitations of this study, such as the influence of the experiment setting (in vitro or clinical) and the influence of differences in hue, value, and chroma on color difference thresholds.

SUGGESTED READING

Paravina RD, Powers JM. Esthetic color training in dentistry. St. Louis (MO): Elsevier; 2004.

Fairchild MD. Color appearance models. 2nd ed. New York: Wiley; 2005.

Leow ME, Ow RK, Lee MH, et al. Assessment of color differences in silicone hand and digit prostheses: perceptible and acceptable thresholds for fair and dark skin shades. Prosthet Orthot Int 2006;30:5–16.

THE BOTTOM LINE

The color appearance of dental restorations should match corresponding tissues to achieve acceptable esthetics. One of the shortest yet most accurate explanations on the importance of color in dentistry was given by Bergen: "Color is unimportant to the physiologic success of a dental restoration, yet it could be the controlling factor in the overall acceptance by the patient." Indeed, color and appearance are the alpha and omega of esthetic dentistry: if a huge color mismatch exists, there is no esthetics, regardless of everything else.

The most important questions we have to address are "What is a color match in dentistry?" and "How good a match is good enough?" This Critical Appraisal aims to provide some elements relevant to addressing these questions. The answers are probably applicable to all esthetic restorations in dentistry. Three major groups of issues should be considered:

1. Color compatibility—between dental material and human tissues, and among various dental materials; this category includes color compatibility of shade guides
2. Color stability—during reproduction/clinical placement, after placement (aging and staining), and effects of tooth whitening on teeth and dental materials
3. Color interactions—color shifting of esthetic restorative materials: changes in perceived color because of blending, physical translucency, and/or masking potential (layering)

Studies on perceptibility and acceptability visual judgments and thresholds in dentistry have been mostly focused on tooth-colored materials. The variability of reported thresholds suggests that a systematic approach and standardization of methods are needed.

The 50 : 50% perceptibility threshold is the color difference between compared objects that can be detected by 50% of observers, whereas the other 50% of observers will notice no difference. A color match in dentistry therefore can be defined as a color difference at or below the 50 : 50% perceptibility threshold. According to literature, when color differences are slightly above the perceptibility threshold (suprathreshold), perceptibility and acceptability judgments are frequently identical. As the difference in color increases, they become different. The so-called "just-perceptible difference" is usually too small as compared with what would be considered an acceptable color difference in dentistry, and the same is true for other industries. Color difference tolerance can therefore be defined as the just-perceptible difference increased by a commercial factor (Berns). The 50 : 50% acceptability threshold is the color difference that is considered acceptable by 50% of observers, whereas the remaining 50% of observers would replace or correct the restoration because of color mismatch. Analogously, an acceptable color match in dentistry is a color difference at or below the 50 : 50% acceptability threshold.

After defining the questions on color match, 50 : 50% perceptibility and acceptability thresholds, and three groups of color-related topics, it is relatively simple to implement the thresholds to answer our questions related to color compatibility, color stability, and color interactions. Color difference below the 50 : 50% perceptibility/acceptability threshold is outstanding and acceptable, respectively. The exceptions are tooth whitening and blending, where color difference above the 50 : 50% perceptibility/acceptability threshold is acceptable and outstanding, respectively.

The 50 : 50% perceptibility and acceptability visual thresholds are very convenient for the interpretation of color differences in dentistry. Combined visual and instrumental methods are necessary to quantify these thresholds. Although beyond the scope of this Critical Appraisal, it should be mentioned that other elements of appearance, including gloss and translucency, affect the color appearance and overall esthetics of dental restorations.