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Review

Shade compatibility of esthetic restorative materials—A review

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ABSTRACT

Objectives. The objectives of this study were to review the shade compatibility of esthetic restorative materials and to provide a visual method to harmonize the color of them.
Methods. Published reports on the color ranges and distributions of shade guides, color differences between restorative materials and the referenced shade guides, and those between the identical shade designated restorative materials were reviewed.
Results. Several limitations in shade guides should be considered in color matching such as (1) color ranges and distributions of shade guides are different from those of human teeth, (2) arrangements of shade tabs in shade guides are not ideally logical, and (3) color of marketed esthetic restorative materials and the referenced shade tabs is significantly different. Color coordinates of restorative materials of the identical shade designations vary by the kind and brand of the restorative materials. Color differences between restorative materials and the referenced shade guides and those between the identical shade designated restorative materials are generally higher than perceptible limits. A visual color harmonization method was suggested, and the considerations for the instrumental color harmonization were provided.
Significance. Visual color matching would result in color mismatching by the kind and brand of the restorative materials. The first step to improve the color matching performance would be the harmonization of the color of restorative materials with those of the corresponding shade tabs.

Contents

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1. Introduction

Recent advances in color matching have been driven by market demands for high quality esthetic restorations. Improved shade guides, availability of shade-taking devices and researches in the area of human color vision have improved the potential of achieving excellent color matched restorations [1]. Nonetheless, color matching still remains as one of the most challenging tasks in clinical dentistry [2]. Based on previous studies on the color inconsistency of esthetic restorative materials [3–5], one of the problems in color matching is that the color of identical shade designated esthetic restorative materials is not consistent by the kind and brand of materials. Therefore, acceptable methods with which the color of the identical shade designated esthetic restorative materials can be harmonized should be established.

Color matching of esthetic restorations is evaluated visually or instrumentally, and it is generally agreed that instrumental measurement would provide objective and quantified data for color matching of natural teeth and restorations to clinical shade guides [6]. For an overview of the instrumental color measurement, a recent review concerning the correlations between spectral, three-dimensional and color difference aspects of color and geometrical aspects of color measuring systems would be helpful [7].

Instrumental color measurement usually employs the CIELAB system [8]. In the CIELAB color space, three color coordinates such as CIE L^*, a^* and b^* values are determined. CIE L^* is a measure of lightness. CIE a^* value is a measure of redness or greenness, and CIE b^* is a measure of yellowness or blueness. Chroma is calculated as $C^*_{ab} = (a^{*2} + b^{*2})^{1/2}$. Color difference is calculated as $\Delta E^*_{ab} = (\Delta L^{*2} + \Delta a^{*2} + \Delta b^{*2})^{1/2}$ and hue difference is calculated as $\Delta H^*_{ab} = (\Delta E^{*2}_{ab} - \Delta L^{*2} - \Delta C^{*2}_{ab})^{1/2}$ [8]. Instead of the CIELAB color difference (ΔE^*_{ab}) formula, the CIEDE2000 (ΔE_{00}) formula that included weighting and parametric functions was also introduced in dental field [9].

Since shade designations of esthetic restoratives are generally referenced to the Vitapan Classical (VPC), Chromascop (CMS) or VITA Toothguide 3D-Master (3DM) shade guides, color ranges and distributions of these shade guides were reviewed first. After then, color differences between restorative materials (focused on resin composites) and the referenced shade guides, and between the identical shade designated restorative materials were reviewed. Other related subtopics such as the influence of measurement methods including geometry, specimen thickness and surface condition and others, and the influence of translucency, fluorescence and other optical properties on color perception should be reviewed separately. Based on these considerations, a possible method with which the color of restoratives would be harmonized was suggested.

2. Color ranges and distribution of shade guides

Before starting this subtopic, a recent threshold value for color perception should be introduced. As a standard for the color difference at which all-ceramic crowns could not be distinguished from natural teeth, a color difference value of 1.6 ΔE^*_{ab} units was suggested [2]. Therefore, this value can be used as a perceptible threshold in the instrumental color matching of the shade tabs, teeth and restorations. Another aspect to be considered is the deviations in color matching performances by the shade and kind of materials. Based on a study of the influence of individual shades in shade guides on the reliability and validity in color matching process [10], color matching process with shades of different materials was not accurate; some shades produce more reliable and valid matches than others; and teeth are matched with relative difficulty to shade guides.

One critical prerequisite for shade guides is to match the color range and distribution of human teeth [11]. Several studies on the correlations of ranges and distributions of color between human teeth and shade guide tabs were performed. Coverage errors (CEs) of three shade guides were compared based on the color of 359 anterior teeth [12]. As results, 3DM (CE: 3.9 ΔE^*_{ab} units) showed the lowest CE compared with VPC (CE: 5.4) and CMS (CE: 5.3); therefore, 3DM was recommended as the clinically relevant guide.

There were also several studies for the improvement of shade guides. For example, computer models were designed to develop relevant shade guides [11], in which shade guide models were made based on teeth color ($n = 1064$), and the CEs were compared with that of VPC. As results, the CE of VPC was 4.1 ΔE^*_{ab} units, ranging from 0.5 to 11.5 while those of the designed shade guides were around 2.0 ΔE^*_{ab} units, which demonstrated that new shade guides could provide either similar coverage of teeth color with fewer tabs, or better coverage of teeth color with a similar number of tabs; both cases would increase the chances of satisfactory matches [11]. Based on the color distribution of natural teeth ($n = 564$) sorted by the color attributes of lightness, chroma and hue angle, a shade guide model was suggested through grouping initially by lightness and subsequent by chroma and hue angle [13]. Color distribution of maxillary primary incisors ($n = 400$) was also modeled as a shade guide for primary teeth [14].

Several studies compared the shade tab arrangement and matching performance of shade guides. For the color ranges and distributions of shade guides, it was reported that the color difference range among the tabs in VPC and 3DM was 14.3 and 19.2 ΔE^*_{ab} units, respectively [15]. Compared with VPC, chromaticity ranges of 3DM were extended in the desired directions, and 3DM shade tabs were more uniformly spaced. It was also reported that 3DM allowed clinicians to achieve a better color match of a restoration compared with VPC, since the match of the shades selected with 3DM was judged significantly better by clinicians [16]. Based on a study of the influence of different shade guides and respective shade matching methods on color matching performance [17], the Linearguide 3D-Master (VITA) was superior in a subjective evaluation compared to 3DM and VPC.

Color of VPC and CMS was compared with varied shade groups of resin composites [18], and it was reported that the CIE L^*, a^*, b^* values of resin composites with the identical shade designations were different by the brand of resin composites. Figs. 1 and 2 show the color distributions of shade tabs in VPC and CMS and the white and translucent shades resin composites [18]. There was no logical order in the shade tab arrangements of the two shade guides; therefore, it was