ORIGINAL ARTICLE

Color Management of the Cervical Region Using Different Framework Materials

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ABSTRACT

Background: Color-matching of the cervical area between natural teeth and different crown prostheses is a common clinical problem.

Purpose: The purpose of this study was to compare the color of the cervical region of five commercially available crown systems to an extracted natural tooth and to each other.

Materials and Methods: The color of the cervical region of an extracted maxillary incisor was measured by means of a colorimeter (ShadeVision, X-Rite). Fifty master dies were fabricated, divided into five groups ($N = 10$) according to the framework material; group 1: high-noble gold alloy, group 2: same as group 1 but treated with gold paste material, group 3: precious reinforced alloy, group 4: white zirconium oxide substructure (Lava 3M ESPE), and group 5: shaded zirconium oxide (Lava). A direct comparison of L^*, a^*, and b^* parameters was accomplished between the control natural tooth and the five crown systems, and the mean color differences (ΔE) was calculated. The data were statistically analyzed with one-way analysis of variance and post hoc multiple comparison ($\alpha = 0.05$).

Results: Compared to the natural tooth, the mean color differences (ΔE) values were clinically unacceptable for all groups ($\Delta E > 3.7$). The detected color differences, among different porcelain systems, were not visually perceptible ($\Delta E < 3.7$).

Conclusions: Within the limitations of this study, the cervical color of an extracted natural tooth could not be duplicated using different crowns systems.

CLINICAL SIGNIFICANCE

Color-matching of the cervical region of different crown systems with natural tooth remains a difficult task.

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INTRODUCTION

With increasing demands on esthetics, both clinicians and dental technicians experience a daily challenge of replicating the color of natural tooth. Color is an important parameter for the esthetic appearance of fixed restorations. Dental ceramics have been one of the most widely used materials for esthetic dentistry.[1] Their surface texture and translucency produce excellent aesthetic properties.[2,3] For metal ceramic

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restorations, the final color is a result of the interaction of batch number,[4] thickness of opaque porcelain,[5] thickness of translucent material, porcelain type,[6] extrinsic pigments, number of firings,[7] and type of underlying substructures.[8] The cervical region of the natural tooth usually reveals a yellowish shade and higher chroma than the rest of the tooth structure because of the thin layer of enamel in this area.[9] In spite of numerous attempts to reproduce the optical properties of natural teeth, shade mismatch between porcelain and shade guide is still problematic.[10] However, because of biological concerns, clinicians cannot provide the required thickness for the ceramic veneer, usually 1.5 mm thick, in the cervical region, making color production in this region a real challenge.[11,12]

The optical properties of the framework substructure are part of the primary factors controlling esthetics and the final shade of fixed restorations.[8,12,13] Several studies using spectrophotometric analysis reported that the color of metal ceramic restorations was influenced by the color of the metallic framework used.[13–15] During the last few years, there has been growing interest in metal-free restorations, especially zirconia-based materials combining both high mechanical properties and superior esthetics as well.[16] The basic color of zirconia framework is white, but some manufacturers developed shaded blocks to enhance shade match.

The most commonly used color measurement system was developed by the Commission Internationale de l'Eclairage (CIE), introducing three attributes used to evaluate perception of color. These are L (lightness variable), and a and b (chromaticity coordinates), where a corresponds to the red–green axis and b refers to yellow–blue axis.[17]

However, visual color determination has been found to be unreliable and imprecise.[18,19] The impression of color by the bare eye is rather subjective, and not objective or even measurable and is, therefore, felt differently by every individual[20] due to differences in physiological and psychological responses to radiant energy stimulation, experience, environment, and lighting conditions.[20–22] Electronic shade selection devices have the potential for more accurate and reliable selection of a tooth color,[23,24] since they are not influenced by the previous parameters.[25] Currently available electronic shade-matching devices are spectrophotometers, colorimeters, digital color analyzers, or combinations of these. Colorimeters are useful in quantifying color differences between specimens. These devices measure values according to CIE illuminant and observer conditions.[26]

The aim of this study was to colorimetrically evaluate and compare the color of the cervical region of five crown systems compared to an extracted natural tooth and to each other. The null hypothesis tested was that there was no significant difference between the color of the cervical region of the natural tooth and different crown systems.

MATERIALS AND METHODS

Color Measurement of the Natural Tooth

One extracted sound human maxillary central incisor was selected and all external debris were removed with an ultrasonic scaler. The tooth was examined stereoscopically at 10× magnification to verify the absence of cracks, defects, and dental caries. The spectral reflectance of the cervical area of the extracted tooth was determined using a colorimeter (ShadeVision, X-Rite, Grand Rapids, MI, USA) following the manufacturer's instructions. Shade selection of the natural tooth indicated an A1 in both visual evaluation (Vita Classic shade guide, VITA, Zahnfabrik Bad Sackingen, Germany) and colorimetric assessment. The tooth was placed in a teaching model (typodont), and a silicon key (Sil-Tech, Ivoclar-Vivadent, Schaan, Liechtenstein) was used to duplicate the exact position of the tooth and to verify the amount of required preparation. The model was firmly placed on a leveled base in order to have the optical tip of the instrument perpendicular to the tooth measurement surface; the tip was placed 1 to 2 mm above the cemento-enamel junction in the cervical region. A standardized area of 2 mm in diameter was positioned over the cervical region with partial inclusion of proximal sides. This was

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FIGURE 1. Color measuring set-up used in this study.

achieved through a custom-made template that was fabricated to fit the measuring device. The ShadeVision divided the tooth surface into three areas of color: cervical, middle, and incisal. The values of the cervical region were recorded in the CIE Lab color system (Figure 1). The tooth received a full-coverage crown preparation with 1-mm round-ended finishing line and 1.5-mm incisal reduction, then was immersed in 0.05% Thymol and distilled water solution and stored at 37°C.

Five framework materials were used to fabricate the core of crown restoration of the prepared tooth ($n = 10$): a high gold bonding alloy (V Delta silver free, Metalor Technologies, Neuchatel, Switzerland), same previous substructure but treated with a gold paste (Aurofilm 2000, Metalor Technologies), reinforced alloy (CAPTEK, Precious Chemical Co, Inc., Altamonte Spring, FL, USA), white zirconia, and colored zirconia framework (A1). Manufacturer information and composition of each material are summarized in Table 1.

Crowns Fabrication

The prepared tooth was duplicated with polyvinyl silioxane impression material (Capsil A and B, Precious Chemical Co, Inc.) according to the manufacturer instructions. Five impressions were made for each group and poured with a high strength dental stone (Improved dental stone, GC Fuji rock, GC Europe, Leuven, Belgium). The metallic substructures were produced from standardized wax patterns (0.4-mm thick), invested using phosphate-bonded investment (Hi-temp, GC Fujivest Π, GC Europe), and cast using lost wax technique. The castings were finished to a uniform facial and inter-proximal thickness of 0.3 mm. The cervical area was divided into four quarters; four references points were placed on the cervical area of each framework to aid in the assessment of the metal framework thickness. The thickness of the substructure was measured and recorded at each of the four recording points before the addition of the opaque porcelain. Each measurement was used to determine the thickness of the subsequent porcelain additions. The same procedure was performed for groups 1 and 2 after the application of the Aurofilm 2000 material according to manufacturer instructions.

For the CAPTEK crowns, refractory dies were prepared and the prepared copings were seated on the master dies to allow burnishing of the margins using a rubber wheel and a diamond bur (CAPTEK, Precious Chemical Co, Inc.). The copings were ultrasonically cleaned for 5 minutes. A thin layer of bonder material (Universal Coupler Porcelain, CAPTEK) was applied over the entire surface of the copings then fired in a porcelain furnace (Whip Mix-Pro, Louisville, KY, USA) according to manufacturer's directions.

Ten white and 10 colored (A1) zirconia copings were prepared by milling and sintering zirconia blocks using a CAD/CAM system (Lava, 3M ESPE, Seefeld, Germany) according to manufacturer instructions.

Application of Porcelain Veneer

One commercial veneer ceramic system (Noritake Dental Porcelain, Nishi-Ku-Nagoya, Japan) was selected for layering the prepared frameworks, Super Porcelain EX-3 was used for metallic frameworks, and Noritake Cerabien porcelain ZR was used for

TABLE 1. Material properties

Product	Composition	Manufacturer
Gold metal (V delta)	Au 51.5%-Pd 38.5%-In 8.5%-Ga 1.5%	Metaux precious/Metalor Co, Neuchatel, Switzerland
Aurofilm 2000	Au 99.99%	Metaux precious/Metalor Co, Neuchatel, Switzerland
CAPTEK	Au 88.2%-Pt 9%-Ag 2.8%	Precious Chemical Co Inc., USA
White Zirconium	3 Y-TZP	LAVA, 3M ESPE, USA
Shaded Zirconium (A1.Vita classic)	3 Y-TZP	LAVA, 3M ESPE, USA

zirconia frameworks. Only one batch number of each porcelain material was used. Two layers of opaque porcelain (shade A1 Vita classic shade) were applied on the metallic framework using the brush-on application technique. The average opaque porcelain thickness was 0.1 mm; all layers were fired according to the manufacturer's recommendation. For white zirconia coping, the required shade base porcelain was applied and fired two times (0.2-mm thickness) to achieve the proper color. A digital caliper (Mitutoyo Co., Kawasaki, Japan) was used to assess the porcelain thickness in the four reference points.

One layer of dentine porcelain (A1, Vita classic shade) was applied and fired according to the manufacturer's directions, which was reduced to 1.4 mm thickness and covered by one layer of enamel (E2, Vita classic shade) porcelain and fired. The crowns were overbuilt and ground down to their final measurements using ceramic stones (Dura-Green stones; Shofu Co., Kyoto, Japan). The final thickness of 1 mm was achieved in the cervical region for all groups. Finally, glaze porcelain was applied and fired.

Statistical Analysis

Color parameters of the cervical region of every test group were measured as previously described. Color difference (ΔE) between the investigated groups and the natural tooth was calculated using the following formula:[27]

$$\Delta E = \left([\Delta L^*]^2 + [\Delta a^*]^2 + [\Delta b^*]^2\right)^{1/2}$$

TABLE 2. Mean and standard deviation (SD) of L*, a*, and b* values of different groups

Group	*L*		*a*		*b*	
	Mean	SD	Mean	SD	Mean	SD
Control	78.3	0.5	6.4	0.29	21.3	0.35
1	78.5	0.91	3.8	0.34	12.7	0.63
2	78.6	1.04	3.6	0.33	12.3	0.73
3	79.3	0.753	3.6	0.25	12.3	0.89
4	81.6	1.8	4.3	0.46	12.4	1.2
5	80.9	1.3	4.1	0.69	11.4	0.4

$\Delta E > 3.7$ was considered as a non-acceptable color match clinically[28]. The recorded data (color coordinates L^*, a^*, and b^*) were analyzed with one-way analysis of variance (ANOVA) and Bonferroni multiple comparison tests using a computer software (SPSS 14.0, SPSS Inc., Chicago, IL, USA) ($\alpha = 0.05$).

RESULTS

Regarding colorimeter data analysis, L^*, a^*, b^* parameters of the tested groups are summarized in Table 2. One-way ANOVA revealed significant differences among the tested groups ($F = 31$, $p < 0.001$). Both white zirconium coping and shaded zirconium copings (groups 4 and 5) showed higher L^* values that were significantly different from the natural tooth and the other metallic systems. The a^* and b^* values of all tested ceramic systems were significantly lower than the a^* and b^* values of the natural tooth. Both white and

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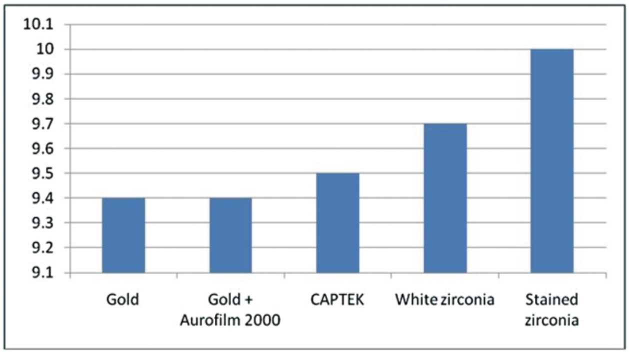

FIGURE 2. ΔE value of the five tested crown systems indicated significant color mismatch against the selected tooth at the cervical region.

shaded zirconium showed significantly higher a^* values compared to the metallic copings. The b^* value of shaded zirconium was significantly lower ($p < 0.001$) than any other group in the study.

The calculated mean color difference of all groups compared to the natural tooth produced ΔE values higher than 9.4 (clinically non-acceptable color match, Figure 2), whereas the differences between the systems themselves produced ΔE lower than 3.1 (all systems produced similar color parameters).

DISCUSSION

An inherent problem with color evaluation of ceramic restorations lies in the color mismatch of the cervical region between adjacent natural teeth and artificial crowns. In this study one threshold value was selected to evaluate clinical acceptability and perceptibility of color difference ($\Delta E > 3.7$).[28] The color differences (ΔE) of two objects can then be determined by comparing the differences between respective color coordinates value for each object.[26,27] It has to be emphasized that using ΔE value has a major certain limitation; although indicative of color differences, the magnitude of ΔE gives no information of the character or appearance of the color of the specimens because it does not indicate the quantity and direction of the CIE Lab components. O'Brien and colleagues proposed a different color equation ($\Delta Em = \Delta H/5 + 7\Delta V + 4\Delta C$) to assess small color differences between dental shades and different shade guides.[29,30]

In this study, A1 shade was given by the colorimeter to match the color of the natural tooth. When comparing the Lab values of the cervical region between the natural tooth and the different framework systems, the result showed unacceptable color match ($\Delta E > 3.7$). Considering the results obtained in this study, the proposed null hypothesis was rejected. Colorimetric machines are not able to provide a certain formula that can be used for porcelain application to create the desirable shade. Providing L^*, a^*, b^* parameters is not sufficient to produce an intended shade. It would be very useful to create an understandable formula provided by colorimetric machines that can be used by reliable technicians to match the color of the tooth. For instance, type of porcelain, mixing ratios, thickness of dentine or enamel porcelain, and firing cycles; manufacturers have to elaborate more on such information.

In this study, the standard porcelain build-up formula, followed by most dental technicians, was applied, including the application of opaque, dentin, then enamel porcelain.[31] However, in order to overcome the deficiency in color duplication inherent in any porcelain system, the ceramists might modify porcelain color through the use of porcelain modifiers and internal or external pigments.[32] These modifiers include: intrinsic and extrinsic colorants, opaque modifiers, opaque dentine porcelain, and application of different shades. In most practices, after the dentist prepares the tooth and takes an impression, it becomes the dental technician's responsibility to duplicate the desirable color.

One approach to standardize porcelain build-up procedure is to standardize the color of the first applied layers provided by different manufacturers before application of dentine and enamel porcelain. That is to say, whereas metallic frameworks require an opaque or gold bonder material, zirconia frameworks require a framework modifier or intrinsic staining; these crown systems must reach a standardized color before application of dentine and enamel porcelain. In such cases, all crown systems will start from the same color used as a base for the layering technique.

The result of the present study confirmed failure of the conventional formula of porcelain build-up that is used by many ceramists to match the color of the cervical region of an extracted tooth. Even though the seven major contributing factors (shade designation, opaque porcelain thickness, dentin porcelain thickness, enamel porcelain thickness, firing cycles, brand of porcelain, and batch numbers of porcelain) were standardized. A colorimetric study evaluating the color differences between a requested shade and the color of the actual metal ceramic crowns fabricated by five commercial dental technicians reported that the amount of variability within each ceramist was high, indicating the role of the human factor in this matter.[33] Most crowns manufactured by different laboratories, when compared to the prescribed shade tab, were above the clinical threshold for an acceptable shade match under intraoral conditions ($\Delta E > 3.7$).

In this study, it was found that the natural tooth had a tendency to be more reddish ($+a^*$) and more yellowish ($+b^*$) when compared with the tested ceramic systems that were likely to be more greenish and more bluish. The results also demonstrated that metal-ceramic, metal treated by Aurofilm 2000, and CAPTEK have a similar ability to match the brightness of the cervical area; such a conclusion cannot be generalized, as only the color of one tooth was used as a standard. Further studies might be necessary to verify the position of cervical color of the natural teeth in the CIE-Lab color space before making a general conclusion. Both a^*(redness–greenness) and b^*(yellowness–blueness) parameters of all study groups showed a significant difference when compared to the natural tooth. It is recommended to group together different tooth shades where each group could start the layering procedure by applying one opaque or framework modifier materials and subsequently obtaining required shade from using the corresponding shade of dentine and enamel porcelain. Such a technique will simplify color selection for dental ceramists and would reduce the number of components in each porcelain build up kit.

The results of this study also showed that CAPTEK and all-ceramic zirconium frameworks produced brighter restorations (higher L^* value) than both gold and gold treated with Aurofilm 2000 material. This may be attributable to the thickness of opaque porcelain or shade base and/or dentin porcelain. The CAPTEK manufacturer recommends the application of powder opaque porcelain on the framework; however, for the purpose of standardization, only opaque paste was applied among all metallic frameworks to prevent changing the surface texture of the frameworks.[34] Several studies reported an increase in the L^* value by increasing the thickness of opaque porcelain and reducing the thickness of dentine porcelain.[34–36]

The tested zirconium restorations (white and shaded) were more reddish (higher a^* value) than metal ceramic restoration. Stained zirconium was less yellowish (less b^* value) than white zirconium, which might be explained by the fact that stained zirconium did not require the application of shade base material or opaque porcelain as white zirconium or metallic frameworks. Therefore, the thickness of dentine and enamel porcelain for the shaded zirconium was higher when compared with other ceramic systems.

Different colorimetric devices have been used in various studies to evaluate the color parameters.[23–27] These devices are subjected to "edge loss effect," which may result in inaccuracies in color measurement due to variation in the absorption and scatter of light at the surface of the specimens.[37] This phenomenon occurs during conventional reflectance measurement of translucent material.[38] On translucent specimens, light escapes through the margin of the specimens and does not return to the sensor, leading to errors in the data obtained.[37,38] However, the ShadeVision unit can offer more accurate results because the tip of the instrument can read the properties of the tooth or crown through various angles of reflected light.[8] Such a feature enhances the ability of the machine to accurately record the color and avoid the edge effect. The device also has an interesting feature, virtual biscuit try-in, which allows the ceramist to compare the color of the fabricated restoration to that obtained

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by the dentist before delivery and thus reduces errors during try-in procedure.[39]

CONCLUSIONS

Within the limitations of this study, the tested crown systems failed to produce the required color at the cervical region, which was not influenced by the type of framework material used.

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