RESEARCH ARTICLE

Color Effects of Gingiva on Cervical Regions of All-Ceramic Crowns

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ABSTRACT

Statement of Problem: The final color of all-ceramic crowns is influenced by the color of both the remaining tooth structure and the surrounding gingival tissue. The optical effects of gingival tissue on an all-ceramic crown have never been fully studied.

Purpose: The purpose of this study is to investigate the effects of gingival color on ceramic crowns in the cervical region.

Materials and Methods: Thirty-one all-ceramic crowns of differing shades were included in this study. Using a spectrophotometer, the color values of each crown were measured on a typodont in the absence of an artificial gingiva (control group) and in the presence of an artificial gingiva (test group). CIELAB color coordinates (L*, a*, b*) were collected from three regions of the cervical area in descending order from the gingival margin (upper region, middle region, and lower region). Color difference values (ΔE*) were calculated for each cervical region between the test and control groups. ΔE* between the test and control groups from the upper to lower cervical regions was also compared with each other. The statistical analysis was performed using the student *t*-test and one-way analysis of variance (ANOVA) test.

Results: The mean ΔE* values between the test group and control group at the upper, middle, and lower cervical regions were 5.8, 2.8, and 1.8, respectively. Significant color differences between the test and control group were detected in all three incremental regions ($p < 0.001$ at $\Delta E^* = 1.6$ threshold), with all color coordinates (L*, a*, and b*) contributing significantly to the color differences in these regions ($p < 0.001$). The color variations in the cervical area also varied significantly from the upper region to the lower region, with L* and a* contributing most to the differences.

Conclusions: The presence of artificial gingiva is a critical factor in precise color matching and color reproduction for all-ceramic crowns.

CLINICAL SIGNIFICANCE

Gingival tissue has significant optical effects on the color of all-ceramic crowns at the cervical areas; therefore, it is suggested that artificial gingiva be used by both dentists and ceramists while matching and replicating tooth color with ceramic restorations.

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INTRODUCTION

Determining the shade of a natural tooth and reproducing that shade in porcelain is a challenging task that both dentists and dental technicians face on a daily basis. The increased emphasis on dental esthetics in recent years has driven the search for more accurate shade matching and reproduction procedures. Extensive research has been aimed at developing and improving techniques for communication between dentists and dental laboratories regarding laboratory-fabricated dental restorations, including shade-matching techniques. For example, over the last decade, instrument-based shade matching and digital image analysis have gained popularity as a way to obtain and convey objective color information. However, the interaction between the color of periodontal or peri-restoration gingival tissue and the shades of natural teeth or restorations has not been adequately investigated. Studies have reported that the colors of soft tissue around titanium implants[1–3] and porcelain-fused-to-metal restorations[4] were significantly different when compared with the tissues around the natural teeth. Although a few studies have investigated the optical effects of gingival tissue on the color perception of a tooth or a crown, it has not yet been addressed whether these effects would negatively influence shade matching and shade reproduction.

The comparison of a patient's tooth with a color standard, such as a commercially available shade guide, is a method frequently used in clinical dentistry for communication regarding the fabrication and shade matching of indirect restorations.[5] The determination of tooth color by visual means is considered highly subjective. General variables such as external light conditions, oral conditions (gingival color), surrounding conditions, and position of the shade tabs are known to result in inconsistencies.[6–8] When selecting a shade with the traditional visual shade systems, one limitation is the optical illusion which occurs due to color contrast within the oral environment.[9,10] For example, a dentist is likely to select a tooth color shade that is too light for patients who have dark gingiva, and, conversely, likely to select a shade that is too dark for patients who have light gingiva. This phenomenon demonstrates that gingival color may play a significant role in tooth shade selection. Moreover, in a dental lab, porcelain restorations are often constructed without knowledge of the surrounding oral cavity and soft tissues of the patient. Cast models of both teeth and related gingiva are made of white or yellow dental stone, which obliterates the true color relationship between the reddish gingival tissue and the intended ceramic restoration. Even now, many dental technicians do not attach artificial gingiva onto the dental cast models while replicating or double-checking the color match of ceramic restorations and the patient's natural tooth. This lack of information regarding the dento–gingival optical relationship on cast models creates the potential for inaccurate shade reproduction.

In view of the fact that the optical effect of gingival tissue on an all-ceramic crown has never been fully studied and that a better understanding of this effect qualitatively and quantitatively is important to achieve better color matching, this study aims to investigate effect of gingival tissue on the color of all-ceramic crowns in the cervical regions in vitro. The specific aims of this study include: (1) investigation of the difference in color of cervical regions of all-ceramic crowns both in the presence and in the absence of artificial gingiva and (2) analysis of the effects of gingival color transmitted to the crown by region. The null hypothesis is that the presence or absence of artificial gingiva does not affect color in cervical region of all-ceramic crowns.

MATERIALS AND METHODS

Sample Preparation

Thirty-one all-ceramic maxillary central incisor crowns were included in this study. All of these crowns were custom-made zirconia crowns (Katana; Noritake, Japan) in differing shades. The clinical procedures were performed based on the standard of Harvard Dental Center, and all-ceramic crowns were fabricated at the same dental laboratory (Cusp Dental Research, Boston, MA). Each crown was placed over an abutment made of tooth-shade die material and inserted into the socket

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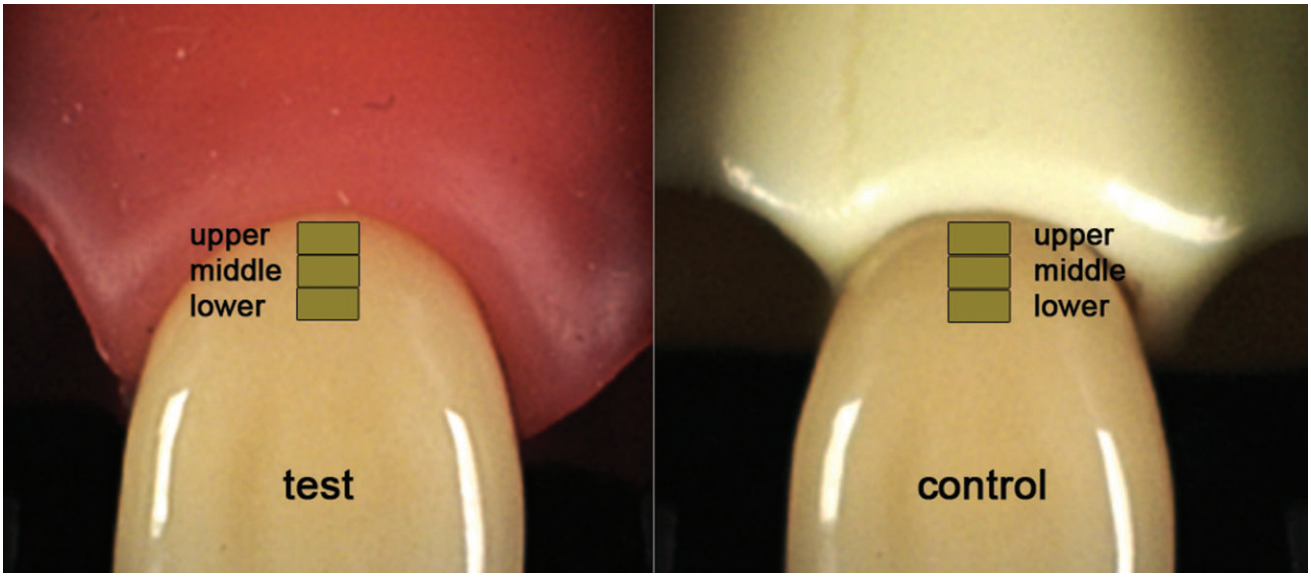

FIGURE 1. Three incremental areas for the color measurement.

of a typodont, which was mounted onto a black inspection box (Olympus Co., Tokyo, Japan) simulating the lighting conditions of an oral cavity. Artificial gingiva of pink color was attached around the cervical area of crown in order to simulate the real dental–gingival relationship. The margin of the artificial gingiva was kept in tight contact with the surface of crowns. The color values of each crown on the typodont were measured in the crown cervical area both in the absence of an artificial gingiva (control group) and in the presence of an artificial gingiva (test group). Measurements are in three 1-mm increments (upper, middle, and lower cervical regions, respectively) (Figure 1).

Color Measurements

A dental spectrophotometer, Crystaleye (Olympus, Tokyo, Japan), was used for the color measurements. This spectrophotometer utilizes seven light-emitting diodes (LEDs) as illuminant with 45/0-degree geometry. It can capture images of a single tooth, the dentition, and the face of the patient. The captured image and the spectral data are transferred to a personal computer and analyzed using the supporting software (Crystaleye Application v.1.4, Olympus). Prior to each measurement, the spectrophotometer is calibrated according to the manufacturer's recommendation. All measurements were performed by the same prosthodontist who was extensively trained in handling the spectrophotometer. To ensure the consistency of the measurement, the guide frame displayed on the liquid-crystal display (LCD) monitor of the spectrophotometer was referred to during each measurement. The spectral data of each crown and the captured images were transferred to a personal computer (ThinkPad T41; IBM, Armonk, NY).

Spectral data of each crown with artificial gingiva (test group) and without artificial gingiva (control group) were automatically analyzed with the supporting software. The color data (CIELAB color coordinates; L*, a*, and b*) in three incremental areas of 1×2 mm from the gingival margin toward the incisal direction were calculated based on the reflectance values from the wavelength of 400 nm–700 nm. Three color measurements were taken for each region, and the average of these measurements was used for data analysis. The difference in color values ΔE^*, ΔL^*, Δa^*, and Δb^* in each of three incremental areas between test and control group were calculated using the following formulas[11]:

$$\Delta L^* = L^*\text{test} - L^*\text{control}$$

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$$\Delta a^* = a^*test - a^*control$$

$$\Delta b^* = b^*test - b^*control$$

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

Previous studies have investigated color mismatch with respect to the ΔE* values. A ΔE* value of 1.6 is considered to be an excellent color match, whereas a value over 3.6 is considered to be a clinically distinguishable color difference.[11–13] In this present study, a critical threshold of ΔE* 1.6 for intraoral color distinction was used.[14]

Statistical Analysis

Statistical analyses were performed using SPSS18.0 statistical software (SPSS, Inc., Chicago, IL), and data were expressed as the mean ±standard deviation. The mean L*, a*, b* values for each of the three incremental regions of the test and control group crowns were plotted, and statistically analyzed with paired *t*-test, in order to determine if there were significant differences in these color coordinates between the two groups. Thereafter, mean ΔE* values between the two groups at the three cervical regions were calculated and one-sample *t*-test was used to compare the mean ΔE* with threshold value 1.6 (one-tail), aiming to test if there is a clinically detectable color difference between test and control groups. Furthermore, the mean ΔE*, ΔL*, Δa*, and Δb* in the three regions were also compared with each other by one-way analysis of variance (ANOVA) in order to verify if there's a significant difference in these color discrepancies among different areas. Scheffe's test was chosen as a test for multiple comparisons. The level of significance was established as $\alpha = 0.05$.

RESULTS

Descriptive data analysis revealed that in all three cervical regions, the color of the test group (with gingiva) demonstrated higher mean values of a*, as well as lower mean values of L* and b*, than the control group (without gingiva) (Table 1 and Figure 2). There was also a significant difference ($p < 0.001$) between the test and control groups in the mean L*, a*, and b* values in all three incremental regions. The color coordinates showed higher values of a* and lower values of L* and b* for the test group as compared with the control group, indicating more darkness, more redness, and less yellowness in crown color, respectively, when an artificial gingiva was attached to the cervical area of ceramic crowns. The discrepancies were larger in areas closer to the gingival margin and less so in the incisal direction.

TABLE 1. Optical data of three incremental areas for the test (with artificial gingiva) and control (without artificial gingiva) groups ($N = 31$)

Area	Upper		Middle		Lower	
Group	Test	Control	Test	Control	Test	Control
L*						
Mean	63.69	66.45	67.73	69.16	69.88	70.68
SD	2.80	3.28	2.80	2.91	2.74	2.75
a*						
Mean	6.96	2.03	3.73	1.63	2.46	1.46
SD	1.42	1.25	1.12	1.10	1.06	1.12
b*						
Mean	18.54	19.02	18.37	19.07	17.75	18.56
SD	3.95	3.98	3.68	3.70	3.75	3.81

The mean ΔE* values between the test group and control group at the upper, middle, and lower cervical regions were 5.8, 2.8, and 1.8, respectively (Table 2 and Figure 3). One sample *t*-test revealed that the mean ΔE* values in all the three incremental cervical regions of the ceramic crowns were significantly larger than the clinical perceptual threshold of ΔE* 1.6 ($p < 0.001$ for upper and middle regions, and $p = 0.018$ for lower region). One-way ANOVA and Scheffe's multiple comparison tests were performed to compare the

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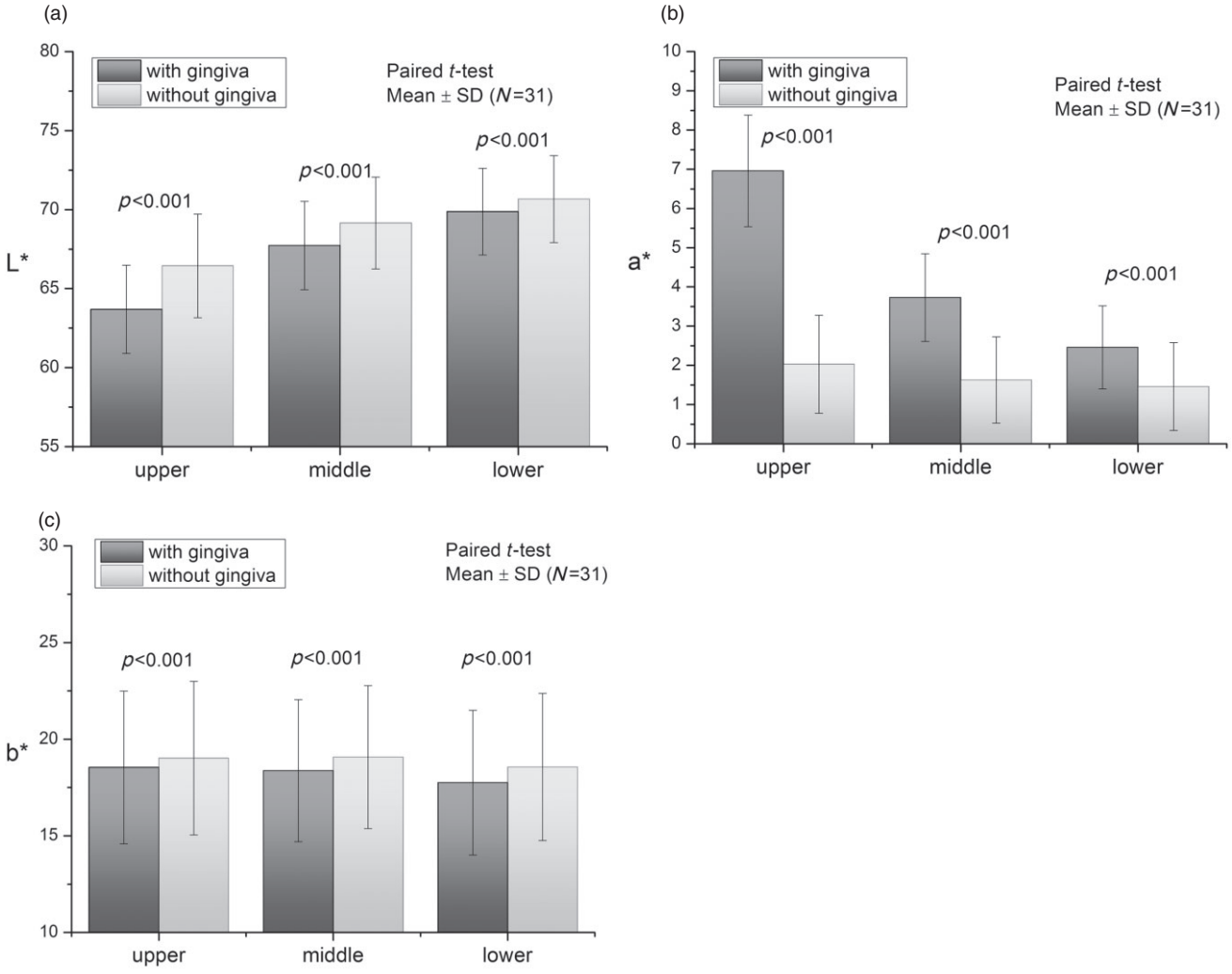

FIGURE 2. Color coordinates L*, a*, and b* between the test group and control group in all three incremental regions. Paired *t*-test was performed to compare the mean L*, a*, b* values for test and control group in each of the three incremental regions, and the *P* value for each comparison was shown above the column in the graph.

TABLE 2. Optical differences (ΔE*, ΔL*, Δa*, and Δb*) between the test group and control group in three incremental areas (mean ±standard deviation, $N = 31$)

	ΔE*	ΔL* (L*test – L*control)	Δa* (a*test – a*control)	Δb* (b*test – b*control)
Upper	5.82 ± 1.07	–2.75 ± 1.36	4.93 ± 0.68	–0.48 ± 0.80
Middle	2.82 ± 0.75	–1.43 ± 0.95	2.10 ± 0.44	–0.69 ± 0.70
Lower	1.83 ± 0.59	–0.80 ± 0.94	1.01 ± 0.44	–0.81 ± 0.59

mean ΔE*, ΔL*, Δa*, and Δb* values across the three incremental areas (Table 2 and Figure 4). The results showed that the color variations in the cervical area varied significantly from the upper region to the lower region ($p < 0.001$), with L* and a* contributing the most to the differences. No significant difference was detected for Δb* values from the gingival margin toward the incisal aspect ($p = 0.175$).

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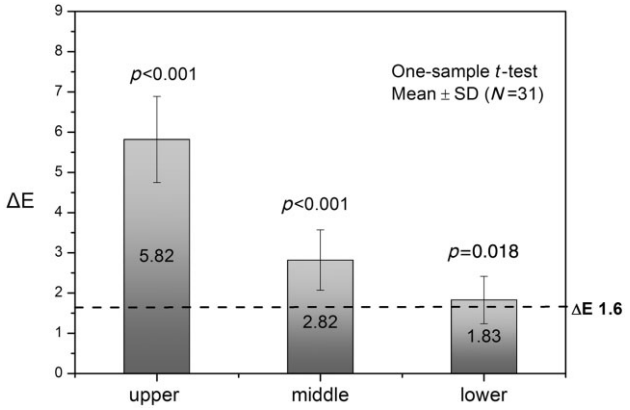

FIGURE 3. Color difference ΔE with and without the artificial gingiva. One sample *t*-test revealed that the mean ΔE* values in all the three incremental cervical regions were significantly larger than the clinical perceptual threshold of ΔE* 1.6 ($p < 0.001$ for upper and middle regions and $p = 0.018$ for lower region).

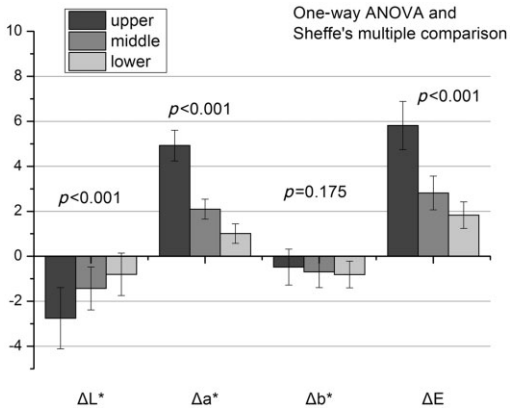

FIGURE 4. Color coordinates ΔL*, Δa*, Δb*, and ΔE* between the test group and control group in all three incremental regions. One-way ANOVA and Scheffe's multiple comparison tests show that the mean ΔL*, Δa*, and ΔE* values varied significantly from the upper region to the lower region ($p < 0.001$). In contrast, no significant difference was detected for Δb* values from the upper region to the lower region ($p = 0.175$).

DISCUSSION

Color is a phenomenon of visual perception that responds to the light reflected or transmitted from an object. Successful color match of a ceramic dental restoration requires proper shade selection and reproduction.[15,16] However, current shade communication in dentistry is affected by many factors, resulting in frequent errors both from the dentist in shade selection as well as from the ceramist in shade reproduction. One of the factors that compromise shade matching is the lack of attention by both dentists and ceramists to the optical effects of the surrounding oral cavity and soft tissues on the color of porcelain restorations. When a dental restoration is being fabricated, the surroundings of the teeth, especially the shade of the gingival tissues, are crucial factors for the color integration of the restoration. With the conventional visual shade determination, so-called simultaneous contrast effects and contrast increases occur.[6–8] When a shade selection is performed in a reddish environment, such as in the presence of skin, lips, and gingival tissues, there is a resulting marked decrease in the receptiveness of this area to the red color spectrum. The brain replaces the apparent excess of red with the complementary shades from green to yellow. This leads to a subjectively modified color perception, which expresses itself in a tendency toward seemingly objective yellowish shades. This contrasting effect may also influence the color perception of dental ceramists when replicating the shade of porcelain restorations. Without the presence of red gingival color on the stone cast model, ceramists are prone to inaccurate color perception of the restorations particularly around the cervical areas. In order to neutralize the influence of the color contrast of the gingiva, a gingival indicator to mimic the surrounding gingival tissue of natural teeth has been created.[16,17] However, this gingival indicator can only be used in combination with shade tabs in the process of shade matching, and it cannot be utilized during the fabrication of ceramic restorations.

In view of the above considerations, the present study was designed and performed to investigate the color effect of gingiva on cervical regions of all-ceramic crowns. The color of all-ceramic crowns at the cervical areas was measured with and without the presence of an artificial gingiva, and the measurements between test and control groups were paired and compared. The results revealed that the null hypothesis, which states that there is no clinically detectable difference in the color values of the ceramic crowns in the cervical

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region with and without artificial gingiva, is rejected. The mean ΔE* values in all the three incremental cervical regions of the ceramic crowns were significantly larger than the clinical perceptual threshold of ΔE* 1.6 ($p < 0.05$). Simultaneously, significant differences in color values (L*, a*, b*) at the three incremental cervical areas of all-ceramic crowns were also detected between the test and control group. All of the three color coordinates (L*, a*, b*) significantly contributed to the color differences (ΔE*) between test and control groups. The mean ΔE* at the upper region has the largest color discrepancy, 5.82, and decreases toward the incisal area (ΔE* 2.8 and 1.8 for middle and lower regions, respectively). This shows that gingival tissue has an optical effect on the color of the crown at the cervical area, and this effect is greater in areas closer to the gingival margin, decreasing in the incisal direction. It could be assumed that the color difference would not be observed by naked eyes in areas closer to the incisal edge.

The analyses for all the single color values (L*, a*, b*) demonstrated higher values of a* and lower values of L* and b* for the test group compared with the control group, indicating the presence of artificial gingiva creates more darkness, more redness, and less yellowness in the cervical color of the ceramic crowns. The possible reason for this phenomenon may be that when light is cast on the gingival tissue, part of the light flux is scattered and transmitted into the cervical area of the tooth. This scattered flux, with a color similar to that of the gingival tissue, overlaps with the reflected light from the tooth surface, forming a combined light from both the gingiva and the tooth. The final combined reflected light is translated into our perception of the tooth shade. As a result, the mix of gingival colored light results in an altered tooth shade with less lightness and more redness compared to that without gingiva.

Mean ΔE*, ΔL*, Δa*, and Δb* values across the three incremental areas were compared, and the results show that the color variations in the cervical area varied significantly from the upper region to the lower region ($p < 0.001$), with L* and a* contributing most to the differences ($p < 0.001$). No significant difference was detected for Δb* values from gingival margin toward the incisal aspect ($p = 0.175$), indicating that the presence of gingival tissue has little effect on the color variation in yellowness/blueness for the tooth.

These optical phenomena resulting from the scattering and absorbance of light are also related to the thickness of layering ceramics and the type of restorations. Porcelain fused to metal crowns will have a decreased effect due to the existence of the metal substrate, which can block light transmission. Conversely, all-ceramic crowns will be significantly affected. The study indicates that the translucency of a ceramic substrate for the all-ceramic crowns depends on material and thickness.[18] Light transmission through zirconia is significantly lower than a new generation of lithium disilicate glass ceramics, and Lava 0.3 mm and 0.5 mm demonstrates 71.7% and 63.9% of the translucency of 0.5-mm-thick IPS e.max press specimens, respectively.[18] However, zirconia is not a completely opaque material. It was also reported that 0.5 mm zirconia core (In-Ceram Zirconia) with 1.0 mm dentin overlay (All Ceram) is completely opaque, based on the contrast ratio calculated from the luminous reflectance (Y) of the specimens with a black (Yb) and a white backing (Yw), yielding Yb/Yw.[19,20] However, some translucency has been observed on zirconia ceramic cores (Katana, Noritake and Lava 3M) filled with a black and a white backing.[21] The color difference, ΔE*, between a zirconia ceramic core of 0.5 mm thickness placed on an A1 shade abutment and an A4 abutment was over 4.0.[21] Therefore, color transmission through all-ceramic crowns occurs regardless of which ceramic substrate materials are used; and light transmission from gingiva is an important factor in selecting and recreating the final color of ceramic restorations.

Another factor to address when assessing the results of this study is the value of color difference ΔE* as a color perceptibility threshold. The perceptibility and acceptability of color difference between crown and target teeth have been studied previously. Ragain and Johnston[22] reported an average clinical acceptability threshold of 2.72 ΔE* units. Another study found an ΔE* value of 3.7 to be considered an acceptable match in the oral environment.[13] Douglas and colleagues[23] used a spectroradiometer (PR705; Photo Research Inc.,

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Chatsworth, CA) that was not designed for intraoral use. Their study utilized maxillary complete denture teeth, and concluded that 50% of the dentist observers could perceive a color difference at ΔE* of 2.6 (perceptibility threshold), and would remake the restoration at ΔE* of 5.6 (acceptability threshold). The study which assessed color match of anterior crown with the natural tooth indicated that the mean ΔE* value of accepted crowns was 2.69 ± 0.98.[24] The most recent related study, conducted by Ishikawa-Nagai and colleagues[14] measured the color difference between natural intact central incisors and all-ceramic restorations which were considered a clinically "perfect/excellent color match" by three experienced observers. They found a ΔE* value of 1.6 represented a color difference that could not be clinically detected by the human eye. Since our present study has similar experimental conditions to the above reference literature,[14] a ΔE* value of 1.6 was selected as the threshold for clinically detectable color difference for the statistical analysis in our study.

One of the limitations of this study is that only one color of gingiva was used for the comparison. In the future study, multiple colors of gingiva should be used to assess the optical effects on the ceramic crowns.

CONCLUSIONS

Within the limitations of this study, the following conclusions were made:

1 Gingival tissue has significant optical effects on the color of all-ceramic crowns at the cervical areas, and the effects are more significant in areas closer to the gingival margin and decrease in the incisal direction.
2 The presence of artificial gingiva results in greater darkness, more redness, and less yellowness in the cervical color of the ceramic crowns.
3 In dental laboratory, artificial gingiva is recommended for use when matching and replicating tooth color in ceramic restorations.

Further investigation of the optical effects of different color gingival tissue on the shade of teeth is necessary.

DISCLOSURE

The authors do not have any financial interest in the companies whose materials are included in this article.

REFERENCES

1. Park SE, Da Silva JD, Weber HP, Ishikawa-Nagai S. Optical phenomenon of peri-implant soft tissue. Part I. Spectrophotometric assessment of natural tooth gingiva and peri-implant mucosa. Clin Oral Implants Res 2007;18:569–74.
2. Bressan E, Paniz G, Lops D, et al. Influence of abutment material on the gingival color of implant-supported all-ceramic restorations: a prospective multicenter study. Clin Oral Implants Res 2011;22:631–7.
3. Jung RE, Sailer I, Hämmerle CH, et al. In vitro color changes of soft tissues caused by restorative materials. Int J Periodontics Restorative Dent 2007;27:251–7.
4. Jung RE, Holderegger C, Sailer I, et al. The effect of all-ceramic and porcelain-fused-to-metal restorations on marginal peri-implant soft tissue color: a randomized controlled clinical trial. Int J Periodontics Restorative Dent 2008;28:357–65.
5. van der Burgt TP, ten Bosch JJ, Borsboom PC, Kortsmit WJ. A comparison of new and conventional methods for quantification of tooth color. J Prosthet Dent 1990;63:155–62.
6. Wyszecki G, Stiles WS. Color science concepts and methods, quantitative data and formulae. 2nd ed. New York: Wiley; 1982, pp. 83–116.
7. Hunter RS, Harold RW. The measurement of appearance. New York: Wiley; 1987, pp. 3–68.
8. Berns RF. Billmeyer and Saltzman's principles of color technology. 3rd ed. New York: Wiley; 2000, pp. 75–104.
9. Egger B. Shofu ShadeEye: Der Sinn computergestützter Farbreproduktions-Systeme-ein einjähriger Erfahrungsbericht. Quintessenz Zahntech 1999;25:409–16.
10. Yamamoto M. Die Entwicklung des Vintage-Halo-CCS-Systems-Computergesteuerte Farbbestimmung und innovative Keramikwerkstoffe. Berlin: Quintessenz; 1997.
11. Ishikawa-Nagai S, Ishibashi K, Tsuruta O, Weber HP. Reproducibility of tooth color gradation using a computer color-matching technique applied to ceramic restorations. J Prosthet Dent 2005;93:129–37.
12. Ruyter IE, Nilner K, Moller B. Color stability of dental composite resin materials for crown and bridge veneers. Dent Mater 1987;3:246–51.
13. Johnston WM, Kao EC. Assessment of appearance match by visual observation and clinical colorimetry. J Dent Res 1989;68:819–22.

 DOI 10.1111/j.1708-8240.2012.00538.x

14. Ishikawa-Nagai S, Yoshida A, Sakai M, et al. Clinical evaluation of perceptibility of color differences between natural teeth and all-ceramic crowns. J Dent 2009;37S1:e57–63.
15. Rosenstiel SF, Land MF, Fujimoto J. Contemporary fixed prosthodontics. 4th ed. St. Louis (MO): Elsevier; 2006, pp. 712–25.
16. Kim-Pusateri S, Brewer JD, Davis EL, Wee AG. Reliability and accuracy of four dental shade-matching devices. J Prosthet Dent 2009;101:193–9.
17. Kim-Pusateri S, Brewer JD, Dunford RG, Wee AG. In vitro model to evaluate reliability and accuracy of a dental shade-matching instrument. J Prosthet Dent 2007;98:353–8.
18. Spyropoulou PE, Giroux EC, Razzoog ME, Duff RE. Translucency of shaded zirconia core material. J Prosthet Dent 2011;105:304–7.
19. Heffernan MJ, Aquilino SA, Diaz-Arnold AM, et al. Relative translucency of six all-ceramic systems. Part I: core materials. J Prosthet Dent 2002;88:4–9.
20. Heffernan MJ, Aquilino SA, Diaz-Arnold AM, Haselton DR. Relative translucency of six all-ceramic systems. Part II: core and veneer materials. J Prosthet Dent 2002;88:10–5.
21. Yoshida A, Ishikawa-Nagai S, Da Silva JD. Opacity control for zirconia restorations with a factor of abutment color. Quintessence Dent Technol 2010;33:173–85.
22. Ragain JC, Johnston WM. Color acceptance of direct dental restorative materials by human observers. Color Res Appl 2000;25:278–85.
23. Douglas RD, Steinhauer TJ, Wee AG. Intraoral determination of the tolerance of dentists for perceptibility and acceptability of shade mismatch. J Prosthet Dent 2007;97:200–8.
24. Da Silva JD, Park SE, Weber HP, Ishikawa-Nagai S. Clinical performance of a newly developed spectrophotometric system on tooth color reproduction. J Prosthet Dent 2008;99:361–8.

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