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Effect of the condition of adjacent teeth and shade tab combinations on teeth colorimetry

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We investigated the effect of the condition of adjacent teeth and combinations of shade tabs on the colorimetry of maxillary central incisors. For natural teeth, we considered two conditions: one with a masking device to conceal adjacent teeth and the other without masking. For shade tabs, we assessed two conditions: one with only one A2 shade tab and another with three A2 shade tabs. In addition, we explored various color combinations of the three shade tabs. Photographs were recorded using a digital camera in a dark room with no ambient light to ensure consistent conditions. The condition with the masked natural teeth and that with only one shade tab exhibited reduced levels of lightness and chroma, with a noticeable yellowish hue. No significant differences were noted in visual coloration among the different shade tab combinations. However, significant differences were noted in lightness, chroma, and hue angle. These results emphasize the importance of arranging shade tabs correctly when determining and recording the color of natural teeth, particularly when making visual shade comparisons. (J Osaka Dent Univ 2024; 58: 59-70)

Key words: Adjacent teeth; Shade tab combinations; Shade tab; Natural teeth; Digital camera

INTRODUCTION

When fabricating an esthetic prosthetic device, dentists carefully observe and evaluate the color tone, morphology, and alignment of patients' teeth and then relay this information, along with captured images, to dental technicians. In this process, achieving the correct shade is crucial. While colorimeters are available for this purpose, the visual colorimetric method using shade tabs is often used in clinical practice. To perform this colorimetric method effectively, several factors must be taken into account, and many studies have been published on various environmental conditions that can influence the process.[1-5] We focused this study on the environmental conditions surrounding the target teeth and reported the effect of background color on shade matching.[1] This study attempted to clarify the effect of the condition of adjacent teeth and combinations of shade tabs on teeth colorimetry.

MATERIALS AND METHODS

Objects photographed

We captured photographs of both the natural teeth and the shade tabs. The natural teeth selected for photography were healthy maxillary central incisors on either side of 12 male students (22.4 ± 4.58 years old) from the Department of Oral Engineering and Research, Faculty of Medical and Health Sciences, Osaka Dental University. They received a thorough explanation of the study and provided written consent to participate. The A2 shade tab was selected as the basic color from the Vintage Halo NCC Shade Guide (Shofu, Kyoto, Japan), as many participants were in their 20s (Fig. 1).[6]

Photography

Photographs were recorded under the illumination

Fig. 1 The Shofu Vintage Halo NCC Shade Guide.

Fig. 2 Masking device fabricated on the working model.

NM

TM

Fig. 3 Digital images before and after using the masking device for adjacent teeth.

of a fluorescent lamp (FL40S.D-EDL-D65; Toshiba Lighting & Technology, Kanagawa, Japan) in a dark room with no external light. A commercially available intraoral camera (DCN-7 LV / GP 2; Sonic Techno, Tokyo, Japan) was used, and digital camera settings were made according to the manufacturer's recommendations. White balance was set at Custom WB (PRE), shutter speed at 125, F-stop at 20 and ISO at 100. The exposure distance was approximately 20 cm, which is the same as the focal length of the lens. Digital images with excessive halation, blurring, or poor focus were deleted and recorded again.

Natural teeth photography conditions

For the natural teeth images, we created a masking device to cover adjacent teeth during imaging. Individual alginate impressions were made for each participant and working models were fabricated. We crafted a masking device on the working model designed to cover the teeth adjacent to the target tooth (Fig. 2). The masking area was colored black by mixing self-curing acrylic resin (PROVINICE®; Shofu) with color additives (Syokuyousikiso kuro; Kyoritsu-Food, Tokyo, Japan). The area covered the six anterior teeth except for the target tooth. 3 to 4mm of the marginal gingiva was covered. The thickness was approximately 2 mm. Fig. 3 shows the two imaging conditions for natural teeth, one with the masking device on the adjacent teeth (TM) and one without the masking device (NM). Fig. 4 shows natural teeth being photographed. A chin rest table was fabricated and used to fix the position of the participant's face. A mouth retractor was used to ensure that the lips did not interfere with imaging. Intraoral Photo Black Background Board for Dentistry (Contrastor for anterior teeth; YDM, Tokyo, Japan) was used for the background, and a shutter release cable was employed to eliminate the possibility of camera shake. The natural teeth were photographed for each condition only once per person.

Fig. 4 Natural teeth being photographed.

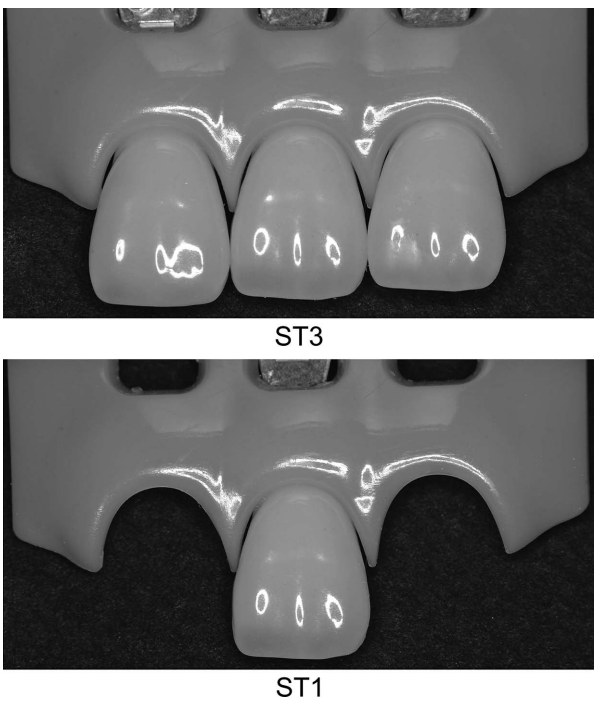

Fig. 5 Digital images of the conditions of the adjacent teeth in shade tabs.

Shade tab photography conditions

To replicate intraoral conditions more accurately, we opted to utilize gingiva-colored shade tab holders (Vintage Gumy①; Shofu) with attached shade tabs. Black paper was used for the background. Fig. 5 shows the conditions for the number of shade tabs to be used. We examined two conditions, one with a single A2 shade tab (ST1) and another with three A2 shade tabs (ST3). Furthermore, for the ST3 condition with three shade tabs, as illustrated in Fig. 6, we explored five different shade tab combinations. The first had an A2 shade tab in the center and A1 shade tabs on both sides (A1-A2-A1), the second had A2 shade tabs on both sides (A2-A2-A2), the third had A3 shade tabs on both sides (A3-A2-A3), the fourth one had A1 placed mesially and A3 placed distally (A1-A2-A3), and the fifth one had A3 placed mesially and an A1 placed distally (A3-A2-A1). Fig. 7 shows the shade tabs

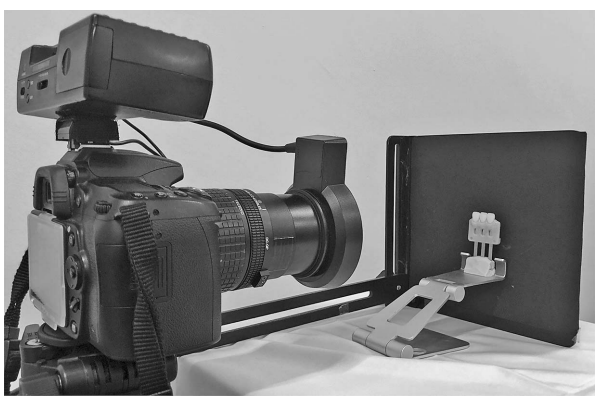

Fig. 7 A shade tab being photographed.

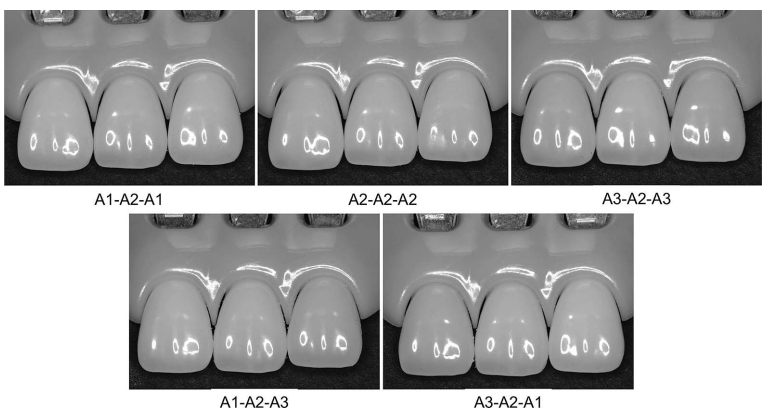

Fig. 6 Digital images for each condition recorded using different combinations of shade tabs.

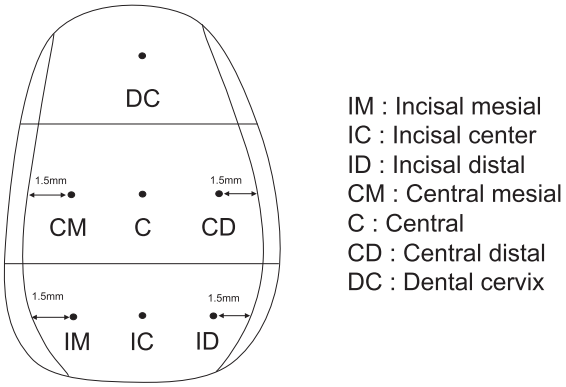

Fig. 8 Measurement regions on the surface of the tooth.

being photographed. Each combination was captured 10 times.

Measurement regions of the surface of the tooth

For colorimetry, we divided the surface of the shade tabs and natural teeth into seven distinct regions (Fig. 8). The incisal and central proximal regions were calorimetrically measured 1.5 mm medially from the mesial and distal labial ridges.

Colorimetry methods

Color quantification was carried out using the CIEL*a*b* color space, which is a widely used framework in dental color studies.[1-4] In this space, L* is the numerical value for lightness, C* represents chroma, and h in the hue angle.[7] Colorimetry was performed from digital images recorded with a digital camera using digital image color analysis software (Feelimage Analyzer 2.0; VIVA Computer, Osaka, Japan). C* (Equation 1), and h (Equation 2) were calculated from the colorimetric L*a*b*.[7-9] For color differences, we used CIEDE2000 (ΔE_{00}), which better reflects color differences perceived by the human eye. ΔE_{00} is calculated from the L*a*b* values of the two colors to be compared (Equation 3).[10, 11]

$$C^* = \sqrt{(a^*)^2 + (b^*)^2} \quad \text{(Equation 1)}$$

$$h = \tan^{-1}\left(\frac{b^*}{a^*}\right) \quad \text{(Equation 2)}$$

$$\Delta E_{00} = \sqrt{\left(\frac{\Delta L'}{k_L S_L}\right)^2 + \left(\frac{\Delta C'}{k_C S_C}\right)^2 + \left(\frac{\Delta H'}{k_H S_H}\right)^2 + R_T\left(\frac{\Delta C'}{k_C S_C}\right)\left(\frac{\Delta H'}{k_H S_H}\right)} \quad \text{(Equation 3)}$$

The color difference before and after placement of the masking device was calculated for natural teeth. The color difference from ST1 was calculated based on the mean value of ST3 for the adjacent teeth condition of the shade tab. In the shade tab combination conditions, the color difference from the other shade tab conditions was calculated based on the average value for A2-A2-A2. To establish a standard for assessing results, we defined color differences of less than 2 as tolerable.

Statistical analysis

Statistical analysis was conducted using BellCurve for Excel (Social Survey Research Information, Tokyo, Japan). The Tukey-Kramer method was used for multiple comparisons after a one-way analysis of variance (ANOVA) for ΔE_{00}. A paired t-test was used for TM and NM in the natural teeth and ST3 and ST1 in the shade tabs for L*, C*, and h for each region. Comparisons by shade tab combinations were made after one-way ANOVA, and the Tukey-Kramer method was used for multiple comparisons. The statistics of the hue angles were based on the reports of Suzuki[12] and Hatakeyama.[13] Statistical significance was set at 5%.

RESULTS

Comparison of the ΔE_{00}, L*, C* and h between NM and TM on natural teeth

Fig. 9 illustrates images comparing the mesial and distal halves of a natural tooth before and after placement of the adjacent surface masking device based on the center of the crown. The color difference between the mesial and distal halves of the natural teeth was observed visually. Fig. 10 shows the color difference ΔE_{00} between NM and TM for each measurement region of the natural tooth. There was no color difference at DC below the set tolerable color difference of 2.0. However, in other regions, the color difference was greater than 2.0. No significant differences were found in region-specific comparisons. Fig. 11 shows the comparison of L* in NM and TM the natural tooth regions, C* is shown in Fig. 12, and h in Table 1. Significant differences in L* were observed between the two

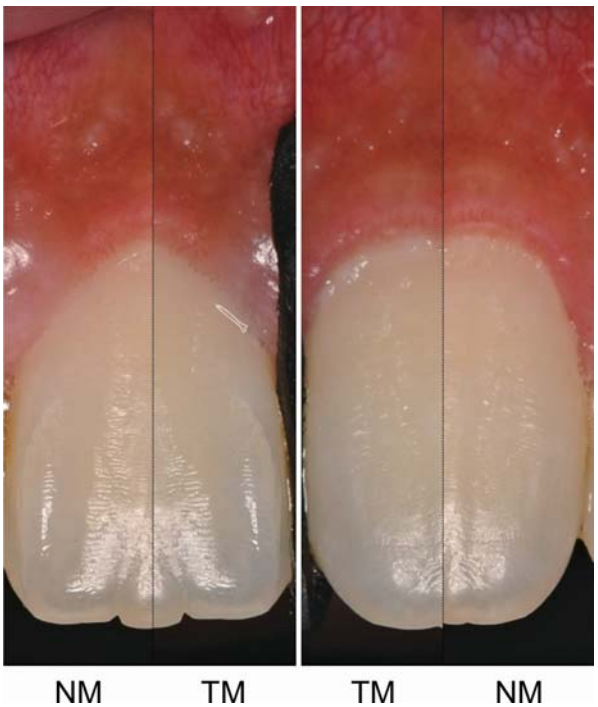

Fig. 9 Comparison of before and after application of the masking device with reference to the crown center. Left: Comparison of half of the mesial surface. Right: Comparison of half of the distal surface.

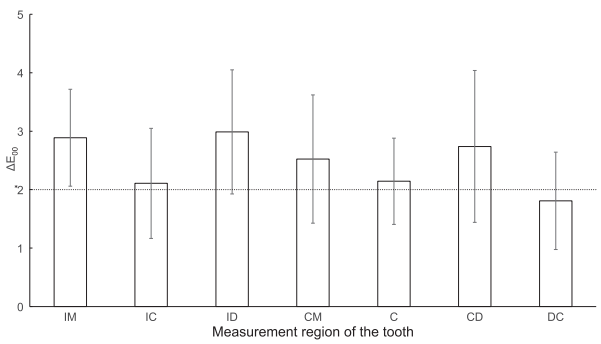

Fig. 10 Natural tooth color differences ΔE_{00} without the masking device (NM) as a control and with the masking device (TM) where *2 has been set as the tolerable color difference.

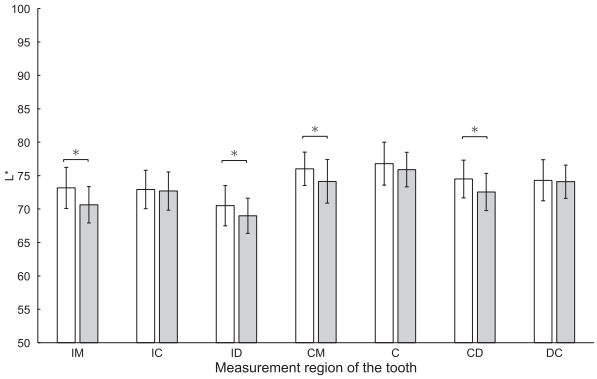

Fig. 11 Comparison of NM (□) and TM (▨) for L* of natural teeth.

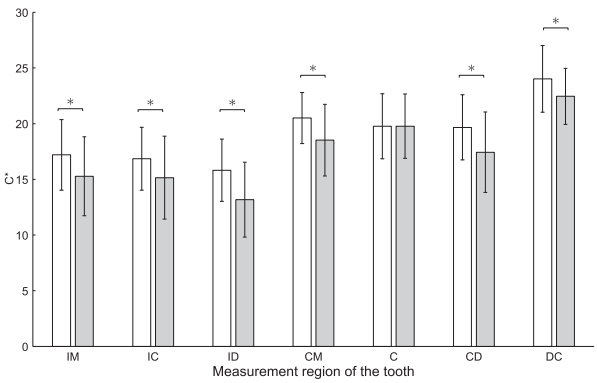

Fig. 12 Comparison of NM (□) and TM (▨) for C* of natural teeth.

adjacent surface sites except for the three central crown sites IC, C, and DC. Significant differences in C* were observed in all regions except for C, the central portion of the crown. The adjacent teeth masked with the adjacent teeth masking device (i.e., TM) had lower lightness and chroma in the adjacent region compared to NM. Moreover, h showed differences in all regions except CD and DC. The hue angle was larger in TM than that in NM, and the hue showed a yellowish trend.

Table 1 Comparison of TM and NM for h of natural teeth

	Region						
Comparison	IM*	IC*	ID*	CM*	C*	CD	DC
NM	79.0±2.7	80.2±1.6	78.3±2.2	77.0±3.0	76.9±2.0	77.2±2.5	71.7±2.7
TM	81.8±2.7	82.9±2.7	82.4±3.0	79.5±2.4	81.2±2.0	78.8±2.8	73.1±3.1

Mean±SD, *$p < 0.05$

Comparison of the ΔE_{00}, L*, C* and h between ST3 and ST1 on the shade tab

Fig. 13 shows an image comparing the mesial and distal halves of ST3 and ST1 based on the center of the crown of the shade tab. Visually, we observed regions of color difference between the mesial and distal halves of the shade tabs. Fig. 14 shows the ΔE_{00} between ST3 and ST1 by color measurement regions. IM, ID, and CM regions were above the allowable color difference. In terms of colorimetric regions, there were significant differences among many regions, with many significant differences between IM, IC, ID, CM, and CD at the incisal and adjacent regions, and C and DC in the central region of the crown. The color difference between the incisal and adjacent regions was high, and that between the center of the crown and the cervical region was low. A comparison of L* at ST3 and ST1 by shade tab region is shown in Fig. 15, C* in Fig. 16, and h in Table 2. Significant differences were observed in L* values for all regions. Significant differences in C* were observed in all regions except C. Significant differences in hue angle were observed among IC, CM, C, and DC. The absence of shade tabs on both sides of the included teeth resulted in lower lightness and chroma in many areas and a slightly larger hue angle.

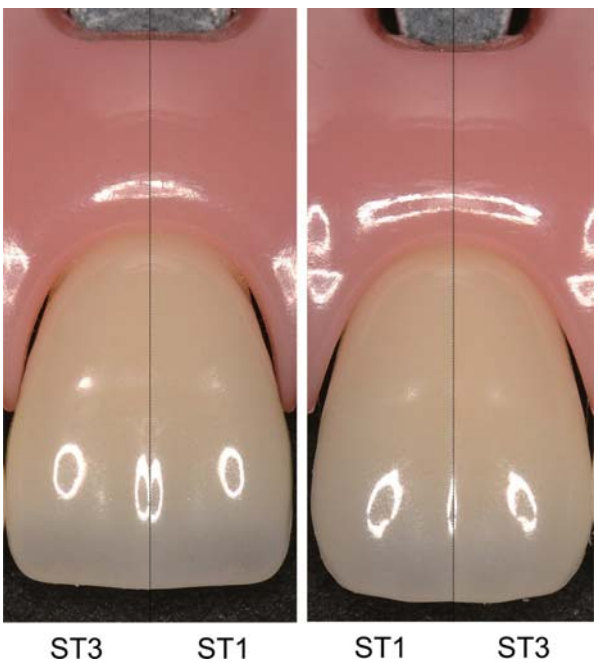

Fig. 13 Comparison of the shade of the ST3 and ST1 target teeth based on the crown center. Left: Comparison of half of the mesial surface. Right: Comparison of half of the distal surface.

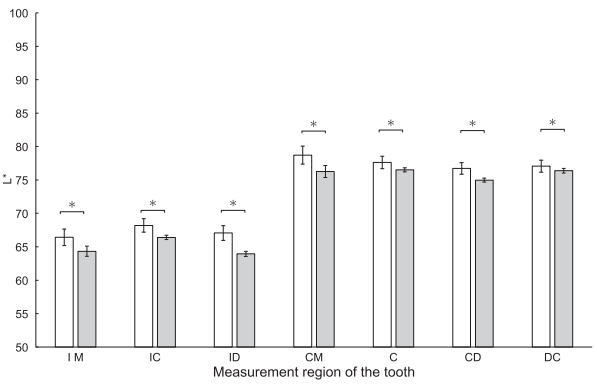

Fig. 15 Comparison of ST3 (□) and ST1 (▒) for L* of shade tabs.

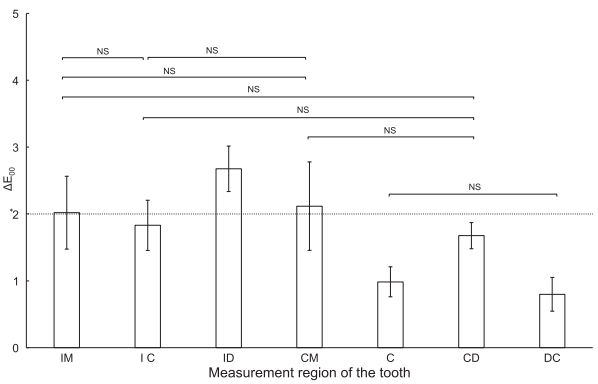

Fig. 14 Shade tab color differences ΔE_{00} between ST3 as a control and ST1 (NS: No significant difference).

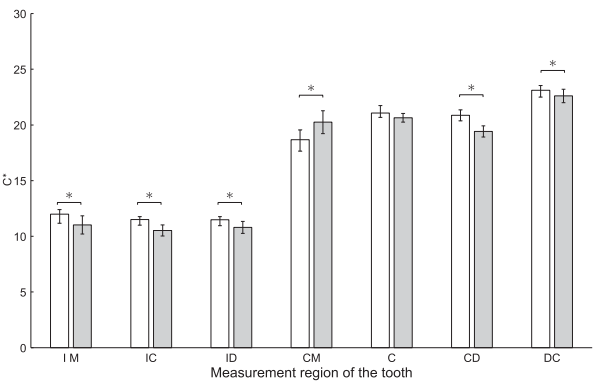

Fig. 16 Comparison of ST3 (□) and ST1 (▒) for C* of shade tabs.

Table 2 Comparison of ST3 and ST1 for h of shade tab

	Region						
Comparison	IM	IC*	ID	CM*	C*	CD*	DC
ST3	80.1±1.7	79.7±1.4	79.7±1.0	77.4±1.6	77.2±0.8	78.1±1.3	75.9±0.8
ST1	81.7±1.5	82.6±1.8	80.4±2.2	78.9±1.4	78.3±0.8	79.4±1.4	75.9±1.3

*$p < 0.05$

Comparison of the ΔE_{00}, L*, C* and h by shade tab combinations

Images comparing the mesial and distal halves of each condition for A2-A2-A2 are shown in Fig. 17, and the results of multiple comparison tests are shown in Table 3. Fig. 18 shows the ΔE_{00} for each condition for each shade tab combination based on A2- A2-A2. No significant visual differences were observed because all regions were below the acceptable color difference. Significant differences in ΔE_{00} were observed between IC and CM for different combinations of shade tabs. The comparison of L* for the combinations of shade tabs by region is shown in Fig. 19, the results of the multiple comparison test in Table 4, C* in Fig. 20, the results of the multiple comparison test in Table 5, h in Table

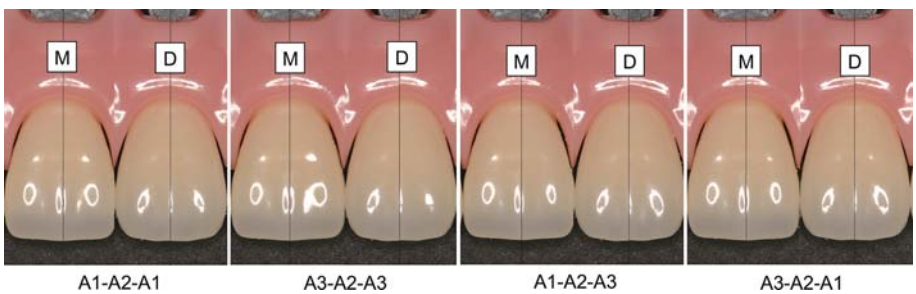

Fig. 17 Digital image comparing the conditions of the shade tab combinations for A2-A2-A2. The left image is the reference A2-A2-A2, and the right is the compared image. M is the image comparing half of the mesial surface. D is the image comparing half of the distal surface.

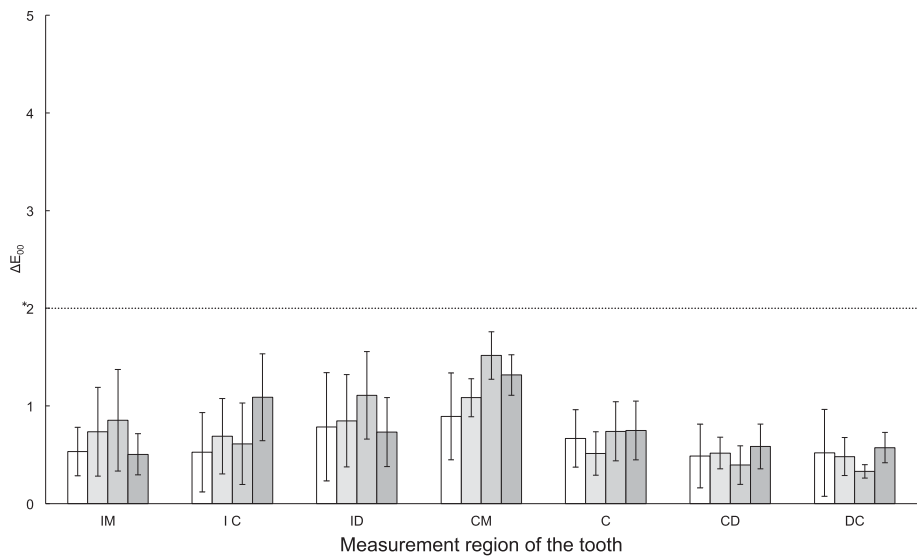

Fig. 18 Shade tab color differences ΔE_{00} between A2-A2-A2 as a control and each shade tab combination conditions (A1-A2-A1, A3-A2-A3, A1-A2-A3, A3-A2-A1).

Table 3 Multiple comparison tests of ΔE_{00} for different combinations of shade tabs

		Region						
Comparison		IM	IC	ID	CM	C	CD	DC
A1-A2-A1	A3-A2-A3							
A1-A2-A1	A1-A2-A3				*			
A1-A2-A1	A3-A2-A1		*		*			
A3-A2-A3	A1-A2-A3				*			
A3-A2-A3	A3-A2-A1							
A1-A2-A3	A3-A2-A1							

*$p < 0.05$

Table 4 Multiple comparison tests of L* for different combinations of shade tabs

		Region						
Comparison		IM	IC	ID	CM	C	CD	DC
A1-A2-A1	A2-A2-A2							
A1-A2-A1	A3-A2-A3			*				
A1-A2-A1	A1-A2-A3			*	*			
A1-A2-A1	A3-A2-A1							
A2-A2-A2	A3-A2-A3							
A2-A2-A2	A1-A2-A3				*			
A2-A2-A2	A3-A2-A1					*		
A3-A2-A3	A1-A2-A3							
A3-A2-A3	A3-A2-A1			*				
A1-A2-A3	A3-A2-A1			*		*	*	*

*$p < 0.05$

Table 5 Multiple comparison tests of C* for different combinations of shade tabs

		Region						
Comparison		IM	IC	ID	CM	C	CD	DC
A1-A2-A1	A2-A2-A2							
A1-A2-A1	A3-A2-A3				*			
A1-A2-A1	A1-A2-A3			*	*	*		
A1-A2-A1	A3-A2-A1				*			
A2-A2-A2	A3-A2-A3				*		*	
A2-A2-A2	A1-A2-A3			*	*	*		
A2-A2-A2	A3-A2-A1				*			
A3-A2-A3	A1-A2-A3			*		*	*	
A3-A2-A3	A3-A2-A1						*	
A1-A2-A3	A3-A2-A1	*		*				

*$p < 0.05$

6, and the results of the multiple comparison test in Table 7. In L*, significant differences were observed in ID, CM, C, CD, and DC due to the different combinations. In C*, there were significant differences in IM, ID, CM, C, and CD due to the different combinations. L* and C* were found to be affected by many different combinations of shade tabs. Significant differences were observed in the hue angle between the DC A1-A2-A1 and A3-A2-A 1 combinations, with A3-A2-A1 having a larger hue angle. The variation of h was less with shade tab combinations than that of theΔE_{00}, L*, or C* values.

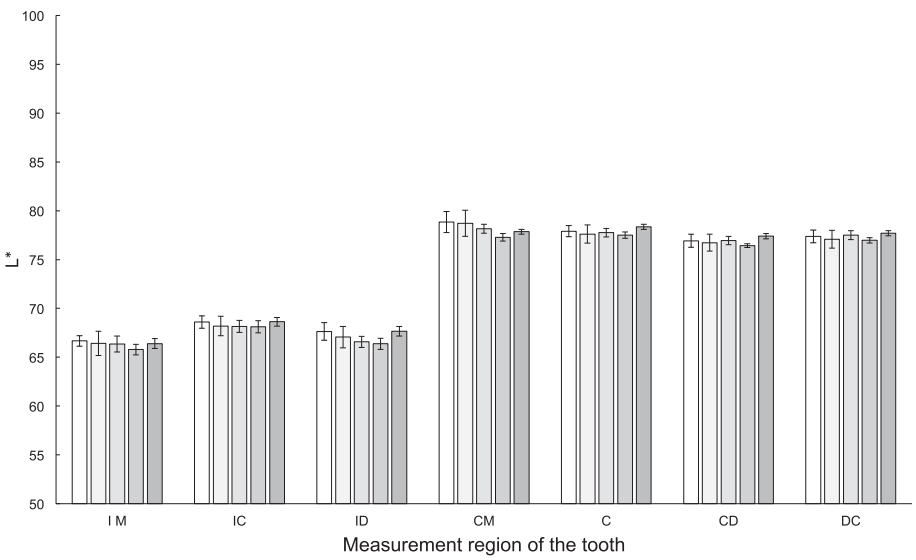

Fig. 19 Comparison of L* for shade tab combination conditions. (□A1-A2-A1, □A2-A2-A2, □A3-A2-A3, □A1-A2-A3, □A3-A2-A1).

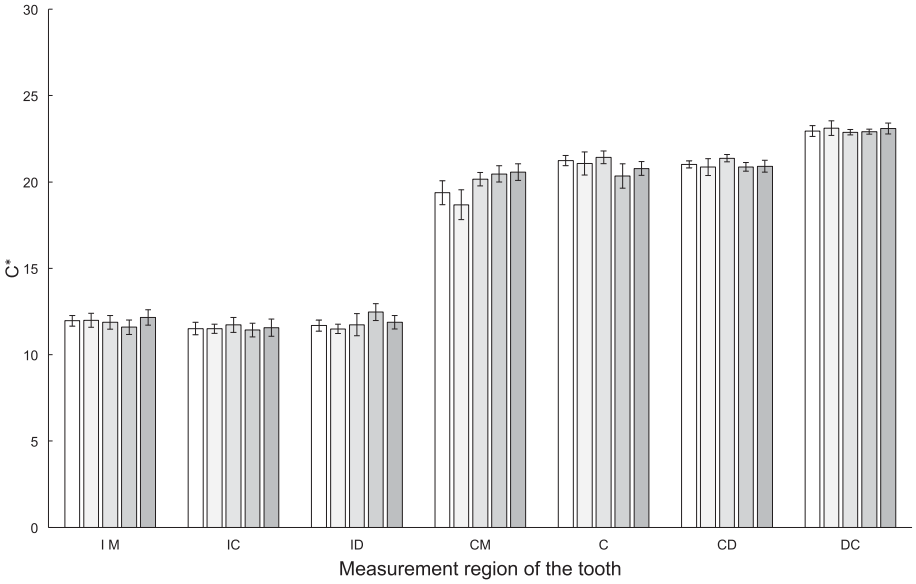

Fig. 20 Comparison of C* for shade tab combination conditions. (A1-A2-A1, A2-A2-A2, A3-A2-A3, A1-A2-A3, A3-A2-A1).

Table 6 Comparison of h for different shade tab combinations

	Region						
Condition	IM	IC	ID	CM	C	CD	DC
A1-A2-A1	80.8±1.0	80.0±0.9	80.5±1.4	77.6±1.2	78.3±1.0	78.5±0.7	75.2±0.9
A2-A2-A2	80.1±1.7	79.7±1.4	79.7±1.0	77.4±1.6	77.2±0.8	78.1±1.3	75.9±0.8
A3-A2-A3	80.0±2.0	79.9±2.2	79.0±2.5	78.3±1.3	77.5±1.0	78.3±0.9	76.1±0.6
A1-A2-A3	79.5±2.4	80.4±1.8	80.9±2.3	78.6±1.1	77.9±1.3	78.7±0.7	76.2±0.6
A3-A2-A1	79.9±0.9	80.1±1.6	80.5±1.4	78.4±1.2	78.2±1.0	78.0±0.8	76.2±0.8

Table 7 Multiple comparison tests of h for different combinations of shade tabs

		Region						
Comparison		IM	IC	ID	CM	C	CD	DC
A1-A2-A1	A2-A2-A2							
A1-A2-A1	A3-A2-A3							
A1-A2-A1	A1-A2-A3							
A1-A2-A1	A3-A2-A1							*
A2-A2-A2	A3-A2-A3							
A2-A2-A2	A1-A2-A3							
A2-A2-A2	A3-A2-A1							
A3-A2-A3	A1-A2-A3							
A3-A2-A3	A1-A2-A3							
A1-A2-A3	A3-A2-A1							

*$p < 0.05$

DISCUSSION

Photographic conditions

Achieving accurate tooth color recording with a digital camera involves various factors, and it is crucial to maintain consistent stable settings for both the camera and the surrounding environment. In this study, We utilized a digital camera designed for intraoral photography, according to recommended settings. Since ambient lighting can affect digital camera photography, daylight-colored D65 fluorescent lamps were used for illumination in a dark room with no ambient light.[3] This recommended controlled setup was essential to ensure reliable color recording. The shade guide and natural teeth, which were the objects of the photography, were used with a black background because they have

translucent areas that can be influenced by the background color.[1]

Colorimetry using a digital camera

The process of shade matching can be accomplished through either a colorimeter or a visual colorimetric method using shade tabs. A colorimeter is simple and easy to use and is less affected by the skill of the user because it is a machine. However, it is difficult to record only a portion of the tooth surface or only the tooth, and it is difficult to convey information other than color. Meanwhile, although the visual colorimetric method using shade tabs is less accurate because it requires visual confirmation, it is commonly used in daily clinical practice. Colorimetry using digital images is employed in many studies.[1, 8, 9, 14] By recording pictures with a digital camera, dental technicians and dentists can share information necessary for the fabrication of prosthetic devices, including facial features and lip characteristics, in addition to tooth color tone, thus facilitating smooth and effective communication. Based on the above, we conducted colorimetry using digital images obtained with a digital camera.

Photographic conditions of natural teeth and use of adjacent surface masking devices

To clarify the influence of adjacent natural teeth on tooth colorimetry, the adjacent natural teeth would have to be extracted, which is clinically not feasible. Therefore, we designed and provided participants with masking devices for the adjacent teeth. These devices covered the adjacent teeth while leaving exposed the healthy central incisor, our target tooth for colorimetry. Black was selected as the color for this device because it absorbs light and is suitable when no adjacent teeth are present.[15]

Photographic conditions of shade tabs

To ensure that esthetic prosthetic devices seamlessly blend with the surrounding teeth in terms of color, we rely on the color information of the target natural tooth and its associated shade tabs. These shade tabs can be used individually or in combinations (multiple tabs in a row). To use multiple shade tabs side by side, it is essential to select shade tabs with different colors. However, there is no established guideline regarding the number of shade tabs or the specific combinations to use. To clarify the effect of the adjacent teeth, we decided to compare conditions where the number of shade tabs varied between one and three, as well as conditions involving changes in the bilateral shade tab combinations.

Measurement regions of the surface of the tooth

For colorimetry, we followed the approach outlined by Nakagawa.[16] and divided the surface of the shade tabs and the natural teeth into three regions mesiodistally (i.e., mesial, central, and distal) and three regions vertically (i.e., cervical, central, and incisal), resulting in a total of seven regions. While shade guides come pre-made with specific forms and colors, natural tooth morphology is unique to each individual and categorized into various forms.[17, 18] Additionally, individual differences exist in the size and position of the labial ridge due to variations in crown morphology.[19] Considering that the development of the mesial and distal labial ridge and position of the ridge would cause a discrepancy in the colorimetric location, it was decided to measure 1.5 mm in from the outer surface of the tooth.

Tolerable color differences

Color is confirmed by sight, and there are individual differences in the way people see color. Although color differences have been standardized and NBS units of color difference have been established by the National Bureau of Standards (NBS),[20] various studies have been conducted on the range of acceptable values for color differences in dentistry. The values of acceptable color differences vary depending on the content of the studies, and have not been established.[4, 21, 22] For color differences surveyed mainly by Japanese Industrial Standards (JIS), the standard for recognizing the same color when judged at a distance is 2.5, while the standard for most people to easily recognize a color difference when judged side by side is 1.2.[23] Under

the conditions of color comparison by the visual colorimetry method, the criterion of acceptable color difference is different when comparing colors side by side than when comparing them at a distance. In the context of shade matching for central incisors, where the prosthesis is adjacent to the target tooth, it is necessary to consider stricter criteria for color differences. Based on the criteria used in the above studies and the standards established, we defined a color difference of less than 2.0 as tolerable.

Color changes due to the influence of adjacent teeth on natural teeth and shade tabs

In terms of lightness and chroma, having adjacent teeth on both natural teeth and shade tabs resulted in brighter and more vivid tooth surfaces. Conversely, the absence of an adjacent tooth led to darker tones on the neighboring tooth surface. Both natural teeth and shade guides exhibited a yellowish hue when there were no adjacent teeth. The cervix of natural teeth experienced a tolerable color difference of less than 2.0, which was less influenced by adjacent teeth. However, the mesial and distal incisal regions, and the central mesial region of the shade tabs had a tolerable color difference of 2.0 or more, while the rest of the regions had an acceptable color difference of 2.0 or less. The central and cervical portions of the crown were less affected by adjacent teeth and showed minimal color change. The loss of adjacent teeth resulted in a visual color change for both natural teeth and shade tabs, presumably due to the adjacent teeth reflecting more light. Natural teeth exhibited more color variation with adjacent teeth compared to shade tabs, likely attributed to their layered structure of enamel and dentin. Shade tabs, on the other hand, are made of a single mass of the same material. Although variations in lightness, chroma, and hue angle were observed with different combinations of shade tabs, the color differences were tolerable, making it difficult to visually perceive any distinction. Therefore, it is suggested to use shade tabs alongside adjacent teeth rather than on their own. Additionally, the absence of adjacent teeth also affected the color tone of the missing side in natural teeth.

Future issues

Natural teeth were measured calorimetrically without classifying the morphology or color tone of the participants' teeth. The morphology, coloration, and surface properties of natural teeth can vary from individual to individual, which means that the effect of adjacent teeth may also vary depending on the target tooth. The colorimetry in the shade tabs was based on A2 shade tabs. Different types of shade tabs exist based on lightness and hue, so changing the type of shade tab used may be influenced by the presence or absence of adjacent teeth or different color combinations. Therefore, it is necessary to examine the effects of adjacent tooth color, morphology, surface characteristics, and enamel thickness on natural teeth, as well as the effects of shade tabs with different lightness and hue on one another.

CONCLUSION

Natural teeth and shade tabs showed a visual color difference in tooth surface tones due to the absence of adjacent teeth, with lower lightness and chroma and larger hue angles in adjacent areas, indicating a yellowish tendency. It was found that the color combinations in which the shade tabs were used did not change the visual color; however, there were significant differences in lightness, chroma, and hue angle. These results suggested that it is necessary to properly arrange the shade tabs when determining and recording the color of natural teeth while comparing the surface shade visually.

This study was conducted with the approval of the Osaka Dental University Institutional Review Board (Approval No.111072).

Conflicts of Interest

The authors declare no conflicts of interest associated with this manuscript.

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