Spectrophotometric Analysis of Tooth Color Reproduction on Anterior All-Ceramic Crowns: Part 2: Color Reproduction and Its Transfer from In Vitro to In Vivo

AKI YOSHIDA, RDT*
LLOYD MILLER, BS, DMD†
JOHN D. DA SILVA, DMD, MPH, ScM‡
SHIGEMI ISHIKAWA-NAGAI, DDS, MSD, PhD§

ABSTRACT
Color reproduction of an anterior tooth requires advanced laboratory techniques, talent, and artistic skills. Color matching in a laboratory requires the successful transfer from in vivo with careful considerations. The purpose of this study was to monitor and verify the color reproduction process for an anterior all-ceramic crown in a laboratory through spectrophotometric measurements. Furthermore, a crown insertion process using composite luting cements was assessed, and the final color match was measured and confirmed.

An all-ceramic crown with a zirconia ceramic coping for the maxillary right central incisor was fabricated. There was a significant color difference between the prepared tooth and the die material. The die material selected was the closest match available. The ceramic coping filled with die material indicated a large color difference from the target tooth in both lightness and chromaticity. During the first bake, three different approaches were intentionally used corresponding with three different tooth regions (cervical, body, and incisal). The first bake created the fundamental color of the crown that allowed some color shifts in the enamel layer, which was added later. The color of the completed crown demonstrated an excellent color match, with ΔE 1.27 in the incisal and 1.71 in the body. In the cervical area, color match with ΔE 2.37 was fabricated with the expectation of a color effect from the underlying prepared tooth. The optimal use of composite luting cement adjusted the effect from the underlying prepared tooth color, and the color match fabricated at a laboratory was successfully transferred to the clinical setting. The precise color measurement system leads to an accurate verification of color reproduction and its transfer.

CLINICAL SIGNIFICANCE

The use of a dedicated dental spectrophotometer during the fabrication of an all-ceramic crown allows the dentist and the laboratory technician to accurately communicate important information to one another about the shade of the tooth preparation, the shade of the contralateral

*Registered Dental Technician (RDT), Gnathos Dental Studio, Weston, MA, USA
†Clinical professor, Graduate and Postgraduate Prosthodontics, Tufts University School of Dental Medicine, Boston, MA, USA
‡Instructor, Department of Health Policy and Epidemiology, Harvard School of Dental Medicine, Boston, MA, USA
§Assistant professor, Department of Restorative Dentistry and Biomaterials Sciences, Harvard School of Dental Medicine, Boston, MA, USA

DOI 10.1111/j.1708-8240.2009.00312.x

target tooth, and the influence of luting cement on the final restoration, thereby allowing the technician better control over the outcome of their tooth color matching efforts and the final color match of an all-ceramic restoration.

(*J Esthet Restor Dent* 22:53–65, 2010)

INTRODUCTION

Color reproduction of an anterior natural tooth is one of the most challenging tasks in esthetic dentistry. It can only be achieved through successful clinical and laboratory performance.

Once tooth color is accurately determined and the color information is transferred to the laboratory in a complete and accurate way, a laboratory technician can interpret all of the information and create a blue map for the ceramic fabrication. In order to create the multidimensional natural tooth color, value and chroma have to be coupled, and semitranslucency has to be harmonized with depth, emphasizing the complexity of the optical properties of the natural tooth.[1,2] Talented and experienced dental technicians can control value and chroma separately, and they can reproduce a depth of color with harmonized translucency and intrinsic characteristics. They must place each layer with careful colorimetric intensions to create multidimensional tooth color. In fact, there have been many clinical cases that demonstrate excellent tooth color reproduction on ceramic restorations. However, no assessment methods have been used to analyze the porcelain work for color reproduction based on scientific data. With current advanced computer-based technology, a precise color measurement system provides an "accurate virtual try-in."[3] This makes verification and quality control possible in a dental laboratory, which is the crucial step for success in color matching.

In color matching of all-ceramic crowns, there are three factors that can alter the final color of the crown: (1) the color of the prepared tooth; (2) the color of a crown; and (3) the color of the luting cement. These three layers (or components) have to be optically harmonized to reproduce natural tooth color. Assuming excellent color matching is verified in the laboratory, it should be correctly transferred to the clinical setting. Die materials that represent a prepared tooth color are available; but there is a limited number of die material shades. Therefore, there is quite often a discrepancy between die materials and the actual color of a prepared tooth. This color discrepancy will be more critical when we use a translucent all-ceramic crown. This discrepancy can be compensated for by using the luting composite cement. There are composite luting cement systems, which include several shades of cement to modify the final color of all-ceramic crowns. The effects of cements on all-ceramic crowns merit further investigation because there are no scientific guidelines for the use of luting cements in adjusting or modifying crown color.

In this case study, each step of the process of color reproduction in the laboratory was monitored and assessed by scientific color data. Furthermore, the clinical step of crown insertion with the use of the optimal luting composite cement was analyzed, and the final color matching was verified by spectrophotometric measurements.

MATERIALS AND METHODS

A clinical case of an all-ceramic crown on a maxillary central incisor fabricated by a zirconia coping (Lava, 3M ESPE, St. Paul, MN, USA) and layered porcelain (Seribian Zirconia, Noritake, Nagoya, Japan) was analyzed during the steps of color reproduction in the laboratory. The process

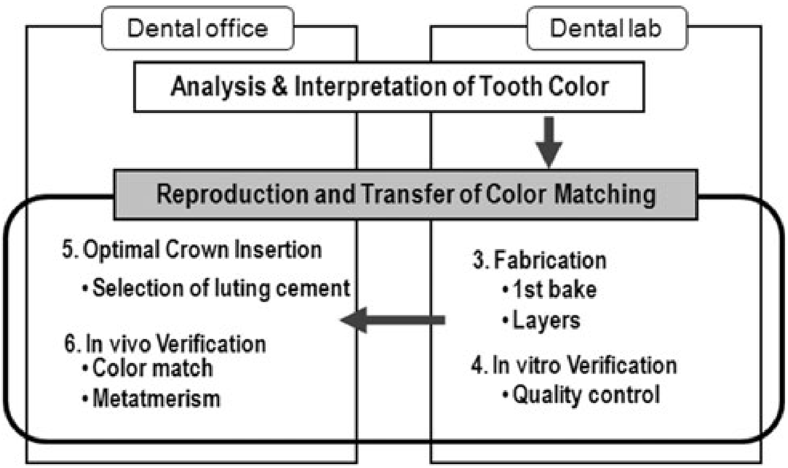
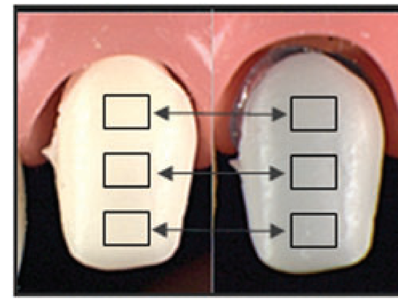


Figure 1. The scheme of process for tooth color reproduction and its transfer from in vitro to in vivo.



Opacity index		
Cervical	Body	Incisal
72	80	80

Figure 2. Spectral images for the coping filled with a black silicone and a white silicone.

of crown insertion with luting composite cement was assessed, and the final color matching was confirmed (Figure 1). For the color measurements, the dental spectrophotometer system (Crystaleye, Olympus, Tokyo, Japan) was used.

Optical Analysis of Ceramic Coping

The ceramic coping Lava shade A2 was filled with a black silicone and a white silicone (Fit Checker, GC America Inc., Alsip, IL, USA) and inserted into the area of tooth #8 on a typodont (Figure 2; D16-500A, Nissin, Kyoto, Japan). The color measurements of the coping were performed on the typodont, which was placed in a black box (inspection kit, Olympus, Tokyo, Japan). The opacity index was calculated in each of the three areas by using the following equation:

$$\text{Opacity} = L^*_{\text{with a white silicone}} / L^*_{\text{with a black silicone}} \times 100$$

The coping was then filled with a die material shade ST9 (IPS Natural Die Material, Ivoclar Vivadent, Schaan, Liechtenstein), and the color difference between the coping and the target tooth was analyzed in each of the three areas (body, incisal, and cervical) as a baseline of color reproduction.

Color Verification after the First Bake and Crown Completion

After the first bake, the crown was filled with the die material, and a thin layer of glycerin was applied on the crown surface. The color of the crown was measured, and it was compared with the target tooth by using the same process mentioned above. Having the color information of the first bake, the porcelain was layered to reproduce the target color for the final color match. The color of the completed crown was measured, and the color match was analyzed for verification.

Crown Insertion

The completed crown was placed on the prepared tooth using glycerin and a try-in paste of the luting cement system (Valiolink II, Ivoclar Vivadent). The color of the crown was compared with that of the target tooth, and the optical effects of altering the luting cement were analyzed.

The Verification of the Final Color Match

The final color of the completed crown was checked in three areas by the spectrophotometer. The color match was assessed

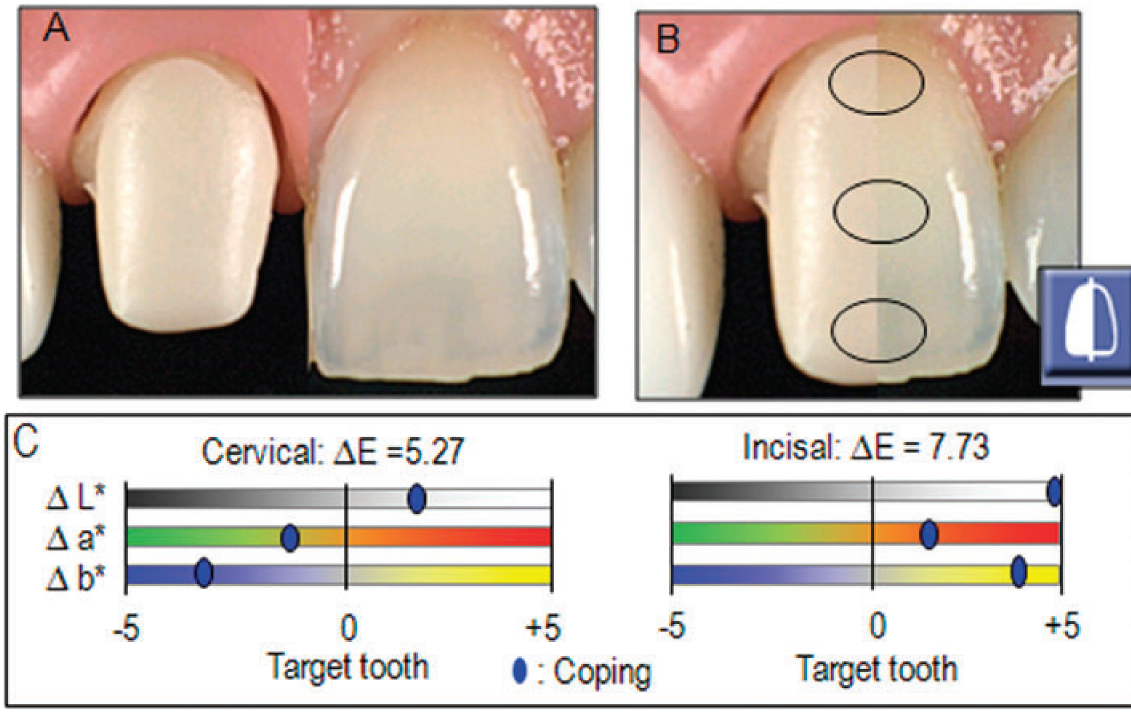


Figure 3. Color analysis of the ceramic coping. A, *Spectral images of the ceramic coping filled with a die material and the target tooth.* B, *Split image of the coping and the target tooth.* C, *Numerical color data of the difference between the coping and the target tooth (ΔL*: difference of lightness; Δa*: difference of redness; Δb*: difference of yellowness).*

under four different light sources to determine the effect of metamerism or the influence of different light sources. Light from D65, Fluorescence, Blue sky, and Xenon were analyzed using software (MSC 2.1, Olympus), and the effect of metamerism was determined.

RESULTS

Optical Properties of the Ceramic Coping

There was a significant color difference between the ceramic coping with a white background and a black background. Opacity index was approximately 80 in the body and the incisal region and 72 for the cervical region. This indicated that the ceramic coping was not perfectly opaque, and the cervical region will be affected more than the other areas by the underlying color of the prepared tooth (Figure 2).

The color difference between the ceramic coping of shade A2 filled with die material ST9 and the target tooth varied in the three regions. In the body area, there was only a slight difference in all three color components: lightness (L^*), redness (a^*), and yellowness (b^*); and the color difference ΔE was 1.61. In contrast, in the cervical and incisal area, there was a large color difference in both lightness (L^*) and chromaticity (a^* and b^*). In both the cervical and incisal areas, the coping indicated more lightness (Figure 3). The coping indicated less chromaticity in the cervical and higher chromaticity in the incisal. These optical phenomena were taken into account by the dental technician during color reproduction in the first bake.

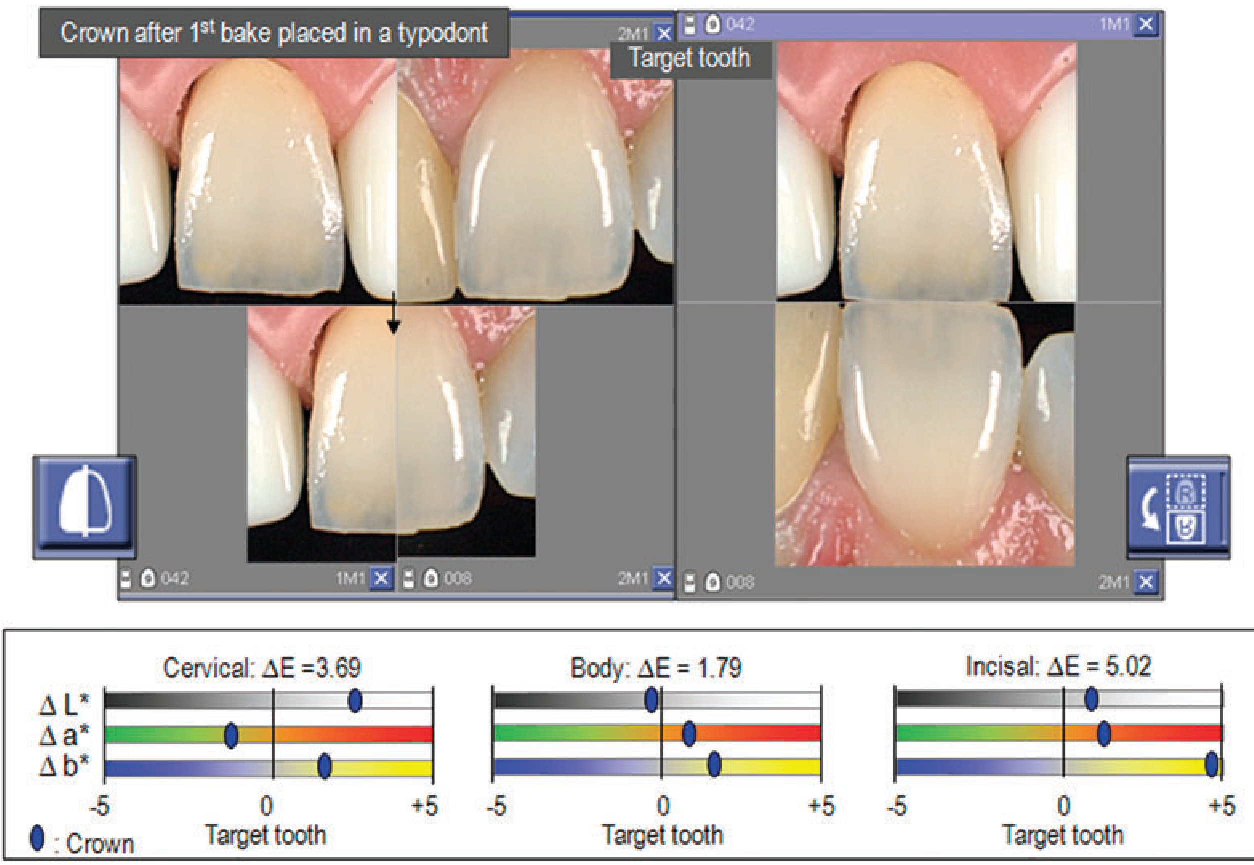


Figure 4. Color analysis of the crown after first bake. Display image analysis and numerical data comparison for the crown after first bake and the target tooth.

Color Verification after the First Bake and Completion of Layers

The first bake created the foundation for reproducing the internal color (Figure 4). In the body area, the lightness of the ceramic coping was kept by applying a neutral white porcelain addition to B1 dentin, and the color that was created was close to the target tooth with ΔE 1.79. In the cervical area, the lightness was decreased and chromaticity was increased, keeping redness lower by applying B1 dentin and reddish/brown internal staining. The color of the cervical area was intentionally made with ΔE 3.6, which is considered a perceptible color difference expecting possible color effects through the prepared tooth and marginal gingival. In the incisal area, the lightness was dramatically decreased by creating chromaticity in the internal structure. The detailed internal structure was created with mamelons color matched in lightness and redness. Yellowness was made with a higher value to allow for decreasing chromaticity from the enamel layer.

The color match after the first bake in the body area was kept by applying translucent porcelain mixed with a small amount of white modifier (Figure 5). The translucent porcelain mixed with white modifier was applied in the incisal area in order to mimic bleached enamel. The optimal

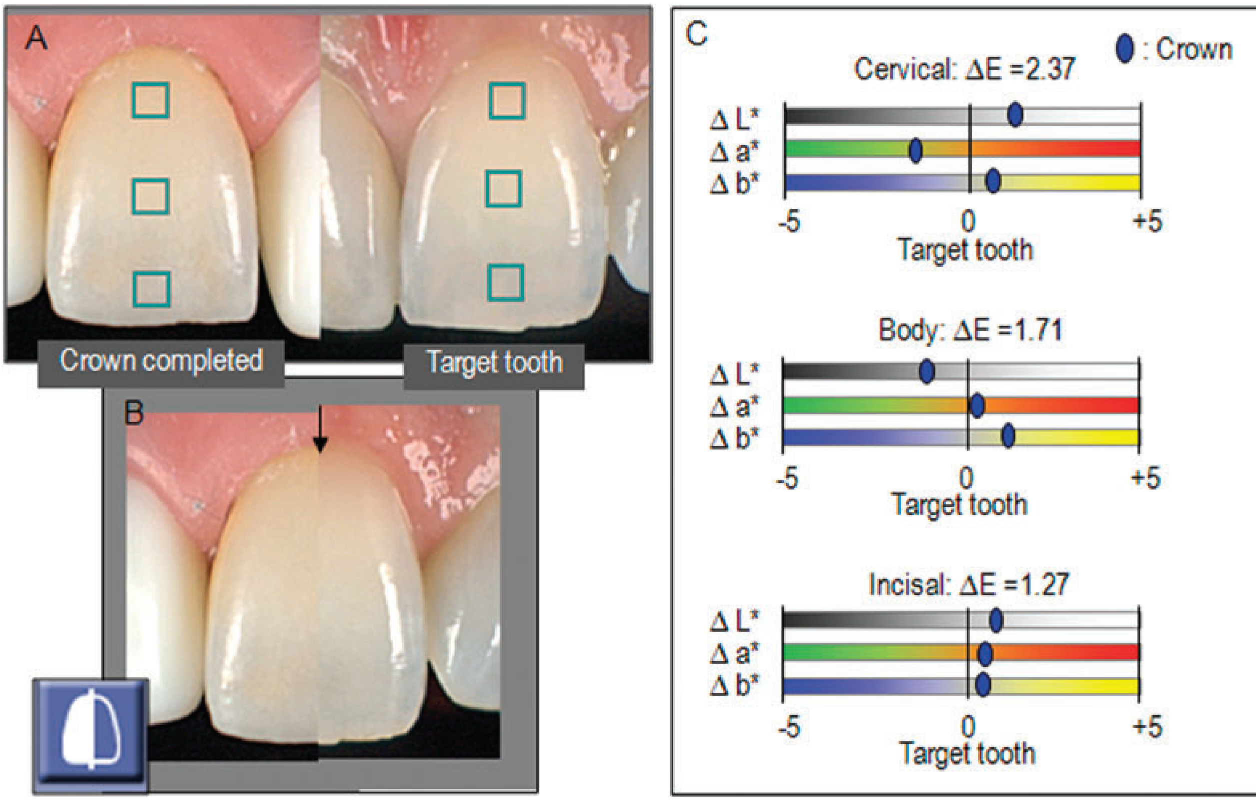


Figure 5. Color analysis of the completed crown. A, *Spectral images of the crown filled with a die material and the target tooth.* B, *Split image of the crown and the target tooth.* C, *Numerical color data of the difference between the crown and the target tooth.*

mixing ratio of a white modifier reduced yellowness while maintaining the same level of lightness. This provided an excellent color match with Δ*E* 1.27. In the cervical area, the translucent layer decreased lightness and yellowness, resulting in Δ*E* 2.37.

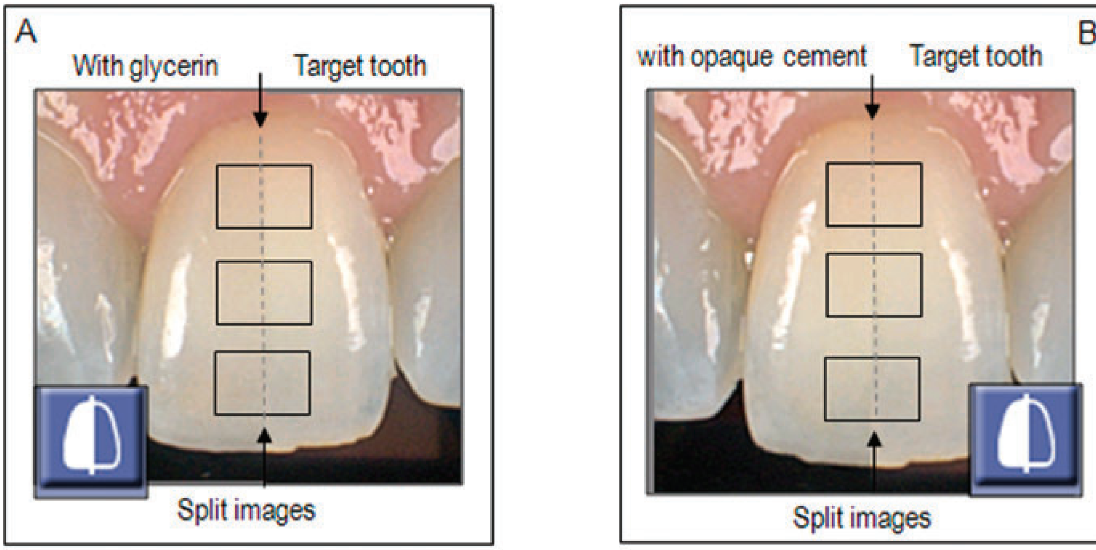
Crown Insertion

The color difference Δ*E* value between the crown with glycerin and the natural tooth (#9) was 2.48 in the cervical area, 1.92 in the body region, and 2.84 in the incisal area. An opaque shade of luting cement improved the color match of the crown by increasing lightness and decreasing the chromaticity. The Δ*E* values dramatically decreased especially in the cervical and body area, but increased in the incisal area (Figure 6).

The crown cemented using a mixture of luting cement (Opaque 30% + Bleach XL 70%) resulted in a color difference Δ*E* below 1.4 in all three areas. CIE (Commission Internationale de l'Eclarirage) color coordinates Δ*L**, Δ*a**, and Δ*b** showed the same trend in all three areas (Figure 7). The color of the crown and the natural tooth under four different light sources differed; however, an excellent color match was achieved under all four light sources (Figure 8). The esthetically well-colored matched crown was indistinguishable in the arch.

DISCUSSION

When reproducing the tooth color with ceramic, the laboratory



C	Cervical				Body				Incisal			
	ΔE	ΔL*	Δa*	Δb*	ΔE	ΔL*	Δa*	Δb*	ΔE	ΔL*	Δa*	Δb*
Glycerin	3.2	-3.1	±	±	2.5	-2.4	±	±	1.4	±	±	0.3
Opaque	1.3	-0.8	±	±	1.6	0.3	±	±	2.3	±	±	2.1

Figure 6. Color analysis of optical effect of the luting composite cement. A, *Split image of the crown seated with glycerin and the tooth.* B, *Split image of the crown seated with an opaque cement and the tooth.* C, *Color analysis data of optical effects of the cement.*

technician must have three phases: interpretation, fabrication, and verification, which all interact with each other. Although the quality of interpretation and fabrication may vary for individual technicians, the method used for verification is critical and has to be accurate. This case study analyzed each step of the crown fabrication using spectrophotometric measurements as an accurate tool for verification. Throughout the assessment, essential factors for an accurate color reproduction of the natural tooth in ceramic restorations were reviewed.

The translucency of the ceramic coping is an important factor in establishing a better color match. Although several studies have suggested that a zirconia coping has more opacity than the other types of copings for all-ceramic crowns,[4,5] it is not clear how much the ceramic coping will be affected by the color of the underlying layer. This study indicated that the Lava coping was not opaque and the effect of the prepared tooth color had to be expected. The color of a ceramic coping filled with a die material would be the baseline for the color reproduction process. The ceramic coping shade A2 (Lava) filled with a die material indicated a higher value than the target tooth. The layering ceramics can increase or decrease chromaticity but always leads to a decrease in value. Therefore, having higher

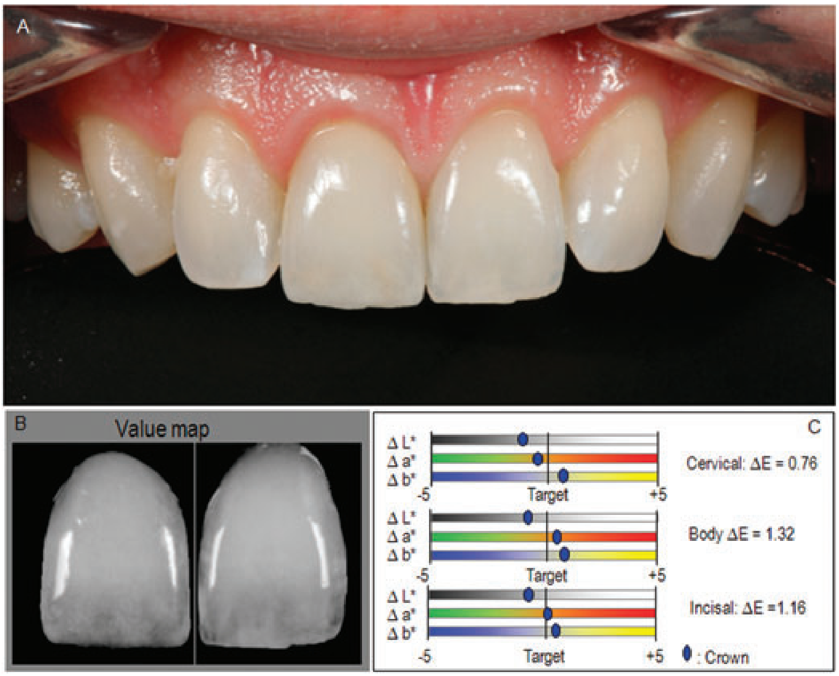


Figure 7. Color comparison of the completed crown and the target tooth. A, *Color comparison under D65 light.* B, *Value comparison.* C, *Numerical color data of the difference between the completed crown and the target tooth.*

value on the ceramic coping was important in the color matching process because it will compensate for a decrease in value caused by layering porcelain. In this case, selecting an A2 coping with a higher value was a rational strategy for porcelain color reproduction.

Natural tooth color is created by layers that result in tooth color with depth. In order to create three-dimensional color with depth, the first bake is an important step in reproducing internal anatomical tooth color. Furthermore, the color effect of an enamel layer has to be predicted when the initial bake is performed. For this case, several shades of internal staining were applied by adding to the dentin layer. At this stage, part of the color match was made and further changes were intentionally left to the enamel layer. As the results show, the internal staining increased chromaticity, and white modifier porcelain mixed with translucent enamel porcelain worked to maintain lightness. In the first bake, the fabrication of internal tooth color was performed based on experienced interpretation, and the results were confirmed by a spectrophotometric analysis.

As the results show in Figure 5, the color of the completed crown in the incisal and the body region indicated an excellent match with very small ΔE 1.27 and 1.71, respectively, which are considered to be clinically indistinguishable.[4–9] In the cervical region, because there was a large discrepancy between the die material and the prepared tooth, especially in a^* and L^* values, the color was intentionally created with less redness (negative a^*) and slightly more lightness (positive L^*). This information can be sent to the dental office as additional advice for successful crown cementation.

The virtual try-in is an important step in verifying the color created leading to successful color reproduction. The precise virtual try-in, based on the spectrophotometric measurements, can provide useful information on color reproduction in the laboratory and can also give useful feedback from the laboratory to the dental office for final color matching with composite luting cements. The most important factor for the virtual try-in is an accurate color measurement. The most vital and indispensable factor for precise tooth color measurement is translucency and the inhibition of light loss from the

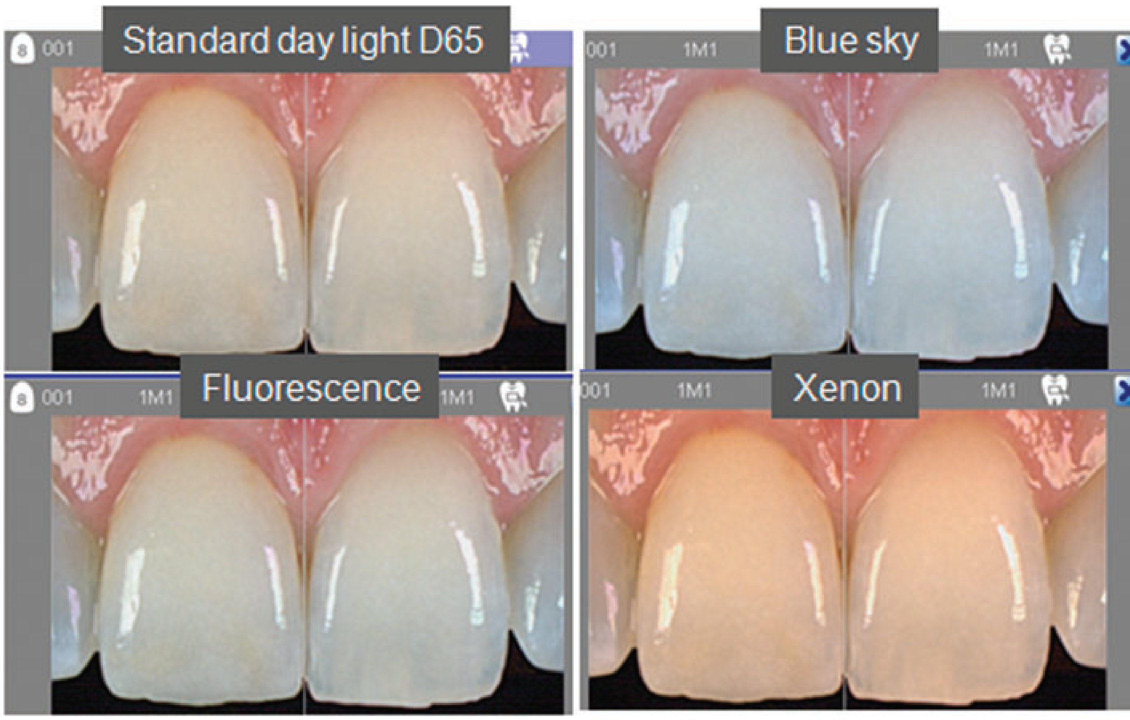


Figure 8. The spectral images of the crown and the target tooth under different light sources. (Color difference ΔE = 1.32 with day light D65; ΔE = 1.31 with Blue sky; ΔE = 1.32 with Fluorescence; ΔE = 1.34 with Xenon.)

aperture of the spectrophotometer or colorimeter. This light loss is commonly referred to as "edge-loss error," and leads to low recorded values of L^*.[10,11] Strong illumination source can also cause "edge-loss error" leading to a loss of reflected light from semitranslucent objects. The present study utilized a spectrophotometer that was designed to be unaffected by "edge-loss error" through the use of relatively weak illumination from seven spectral LEDs (light emitting diodes), which cover the spectrum range from 380 to 720 nm.

Furthermore, the color measurement of the natural tooth and crown in a dental laboratory must be preformed under the same optical conditions. Controlling lighting conditions is a major problem because it is not standardized in the dental office or laboratory. In this case study, a black check box called an inspection kit was used, which provided the same optical condition for the crown measurements as the same conditions as the tooth color measurement. The virtual try-in can make the correct color analysis possible, thus allowing the laboratory process to accurately proceed to the next step.

In order to achieve an accurate color reproduction, the crown insertion is the critical step in the final restoration. Because of their translucency, all-ceramic restorations will be affected by the color of the underlying tooth structure and the color of the luting composite cements. Composite resin cement kits provide various cement shades to facilitate achieving an optimum color match. Luting cements represent an important factor impacting the esthetic outcome, but the optical properties of different shades of resin-based luting cements are not fully defined. The effects of different resin cements on the final appearance of all-ceramic crowns have not yet been investigated. In this clinical assessment, opaque cement was used to mask the color of the prepared tooth, which was much darker with more red/yellow than the best matched die material in the cervical region. However, because of the strong color variation of the prepared tooth from the cervical to the incisal, the whiteness of the opaque cement did not work evenly on the prepared tooth; it had to be adjusted by mixing with a more translucent shade of cement (Bleach XL) to match the color in the body and incisal region. These detailed considerations were critical in order to achieve the ideal final color match of all-ceramic restorations.

Previous studies have reported ΔE thresholds for clinical acceptability and perceptible color difference. Reported thresholds for acceptable color difference were $\Delta E < 1.1$ units for red variations in crowns and $\Delta E < 2.1$ units for yellow variations in crowns.[7] A threshold of $\Delta E \geq 2.72$ was the 50% rejection rate for direct dental restorative materials.[9] A difference exists between the threshold values of ΔE for clinically acceptable and perceptible difference as well.

In this clinical assessment, color difference ΔE was 1.15, 1.32, and 0.76 in each of the three areas from cervical to incisal. These color difference values are smaller than perception thresholds previously reported in the literature, supporting the excellent color match of the crown to the contralateral incisor. The excellent color match was also supported by the patient, who was highly satisfied with the restoration. Additionally, the level of color match obtained was the same under four different light sources, which indicated that a color mismatch would not be apparent because of metamerism.

This clinical assessment was based on one clinical case; however, scientific color investigations monitoring each step of color reproduction from the initial exam to the crown insertion will give useful information for precise color matching.

CONCLUSION

An accurate ceramic powder map and an accurate verification method lead to successful color matching in the laboratory. Based on feedback from the laboratory, careful consideration for the crown insertion with a use of optimal color of the luting cement is crucial in transferring the color match from in vitro to in vivo. Scientific observation can aid the success of clinical and laboratory performance to achieve excellent color reproduction.

DISCLOSURE

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

REFERENCES

1. Chiche GJ, Pinault A. Esthetics of anterior fixed prosthodontics. Chicago (IL): Quintessence Publishing Co. Inc.; 1994.
2. Chu SJ, Devigus A, Mieleszko A. Fundamentals of color. Chicago (IL): Quintessence Publishing Co. Inc.; 2004.
3. Brewer JD, Wee A, Seghi R. Advances in color matching. Dent Clin North Am 2004;48:341–58.
4. Rasetto FH, Driscoll CF, Prestipino V, et al. Light transmission through all-ceramic dental materials: a pilot study. J Prosthet Dent 2004;91:441–6.
5. Heffernan MJ, Aquilino SA, Diaz-Arnold AM, et al. Relative translucency of six all-ceramic systems. Part 1: core materials. J Prosthet Dent 2002;88:4–9.
6. Johnston WM, Kao EC. Assessment of appearance match by visual observation and clinical colorimetry. J Dent Res 1989;68:819–22.
7. Douglas RD, Brewer JD. Acceptability of shade differences in metal ceramic crowns. J Prosthet Dent 1998;79:254–60.
8. Douglas RD, Steinhauer TJ, Wee AG. Intraoral determination of the tolerance of dentist for perceptibility and acceptability of shade mismatch. J Prosthet Dent 2007;97:200–8.
9. Ragain JC, Johnston WM. Minimum color differences for discriminating

mismatch between composite and tooth color. J Esthet Restor Dent 2001;13:41–8.

10. Johnston WM, Hesse NS, Davis BK, Seghi RR. Analysis of edge-losses in reflectance measurements of pigmented maxillofacial elastomer. J Dent Res 1996;75:752–60.

11. Ishikawa-Nagai S, Sato S, Ishibashi K. Using a computer color matching system in color reproduction of porcelain restoration. Part 3: a newly developed spectrophotometer designed for clinical application. Int J Prosthodont 1994;7:50–5.

Reprint requests: Shigemi Ishikawa-Nagai, DDS, MSD, PhD, Harvard School of Dental Medicine, 188 Longwood Avenue, Boston, MA, USA 02115; Tel.: +1-781-698-9688; Fax: +1-617-432-0901; email: shigemi_nagai@hsdm.harvard.edu

This article is accompanied by commentary, "Spectrophotometric Analysis of Tooth Color Reproduction on Anterior All-Ceramic Crowns: Part 1: Analysis and Interpretation of Tooth Color: Part 2: Color Reproduction and It's Transfer From In Vitro to In Vivo," Rade D. Paravina, DDS, MS, PhD, DOI 10.1111/j.1708-8240.2009.00313.x