Spectrophotometric Analysis of Tooth Color Reproduction on Anterior All-Ceramic Crowns: Part 1: Analysis and Interpretation of Tooth Color

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ABSTRACT

Color matching of a natural maxillary central incisor is one of the most difficult challenges in clinical dentistry. Accurate color determination and interpretation of tooth color information in ceramic work is an important step in achieving success in ideal color reproduction. In this case study, factors that influence tooth color determination were analyzed, and the process of interpretation of tooth color information was assessed based on scientific color data using a novel dental spectrophotometer system.

An all-ceramic crown for a maxillary right central incisor was the subject of this color assessment. The contralateral incisor was an intact natural tooth that was bleached and then used as the target shade for an all-ceramic crown. The dental spectrophotometer (Crystaleye, Olympus, Tokyo, Japan) was used for tooth color measurement and analysis. The target tooth, prepared tooth, maxillary arch, and face images were captured for color information. Tooth color stabilization related to tooth bleaching and tooth dehydration was assessed. Based on tooth color data obtained by the dental spectrophotometer, color was analyzed in several different areas of a tooth using CIELAB (Commission Internationale de l'Eclarirage) color coordinates L^*, a^*, b^*, and color difference ΔE. Interpretation of the tooth color information was made in each of porcelain layers on a blue map, and its intensions for color reproduction were described.

Throughout this spectrophotometric assessment, the process of stabilized tooth color determination, tooth color analysis, interpretations, and fabrication of a blue map for porcelain work was clarified with color data as scientific evidence.

CLINICAL SIGNIFICANCE

The use of a dedicated dental spectrophotometer allows the evaluation and measurement of the color of a bleached tooth. This allows the laboratory technician to more precisely understand the bleached tooth shade as well as when the bleached tooth color has become stable enough to match to a contralateral all-ceramic crown restoration.

(*J Esthet Restor Dent* 22:42–52, 2010)

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DOI 10.1111/j.1708-8240.2009.00311.x

INTRODUCTION

Color matching in dentistry is a complex task that is affected by many factors. The major problems are the subjective variability of shade matching, the polychromatic nature of teeth, and the limitations of dental shade guides that incompletely represent the color space of natural teeth.[1–5] These factors have always been major problems for visual shade matching. Furthermore, tooth color matching has become more complicated as materials and techniques have advanced and patient expectations have risen.

In order to achieve success in tooth color matching, tooth color must be precisely determined, and the information must be transferred to the laboratory in a complete and accurate way. Despite the fact that the inaccuracy and subjectivity of visual perception and the limitations of shade guides have been pointed out, visual shade matching with a dental shade guide is still one of the primary methods of color matching. Over the last decade, digital photography has gained popularity as a way to convey color information to dental laboratories. The quality of the image is important; it can vary depending on the type of camera, the camera settings, lighting conditions, size of the image captured, the relative position of teeth, and shade guides. Each of these factors can undermine the integrity of the captured image. An inferior image provides no information and may create confusion and errors. There are several reports indicating the inaccuracy of the color information obtained using photography.[6,7] A digital photograph is a potentially useful tool for color communication, but only if images are acquired under appropriate conditions with appropriate techniques. Furthermore, a digital photograph, as used in clinical dentistry, does not provide the objective scientific color data necessary for the optimal interpretation of information in crown fabrication. The interpretation of tooth color using a digital photograph is highly dependent on the individual and can be subjective and often inaccurate.

In contrast, instrument color measurement has the potential of eliminating the subjective variables of shade selection. A number of color-measuring instruments are commercially available such as ShadeVision (X-Rite, Grand Rapids, MI, USA), which is a colorimeter; Easyshade (Vita Zahnfabrik, Bad Sackingen, Germany), which is a spectrophotometer that does not provide images; and SpectroShade Micro (MHT, Verona, Italy) and Crystaleye, which are spectrophotometers that also provide images. Spectrophotometers, generally, can provide more systematic and precise measurements than colorimeters because of their ability to measure the amount of light reflected from objects throughout the visible spectra range. A color-measuring instrument with computerized color analysis allows for standardized and accurate color matching compared with conventional techniques.[8–10] A spectrophotometer that provides a sufficient two-dimensional image of the target tooth should theoretically improve tooth color analysis and communication with the dental laboratory for the reproduction of natural tooth color.[10]

The stabilization of tooth color is one of the important factors for color matching. In the last several decades, tooth bleaching has become a common procedure in dental practice. Patients have easy access to tooth whitening either through the dental office or through commercially available over-the-counter products. Tooth whitening has created an extension of the observed color spectrum of natural teeth. It was reported that tooth whitening makes teeth less chromatic and lighter,[11] but the magnitude of color change is highly dependent on the original tooth color.[12] The confirmation of a stabilized tooth color after bleaching is an important issue for shade determination. Furthermore, tooth dehydration is another important factor that can impact precise shade determination.[13] Since natural teeth can easily become dehydrated when they are not covered with saliva, shade-taking procedures should be performed prior to any other dental procedures during the office visit.

Although the metal-ceramic crown became the most common anterior restoration after its introduction in the 1960s, presently, all-ceramic crowns are widely accepted for anterior teeth requiring supreme esthetics. One of the most important benefits of the all-ceramic crown is its semitranslucent characteristic that allows some light to traverse the crown. This optical property creates better esthetics in ceramic crowns compared with the metal-ceramic crowns that predominately reflect light and do not allow light to pass through the metal substrate. The translucency of all-ceramic restorations allows the color of the underlying prepared tooth to impact the final tooth color. Understanding the influence of the underlying tooth color on the clinical appearance of the final crown is critically important.[14–17]

Even though accurate color information for the target tooth and prepared tooth is given, interpretation of color data to the map of the ceramic powder layering is still a major challenge. The natural tooth color is truly multidimensional, and only talented and experienced dental technicians may be able to interpret color information and correctly apply it to the actual ceramic work. In this case study, factors that influence the tooth color determination were analyzed, and the process of tooth color analysis and interpretation of tooth color information into the ceramic design was assessed based on scientific color data using the dental spectrophotometer system.

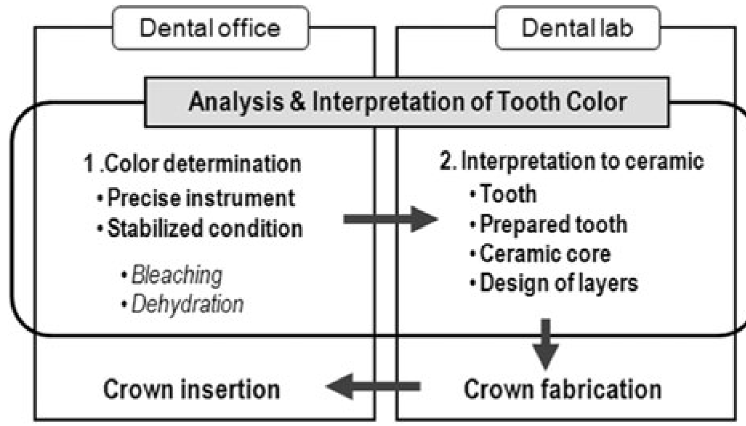

Figure 1. The scheme of tooth color analysis and interpretation.

MATERIALS AND METHODS

The clinical process of tooth color determination for a case of an all-ceramic crown on the maxillary central incisor was assessed, and interpretation of tooth color data on the ceramic work was investigated (Figure 1). A 36-year-old healthy Caucasian male with a chief complaint of "My front tooth is discolored" was the subject in this study. The maxillary right central incisor (#8) was fractured 10 years prior and was restored with a direct composite veneer. Endodontic treatment was performed, and the patient was referred for a full-coverage restoration. The contralateral tooth (maxillary left central incisor: #9) was intact with no restorations. Tooth #8 was prepared for an all-ceramic crown, and a custom-cast post and core with porcelain coverage on the visible portion was cemented with adhesive resin cement (Relyx ARC, 3M ESPE, St. Paul, MN, USA). An impression was made with a polyether impression material (Impregum, 3M ESPE), and an acrylic resin temporary crown was fabricated and cemented with provisional cement (Tempbond, Kerr, Orange, CA, USA).

Color Measurement

A dental spectrophotometer was used to measure tooth color (Figure 2; Crystaleye). This spectrophotometer uses seven LEDs (light emitting diodes) as an illumination

Figure 2. The dental spectrophotometer used and spectrophotometric images obtained.

source, with a 45°/0° geometry.[10] Prior to data acquisition, the instrument was calibrated using a calibration plate. The spectral data from the tooth was acquired by the spectrophotometer at the same time as an image of the tooth was captured. The device was also used to acquire full-arch and full-face images of the patient. The reflectance values ranging from 380 to 700 nm, with 1-nm intervals in each pixel, were transferred from the spectrophotometer to a personal computer (ThinkPad T41, IBM, Armonk, NY, USA). The full-arch and face images were color calibrated using the spectral data of the tooth as a reference. Multiple factors were analyzed in terms of color matching process using the CIELAB (Commission Internationale de l'Eclarirage) color coordinates[18] described below.

$$\Delta L^* = L^*_{\text{target}} - L^*_{\text{experiment}}$$
(L^*: lightness)

$$\Delta a^* = a^*_{\text{target}} - a^*_{\text{experiment}}$$
(a^*: green-red)

$$\Delta b^* = b^*_{\text{target}} - b^*_{\text{experiment}}$$
(b^*: yellow-blue)

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

Confirmation of Stabilized Tooth Color

Tooth bleaching (Zoom, Discus Dental, Culver City, CA, USA) was performed for maxillary and mandibular arches (3×15 minutes) followed by home bleaching (Night White; Discus Dental) for 2 weeks. Tooth color was measured prior to bleaching, and at weeks 4, 6, and 8 post treatment. Color changes from bleaching were analyzed, and stabilization of tooth color was confirmed when $\Delta E^* \leq 2.0$ between two consecutive measures was observed. Color measurements were also taken prior to dental treatment and again at the end of the treatment in order to assess

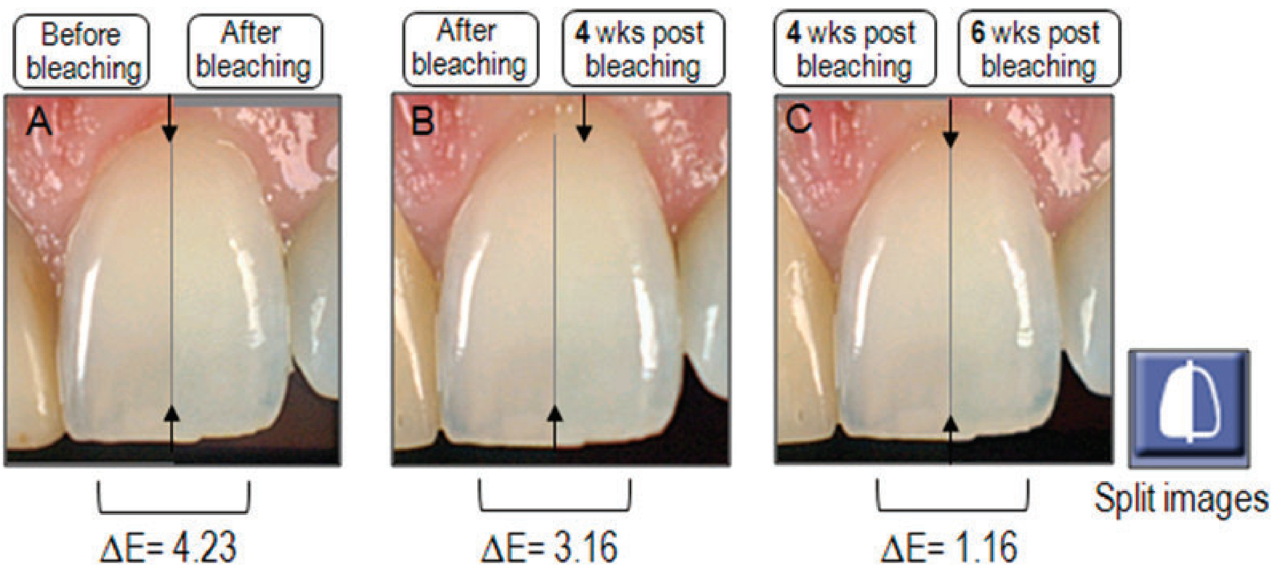

Figure 3. Tooth color changes (ΔE) by tooth bleaching.* A, *Split image of before and just after bleaching.* B, *Split image of just after bleaching and 4 weeks post bleaching.* C, *Split image of 4 weeks and 6 weeks post bleaching.*

the color difference that occurs due to tooth dehydration.

Interpretation of Color Data into Ceramic Fabrication

Based on the tooth color data acquired, a blue map for ceramic work was made. The blue map for ceramic work was fabricated based on the interpretation of the color data of the target tooth and prepared tooth using spectral image display and numerical color data of the CIELAB color system.

RESULTS

Confirmation of Stabilized Tooth Color

Bleaching resulted in tooth color change with a shift toward higher L^* value and lower b^* value, with $\Delta E^* = 4.23$ in the cervical region after bleaching. Color change continued for 4 weeks after bleaching ($\Delta E^* = 3.16$), but there was only $\Delta E^* = 1.16$ observed between 4 and 6 weeks, which can be considered as indistinguishable color difference (Figure 3).

Tooth dehydration during treatment resulted in changes in color toward higher L^*, lower a^*, and lower b^*, which indicate increased lightness and decreased chromaticity (Figure 4). The resulting color change was $\Delta E^* = 2.56$.

Interpretation of Tooth Color Data

Using spectral image display, the following observations were obtained (Figure 5):

1. 1M1 seemed to be the closest shade in body area.
2. Incisal area had a strong translucency and opacity next to each other due to dentin anatomy, and there was no shade that was an adequate match.
3. Cervical area had more chroma than A1 but less than 1M1.
4. 2R1.5 seems to have a similar translucency in the most translucent area in the incisal edge.
5. Prepared tooth had a strong color variation, and no die material matched.

Looking into more detail using numerical color data, more specific

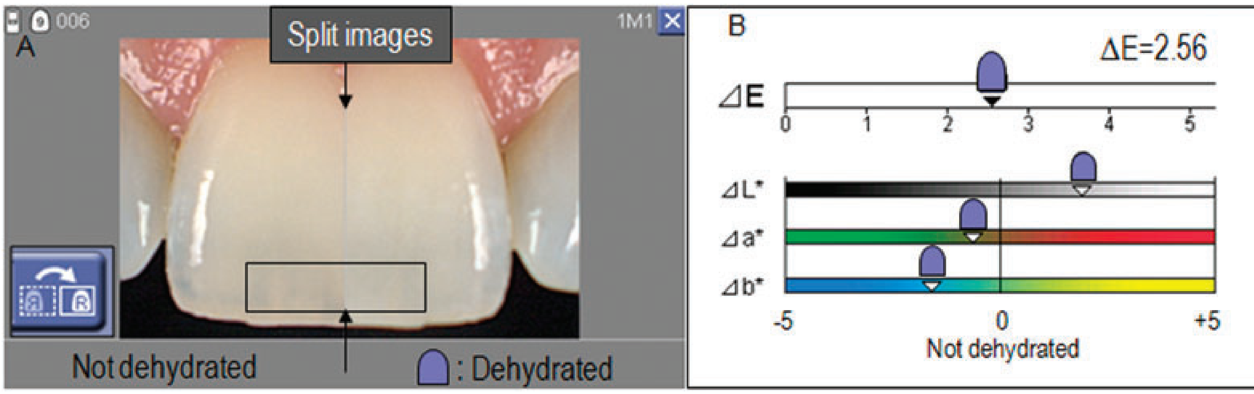

Figure 4. Optical changes caused by dehydration. A, Split image of tooth dehydrated and not dehydrated. B, Numerical color data of difference caused by dehydration. (ΔL: difference of lightness; Δa*: difference of redness; Δb*: difference of yellowness).*

information was observed (Figures 6 and 7).

1. There was no shade that could be used without modification in all three areas.
2. Body area had 1M1 as the closest shade with $\Delta E = 2.53$, which means that 1M1 cannot be simply used for the body area. The tooth was darker than 1M1 and indicated less yellowness and slightly less redness.
3. Cervical area needed to be made with more lightness than 2R1.5, and there was a need to slightly reduce redness and yellowness.
4. In the incisal, the closest shade to the translucent area was 2R1.5, with $\Delta E = 3.19$, which indicated substantial color difference. Lightness was very close, but yellowness needed to be added. Next to the translucent area, there was a highly opaque area with $\Delta E = 3.10$ with 3M-1. This area required the use of a technique for internal color reproduction.
5. The shade ST9 of die material was the closest shade to the body area in spite of $\Delta E = 4.98$, and ΔE was remarkably larger in the incisal and cervical and CIE color coordinates varied in three areas. This leads to the selection of an all-ceramic crown, which is considered less translucent.

Putting all color information together, a blue map for color reproduction was created (Figure 8).

DISCUSSION

Tooth color matching is a complex procedure and is considered one of the most difficult challenges in clinical dentistry. Recently, a spectrophotometer for tooth color measurements has become available with clinical and statistical relevance for its use.[8–10] One study showed that the use of a dedicated spectrophotometer produced significantly better color-matched crowns and a lower rate of rejected crowns compared with a conventional shade-matching method.[10] The greatest advantage of using a spectrophotometer for shade determination compared with a colorimeter is accuracy.[19] The spectrophotometric data is not affected by ambient light, and the amount of light reflected from objects is measured over a full spectral wavelength. In this study, the dental spectrophotometer,

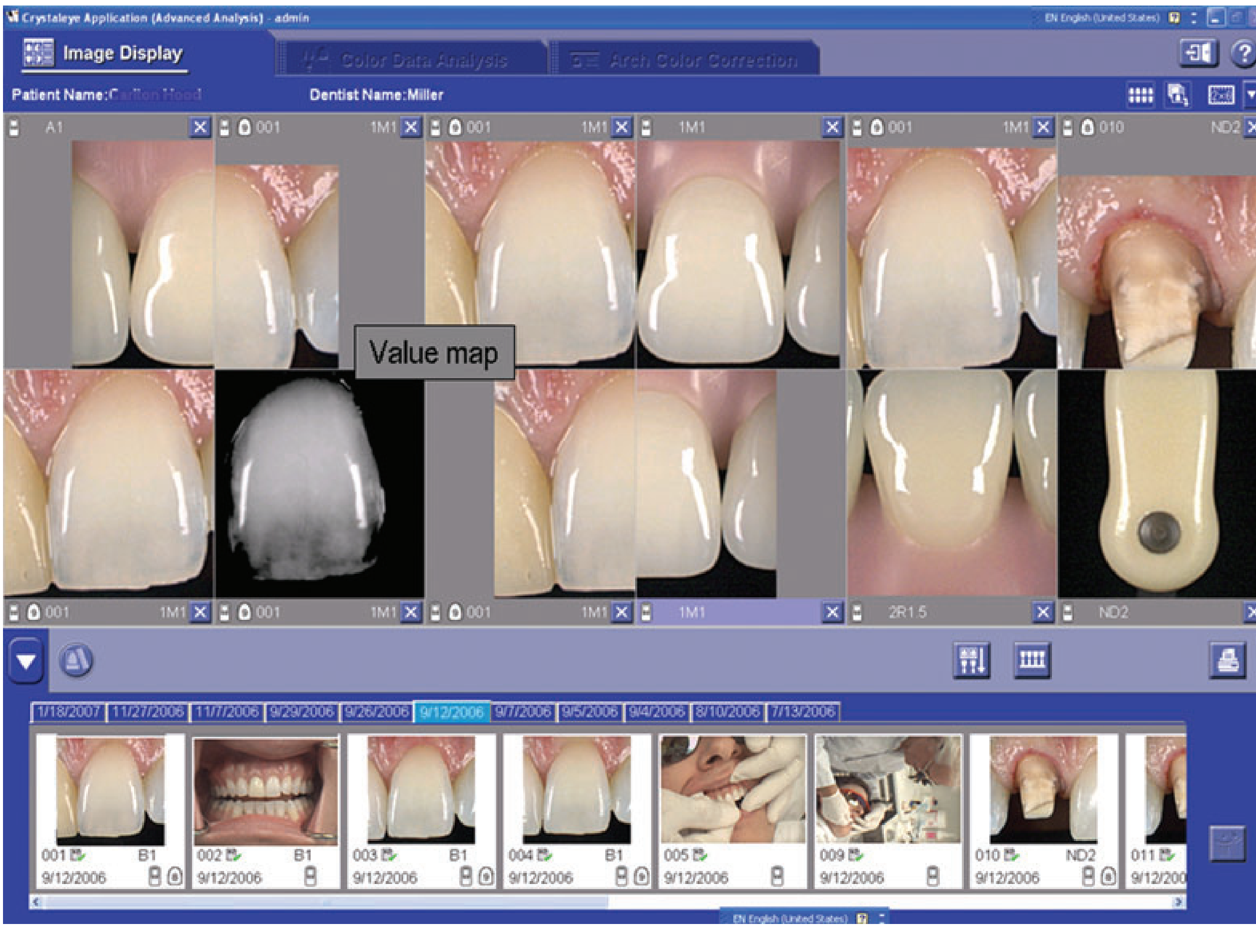

Figure 5. Image display. This allows the visual shade comparison of the teeth with shade guides.

which provides two-dimensional spectrophotometric images with color data analysis, was used to assess the tooth color perceptually. The visually matched images should theoretically improve color determination and communication with a dental laboratory for more precise color matching compared with other color-measuring instruments that only provide a spot measurement or an averaged overall shade.

There are other clinical factors that have to be taken into account to achieve success in color matching. Tooth bleaching is one of the important factors that alter the target tooth color to be reproduced in a ceramic restoration. Three of the key factors in determining overall tooth whitening efficacy from peroxide-containing products are the concentration of peroxide, the frequency, and the duration of application. One study, which compared in vitro tooth bleaching efficacy of gels containing 5% to 35% hydrogen peroxide, found that the higher the concentration, the lower the number of gel applications required to produce uniform bleaching.[20] However, another study showed that the efficacy of 5% gels approached that of the higher-concentration gels when the treatment time was extended.[21] Although in most clinical studies the duration of application of peroxide is 2 to 4 weeks, there are no guidelines on how

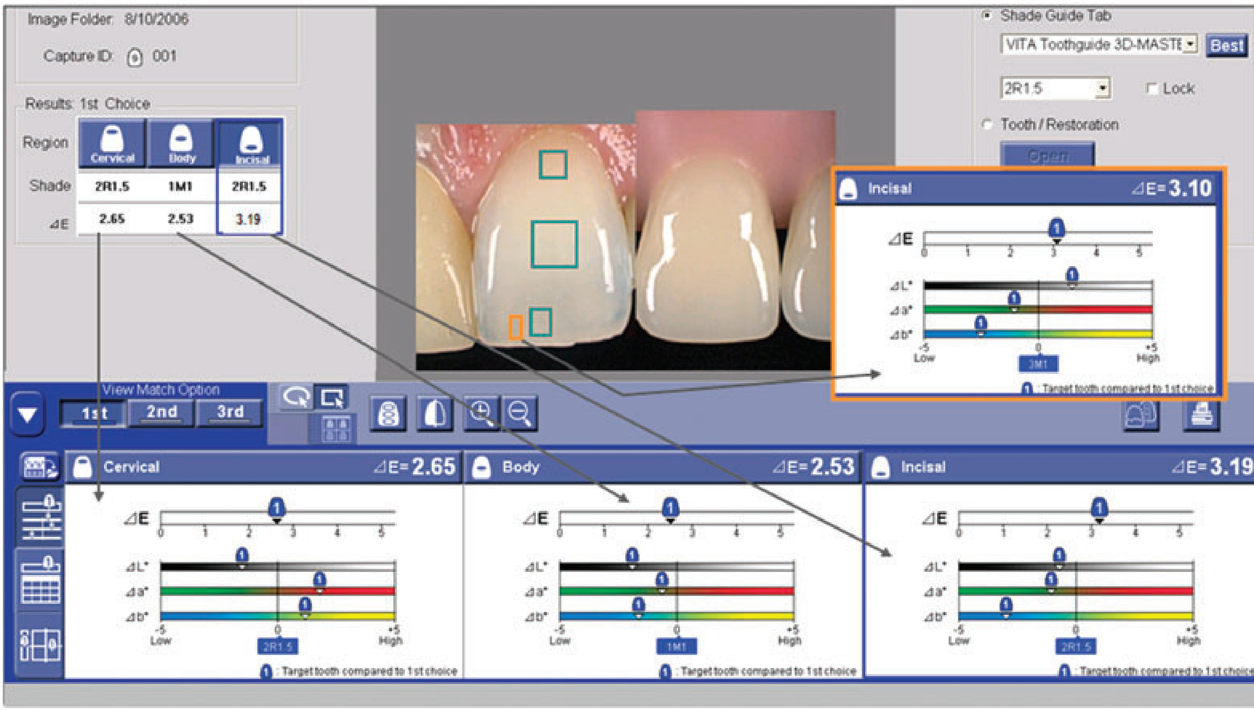

Figure 6. Numerical color analysis for the target tooth.

long color changes will continue after the termination of the application of peroxide. In this study, it was found that the tooth color changed for up to 4 weeks post bleaching. The stabilization was quantified by two consecutive measures of $\Delta E^* \leq 2$. This is a critical factor in the determination of the final tooth color.

Tooth dehydration is highly related to tooth bleaching; it also occurs during regular dental treatments.[2] It has been suggested that tooth color determination must be performed prior to any dental treatment. Teeth with very minor fluorosis hypocalcification may demonstrate excessive whiteness after even slight dehydration over a nominal period. The optical data obtained in this study indicated that lightness of tooth color was increased and chromaticity, such as the red and yellow components, was decreased due to dehydration. The color differences obtained due to dehydration in this case were quantified $\Delta E^* = 2.56$. Although not substantially large, they are still perceptible color differences.[22] As dehydration clearly alters the determination of tooth color, close attention should be paid to avoid tooth dehydration.

The color of a prepared tooth is one of the most important factors for color reproduction in an all-ceramic crown. One common method to duplicate prepared tooth color is through the use of a die material. However, mismatching of the die material color to the prepared tooth occurred at the first step of color reproduction in this case. This particular case involved a relatively complex prepared tooth color, with variation from the cervical to the incisal. No available die materials adequately matched the prepared tooth color, and significant discrepancy between shade of die material and prepared teeth (dentin color) was seen in this case. The major benefit of anterior all-ceramic restoration

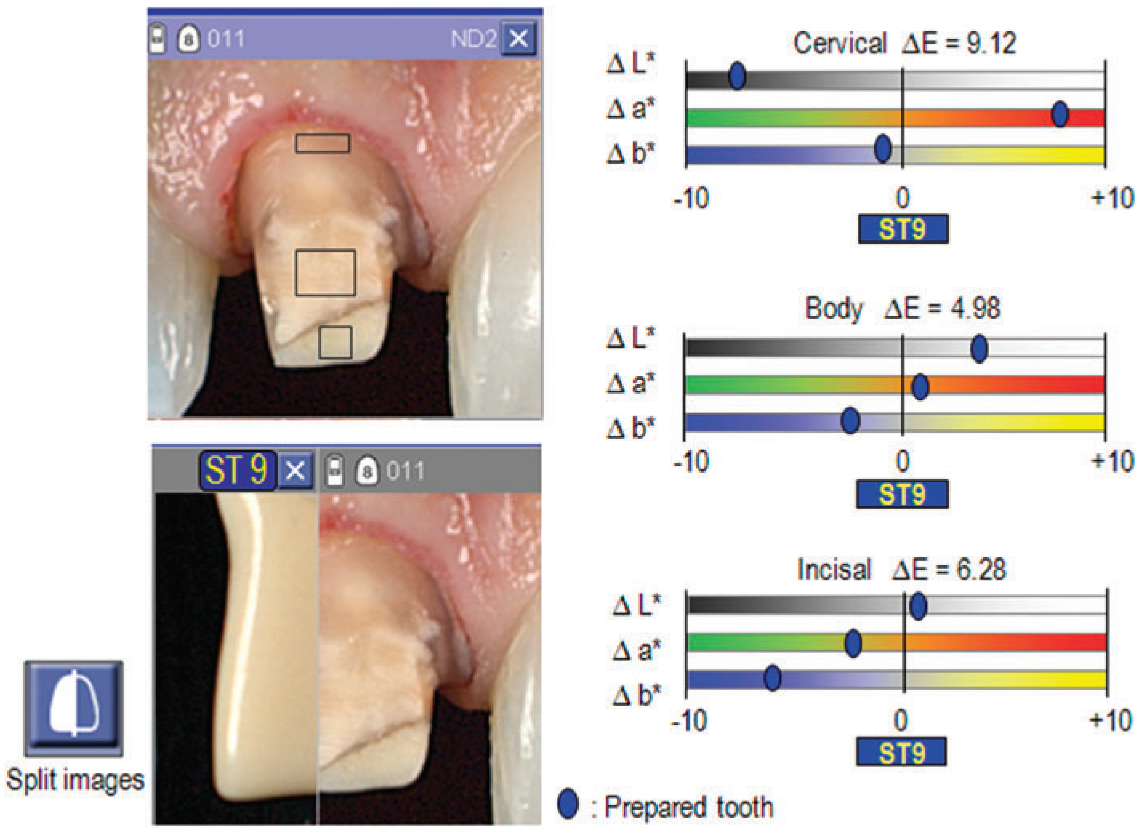

Figure 7. Color analysis for the prepared tooth comparing with die material.

is the semitranslucency that mimics the appearance of a natural tooth. Therefore, color matching has to account for the color of the prepared tooth as well as the crown and cement layer. The prepared tooth color, which is the base layer, must be precisely reproduced to allow for optimal esthetics. In this case, a large color mismatch between the die material and the prepared tooth had to be taken into account during the entire process of color matching.

In order to create an optimal map for ceramic powder layering, accurate tooth color information is essential, and interpretation skills are crucial as well. The dental spectrophotometer used in this study can provide sufficient tooth images and numerical color data together. Image display provides many useful tools that cannot be performed at chairside with patients, such as overlapping images, image inversion, and image enhanced color mapping for each color coordinate. These functions help obtain better perceptual assessments. Then, the numerical color data confirms perceptual assessments, and it can lead to creating a scientific blue map. The efficient software functions can be considered to mimic the skill of a talented and experienced technician, which is very difficult to achieve. Although all of the information needed is provided by the spectrophotometric system, successful tooth color reproduction

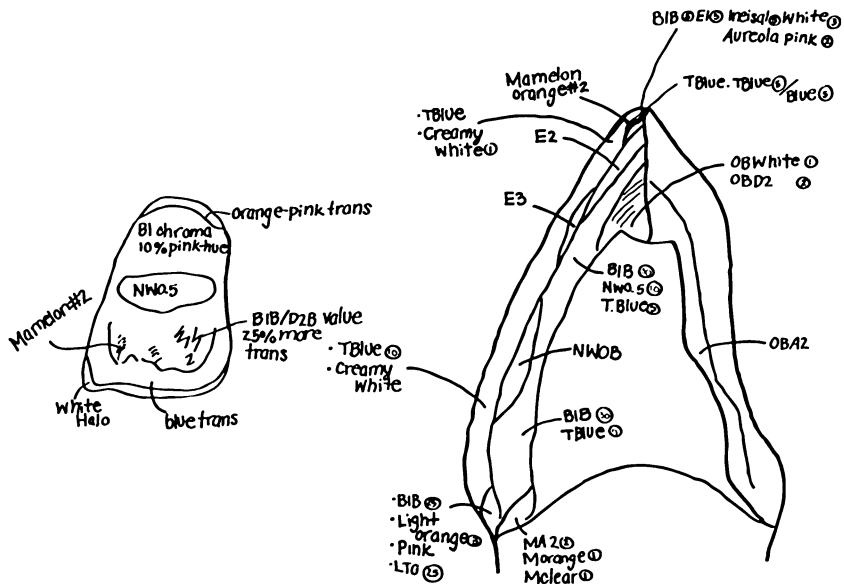

Figure 8. Interpretation of a tooth color for ceramic.

still requires a very technique-sensitive process. However, the scientific investigations of this clinical case could be an educational aid for dentists and technicians to achieve better color reproduction.

CONCLUSION

In this clinical investigation, the importance of an optimal process of accurate tooth color determination was emphasized. The detailed interpretation of tooth color data to ceramic work was explained based on the new technology of the dental spectrophotometer, which combines perceptual observation and scientific color data.

DISCLOSURE

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

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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