Use of a Reflectance Spectrophotometer in Evaluating Shade Change Resulting from Tooth-Whitening Products

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ABSTRACT
Historically, shade change assessment associated with vital bleaching treatment regimens has been visually evaluated through the use of shade guide tabs. Innovations in the industry of dentistry have brought forth new technologies capable of measuring such changes via the capture and analysis of reflected wavelengths of light.

CLINICAL SIGNIFICANCE
This article introduces the use of a 45/0 reflectance spectrophotometer and identifies the advantages and limitations associated with such a technology in the assessment of shade change owing to vital bleaching.

Vital tooth bleaching through the use of peroxide-based products for cosmetic purposes has become extremely popular.1 Although these products may differ in chemical composition, regimens, frequency of application, and carrier mechanisms (eg, trays, strips, paint-on formulas), the net result is the whitening of teeth.2 It is important for the manufacturers of these products to demonstrate their efficacy so that the professional dental community can recommend their use with predictability and confidence.3

One method of demonstrating clinical efficacy is to conduct clinical trials.4 The objective of these studies is to evaluate the clinical performance of the products by measuring the relative degree of tooth whitening that has occurred over the duration of the study.5 Human visual perception of tooth whitening is presently the most clinically relevant and significant method of assessing performance since it most closely matches the patient’s perspective.6 The human visual system is capable of detecting even very small differences in color and color changes.7 Nonetheless, it is somewhat subjective and can be influenced by external variables (eg, illumination, metamerism, simultaneous contrast effects; Figure 1). Therefore, clinical researchers have sought methods that can objectively assess changes in tooth color while accurately representing the perception of the human visual system.8 Several of these “traditional” methods of assessment (eg, shade tabs) have been reviewed and presented in the dental literature9; however, the use of technology-based shade analysis instruments has not yet been reported to any significant degree regarding tooth-whitening assessment.

This paper specifically elucidates the use of a shade analysis instrument based on the reflectance spectrophotometer (SpectroShade System®, MHT International) in evaluating tooth-whitening products.

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To understand the benefit of using a reflectance spectrophotometer in this type of clinical study, one must first have a basic understanding of color theory and color perception. Color results from an interaction of three elements: a light source, an object, and the human eye. Light is modified by an object and can be reflected and/or absorbed. Consequently, the viewer perceives the modified light as a distinct color (Figure 2).

Color involves an abstract science and is not part of light; it is light in that it is the visible portion of the electromagnetic spectrum. Visible light waves occupy a small portion of the massive electromagnetic spectrum, which also includes invisible waves such as x-rays, ultra violet rays, and radar and radio waves (Figure 3). Waves are measured in wavelengths, which are defined as the distance between the crests (peaks) of the waves. Wavelengths are measured in nanometers, 1 nm being one billionth of a meter. The region of the electromagnetic spectrum that is visible to the human eye is found in the 400 to 700 nm range and is commonly recognized by the acronym ROY G BIV (red, orange, yellow, green, blue, indigo, and violet; Figure 4). As stated...
previously, color is not inherent in objects. Rather, the surface of an object reflects some wavelengths of light and absorbs all the others. We perceive only the reflected wavelengths as the color of the object. Each color has a unique wavelength pattern that is analogous to a fingerprint. This pattern is called spectral data and can be plotted as a spectral curve, which provides a visual representation of the color’s fingerprint (Figure 5).

**OPTICAL INSTRUMENT SHADE ANALYSIS**

Traditional shade selection has been determined visually. Although this remains standard protocol in many clinical studies, new methods to quantify shade differences have been brought to market to address the subjectivity issues of traditional shade tabs. Historically, assessing shade visually has been characterized by several innate difficulties: metamerism, poor lighting, and illumination type (Figure 6) as well as the viewer’s age, eye fatigue, and susceptibility to mood and drugs/medications.

Technology-based shade guide systems encompass spectrophotometers and colorimeters. Spectrophotometers differ from colorimeters in that they measure the reflectance of light within the entire visible spectrum, whereas colorimeters measure reflected light in the visible spectrum. However, colorimeters often do not measure the total light reflected, which can make small differences in shade appear larger.

Figure 5. A spectral curve or “fingerprint” of an object is unique for each object, not unlike the fingerprints of an individual’s hand. The spike in the wavelength denotes the dominant hue of the object.

Figure 6. One image under different lighting conditions, such as incandescent, fluorescent, and daylight, can appear quite different since the dominant color of the light source bathes the object and projects or biases that hue onto the object. Therefore, the color observed may not be truly representative of the actual color of the object.
light in only three wavelengths (red, green, and blue).

Optical instruments interpret the reflected wavelengths of light as numeric values. These numeric values can be expressed as $L^*a^*b^*$ or $L^*c^*h^*$, which are called tristimulus data. This paper focuses on the use of spectrophotometers for determining tooth color changes.

**SPECTROPHOTOMETERS**

Spectrophotometers are highly precise and accurate instruments that are relatively simple and easy to use. They measure light wavelengths reflected from an object at many points along the visual spectrum (approximately every 10 nm), and these measurements provide spectral color data (Figure 7). A spectrophotometer measures and records the amount of visible radiant energy for each hue present in the entire visible spectrum. The lightness and darkness within the entire visible spectrum of each hue present is measured. Spectrophotometry-based devices measure the fundamental reflectance of an object across the visible light spectrum—the amount of light energy reflected from an object at several intervals along the visible spectrum. These instruments typically divide and measure the visual spectrum into multiple parts, resulting in 16 to 32 data points across that range. These measurements result in a complex data set of reflectance values, which are interpreted visually in the form of a spectral curve.$^{8,11}$

**Optical Geometry**

There are two basic optical light geometries that are used in reflectance spectrophotometry instruments: illumination at 0° and observation at 45° (0/45), or illumination at 45° and observation at 0° (45/0). Owing to the limited access afforded by the oral cavity, only the 45/0 option is suitable for clinical use (Figure 8).

**Calibration**

The SpectroShade System (Figure 9) can be used to measure baseline prebleaching and postbleaching shade spectral data. This system uses polarization filters to eliminate surface gloss owing to excessive reflection during image capture. Resultant images consist of 300,000 pixels. Commission Internationale de l’Eclairage (CIE) $L^*a^*b^*$ and $L^*c^*h^*$ parameters for each object are then calculated from the 17 spectral data curves of each object. The spectrophotometer is calibrated before each image-capture session to a white and green ceramic tile supplied by the manufacturer that is specific for each individual unit. The calibration process compensates for any deviation in the quantity of illumination output from the internal light source.

Tooth color is easily expressed in accordance to commonly used shade guides (cross-referenced data

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Figure 7. Spectral data is recorded every 10 nm and plotted (y-axis) against the percentage of reflectance (x-axis) to create a spectral curve or “fingerprint” of an object.

Figure 8. The image-capture device or head of the MHT unit presented diagrammatically. This spectrophotometry-based device employs 45/0 optics to capture and record images. This means that the illumination device is a dual-light source device with an incidence angle of 45° to the object (tooth) and reflected light gathered at a 0° angle.
information) or in CIE L*a*b* color parameters.

**IMAGE-CAPTURE VERIFICATION**

Three images are usually taken and cross-referenced using a synchronized image program. Image capture is verified by a ΔE (measure of overall color change) difference of <1 during image comparison within the synchronization program (Figure 10). Images of ΔE > 1 are discarded (Figure 11).

Paul and colleagues have shown that image-capture accuracy is not sensitive to discrepancies in angulation and placement in the horizontal and vertical planes of up to ±12° and ±5 mm, respectively. However, the capture device is very sensitive and is susceptible to “fogging” of the optical lens, which leads to images that are commensurate with falsely dark data. For instance, a fogged image will record a Vitapan® (Vita Zahnfabrik, Bad Säckingen, Germany) D2 shade when the tooth is actually an A1 shade. Even though the software program has a built-in antifog program, operators should check for such false image captures by scrutinizing the color/darkness of the gingival tissues in the image—dark tissues in the image are indicative of image fogging (see Figure 11).

**ASSESSMENT OF SHADE CHANGE**

A baseline shade is established prior to bleaching (Figure 12). Tooth-whitening products are used according to the manufacturer’s recommendations, and postbleaching shade assessment is made at 2 weeks after the initial use (Figure 13). Final shade assessment is made at least 2 weeks after the cessation of bleaching to account for shade rebound. Shades are thoroughly analyzed with the smallest ΔE value. Within a finite ΔE confidence level, a base shade and final shade are then established and compared. Same-tooth images, pre- and post-bleaching, are cross-referenced, and...
\( \Delta E \) differences are calculated in terms of pure \( L^*a^*b^* \) and \( L^*c^*h^* \) values (Figure 14). Shade change/differentiation is cross-referenced with respect to O’Brien and colleagues’ Vita shade guide scale.\(^{13}\)

**ADVANTAGES AND DISADVANTAGES**

The advantages of using a spectrophotometer to measuring tooth-whitening change are obvious. The instrument generates a highly accurate spectral curve indicating the exact color of the tooth before and after bleaching. This feature allows relatively easy conversion to any of the tristimulus values (RGB/XYZ/L^*a^*b^*/L^*c^*h^*). Further, the measurements can be cross-referenced to existing shade tabs, so there is immediate clinical relevance to the numeric data generated. Finally, use of the split-screen option and the ability to synchronize before and after images allow for a very accurate assessment of change in tooth color, which can be numerically quantified and \( \Delta E \) differences assessed (Figure 15).

Unfortunately, there are some disadvantages associated with the use of spectrophotometry-based instruments. Because of the high degree of precision and accuracy, they are expensive to manufacture. Minor patient discomfort during image capture can occur since the head of the instrument must be held stable against the gingival tissues. The system is limited to the anterior teeth and should not be used on severely rotated or malaligned teeth since the information received will not be accurate. The entire unit is relatively large and is therefore not easily transported. It can be difficult to accurately position the optical head of the instrument on the mandibular teeth not only because of the size of the instrument but also because it can only read color data in one direction (gingival to incisal). Finally, fogging of the optical device can occur, which can lead to inaccurate readings (ie, erroneously dark).
There are properties of teeth that complicate the use of spectrophotometers in the mouth also. Translucency, an inherent property of teeth, is abstract and intangible and is currently difficult to measure and standardize. Since it is not uniform across the surface of a tooth (greater at the incisal area), it may complicate the use of a 45/0 reflectance spectrophotometer. Furthermore, the curved surface of the tooth may be problematic since it might negatively impact upon the uniform reflectance of light to the spectrophotometer.

Translucency can be measured when using a spheric optical spectrophotometer designed for industry and research that captures light reflectance from an object in three dimensions (Figure 16). However, this type of instrument is not designed for clinical use since the object to be measured must be placed within the chamber of the spectrophotometer.

Clinically the surface curvature of teeth does not appear to present significant problems in accuracy of shade analysis since there is consistency of measurement between teeth and within a tooth. Furthermore, the database of shade guide tabs presents the same issues. Also, the smallest $\Delta E$ values (< 1 for image capture and $\Delta E < 4$ for shade matching) typically are used to establish the closest shade reference point.

**CONCLUSIONS**

The use of a reflectance (45/0) spectrophotometer has some inherent advantages over conventional shade tab assessment. The capture of an image is precise, accurate, and relatively easy, with less subjectivity than the human visual system (Figure 17). These qualities allow accurate com-
parisons of the efficacy of bleaching treatments. Many factors can influence the perception of color. By taking advantage of contemporary instrumental shade-assessing technology, such as a reflectance spectrophotometer, the subjectivity of color assessment can be minimized and shade differentiation can be more objectively compared.

DISCLOSURE

REFERENCES


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