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Digital Photographic Procedure for Comprehensive Two-Dimensional Tooth Shade Analysis

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Abstract

Current commercially available restorative materials vary in their esthetic properties, depending on brand and shade. Variations are related not only to basic color parameters such as hue, chroma, and value, but also to other important properties that affect the overall esthetic restorative outcome, such as opalescence, fluorescence, translucency, and metamerism. Fluorescence and bluish opalescence, though associated with the ingredients and chemical composition of the material, may be controlled and refined by a proper layering technique if that pretreatment analysis has been performed with the aid of appropriate photographic techniques. Digital cameras and dental photography have long been imperative tools for clinicians in their daily practice. Traditionally, digital photography has been used for recordkeeping, documentation, presentation, and informing patients of their oral status before and after treatment. Today, evolved techniques facilitate clinicians' ability to compare the esthetic properties of restorative materials with those of natural teeth for delivery of natural-looking restorations. Moreover, documentation obtained before and after restoration may be used for more comprehensive information for the patient.

Shade matching between natural teeth and composite materials is critical when creating esthetic restorations.[1-6] Hue, chroma, and value are basic color parameters that influence the esthetic outcome of a tooth-colored restoration.[7-13] The shade of contemporary enamel and dentin composite materials should, and most likely do, accurately mimic the shade of enamel[14-17] and dentin.[18,19] Unfortunately, commercially available composite materials, even of the same shade, vary in fundamental properties, such as opalescence,[20-24] fluorescence,[25-33] translucency[34-48] and metamerism[49,50], between different brands and shades. Clinicians should be able to determine the variations of these properties and either correct any mismatch in the course of the layering technique[51-58] or at least keep a record of non-correctable differences. The application of appropriate digital photography techniques is the procedure of choice to control and document the esthetic properties of current materials.

Digital cameras have undergone impressive evolution since their development in the early 2000s[59,60] incorporating emerging technologies to make photography highly accurate, simple, and economic. Digital photography[61-65] has long been a necessary tool in dentistry for recording, diagnosing, communicating, presenting, informing, and documenting[66,67] the oral status of the patient before and after treatment. A digital single lens reflex (DSLR) system should be considered standard equipment for dental photography. A DSLR camera body using an 80-mm to 105-mm macro lens and a ring flash or a twin flash system is the basic setup for capturing detailed extraoral and intraoral images. Most current digital camera bodies are efficient enough in terms of resolution, aperture, and exposure settings. ISO configuration is considered an important and sensitive parameter to be investigated, especially for advanced fluorescence, red-orange opalescence, and translucency recording. Macro lenses of 80 mm to 105 mm provide an ideal combination of proper magnification within convenient working distance for intraoral close-up photography. A life-size reproduction of the photographed object is referred to as 1:1 magnification and, in frontal dental photography, comprises the four maxillary incisors. Electronic flashlight is necessary for proper illumination of the dark areas within the intraoral environment. The two main types of flash systems for dental purposes are a ring flash and a twin-light flash. The light of a ring flash eliminates shadows in the oral cavity but may produce undesirable specular reflections. The illumination by a twin flash produces a soft and 3-dimensional lighting effect with prominent and detailed surface morphology.

Evolved capturing techniques[68-70] enable clinicians to observe the physical characteristics and properties of natural dentition. Surface details, such as macro- and micromorphology, texture, luster, gloss, enamel cracks and striations, chromatic mapping, and dentinal architecture, can be revealed and recorded with direct reflective lighting techniques using different illumination angles. In addition, photographic applications for daily clinical practice have recently been developed to address the refinement or diagnosis of material properties, such as opalescence, fluorescence, translucency, and metamerism.

The purpose of this article is to explore through the eye of the lens these optical properties, while demystifying and describing the respective photographic applications from a clinical and technical point of view.

Photographic Equipment

DSLR Camera, Lens, and Flash

A DSLR Canon 550D camera (Canon U.S.A., Inc., usa.canon.com) with a Canon 100-mm macro lens and a Canon MT-24EX twin-light flash were used in the photographic protocol presented. A custom-fabricated plastic o-ring, with four metallic screws at 0o, 90o, 180o, and 270o, was fixed with silicone to the original flash framework, ready to receive the interchangeable add-on filters (and).

Flash Plastic Diffusers

The full excitation wavelength range of the xenon flash lamps is between 300 nm and 800 nm. When the original protective plastic diffusers cover the flash lamps, the range is limited within the visible light of 400 nm to 700 nm. In the case of fluorescence, the appropriate excitation wavelength is in the ultraviolet (UV) range, more precisely at 365 nm. Both plastic diffusers were removed from the flash and attached to the interchangeable plastic framework (and) to protect mechanically both flash lamps and to protect the polarizing membrane (described later) from the increased output of the lamps. For the cross-polarizing add-on filter, the framework with the diffusers and the framework with the polarizing membranes were combined (). Additional caution was taken by placing clear plastics in place of plastic diffusers.

Three interchangeable plastic frameworks with different filters were fabricated and connected to the underlying flash by four magnets, either separately or combined together, in front of the lens and the flash lamps. The first contained the diffusers (), the second the polarizing membranes (), and the third the 365-nm UV glass filters (). Removing the plastic diffusers from the flash may lead to flash warranty loss. Because the purpose of this article is to present the principal technical aspects of the applications, the warranty was not taken into consideration.

Cross-Polarized Filters

Two pieces of a polarized plastic membrane were placed in parallel on both sides of the plastic framework. Another piece was placed in the center, perpendicularly to the lateral pieces (). The cross-polarized filter may not be used directly on the flash lamps because the membrane might be burned by the energy of the flashes (). For this reason, as mentioned previously, the cross-polarized filters were placed on top of the add-on frame with the plastic diffusers.

365-nm UV Filters

The fluorescence filters were composed of two 365-nm UV glass filters placed on both sides of the plastic framework to cover the flash lamps. No additional filter was required in front of the lens ().

Setup for Metamerism

For metamerism diagnosis, a device with continuous illumination from two different light-emitting diodes (LEDs) (Rite Lite 2™, AdDent, Inc., addent.com) generating three different illumination qualities, such as 5500°K simulating day light, 3200°K simulating incandescent light, and 3900°K simulating fluorescent tube light, was luted to a plastic o-ring with four magnets (). In this way, it was possible to attach it in front of the lens for static images () without flash.

The color rendering index (CRI) is described as the relative ability of a light source to replicate and is reported as a number between 0 and 100. A CRI score of 100 would accurately reproduce the colors on a sunny day at noon. This lighting condition is considered the ideal illumination environment for shade matching in restorative dentistry, even though it is rarely present during shade matching.

Rite Lite 2 has LEDs with high CRI values, varying from 87 to 92, thus approaching the ideal illumination conditions (CRI 100, 5000°K to 6000°K).

Fluorescence

Fluorescence[71-76] is a variation of luminescence. The more fluorescent a material is, the more bright and 'vital' it appears. Fluorescence is defined as the ability of a natural or artificial substance to emit visible light spontaneously when irradiated by UVA illumination. The excitation spectrum of dentin has a center wavelength of 365 nm, and the fluorescence emission peak is observed at 440 nm with a full width at half maximum of 20 nm. Enamel presents a much less intense fluorescence peak at 450 nm, which slowly decreases up to 680 nm. Thus a wide, but not intense, band of fluorescence spectrum is present in enamel. Studies show that dentin is three times more fluorescent than enamel, and that dentin fluorescence intensity increases over time because dentin has higher quantities of minerals, pyrimidine, pyridinoline, tryptophan, and hydroxypyridium.[77-82]

Photographic Application

Fluorescence can be captured with two photographic applications using continuous or flash lighting. The traditional method of continuous lighting is quite complicated. It requires a continuous UV light source and a dark room to avoid any other artificial lighting source in the operatory field to make the light visible because the intensity of the fluorescence is very low. In addition, the photographic recording necessitates long exposure times of several seconds and increased ISO sensitivity of the sensor of the DSLR camera with the disadvantage of increased picture noise, the need for stabilization of the camera on a tripod, and significant irradiation of the patient by UV light ().

Recently, the authors proposed a novel setup that avoids all these practical disadvantages and minimizes the exposure of the patient to UVA light. This setup consists of an interchangeable UVA 365-nm excitation filter placed in front of the commercial macro flash lamps after removal of their plastic diffusers, together with a DSLR camera with a macro lens. This allows for fluorescence documentation under normal dental office conditions in the same way as standard clinical photography using a macro lens and a flash does, without the need of a dark room or extended exposure times ().

Clinical Significance

Fluorescence is considered a clinically significant optical property in esthetic restorations because, under fluorescence, teeth appear more vital, whiter, and brighter. Under black lighting, such as in nightclubs, where UV-coated lamps emit the appropriate excitation light to induce fluorescence, restorations should not be distinguishable from the natural dentition. A perfectly integrated esthetic restoration should exhibit a similar fluorescence to that of the natural dentition, and the practitioner must be able to check on this property in his or her routine clinical setting. Enamel and dentin composite materials should closely mimic the fluorescence emission levels of enamel and dentin. Unfortunately, currently commercially available composite materials vary in their fluorescence, depending on brand and shade.[83-85]

Opalescence

Opalescence[86,87] is defined as the optical property observed in natural tissues or artificial substances to appear bluish-greyish in reflective illumination (opalescent halo) and yellowish-orange-brown under transmitted illumination (counter opalescence). The enamel of natural teeth is opalescent. This optical phenomenon is based on the difference in refractive indexes of the enamel components, which are hydroxyapatite crystals and water. Moreover, the specific dimension and diverse orientation of the hydroxyapatite crystals scatter light within the visible spectrum, more in short wavelengths for bluish effect and less in long wavelengths for yellowish-red effect. These effects are clearly visible, especially at the incisal enamel edge and also on the border between enamel and dentinal lobes.

Photographic Application for Yellowish-red Opalescence

To document and photograph yellowish-red opalescence, transmitted continuous light must be used for illumination, without flashlight. An appropriate illumination source for this application is a white LED in the oral cavity directed toward the palatal surface of the tooth to be examined. The exposure time is increased to 1/60 (but not below, to avoid a shaking effect), the aperture is decreased to around f = 10, and the sensitivity of the sensor is increased to a high value (~ 3200). With these settings, the DSLR camera is sufficiently sensitive to capture enough light without any further increase in the exposure time, which would necessitate a tripod to avoid shaking (). The LED Microlux™ Transilluminator (AdDent) with a 3-mm microtip glass light guide was used for the specific photographic application.

Photographic Application for Bluish Opalescence

To capture bluish opalescence, reflective technique is acquired using normal macro photography and flash lighting. The use of a polarizing filter is helpful, eliminating whitish areas of specular reflections and revealing the exact anatomy of the opalescence zone ().

Clinical Significance

Ideal restorative materials should exhibit comparable properties to natural dentition. Unfortunately, commercially available composite materials, as they do for other optical properties, vary in their opalescence. Bluish opalescence, which is more evident than yellowish-red opalescence in social settings, may be determined with the appropriate photographic technique and controlled at the restorative phase.

Translucency

Translucency is the property of a material that allows for light transmission but also dissipates the light within the material.88-90. As such the material is not completely transparent but has an appearance of a milky glass. In other words, translucency is the relative amount of light transmittance or diffuse reflectance from a material.[91]Factors that influence the transmission of light within composite resins are related to structural components, such as the resin matrix and filler contents, the difference of refraction indexes between them, the size and shape of inorganic fillers, and, finally, pigments and other additives. The aging of the material and the polymerization procedure used may also influence the degree of translucency that current composite materials exhibit.

Photographic Application

To document and photograph translucency, a similar method to the capturing of yellowish-red opalescence is necessary. Thus, transmitted continuous light for illumination, without flash light but in contact with the palatal surface of the tooth to be examined, is required ().

Clinical Significance

Dental enamel is translucent. Consequently, contemporary composite systems have highlighted the importance of this property. Translucency of enamel materials provides a depth of color for the underlying dentin and contributes to shade matching by enhancing the chameleon effect. Enamel becomes more translucent with age.

Metamerism

The metameric effect leads to different color changes under different lighting conditions.[92-97] Two substances that have the same color appearance under certain lightning conditions may have different color appearances when the lightning conditions change. This fundamental effect in the field of restorative dentistry may be influenced by three parameters: the material, the observer, and the lighting conditions. For example, if the spectrophotometric light emission curve of the material in the visible light range is different from the one of the surrounding tissue, then metamerism is observed. This parameter can only be controlled if the curve of the material is known and compared before its use. Regarding the observer parameter, individual subjective color perception of the observer may be biased. This could be due to deuteranopia, for example. Color vision deficiencies by practitioners, especially men, who are much more likely than women to have deuteranopia, should therefore be considered. Finally, daylight in outdoor environments and room and mixed lighting conditions in various indoor environments may influence the appearance of restorations because of metamerism. If composite restorations exhibit a coherent appearance and shade matching under these lighting conditions, then they are considered to have successfully overcome the effect of metamerism.

Photographic Application

Commercially available devices using LED technology can simulate multiple lighting conditions, which may be used for the disclosure of metamerism. One of these devices was adapted in front of the lens of the digital camera to capture images in three different color temperatures (through), disclosing shade differences if metameric effect was present. depicts how the restorations appeared under daylight, under incandescent light, and under ambient light.