# Photo Tips

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# Light in Dental Photography

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## INTRODUCTION

Light and illumination are the basics of photography. The very word "photography" comes from two Greek words, phos meaning light, and graphis meaning drawing. Hence, photography can be described as drawing with light. Photography is about capturing light and recording it, today mostly in a digital format. Over half a century ago, it was nearly impossible to direct the camera's flash into the dark, oral cavity with enough precision to yield adequate intra-oral images for medical purposes. The introduction of ring- and lateral flash systems attached to the end of a macro lens in the 1950s provided adequate illumination where needed for intra-oral photography. The limited availability of camera systems, lenses and flashes along with only a few suitable films for this type of photography created a quasi standard. Already then, authors were saying that standardization in dental photography was necessary in order to increase the quality of documentation (Bengel 1985).

However, with an ever increasing array of digital cameras and lighting systems to choose from, today, we are further away from standards in dental photography than ever before.

## LIGHT SOURCES

Effective lighting is the key to success in photography and particularly in dental photography (Ahmad 2009). Today, different kinds of illuminants, mainly pulsed xenon (D65), what we call flash light, and continuous light emitting diodes (LEDs) are available for dental photography. To benefit from an informed decision-making process, it is useful to understand the two key elements of the spectral properties of an illuminant. These are the role of correlated color temperature (CCT) and that of the color rendering index (CRI).

### Correlated Color Temperature (CCT)

The CCT is a specification of the color appearance of the light emitted by a lamp, relating its color to the color of light from a reference source when heated to a particular temperature, measured in degrees Kelvin (K). The CCT rating for a lamp is a general "warmth" or "coolness" measure of its appearance. However, in contrast to the temperature scale, lamps with a CCT rating below 3200 K are usually considered "warm" sources, while those with a CCT above 4000 K are usually considered "cool" in appearance (http://www.lrc.rpi.edu/education/learning/terminology/cct.asp. Accessed on November 8, 2016 by S. Hein).

### Color Rendering Index

The color rendering index (CRI) of a light source is a quantitative measurement of its ability to reproduce the colors of various objects faithfully in comparison with an ideal or natural light source. In general terms, CRI is a measure of a light source's ability to show object colors "realistically" or "naturally" compared to a familiar reference source, either incandescent light or daylight. Higher CRI values indicate that objects will appear more natural and viewers will be able to distinguish between different colors on those objects more easily (http://www.lrc.rpi.edu/programs/nlpip/lightinganswers/lightsources/whatisColorRenderingIndex.asp#. Accessed on November 11, 2016 by S. Hein). For the purpose of shade estimation in dentistry, a CRI of >90 has been suggested (Dykemia et al. 1986).

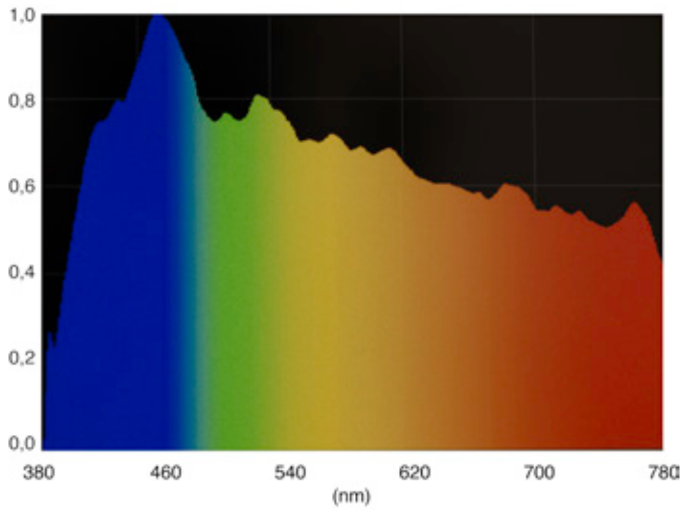



*Fig. 1: Typical emission spectrum of a xenon flash (Canon MT24EX) with an even curve of spectral power distribution resulting in a high CRI of >97*

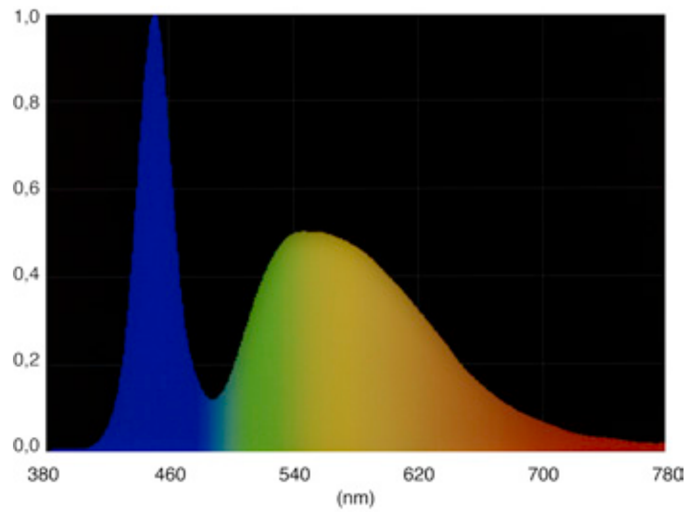



*Fig. 2: Typical emission spectrum of a conventional LED continuous light source (Smile Lite) with a sharp peak in the blue followed by sudden drop in the green and a modest rise of yellow, resulting in an uneven curve of spectral power distribution with a low CRI of 74*


*Fig. 3: Flat lighting resulting from single light source from behind the camera*


*Fig. 4: Side lighting better defines the shape of the subject, casting it in partial shadow for a more 3D look*



## XENON VS. LEDS

### Xenon

Pulsed xenon light sources (i.e. electronic flash) are those most popularly used. They contain a tube filled with xenon gas, where high voltage electricity is discharged to generate an electrical arc that creates a short flash of powerful light. The relative spectral power distribution of xenon is often used to simulate CIE Illuminant D65 (Rea et al. 2004) (Fig 1). This is of special importance in the examination of color matches that depend on the nature of the light source (Berns 2000). Such matches are called *metameric* and are practically always a given in dentistry, where only *conditional color matching* between artificial restorations and natural dentition is possible.

### LEDs

LEDs were first developed in the 1960s, but only in the past decade have LEDs had sufficient intensity for use in more than a handful of lighting applications. Primarily, these applications took advantage of the characteristics of LEDs that made them most suitable for indication (i.e. to be viewed directly as a self-luminous object, such as in signs and signals), not illumination (i.e. to view other objects by the light reflected from those objects). LED lighting systems continue to evolve rapidly and specific benchmarks for performance (e.g., luminous efficacy, light output) are being exceeded on a regular basis (http://www.lrc.rpi.edu/programs/nlpip/lightingAnswers/led/indicationIllumination.asp. Accessed on November 11, 2016 by S. Hein).

The typical emission spectrum of a conventional LED continuous light source (Smile Lite) with a sharp peak in the blue followed by sudden drop in the green and a modest rise of yellow results in an uneven curve of spectral power distribution with a low CRI of 74 (Fig. 2). Due to recent advances in LED technology, CRI values can range between 68 and 94, depending on the product and application.

*Figs 5a - b: Comparison between oblique (45º/0º) (a) and directional illumination (b)*

*Fig. 6: Direct flash*

*Fig. 7: Indirect flash*

### White Balance

White balance (WB) is a linearization process of an image's RGB values using a gray reference card to neutralize camera-specific color bias. This can vary significantly between manufacturers and camera models. Proper camera white balance has to take into account the "color temperature" of a light source, which refers to the relative warmth or coolness of white light. This is typically done using one of the camera's preset modes such as "automatic white balance" (AWB) or "flash" (flash symbol). Alternatively, a gray reference card (white_balance®) can be used to adjust image white balance during digital post-production using software like Adobe Lightroom® or Adobe Photoshop®.

## IMPACT OF LIGHT

Lighting is a key factor in creating a successful image. Lighting determines not only brightness and darkness, but also tone, mood and atmosphere. Therefore it is necessary to control and manipulate light correctly in order to get the best texture, vibrancy of color and luminosity on your subjects. The targeted distribution of shadow and highlights will allow you to create better photographs.

### Positioning Light

A light source that originates from behind the camera, pointing directly toward the subject results in very flat lighting (Fig. 3). Side lighting, on the other hand, produces a far more interesting image, as it better defines the shape of the subject and casts it in partial shadow, giving it a more 3D look (Fig. 4).

The above principles are demonstrated in Figs 5 a - b with oblique (45º/0º) illumination (Fig. 5a) and directional orientation (Fig. 5b, ring flash) after white balancing. The oblique illumination orientation (Fig. 5a) delivers a good approximation of the typical visual appearance and simulates the way the human eye would perceive a sample or an object.

### Shaping Light

Adding a diffuser to your light source can reduce glare on your subject. You need to be aware that reflectors and diffusers can cause a color shift in your images. Figs 6 - 7 show the resulting image when using direct and indirect flash.

*Figs 8a - b: Portrait set-up using two lateral flashes and a reflector*

*Fig. 9a: Image using polar_eyes filter*

*Figs 9b: Shade and composite material selection using polarized images eliminating glare and reflections*

*Fig 10: fluor_eyes filter mounted on Nikon R1C1 macro flash*

**Manipulating Light**
Light can be manipulated to fall on a particular area of interest on your subject. This can be achieved through the use of diffusers and reflectors and is mostly used in portrait photography (Figs 8a - b).

## SPECIAL LIGHT SET-UPS AND CONSIDERATIONS

**Eliminate glare and what remains is color and brightness**
Clinical evaluation of dental shade selection is usually based on direct visual assessment and ordinary flash photography, both of which are compromised by viewer subjectivity. It is difficult to accurately assess individual tooth shade characteristics because ordinary flash photography has inherent limitations owing to the physics of light. Specular reflections (glare) do not permit consistent visualization of subtle enamel characteristics like micro calcifications and tend to blur distinctions between surface and sub-surface dental characteristics. Glare is considered a superficial reflection possessing the unmodified color characteristics of the light source.

Reflective Cross Polarized Light Photography is a technique that significantly improves dental chromatic color evaluation by using bilateral parallel twin polarizers in the illumination path and another polarizer (analyzer) that is perpendicularly oriented to the twin polarizers in front of the camera lens (Figs 9a - b). Through-the-lens (TTL) metering can compensate for the polarizing filter on the camera. However, the exposure value on the flash unit should be increased by 1 to 2 stops to compensate for the filter over the twin flash heads.

There are extensive indications and applications for this technique in dentistry:

1. Elimination of specular reflections and halation for unobstructed viewing (Bengel 2006; Hajto 2006)
2. WSLs assessment and clinical observation among enamel lesions primarily surrounding orthodontic brackets as a diagnostic aid (Benson et al. 2008)
3. Enamel subsurface mapping of characteristics and nuances (Robertson & Toumba 1999)
4. Crack detection and assessment in enamel and restorations
5. Chromaticity assessment for restorative shade selection (hard and soft tissues) with comparative conventional or custom shade tabs
6. Verification of integration of the interim/final restorative prosthesis
7. Bleaching evaluation (Gerlach 2007, Sagel & Gerlach 2007)
8. Translational application in oral medicine and oral pathology for mucosal assessments, diagnostics and guided surgical excision (Jacques et al. 2000, Jacques et al. 2002; Jacques et al. 2008)
9. Medico-legal child abuse assessment (Lawson et al. 2011)
10. Forensic applications





*Figs 11a - b: Cross-polarized (a) vs. fluorescent image (b) of the same intra-oral situation*

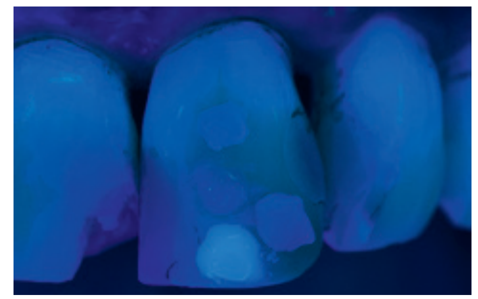


*Fig. 12: Visualization of composite restorations and materials in fluorescent image*

*Fig 13: polar_eyes filter mounted on Nikon R1 C1 macro flash*

**Visual integration of restorative biomaterial in UV-rich environments**
Natural teeth emit a strong whitish-blue light under ultraviolet (UV) radiation. The extent of the effect of fluorescence upon color perception under natural ambient light conditions is debatable; nonetheless, a dental restoration must provide optimal visual integration under multiple lighting conditions, including UV-rich environments such as nightclubs and dancehalls. The fluorescence of natural teeth can be recorded with a customized fluorescence macro flash (fluor_eyes, emulation) developed by the authors (Fig. 10). This macro flash provides an ideal excitation wavelength of 365 nm for UV irradiation to record the fluorescence of natural teeth and/or dental ceramics and composite resins (Figs 11 - 12). This effect can be easily achieved using a shutter speed of 1/125 seconds, aperture of f22, and ISO of 400 to 1600, resulting in images of high fidelity with proper depth of field and eliminating the need for cumbersome UV light set-ups that lack standardization.

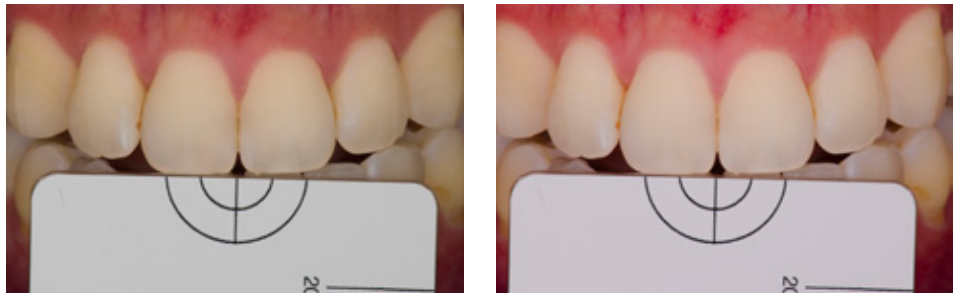
## NEED FOR STANDARDS

As in many applications across the sciences and the field of engineering, standardization provides the basic foundation for repeatability and ultimately for prediction. This should be no different in the field of dental photography, which traditionally has been plagued by a lack of proper standardization.

New aids and tools have been recently introduced to equip the dental photographer to explore and record the appearance of natural dentition and soft tissue accurately and reproducibly through standardization:

**Cross-polarized photography**
The use of a designated cross-polarizing filter (polar_eyes®) eliminates surface glare, allowing for the evaluation of the individual tooth characteristics defined above as well as for quantifying color coordinates using the CIELab system. Due to the mechanics of cross-polarization, this application is ideally suited for a directional type of illumination (90° to 0° geometry) as ideally provided by a ring flash. Alternatively a set of satellite flashes mounted around the lens (Nikon R1C1/Canon MT24EX) can also be used for this purpose (Fig. 13), but particular attention has to be paid to the correct alignment between the polarizers covering the flashes and the analyzer covering the lens.

*Fig. 14: The Axis bracket (emulation) provides fixed oblique (45º/0º) illumination at light weight*



*Figs 15a - b: Comparison between custom white balanced image (a) and unbalanced image (b)*

**Reflected dental photography**
In order to record the optical appearance of natural dentition and dental restorations the way they would appear under everyday light conditions to the average viewer, a lateral flash arrangement is ideally suited to reflected dental photography. Many flash brackets are commercially available that offer multiple adjustment options for the arrangement of flash position. While these might have some merit for the artistically inclined dental photographer, the various adjustment options rarely provide much practical advantage and instead offer ample opportunity for inconsistent results, while adding unnecessary weight to the often already heavy dental photography set-up. At least in theory, the only lateral flash arrangement that would make sense is the 45º to 0º geometry. According to Snell's law, at every boundary where there is a change of refractive index, some of the light is reflected and some is transmitted. The direction of the light beam is changed by an amount depending on the change of refractive index (relative refractive index). Propagation angles can be calculated from Fresnel's reflection formulae, where at an incidence angle of 45º, with an average refractive index of $nd_1$ 1.64 (human enamel) and $nd_2$ 1.00 (air) at a collection angle of 0º (lens), 7% surface reflection can be recorded while 93% of light will transmit into a natural tooth where complicated light scattering behavior can take effect.

The Axis bracket (Fig. 14; emulation) provides fixed oblique (45º/0º) illumination at light weight. It delivers a good approximation of the typical visual appearance and simulates how the human eye would perceive a sample or an object. The modular design allows for interchangeable use of the Nikon R1C1 system (pictured) as well as Canon MT-24EX or other flash system using a conventional hot-shoe connection.

**Neutralizing unwanted color cast**
When dealing with mixed illumination sources (tungsten and fluorescence) in a clinical environment unwanted color casts result. While normally our eyes can compensate for a variety of lighting conditions with different color temperatures, a digital camera needs a calibrated neutral reference with a flat spectral response curve with a luminosity value of 79 in the visible spectrum in order to avoid metameric color shifts. Figs 15a - b show a comparison between a custom white balanced image (Fig. 15a) and unbalanced image (Fig. 15b) in Adobe Standard image mode using a white_balance® card.

## CONCLUSION/OUTLOOK

Digital photography has become an integral part of our daily work. Documentation, communication, treatment planning and shade matching are not possible without digital images.

This article has only discussed light as a small but important aspect with a huge impact on dental photography. Standards also need to be established for the equipment to be used. Camera type, sensor size, lens and light are the variables that create the "look and feel" as well as any distortions. Depending on your shooting style you might select different combinations. For clinical and especially scientific documentation, we need to establish standards for equipment and settings. This issue needs to be addressed in a consensus on dental photography on which a group of dentists and dental technicians are working.

We encourage you to take our survey on dental photography at http://dentist.camera to support our project on standards in dental photography.

PHOTO TIPS

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