The use of a standardized gray reference card in dental photography to correct the effects of five commonly used diffusers on the color of 40 extracted human teeth

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Abstract

Objective: The aim of this *in vitro* study was to investigate the color changes of human teeth caused by five different diffuser materials commonly used in dental photography, as well as software influence, and to confirm whether the use of a standardized gray reference card is effective in correcting these color changes during digital postproduction.

Materials and method: Forty extracted human teeth were obtained from a specialized oral surgery practice in Cham, Germany. Five commonly used diffuser materials were chosen to be investigated, which included: polyethylene (PET), White Frost photographic paper, LumiQuest polyamide (nylon) material, 80 gsm white printing paper, and 3M linear polarizing filter sheet used for cross polarization. A digital single-lens reflex camera (Canon EOS 5D MKII) was used, together with a twin flash suitable for macrophotography (Canon MT-24EX Macro Twin Lite). Images were tethered into Adobe Lightroom CC using the RAW format. A standardized gray reference card (WhiBal, Michael Tapes Design) was used for exposure calibration and white balancing. Classic Color Meter software (Ricci Adams, version 1.6 (122)) was used to obtain *CIE* L*a*b* values of the specimens before and after white balancing and exposure correction.

Results: All diffusers caused visually perceivable color changes on the extracted teeth: White Frost (Δ*E** 1.24; sd 0.47), 80 gsm printing paper (Δ*E** 2.94; sd 0.35), LumiQuest polyamide (Δ*E** 3.68; sd 0.54), PET (Δ*E** 6.55; sd 0.41), and 3M linear polarizing filter sheet (Δ*E** 7.58; sd 1.00). The use of a standardized gray reference card (WhiBal) could correct these values below the visually perceivable threshold: White Frost (Δ*E** 0.58; sd 0.36), 80 gsm printing paper (Δ*E** 0.93; sd 0.54), LumiQuest polyamide (Δ*E** 0.66; sd 0.58), PET (Δ*E** 0.59; sd 0.33), and 3M linear polarizing filter sheet (Δ*E** 0.53; sd 0.42).

Significance: The use of a standardized gray reference card with specified *CIE* L*a*b* values should be considered when diffusers are used in dental photography in order to reveal the color of preoperative situations (ie, shade documentation) and document postoperative results accurately.

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Introduction

The use of dental photography plays an increasingly important role in everyday dental practice as an effective tool for communication between the dental surgery and the dental laboratory. Modern digital single-lens reflex (DSLR) cameras are in common use to document important restorative aspects such as the preoperative situation, the tooth shade, the final result, and long-term performance.[1] Photographic documentation for purely medical purposes requires little more than basic equipment, such as a DSLR camera paired either with a ring or twin flash.[2] In the field of esthetic dentistry, however, elaborate assemblies are often used to depict the restorative process and especially the final result in a rather “emotional” way, with the use of various bouncers and diffusers and adjustable brackets.[3] On the other hand, cross polarized photography is a useful method to reveal intrinsic shade variations of natural teeth for the purpose of shade analysis.[4] This is achieved with the help of a linear polarizing filter sheet that is placed over the electronic flash in an orientation which is perpendicular to that of another linear polarizing filter simultaneously placed over the lens, resulting in the exclusion of diffuse light and specular reflection from the labial surface of natural teeth and dental restorations alike.[5]

Clinical experience has shown that *in vivo* photographs of natural dentition routinely show significant color alterations of teeth and soft tissue when certain types of diffusers are used.[6] When a diffuser is placed in front of an illuminant (ie, an electronic flash), not all wavelengths will pass through. Due to absorption, only specific wavelengths that are characteristic of the material will be transmitted. Hence, all the power that is transmitted is concentrated in a few narrow wavelength regions,[7] causing large color distortions, since they affect both the Correlated Color Temperature (CCT) and the Color Rendering Index (CRI) of the emitted light, making it difficult to judge shade differences between a shade tab or dental restoration and the surrounding natural dentition on a digital image. Preliminary relative irradiance measurements of five commonly used diffuser materials which were included in this study, using a radiospectrometer (Sekonic C-700, Sekonic), in conjunction with a commonly used electronic flash (Canon MT-24EX Macro Twin Lite), revealed that different diffuser materials did indeed influence CCT and CRI, but only slightly. However, the visually perceivable effects appeared noticeable in the digital images, suggesting that software interpretation might play a significant role (Fig 1). The use of a standardized gray reference card promises to overcome this limitation through a remapping process of the original RAW image to a defined standard. However, natural teeth are heavy light scatterers, and irradiation with an intermittent spectral power distribution may affect their color within the threshold of visual perception. The aim of this study was to determine the effects that five commonly used diffuser materials have on tooth color, to identify their origin, and to determine if the use of a gray reference card is effective in correcting these changes.

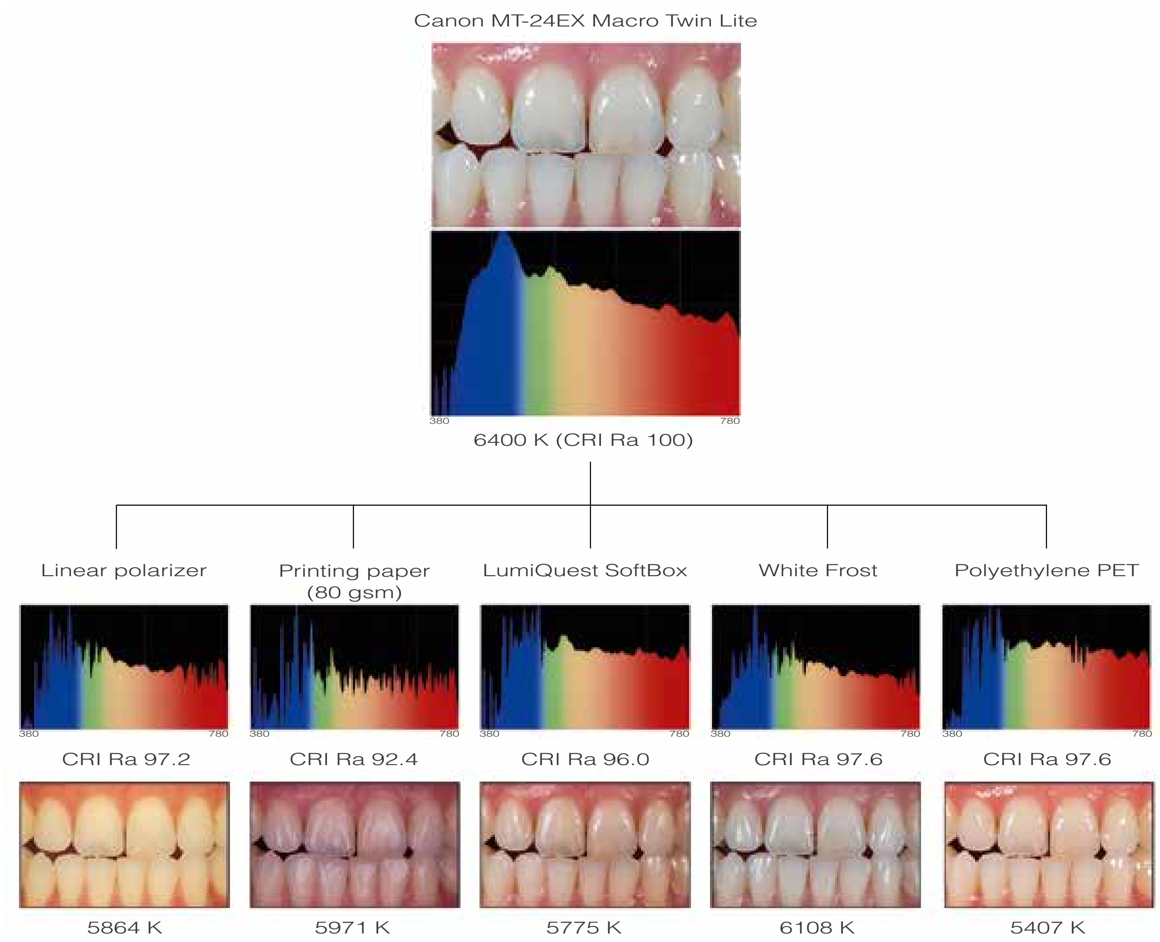


Fig 1 Relative irradiance measurements reveal small influences on the Color Rendering Index (CRI) and Correlated Color Temperature (CCT) caused by five diffusers when placed in front of an electronic flash. Note that a variance in the rendering of the images occurs due to software interpretation of the DSLR camera.

Materials and method

Camera set-up

A digital single-lens reflex camera (Canon EOS 5D MKII) was used, together with a twin flash suitable for macro photography (Canon MT-24EX Macro Twin Lite) (Figs 2 and 3). Images were tethered into Adobe Lightroom CC using the RAW format and a USB 2.0 cable. The screen (Cinema Display, Apple) was calibrated using a spectrophotometer (ColorMunki, Pantone). The working distance between the front of the lens and the labial surface of one randomly selected test specimen was varied to achieve life-size magnification (1:1) at a constant distance of 130 mm, as would be the case in a clinical situation, and

Figs 2 and 3 The experimental setup consisted of a DSLR camera paired with a twin flash commonly used for dental photography. In order to minimize specular reflection from the labial surface of the teeth, both electronic flash guns were arranged in two azimuthal illumination angles corresponding to 0 degrees/45 degrees geometry using two aluminum rails and two custom 3D-printed variable sled assemblies.

hence this value was chosen as the standard distance for all measurements. Using the camera's manual mode, exposure time and aperture were set to a constant value of 125/sec and f 32. The twin flash normally operates with four AA Mignon batteries (Energizer Ultimate Lithium, +AA 1.5 V, 3000 mAh). However, preliminary tests showed noticeable variations in flash intensity after a few measurement cycles due to battery depletion and increased recycle time. In order to overcome these limitations, a compact battery pack which normally holds eight additional AA Mignon batteries (Canon CP-E4) was modified to be attached to a 12 V, 1500 mAh direct current transformer (Yumatron, Model NT6), ensuring steady flash intensity and short recycling times (< 5 s). The camera was attached to a microcomputer (Stack Shot, Cognisys) that was programmed to trigger the camera shutter nine times in a row, with a precisely timed interval of 15 s.

Diffuser materials

Five commonly used diffuser materials were chosen for the study: polyethylene (PET), White Frost photographic paper (ProTech Lighting), Mini SoftBox polyamide (nylon) material (LumiQuest), 80 gsm white printing paper, and 3M linear polarizing filter sheet used for cross polarization. The materials were cut into squares and attached to a set of cus-

Fig 4 Five commonly used diffuser materials were chosen for the study. They included polyethylene (PET), White Frost photographic paper, LumiQuest polyamide (nylon) material, 80 gsm white printing paper, and 3M linear polarizing filter sheet used for cross polarization. Each frame had an open window of 80 mm x 55 mm.

Table 1 Forty extracted human teeth were obtained from a specialized oral surgery practice in Cham, Germany, and deemed suitable for inclusion in the study

Tooth	14	16	17	18	22	23	24	26	27	28	31	33	36	37	38	41	44	46	47
Quantity	4	1	4	2	1	1	1	1	1	5	2	2	4	3	2	1	1	3	1

tom-made frame holders with an open window of 80 mm x 55 mm (Fig 4).

Specimen assembly

In order to minimize specular reflection from the labial surface of the teeth, both electronic flash guns were arranged in two azimuthal illumination angles corresponding to 45 degrees/0 degrees geometry using two aluminum rails and two custom 3D-printed variable sled assemblies. The specimen holder consisted of a square block made of melamine, which was designed to hold one extracted tooth in its middle which could be exchanged and repositioned precisely using a round ABB grid pattern (LEGO). An adjustable slot allowed the attachment of two square pieces of the gray reference card in the same vertical plane as the tooth specimen. The distance from each of the diffusers to the labial surface of a randomly chosen test specimen was 150 mm.

Specimen preparation

Forty-four extracted, unrestored teeth were delivered to the dental laboratory already stored in a 0.9% solution of thymol. The teeth had been previously cleaned and pumiced before visual inspection for suitability was carried out. Four specimens were discarded because they showed severe signs of damage from the extraction surgery. The remaining 40 teeth (Table 1) were mildly sandblasted with 50 µm aluminum oxide to remove the surface gloss from the enamel in order to avoid specular reflection that could obstruct color measurements. The tips of the roots were cut off before they were attached to round ABB grid patterns (LEGO) using superglue gel and accelerator spray, while fixing them in a perpendicular position using the sample holder for guidance. The specimens were numbered and returned to a jar that contained 0.9% thymol solution to preserve their color.

White balance reference card

A standardized white balance reference card (WhiBal, Michael Tapes Design) was used. This particular product was chosen because of its even reflectance and its defined color coordinates (*CIE* L*75; a*0; b*0). The manufacturer claims a chromaticity accuracy of $\Delta C^* < 0.71$ ($a^* \pm 0.5$; $b^* \pm 0.5$) (Fig 5). In a previous investigation, triple measurements of 14 individual new WhiBal cards were carried out with a spectrophotometer (ColorMunki) to confirm this claim (ΔC^* 0.29). One WhiBal card was randomly chosen and cut into two squares to be used on either side of the tooth during the entire measurement sequence.

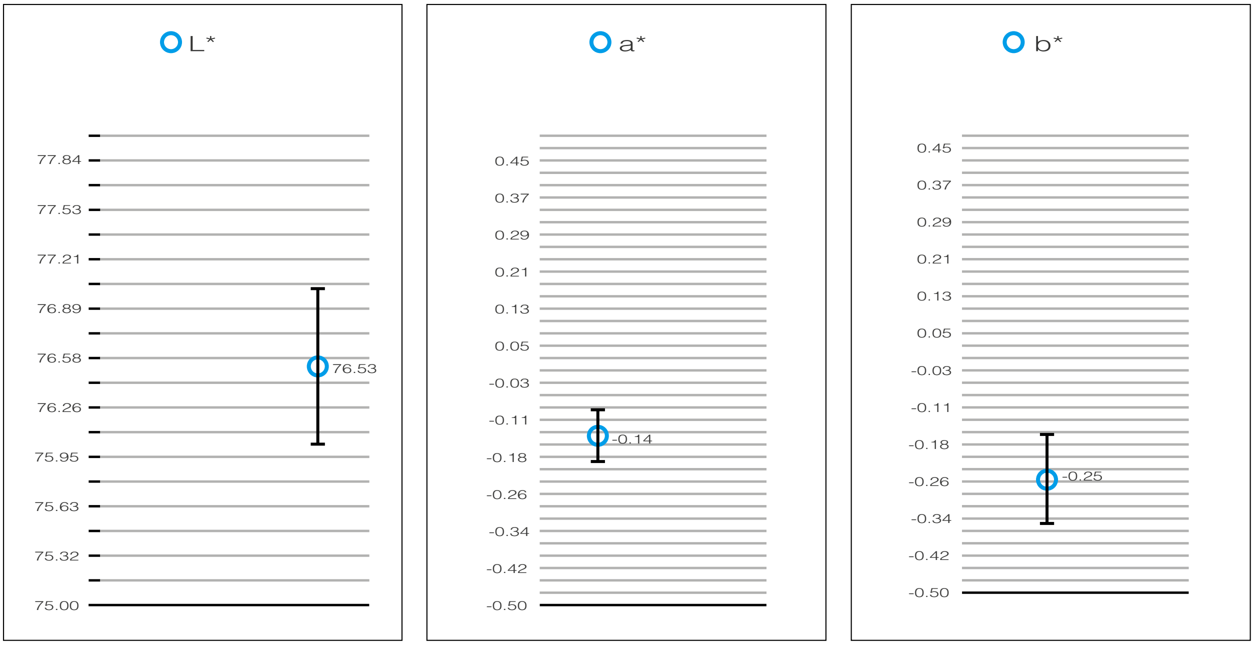


Fig 5 The color accuracy of 14 new gray reference cards (WhiBal) was measured and confirmed to be within the margin of error claimed by the manufacturer ($\Delta C^* < 0.71$; ($a^* \pm 0.5$; b^* 0.5)).

Custom white balance was carried out using the camera's menu function and one WhiBal card, which was positioned in the same horizontal plane and distance as the tooth specimen.

Measurement sequence

Each measurement sequence commenced with a hydrated tooth in place and two squares of WhiBal cards to the left and right of it, with two empty frame holders in front of each electronic flash. The first four photographs were taken in this way, followed by one photograph each using five different diffuser materials: PET, White Frost, LumiQuest, 80 gsm printing paper, and 3M linear polarizing sheet. In order to obtain images with increased tonality and dynamic range, as well as reduced noise, the concept of "exposing to the right" (ETTR) was used, with red–green–blue (RGB) values distributed predominantly to the right of the exposure histogram.[8] The camera ISO was set to a value of 100, and the flash intensity to a value of ½ (half), except for the 80 gsm printing paper and linear polarizing sheet, due to the noticeable attenuation of luminous flux. For adequate comparability with the standard, an adjustment of the ISO to a value of 200, as well as an adjustment of the flash intensity to a value of 1/1 (full) was required with this particular group. Each complete measurement cycle took a total of 135 s.

Digital image development and color measurements

The first image was immediately discarded since it only served to empty the flash capacitor. The following three images taken with no diffuser were exposure balanced by moving the cursor over the gray area of the WhiBal card. Due to the camera's custom white balance, it was merely necessary to adjust the exposure of the image until the luminosity value of the gray card in the photograph matched L*75. The values for chromaticity (a* + b*) were within the threshold of ± 0.5 each time, as claimed by the manufacturer. The same procedure was carried out with the five photographs taken with each diffuser material. Color Meter Classic software (Ricci Adams, version 1.6 (122)) was used to locate an area in the middle of each tooth. The measurement window was adjusted to the maximum size possible within the boundary of the tooth in order to measure *CIE* L*a*b* color coordinates. Once this position was locked, values for each tooth were copied and pasted into a spreadsheet (Numbers (version 3.5), Apple) (Fig 6). In order to determine the standard error caused by subtle variations in flash intensity, the first three sets of color coordinates from the gray card where averaged and compared with the ideal value of L*75; a*0; b*0. If ΔE^* was < 1.0, the measurement sequence was included in the study; if the value was ΔE^* > 1.0, the tooth was to be measured again (which was never the case). Once the color coordinates for the five different diffuser groups were recorded, white balancing was carried out by choosing the eyedropper tool in Adobe Lightroom CC and clicking on a randomly chosen gray area in close proximity to the tooth. In most cases it was then necessary to adjust the exposure values again to obtain L*75; a*0; b*0, before the color coordinates of the tooth could be recorded.

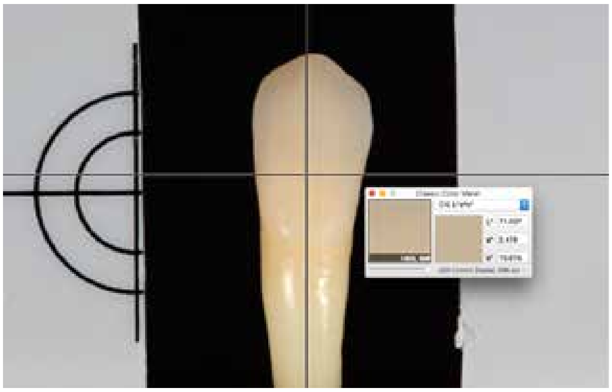


Fig 6 Color measurements were carried out using Classic Color Meter software in the middle of each tooth. The measurement window was adjusted to the maximum size possible within the boundary of the tooth to measure *CIE* L*a*b* color coordinates. Once this position was locked, values for each tooth were recorded in the exact same position.

Results

ΔE^* was calculated as described in the CIE prescriptions:

$$\Delta E^*_{ab} = \sqrt{(L^*_2 - L^*_1)^2 + (a^*_2 - a^*_1)^2 + (b^*_2 - b^*_1)^2}$$

All diffuser materials caused visually perceivable color changes on the extracted teeth. The values for the different diffuser materials before and after white balance correction can be seen in Figure 7: White Frost (ΔE^* 1.24; sd 0.47), 80 gsm printing paper (ΔE^* 2.94; sd 0.35), LumiQuest polyamide (ΔE^* 3.68; sd 0.54), PET (ΔE^* 6.55; sd 0.41), and 3M linear polarizing filter sheet (ΔE^* 7.58; sd 1.00). The use of a standardized gray reference card (WhiBal) could correct these values below the visually perceivable threshold (Fig 8): White Frost (ΔE^* 0.58; sd 0.36), 80 gsm printing paper

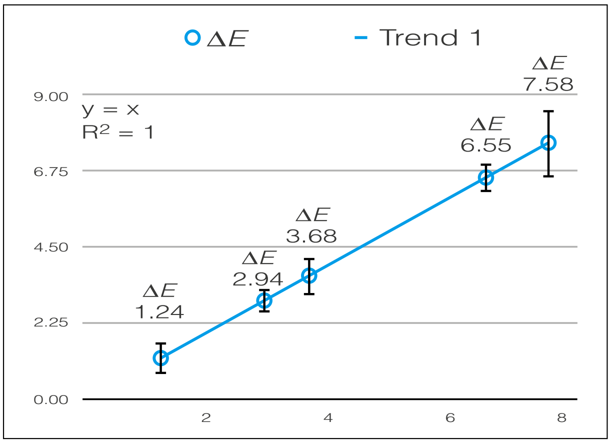


Fig 7 Color changes of 40 extracted teeth caused by five diffuser materials commonly used in dental photography. White Frost (ΔE^* 1.24; sd 0.47), 80 gsm printing paper (ΔE^* 2.94; sd 0.35), LumiQuest polyamide (ΔE^* 3.68; sd 0.54), PET (ΔE^* 6.55; sd 0.41), and linear polarizing filter sheet (ΔE^* 7.58; sd 1.00).

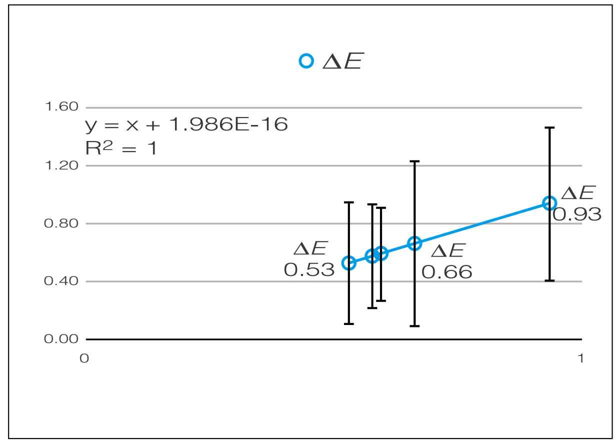


Fig 8 The use of a standardized gray reference card (WhiBal) could correct the color changes below the visually perceivable threshold: White Frost (ΔE^* 0.58; sd 0.36), 80 gsm printing paper (ΔE^* 0.93; sd 0.54), LumiQuest polyamide (ΔE^* 0.66; sd 0.58), PET (ΔE^* 0.59; sd 0.33), and linear polarizing filter sheet (ΔE^* 0.53; sd 0.42).

(ΔE^* 0.93; sd 0.54), LumiQuest polyamide (ΔE^* 0.66; sd 0.58), PET (ΔE^* 0.59; sd 0.33), and 3M linear polarizing filter sheet (ΔE^* 0.53; sd 0.42). The average exposure compensation that was required during digital postproduction is illustrated in Figure 9: White Frost (EV -0.20; sd 0.106), 80 gsm printing paper (EV -0.38; sd 0.114), LumiQuest polyamide (EV -0.55; sd 0.108), PET (EV -0.55; sd 0.197), and 3M linear polarizing filter sheet (EV -0.70; sd 0.116).

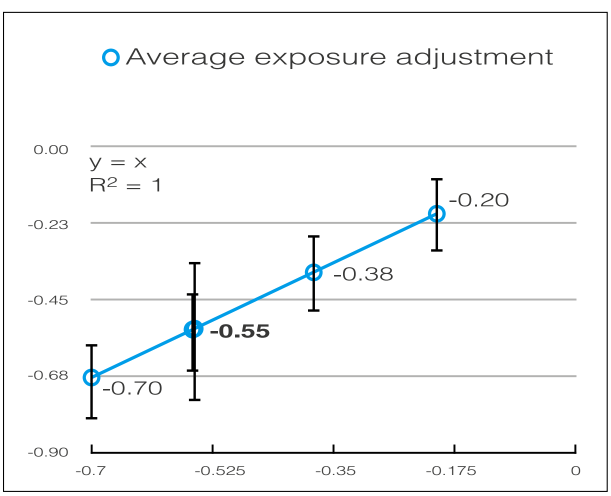
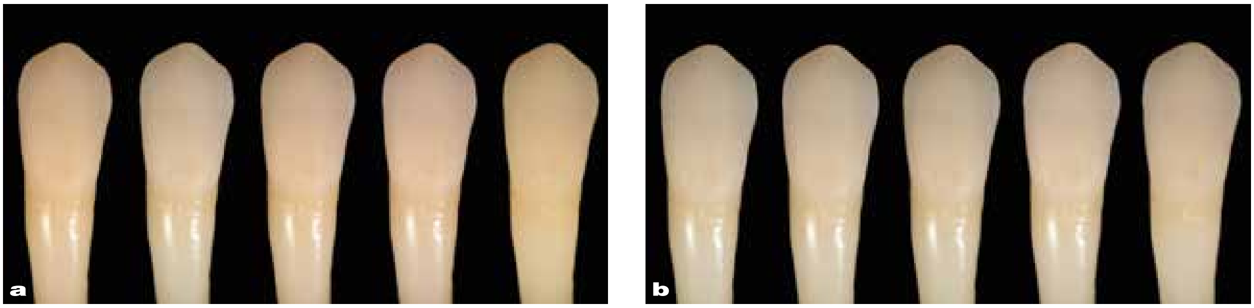


Fig 9 The average exposure compensation that was required during digital postproduction was: White Frost (EV -0.20; sd 0.106), 80 gsm printing paper (EV -0.38; sd 0.114), LumiQuest polyamide (EV -0.55; sd 0.108), PET (EV -0.55; sd 0.197), and linear polarizing filter sheet (EV -0.70; sd 0.116).

Discussion

During the era of film photography, so called “gray cards” (ie, Kodak) were used in conjunction with the camera’s light metering system (TTL) to determine the correct exposure for objects illuminated by continuous light sources like the sun. With the arrival of digital photography, it became necessary to use white balance reference cards, which in their



Figs 10a and b Changes of tooth color caused by different diffuser materials **(a)** before, and **(b)** after white balancing, using a standardized gray reference card.

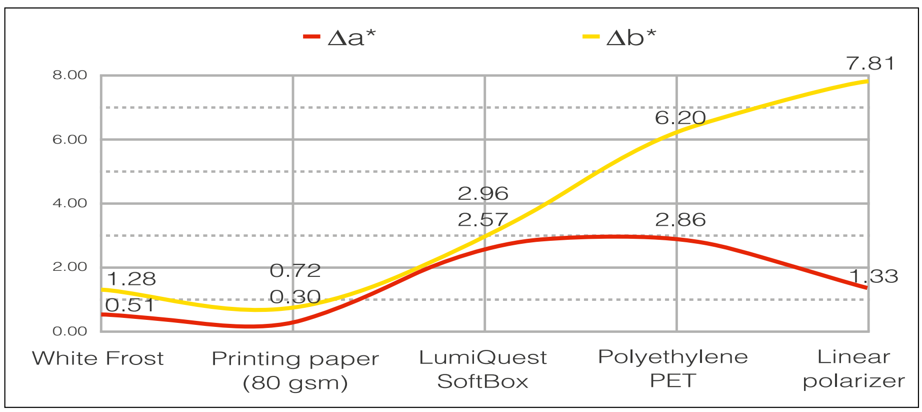


Fig 11 Average change of chromaticity caused by different diffuser materials.

general appearance were similar to the older gray cards but darker, in order to correct the color cast of digital images, either by defining a custom white balance value using the camera's menu, or during postproduction using software.[9] The protocol that has been put forward here is an adapted, simplified version of the one suggested by Meng et al,[10] which combines the correction of white balance with exposure correction to a defined standard.

The use of a white balance reference card was indeed effective in compensating the changes in tooth color caused by different diffuser materials (ΔE^*_{min} 0.53 - ΔE^*_{max} 0.93) and software interpretation. Every diffuser caused characteristic tooth chroma-

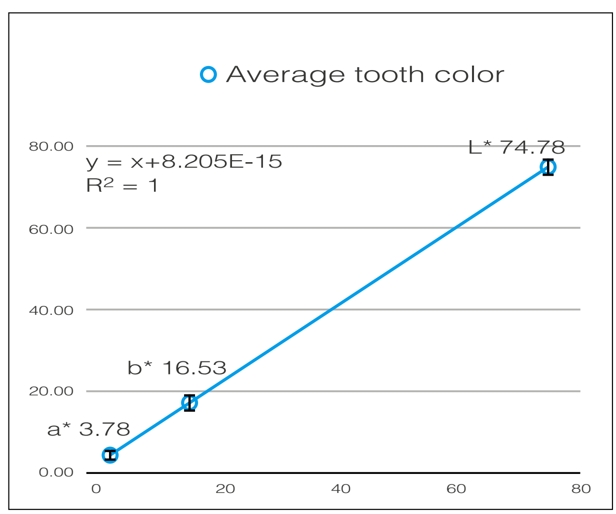


Fig 12 The average tooth color found in this study showed little deviation.

Table 2 The ranking of ΔE* values after white balancing correlated well with the ranking of CRI values for each diffuser, suggesting that software interpretation plays the most significant role in the visually perceivable alteration of tooth color before white balancing

Diffuser material	CRI	ΔE*
Linear polarizer	97.2	0.53
White Frost	97.6	0.58
PET	97.6	0.59
LumiQuest SoftBox	96.0	0.66
Printing paper (80 gsm)	92.4	0.93

Table 3 The closest match to conventional shade guide systems

L*	a*	b*	Shade	ΔE*
72.960	4.336	16.527	1C	1.90
73.928	3.865	14.571	2R2.5	2.14
73.094	3.381	15.003	1A	2.31

ticity changes, which can be seen in Figures 10 and 11. The ranking of Δ*E** values after white balancing correlated well with the ranking of CRI values for each diffuser (Fig 12), suggesting that software interpretation plays the most significant role in the visually perceivable alteration of tooth color before white balancing.[11]

The average tooth color found in this study showed little deviation (Table 2). This result corresponds generally well with those of other studies,[12] but in particular with one *in vivo* study by Gozalo-Diaz et al, which utilized a similar experimental setup and equipment, and which found a similar average tooth color value to that found in this study (Δ*C** 2.99).[13] This supports the suggestions by earlier authors[14-18] that digital cameras can be used confidently for quantification of tooth colors.

The closest match to conventional shade guide systems was the shade 1C (Δ*E** 1.90) from the Ivoclar PE shade guide system, which is made of hard acrylic, followed by Vita 3M shade 2R2.5 (Δ*E** 2.14), and Ivoclar PE shade 1A (Δ*E** 2.31) (Table 3).

A basic protocol for practical use in the dental surgery and dental laboratory is provided in Figures 13 to 15.

Fig 13 White balancing procedure: After importing the RAW file into Adobe Lightroom CC, the color picker tool is selected to click on a randomly selected area of the white balance reference card ideally located in the center of the image. This will neutralize chromaticity values a* and b* towards 0 (± 0.5).

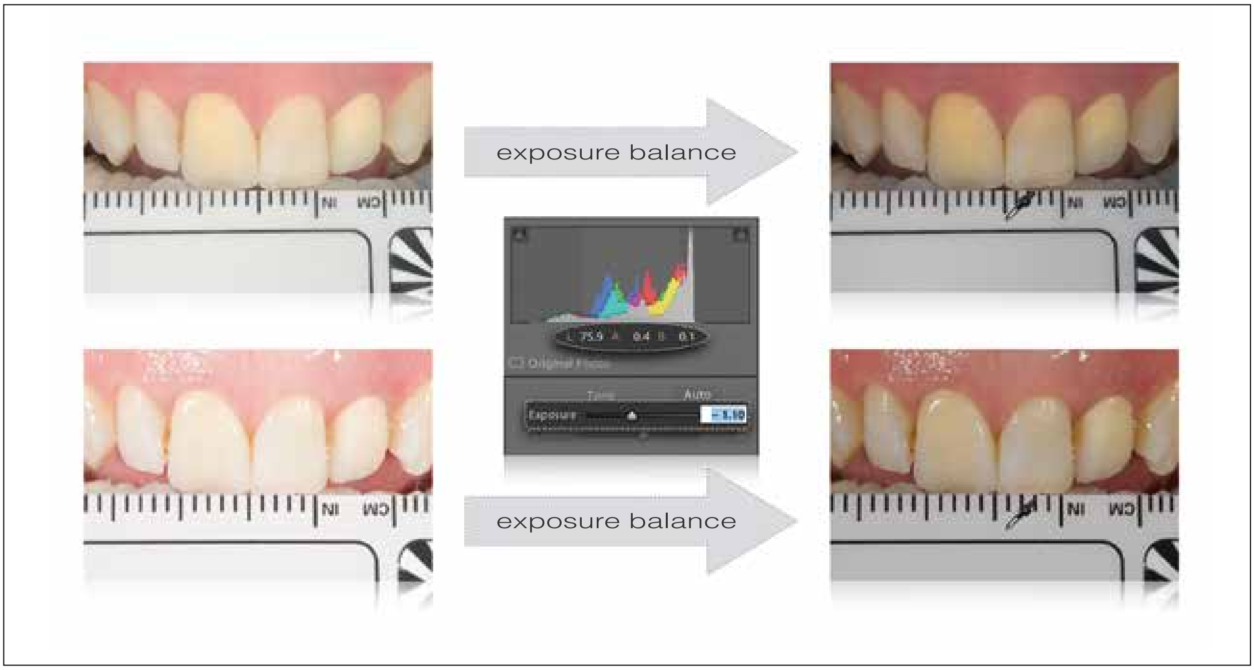


Fig 14 Exposure balancing procedure: The color picker tool is held steadily over the central area of the white balance reference card while the exposure value is adjusted simultaneously until the L* value is as close as possible to the known L* value of the gray reference card (ie, L* 75 WhiBal).

Fig 15 The adjustments during white balancing and exposure balancing can be copied and pasted to achieve synchronicity among images which were obtained with the same type of diffusor.

Conclusion

Within the limitations of this study, the use of a white balance reference card with known color coordinates can be recommended when diffusers are used for dental photography in daily practice to record color accurate images, especially for shade communication and for documentation of clinical results.

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