

CLINICAL RESEARCH

Variability of color matching with different digital photography techniques and a gray reference card



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Color matching in dentistry is considered a subjective process, dependent on 3 main factors: light source, object (tooth), and observer (dentist/patient/society).¹ Although no single method is considered standard,² 2 methods exist to evaluate color in dentistry: visual and instrumental.³ Visual selection by using shade guides is the most common but also the most subjective technique, influenced by factors such as the age of the observer and eye fatigue.⁴ Therefore, instrumental methods such as spectrometers and colorimeters have gained attention; however, they have poor interdevice reliability⁵ and require specific and expensive technology, not always available to the clinician. Digital cameras are a common communication tool in dental offices and can be used for electronic shade registration, although they still present a certain degree of subjectivity in shade selection.⁶

ABSTRACT

Statement of problem. Color matching in restorative and prosthetic dentistry is important for the success of dental treatments, although communication with the dental laboratory remains subjective, and studies of the performance of objective communication methods are lacking.

Purpose. The purpose of this study was to evaluate color differences (ΔE) and compare color luminosity (L^*) values among different types of digital photography equipment used to document tooth color, with and without a gray reference card, and to determine whether the gray card could be used to standardize color assessment in dental photography.

Material and methods. Sixty photographs were made ($n=10$) using different equipment: a D7000 digital camera (Nikon Corp) with an 85-mm lens and wireless close-up flash (DC+WCF); close-up flash surrounded by 80 grams per square meter (gsm; specification of paper thickness) white printing paper (DC+WPP); ring flash (DC+RF); close-up flash attached to a dual-point rigid flash bracket (DC+DPRF); cross-polarizing filter attached to a close-up flash (DC+CPF); and iPhone 7 (I7). For all photographs, a gray reference card with known color values was positioned at the patients' mandibular teeth, acting as a parameter for the analysis of white-balanced digital photographs. Each photograph underwent white balance with the reference card and software. ΔE were obtained from each piece of equipment by comparing images with and without white balance (original photo) with software and the smallest ΔE achieved was used as the gold standard for comparisons of luminosity. Values of luminosity were subsequently obtained for the different equipment with and without white balancing the photographs; these values were compared using a general estimating equation with Huber-White standard error ($\alpha=.05$).

Results. The use of a cross-polarizing filter was used as the gold standard for luminosity evaluation, as the smallest ΔE (3.4) among photographs were observed when those with and without white balance were compared. Luminosity results from the cross-polarizing filter method (DC+CPF) were not significantly different from those of the DC+DPRF ($P=.73$), DC+WPP ($P=.106$), and DC+WCF ($P=.551$) groups but were statistically different from DC+RF ($P=.028$) and I7 groups ($P<.001$). Use of a gray card was significant when a ring flash ($P=.008$) or the iPhone ($P=.023$) were used but not statistically significant for the other groups ($P>.05$).

Conclusions. The use of a cross-polarizing filter results in more color-standardized photographs, while the ring flash system and the iPhone 7 result in less standardized photographs. The gray reference card had a significant effect when a ring flash system or iPhone 7 was used. (*J Prosthet Dent* 2019;121:333-9)

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Clinical Implications

Color matching in restorative dentistry remains subjective. Specific instruments for color matching may be expensive, not usually available for the clinician, and most of all, inaccurate. Digital cameras are extensively used in dental offices, and using a standard gray reference card and a cross-polarizing filter results in a more standardized color pattern, increasing restoration success.

In order to enhance digital photography, calibration and color adjustment are required for accurate color management.⁷ A dental color description with increased precision will improve the color accuracy of the ceramic restorations.⁸

Digital photographs can be easily stored and transmitted to a technician, providing good quality information regarding color across the tooth surface, shape, and characteristic features.⁹⁻¹¹ An improvement in the color matching performance of dentists has been shown with a digital camera⁹; nevertheless, different parameters should be standardized, such as exposure, white balance, film speed, aperture, light source, and resolution.^{12,13} Different tools have been used with digital cameras to improve the standardization of color information. Cross-polarizing filters correct for overestimating the prevalence of white opacities with flash photography by reducing or eliminating specular reflections. They also help in discriminating among color differences in shade guides.^{14,15}

Determination of digital camera exposure is also problematic, as standardization of white values when the automatic white balance option is used for intraoral photography.¹² White balance is the process of removing unrealistic colorcasts from the photographs.¹⁶ Automatic white balance will erroneously add cyan to the image to neutralize the high proportion of red tones from the gingiva while adding a tinge of blue to offset the yellow tones from the teeth.¹² A white balance reference card with known color coordinates has been recommended for accuracy in recording color images in dental digital photography.¹⁷

The CIE Lab system consists of 3 coordinates: L^* , the luminosity of the object to be evaluated, ranging from black to white (0-100); a^* , the chroma in the red-green (positive-negative value) axis; and b^* , the chroma in the yellow-blue axis (positive-negative value) have all been used to record color objectively.¹⁸ Each color has a specific numerical value, thus providing a more objective characterization and assisting in color communication. Luminosity is the parameter that results in higher unacceptable color changes compared with a^* and b^* values,¹ thus, standardization of this parameter is important.

Two measurements of the same object can be compared with their color differences (ΔE), which can be defined if the difference is perceptible and/or acceptable to human observers.¹⁹ Perceptibility refers to the detection of the color difference between a tooth and an adjacent colored restoration, whereas acceptability refers to the acceptance of the color of that restoration.²⁰

The purpose of this study was to determine the magnitude of color difference (ΔE) and compare the color luminosity (L^*) values among different types of digital photography equipment for tooth color evaluation with and without a gray reference card and to evaluate whether its use can standardize colors in dental photography. The null hypothesis tested was that different types of digital image acquisition would not present different ΔE or L^* values when the photographs were white balanced by using a gray reference card, which would not affect standardization of colors in dental photography.

MATERIAL AND METHODS

The study protocol was approved by the Universidad de los Andes, Chile, Institutional Review Board. Ten sixth-year students between 22 and 25 years were selected, research details were explained, and each student signed a consent agreement. Exclusion criteria included tooth bleaching within the last 6 months and anterior teeth with restorations.

Six photographs were made of each 10 students ($N=60$), using different photographic equipment and standardized calibrated parameters (Table 1). Figure 1 illustrates the equipment used. In all photographs, a standard gray reference card (Genuine White Balance Reference; Michael Tapes Design) with known color values ($L^*=75$, $a^*=0$, $b^*=0$) was put close to the mandibular teeth to provide a parameter for white balance analysis of the digital photographs (Fig. 2). Each photograph was evaluated in the same location before and after being white-balanced, using software. Photographs were made at 1-minute intervals to allow consistent flash intensity. To avoid tooth dehydration, patients were asked to close their mouths between photographs. After that, all digital photographs were evaluated with a software (Classic Color Meter version 1.8.1 for MacIntosh AC; Ricci Adams), selected because it encompassed parameters in the CIE Lab color space. Color measurements were made in the center of the maxillary right central incisor (Fig. 2), with all photographs at the same position; the color window was adjusted to the maximum size possible, and the CIE Lab coordinates were measured. Using this model, different colors were represented by 3 numbers. After the original photographs were measured, all images were white balanced using software (Lightroom v6.0, Adobe Photoshop CC; Adobe Systems Inc) and standard gray

Table 1. Type of photographic equipment groupings and standardized calibrated parameters used

Equipment Groups	Standardized Parameters	Instructions
Digital camera + wireless close-up Speedlight flash (DC+WCF): D7000 SLR digital camera (Nikon Corp) equipped with 85-mm lens (AF-S VR Micro-NIKKOR [Nikon Corp]), and a wireless close-up Speedlight flash (4804 R1 wireless close-up Speedlight system [Nikon Corp])	Exposure (1/125 s, f25), film speed (200), flash (ETTL), distance (80 cm), focusing (1:1).	Participants were instructed to remain with their head upright, without rotating and with occlusal plane of the maxillary teeth parallel to the floor. Lip retractors were used, and participants were asked to remain with their mouth closed, maintaining maximum habitual intercuspation. To avoid teeth dehydration, participants were asked to close their mouths between photographs.
Digital camera + wireless close-up Speedlight flash + white printing paper (D7000 SLR digital camera equipped with 85-mm lens (AF-S VR Micro-NIKKOR 85-mm [Nikon Corp]) and a wireless close-up Speedlight flash (4804 R1 wireless close-up Speedlight system [Nikon Corp]). The close-up flash system surrounded by 80 gsm white printing paper	Exposure (1/125 s, f25), film speed (200), flash (ETTL), distance (80 cm), focusing (1:1).	Participants were instructed to remain with their head upright, without rotating and with occlusal plane of the maxillary teeth parallel to the floor. Lip retractors were used, and participants were asked to remain with their mouth closed, maintaining maximum habitual intercuspation. To avoid teeth dehydration, participants were asked to close their mouths between photographs.
Digital camera + ring flash system (D7000 SLR digital camera equipped with 85-mm lens (AF-S VR Micro-NIKKOR 85-mm [Nikon Corp]) and ring flash system (Circular EM – 140 DG for Nikon; Sigma Corp)	Exposure (1/125 s, f25), film speed (200), flash (ETTL), distance (80 cm), focusing (1:1).	Participants were instructed to remain with their head upright, without rotating and with occlusal plane of the maxillary teeth parallel to the floor. Lip retractors were used, and participants were asked to remain with their mouth closed, maintaining maximum habitual intercuspation. To avoid teeth dehydration, participants were asked to close their mouths between photographs.
Digital camera + dual-point rigid flash bracket + wireless close-up Speedlight flash (D7000 SLR digital camera equipped with 85-mm lens (AF-S VR Micro-NIKKOR 85 mm [Nikon Corp]), and wireless close-up Speedlight flash (Nikon 4804 R1 wireless close-up Speedlight system [Nikon Corp]). Close-up flash heads were mounted in a dual-point rigid flash bracket (PhotoMed bracket for Nikon [PhotoMed]), parallel to the floor, one at each side of the camera	Exposure (1/125 s, f25), film speed (200), flash (ETTL), distance (80 cm), focusing (1:1).	Participants were instructed to remain with their head upright, without rotating and with occlusal plane of the maxillary teeth parallel to the floor. Lip retractors were used, and participants were asked to remain with their mouth closed, maintaining maximum habitual intercuspation. To avoid teeth dehydration, participants were asked to close their mouths between photographs.
Digital camera + wireless close-up speedlight flash + cross-polarizing filter (D7000 SLR digital camera equipped with 85-mm lens (AF-S VR Micro-NIKKOR 85 mm [Nikon Corp]) and wireless close-up Speedlight flash (4804 R1 wireless close-up Speedlight system [Nikon Corp]). Close-up flash heads were attached to cross-polarizing filters (Polar eyes; Bioemulation)	Exposure (1/125 s, f25), film speed (200), flash (ETTL), distance (80 cm), focusing (1:1).	Participants were instructed to remain with their head upright, without rotating and with occlusal plane of the maxillary teeth parallel to the floor. Lip retractors were used, and participants were asked to remain with their mouth closed, maintaining maximum habitual intercuspation. To avoid teeth dehydration, participants were asked to close their mouths between photographs.
iPhone 7 (Apple Inc)	Pre-established parameters from mobile phone used, and photographs made in regular parameter, at standardized distance of 30 cm.	Participants were instructed to remain with their head upright, without rotating and with occlusal plane of the maxillary teeth parallel to the floor. Lip retractors were used, and participants were asked to remain with their mouth closed, maintaining maximum habitual intercuspation. To avoid teeth dehydration, participants were asked to close their mouths between photographs.

ETTL, evaluative-through the lens; gsm, grams per square meter (specification of paper); SLR, single-lens reflex.

reference card, and measurements were made in the same spots for comparison.¹⁷ Values obtained from the image with and without white balance with the gray reference card were compared, and ΔE were was obtained for each photographic equipment group. The group with the lowest ΔE value, using the cross-polarizing filter (DC+CPF), was selected as the gold standard for luminosity statistical comparison. Subsequently, values for luminosity from different types of digital image equipment were statistically analyzed by using generalized estimating equations (GEE) together with the Huber-White standard error estimates to identify differences among the methods, independently for use or not of the gray reference card (n=20 per group). Use of a gray card was then analyzed as a possible interaction among the results. When an interaction was found, a second analysis was performed to identify where the use of a gray card had a significant effect. For all

photographs, because one measurement was made in the original photograph and one measurement was made after it was white balanced; white balance was considered a repeated factor. L^* was used because that is the parameter that is more variable concerning colors, whereas a^* and b^* values are more standardized.¹

RESULTS

Table 2 summarizes the mean \pm SD ΔE values (n=10 per group) determined for each type of equipment, as well as mean \pm SD values for L^* (with and without gray card, evaluated from the same photograph with and without white balancing in the software). Statistically significant differences were found among groups ($P<.05$). Use of a cross-polarizing filter was used as the gold standard because it resulted in the lowest values of ΔE . Without the use of the gray card, DC+CPF was not significantly



Figure 1. Digital equipment used. A, D7000 SLR digital camera equipped with 85-mm lens and wireless close-up Speedlight flash (Nikon Corp). B, Close-up flash system surrounded by 80 gsm white printing paper. C, Ring flash system. D, Close-up flash heads mounted on a dual-point rigid flash bracket. E, Close-up flash heads attached to cross-polarizing filters. F, iPhone 7. gsm, grams per square meter (specification of paper thickness); SLR, single lens reflex.

different from DC+DPRF ($P=.73$), DC+WPP ($P=.106$), or DC+WCF ($P=.551$) but was statistically different from DC+RF ($P=.028$) and I7 ($P<.001$). The interaction regarding use or not of a gray card significantly affected groups DC+RF ($P=.008$) and I7 ($P=.023$) but was not statistically significantly different for the remaining groups. Compared with the gold standard (DC+CPF), the use of a gray card did not affect color standardization for the I7 group ($P<.001$ for the group without gray card and white balance versus $P=.008$ when using a gray card), whether it positively affected the DC+RF group ($P=.028$ for the group without gray card and white balance versus $P=1.0$ when using a gray card). Therefore, when a ring flash was used, considering the white-balanced photograph, it made no difference compared with the DC+CPF

group, thus helping to standardize the photographic color; however, for the I7 group, it did not matter whether it was used together or not with the gray reference card, it would not be as standardized as the DC+CPF group.

Figures 3 and 4 show digital photographs made with the different types of equipment, with and without white balance.

DISCUSSION

The null hypothesis tested was rejected because different types of digital image acquisition resulted in different magnitudes of ΔE and L^* values within each other when the digital images were white balanced.



Figure 2. Positioning of standard gray reference card close to mandibular teeth as parameter for posterior analysis. A, Color measured using software at standardized position in center of maxillary right central incisor. B, Color window adjusted to maximum size and CIE Lab coordinates measured.

Moreover, a gray reference card enabled higher standardization of colors for certain types of acquisition methods. Successful color matching is essential to

Table 2. Mean \pm standard deviation of ΔE (n=10) and L* values (n=10 with gray card and n=10 without gray card) determined for each type of equipment

Type of Equipment	ΔE	L* With Gray Card	L* Without Gray Card
Digital camera + wireless close-up Speedlight flash	6.5 \pm 1.1	66 \pm 2.58	64.8 \pm 2.85
Digital camera + wireless close-up Speedlight flash + white printing paper	6.5 \pm 1.7	65.8 \pm 2.48	61.3 \pm 2.45
Digital camera + ring flash system	7.5 \pm 5.7	64.9 \pm 5.62	58.3 \pm 7.86
Digital camera + dual-point rigid flash bracket + wireless close-up Speedlight flash	5.8 \pm 1.6	65.6 \pm 1.71	64.5 \pm 2.79
Digital camera + wireless close-up speedlight flash + cross-polarizing filter	3.4 \pm 1.0	64.9 \pm 2.55	63.9 \pm 3.98
iPhone 7	7.5 \pm 3.9	71.7 \pm 6.63	73 \pm 4.98

ΔE , color differences.

patient satisfaction with esthetic restorations. The authors are unaware of a study that has evaluated differences among different types of digital image acquisition with dental photography. Typically, color-related studies report only results from a single digital camera with different parameters,¹⁷ or 1 type of

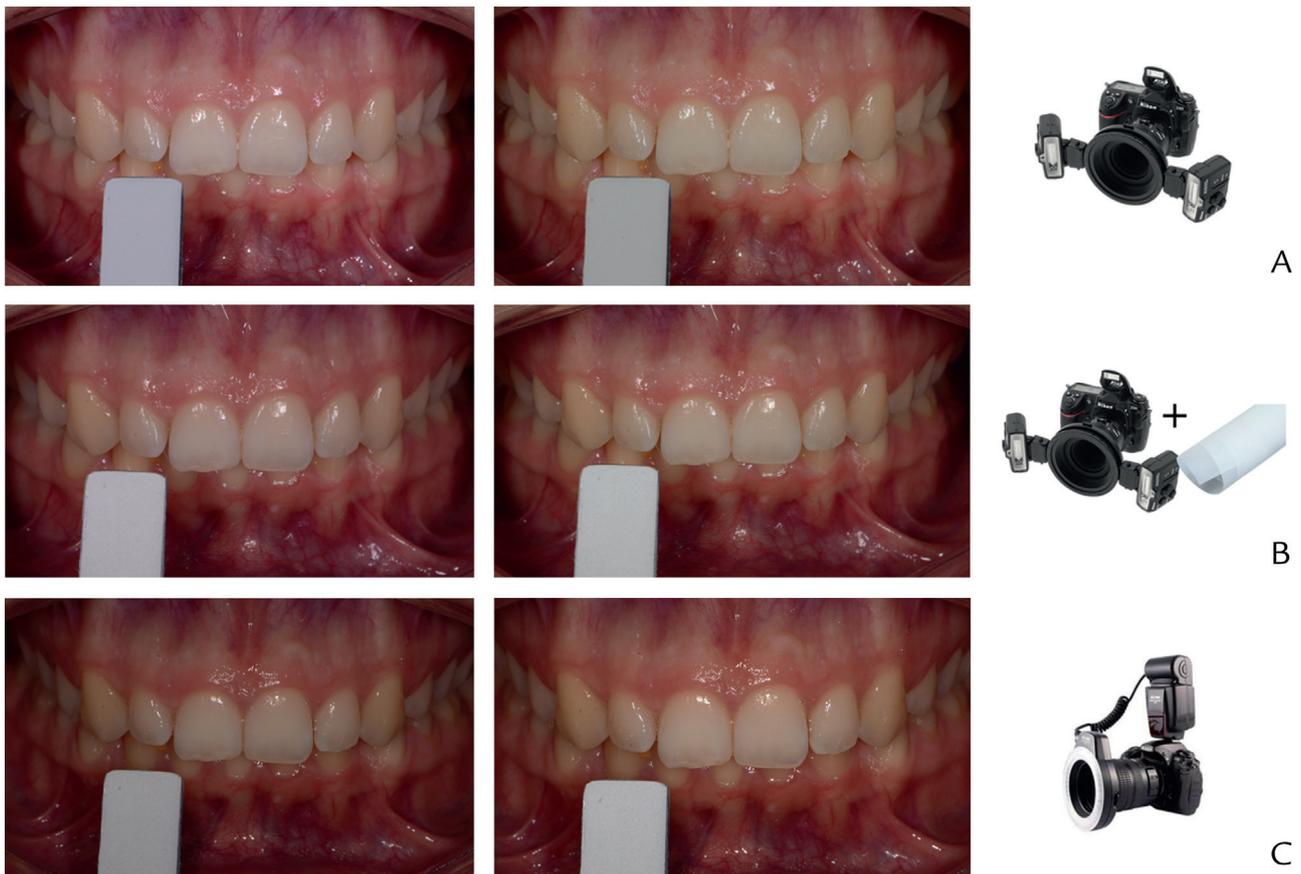


Figure 3. Digital photographs made using different types of equipment with (right column) and without (left column) white balance. A, D7000 SLR digital camera equipped with 85-mm lens and wireless close-up Speedlight flash (Nikon Corp). B, Close-up flash system surrounded by 80 gsm white printing paper. C, Ring flash system. gsm, grams per square meter (specification of paper thickness); SLR, single lens reflex.

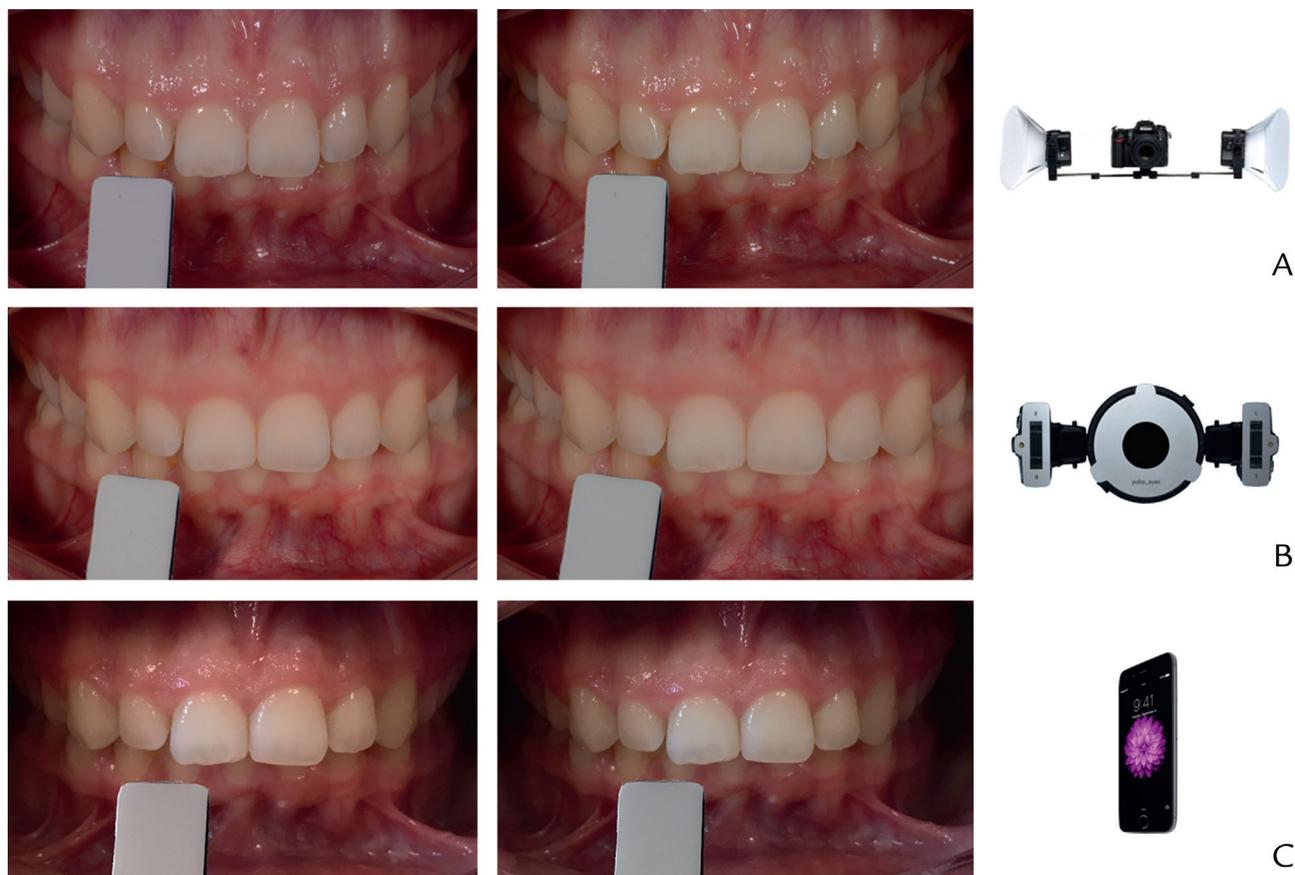


Figure 4. Digital photographs made using different types of equipment, with (right column) and without (left column) white balance. A, Close-up flash heads mounted in dual-point rigid flash bracket. B, Close-up flash heads attached to cross-polarizing filters. C, iPhone 7.

image acquisition¹⁴; thus, information regarding the most standardized way to perform dental photography and dentist/technician color communication is lacking. The present study evaluated the ΔE and L^* values among different types of widely used dental photography and digital cameras with and without a gray reference card.

Changes in lighting conditions can result in changes in perceived color,⁵ which is also related to the white balance of the photograph. White balance is the process of removing unrealistic colorcasts from the photographs.¹⁶ For example, in soft tissues, a correct white balance can distinguish healthy from inflamed tissues. For hard tissues, correct color rendition reveals features such as enamel translucency, caries, erosion and abrasion, and cervical dentin exposure.¹⁶

Johnston and Kao¹⁹ reported a clinically acceptable threshold of visual perception of ΔE 3.7 in the CIELab system.^{1,8,19} Higher ΔE values would result in non-acceptability of the restoration. Although this value has been reported in different studies in a different manner, greatly varying in number, a ΔE value equal to 3.7 is the value most frequently adopted when considering acceptable thresholds.^{1,8,19} In our study, only the group

with the cross-polarizing filter (DC+CPF; $\Delta E=3.4$) showed an acceptable ΔE value, which is why it was used as the gold standard for luminosity analysis. Use of cross-polarizing filters has been previously studied and allow evaluation and comparison of color matching between different shade tabs.¹⁴ Such filters, like the Polar Eyes used in this study, have proved useful in revealing the intrinsic shade variations of natural teeth for shade analysis and remove diffuse light and unwanted reflections caused by the flash that can obscure details in the teeth and cause problems when communicating with the dental laboratory.¹⁵ Thus, according to the results of this study, use of cross-polarizing filters is the most standardized method for color evaluation and communication.

The most variable characteristic among the photographs was the L^* value, corresponding to luminosity, whereas the averages of a^* and b^* showed more similarity (were more standardized), which can also help with acceptability of color correspondence.¹ The photographs from groups with high ΔE appear to be darker (Figs. 3, 4), resulting in high ΔE values when the photographs underwent white balance with the gray reference card. A darker photograph can be

related to a change in the luminosity values. Standardization of white balance by the automatic white balance option when photographing with digital cameras tends erroneously to add cyan to the image to neutralize the high proportion of the red gingival tones, whereas adding blue to offset the yellow tones of teeth gives an inappropriate final image color¹² and should not be considered a reliable option.

The groups with a gray reference card: DC+DPRF, DC+WPP, DC+WCF, and DC+RF, were not significantly different for luminosity values from those of DC+CPF; this means just I7 is not comparable with the gold standard. However, when the gray reference card was not used, besides the I7 group, DC+RF was also statistically different from the gold standard. The gray reference card had been previously used when evaluating photographic diffusers.¹⁷ Whereas all diffuser materials attached to the same digital camera and flash showed perceivable color changes for an extracted tooth, the gray reference card showed a more standardized color evaluation.¹⁷ This finding is consistent with the present study.

This study used computer software to evaluate color in digital photography. This low-cost and rapid procedure allows the dental technician to manipulate the images and identify more detail. Moreover, digital photography is capable of capturing polychromatic color, tooth morphology, surface texture, translucency, color distribution, and details from surrounding tissue.^{10,11} Due to the high variability of dental photography, standardized parameters with a cross-polarizing filter and a gray reference card are recommended. If a cross-polarizing filter is not available, a gray reference card can help improve color standardization of DC+RF; however, it is of no help when using the I7. Although use of a gray reference card produces higher standardized color in general, its effect is not statistically significant for any group, except for the ring flash, thus being a fairly good alternative for this single type of image acquisition.

Use of human subjects instead of standardized color chips in this study better reflects the clinical experience where different teeth colors can be seen. Limitations of this study include the limited number of photographs made and the fact that not all digital imaging combinations were covered; further studies should focus on different combinations of digital imaging and an increased number of photographs per combination.

CONCLUSIONS

Within the limitations of this clinical study, the following conclusions were drawn:

1. The combination of DC+CPF was the most accurate for digital photo acquisition because it showed the lowest ΔE compared with the use or not of a gray reference card.

2. The combination of DC+RF and iPhone 7 was the least accurate.
3. The gray reference card presents benefits when a ring flash was used and improved the standardization of digital imaging, but it does not improve photographs made with the iPhone 7.
4. A white-balanced photograph made with a digital camera with close-up flash and cross-polarizing filter (DC+CPF) with a gray reference card is optimal.

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