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Analyzing Color Difference of Digital Cameras Under Different Color Temperatures

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ABSTRACT

Analyzing Color Difference of Digital Cameras Under Different Color Temperatures

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Purpose : Dental clinics had a variety of lighting conditions, which could affect digital photography. Digital Single-Lens Reflex Camera (DSLR) was usually used to take intraoral photos. Recently, there has been a growing trend to use smartphones with the advancement of technology. The aim of this study was to analyze the differences of photographs taken with digital and smartphone cameras under different color temperature conditions.

Materials and Methods : Three types of camera equipment were used: a DSLR (EOS 800D; Canon, Tokyo, Japan) with a macro lens (EF 100mm f/2.8 Macro USM, Tokyo, Japan) and diffuser (Lumilab, Gimpo, Korea) and two types of smartphones; Galaxy (Samsung, Suwon, Korea) and iPhone (Apple, California, USA) with Smile line MDP (Smile line SA, St-Imier, Switzerland). All photographs were taken 30 times for every 500°K color temperature from 3500°K to 6000°K. Color information was extracted from the central part of the tooth using image editing software (Adobe Photoshop CS4, Adobe, California, USA). ΔE value was calculated by this formula based on CIE L*a*b* color systems. All statistical analyses were performed using SPSS (version 23, SPSS, Chicago, USA), with a significance level of 0.05.

Results : In this study, DSLR showed the highest ΔE value followed by iPhone and Galaxy. DSLR showed minimum ΔE value in 4O00°K, iPhone and Galaxy showed in 4500°K. The lowest L* value was DSLR, followed by iPhone and Galaxy. The highest a* value was DSLR, followed by iPhone and Galaxy, except for 4000°K. The lowest b* value was DSLR, followed by Galaxy and iPhone. So DSLR was the darkest, reddest, and bluest of the three equipment.

Conclusion : Although there was a significant difference from the actual shade, Galaxy showed the most similar color. Because each device showed different results, it was essential to consider the characteristics of each imaging device.

Key words : Color Difference, Color temperature, Digital Camera, Smartphone

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Ⅰ. Introduction

Digital photography is essential for diagnosis and treatment in dentistry and is widely used for communication with patients. In particular, digital cameras have been used as the main tool for a long time. Digital cameras are used to accurately capture the condition of the oral cavity using a variety of settings and techniques. Digital cameras are still used to take dental photographs, but Smartphone cameras are increasingly being used.

Digital cameras have the advantages of cost savings, immediate confirmation of captured images, and convenience when shooting[1]. In addition, each digital camera has different functions and operating methods, and has its own unique techniques and precautions. Because of this, users must become familiar with various setting changes and shooting methods. There are many factors that affect dental photographs taken by digital cameras and smartphone cameras. On the other hand, Smartphone cameras are easily accessible, portable, and easy to shoot and transmit in daily life, but it is difficult to adjust them in detail as a digital camera, and the results are collected with the values set by the software itself. A macro flash system is used to compensate for the lack of light when taking intraoral photography using a digital camera, and assistive devices such as smile line MDP (Mobile Dental Photography) are also used when shooting oral cavity using a smartphone camera[2]. Many flash systems use a color temperature of 5500°K, which mimics the color temperature of natural light, and there is a wide variety of external lighting in the doctor's office, which can affect the color accuracy and quality of digital photographs[3].

When taking pictures of the inside of the mouth in a dental clinic, the results often differ significantly depending on the amount of sunlight at the time or the surrounding light sources, such as the light from the dental chair[4]. If we know for sure how the changes in the light around the chair affect the intraoral dental images for each camera, we can intentionally create the best environment by installing specific auxiliary light sources. Furthermore, it will be possible to predict the influence of the color temperature of the actual chair light used or the color temperature of light sources in the examination room on actual shooting.

Taking the color temperature of the light source into account to obtain a consistent quality digital photograph also reduces communication errors over long distances. For example, to create a prosthesis that is similar to the patient's actual teeth, information such as color and shape is transmitted in the form of digital photographs in the treatment room. Using digital photographs that are as close to the actual teeth as possible will reduce communication errors with the dental laboratory.

The purpose of this study is to analyze the differences in the hue of teeth photographed by digital cameras and smartphone cameras under different color temperature conditions. The first is that there is no significant difference between the color of the teeth captured by the camera and the color of the actual teeth. And the second is that there is no difference in hue between the digital and smartphone cameras.

Ⅱ. Materials and methods

1. Experimental design

The teeth were fabricated and positioned using A3 shade composite resin (Z250; 3M ESPE, St. Paul, USA) at the location of the maxillary middle incisors of the dentiform (Figure 2). A digital camera and two types of smartphone cameras were used. A digital single lens reflex (DSLR) camera (EOS 800D, Canon, Tokyo, Japan) with a macro lens (EF 100mm f/2.8 Macro USM, Tokyo, Japan) and a diffuser (Lumilab, Gimpo, Korea) was used as a digital camera. The smartphone is compatible with the Galaxy (Galaxy note 20; Samsung, Suwon, Korea) and iPhone (iPhone 12 Pro; Apple, California, USA) with Smile lite MDP (Smile line SA, St-Lmier, Switzerland) (Table 1).

The focus of the camera was placed in the center of the resin tooth, and the distance between the resin tooth and the camera lens was fixed at 30 cm. The external light source is a face-emitting light (HS150; Pobi Digital, Seoul, Korea) with adjustable color temperature was positioned 45° upwards from the maxillary middle incisors of the dentiform. The distance between the resin tooth and the external light source was fixed at 1m. A light meter (CL-200, Konica Minolta, Tokyo, Japan) was placed in the maxillary middle incisor of the dentiform to measure the light emitted from the flotation light source, and only the color temperature change occurred under the same illuminance of 2000 Lux(Figure 1)[5]. DSLRs shot in flash mode (5000-5500°K) with shutter speed of 1/125, F32, ISO 3200, and white balance, while smartphone cameras shot in default camera mode.

2. Shooting methods and analysis

The color temperature of the sub-light source was changed from 3500°K to 6000°K at intervals of 500°K, and 6 color temperatures were taken for each experimental group. Thirty shots were taken at each color temperature, and when shooting with a

Table 1. Equipment Used in the Experiment

Group	Product name	manufacturer
DSLR (Digital Single Lens Reflex)	DSLR (Digital Single Lens Reflex)	EOS 800D, Canon, Tokyo, Japan
	Macro lens	EF 100mm f/2.8 Macro USM, Tokyo, Japan
	Diffuser	Lumilab, Gimpo, Korea
Galaxy	Galaxy	Galaxy note 20; Samsung, Suwon, Korea
	Smile lite MDP (Mobile Dental Photography)	Smile line SA, St-Lmier, Switzerland
iPhone	iPhone	iPhone 12 Pro; Apple, California, USA
	Smile lite MDP (Mobile Dental Photography)	Smile line SA, St-Lmier, Switzerland

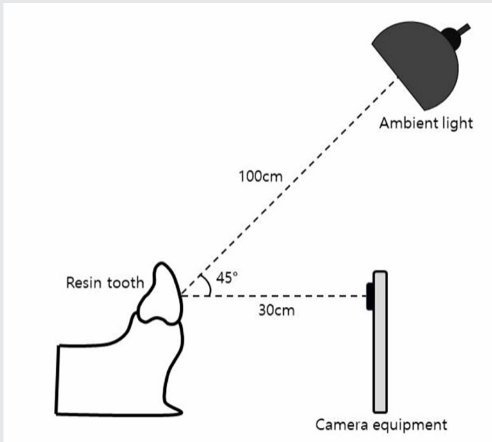

Figure 1. Position of camera equipment and external light source.

Figure 2. Photographs taken by each device. (A) DSLR, (B) Galaxy, (C) iPhone.

digital camera, the shots were taken at intervals of 1 minute to charge the flash, and on smartphones, the photos were magnified by 3 times to get a picture that was as similar as possible to a DSLR connected to a macro lens. All experiments were conducted in a darkroom (Figure 2).

The exact center coordinates of the resin tooth you want to analyze can be transferred to an image editing software (Adobe Photoshop CS4; Adobe, California, USA), and the L*, a*, and b* values for the corresponding coordinates were extracted for each data[6]. Color measurements were made in the center of the maxillary right central incisor, with all photographs at the same position; the color window was adjusted to the maximum size possible, and the CIEL*a*b* coordinates were measured (Figure 3) .

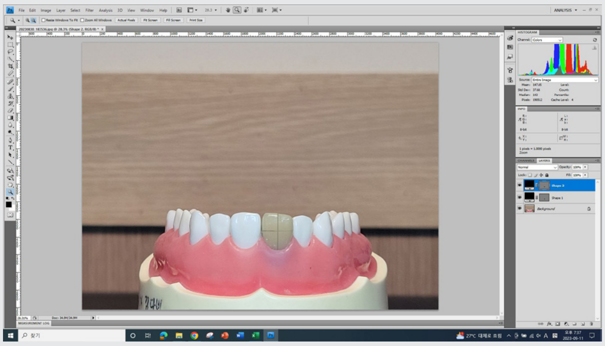

Figure 3. Color was measured using software at standardized position in the center of the maxillary right central incisor.

The color of the resin teeth was measured using a Digital Spectrophotometer (VITA Easyshade V; VITA, Zahnfabrik, Germany). The values were measured as "L*=68.3, a*=1.9, b*=22". Based on these values, the values extracted from the shooting data were derived as ⊿E using the CIE L*a*b* color system.

$$\Delta E = \sqrt{(\Delta L)^2 + (\Delta a)^2 + (\Delta b)^2}$$

3. Statistical analysis

SPSS (version 29, IBM SPSS Statistics, Newyork, USA) was used to compare the difference between DSLR and smartphone photos based on the color temperature of an external light source, and the significance level was 0.05. Since normality was not satisfied, the Kruskal-Wallis test was performed and the post-hoc analysis was performed using the Mann-Whitney test.

Ⅲ. Results

There was a significant difference in the ⊿E values of both DSLRs and smartphone cameras (Table 2). Under the color temperature of all sub-light sources, the highest ⊿E value was found in the DSLR and the lowest ⊿E value was shown in the iPhone and Galaxy. The ⊿E value was lowest at 4000°K Galaxy on DSLR and 4500°K on iPhone.

In the L* value, DSLRs showed significantly lower values than smartphones, while Galaxys showed the highest values (Table 3). DSLRs showed significantly higher values than smartphone cameras in the a* value, while Galaxy showed the lowest value. However, no significant difference was observed between the Galaxy and iPhone at 4000°K (Table 4). DSLRs were significantly lower than smartphone cameras in the b* value, with iPhones showing the highest values (Table 5).

Table 2. Mean and Standard deviation(SD) of ⊿E values according to light temperature of external light

⊿E	3500°K	4000°K	4500°K	5000°K	5500°K	6000°K
DSLR	18.80[a] (0.39)	18.70[a] (0.49)	19.12[a] (0.42)	19.61[a] (0.50)	18.64[a] (0.42)	18.83[a] (0.36)
Galaxy	11.40[c] (0.38)	6.15[c] (0.09)	6.11[c] (0.10)	6.51[c] (0.13)	6.46[c] (0.14)	5.91[c] (0.95)
iPhone	13.53[b] (0.19)	12.70[b] (0.23)	11.30[b] (0.22)	11.75[b] (0.24)	10.96[b] (0.23)	12.05[b] (0.21)

In columns, different superscript letters show significant differences among groups at each color temperature ($p<0.05$).

Table 3. Mean and Standard deviation(SD) of L* values according to light temperature of external light

L*	3500°K	4000°K	4500°K	5000°K	5500°K	6000°K
DSLR	52.63[c] (−2.39)	53.10[c] (−3.25)	52.57[c] (−2.7)	51.93[c] (−3.23)	53.07[c] (−2.86)	52.87[c] (−2.31)
Galaxy	69.20[a] (−1.09)	69.07[a] (−0.58)	68.63[a] (−0.89)	67.63[a] (−1.12)	69.90[a] (−0.99)	69.6[a] (−1)
iPhone	56.27[b] (−1.2)	56.53[b] (−1.43)	57.70[b] (−1.31)	57.43[b] (−1.5)	58.77[b] (−1.52)	69.6[a] (−1)

In columns, different superscript letters show significant differences among groups at each color temperature ($p<0.05$).

Table 4. Mean and Standard deviation(SD) of a* values according to light temperature of external light

a*	3500°K	4000°K	4500°K	5000°K	5500°K	6000°K
DSLR	0.93[a] (−0.74)	0.90[a] (−0.54)	0.77[a] (−0.43)	0.93[a] (−0.58)	0.87[a] (−0.73)	1.10[a] (−0.54)
Galaxy	−2.13[c] (−0.86)	−2.10[b] (−0.54)	−2.67[c] (−0.8)	−3.57[c] (−0.93)	−3.73[c] (−0.98)	−3.60[c] (−0.62)
iPhone	−2.00[b] (0)	−2.00[b] (0)	−1.87[b] (−0.43)	−1.83[b] (−0.98)	−2.53[b] (−0.86)	−2.03[b] (−0.18)

In columns, different superscript letters show significant differences among groups at each color temperature ($p<0.05$).

Table 5. Mean and Standard deviation(SD) of b* values according to light temperature of external light

b*	3500°K	4000°K	4500°K	5000°K	5500°K	6000°K
DSLR	11.77[c] (−0.93)	11.33[c] (−0.71)	11.30[c] (−0.65)	11.40[c] (−0.72)	11.47[c] (−0.77)	11.33[c] (−0.6)
Galaxy	11.47[b] (−2.14)	17.53[b] (−1.04)	18.3[b] (−1.31)	18.97[b] (−1.15)	19.67[b] (−0.88)	21.0[b] (−1.01)
iPhone	17.23[a] (−0.43)	19.1[a] (−1.4)	22.33[a] (−0.8)	24.13[a] (−0.5)	24.87[a] (−0.43)	27.2[a] (−0.76)

In columns, different superscript letters show significant differences among groups at each color temperature ($p<0.05$).

Ⅳ. Discussion

The CIE L*a*b* color system is a theory formulated by the Commision Internationale de I'Eclairage in 1931 that can nearly match the color difference that our eyes can detect and the color difference expressed numerically in the color space[7]. The color difference between the two colors that humans feel and the color difference that appears in the calculated value shows a lot of difference depending on the color. On the other hand, the CIEL*a*b* color system is a uniform color spatial coordinate that is now standardized and used worldwide because it shows very close differences in the eye area. L* value indicates brightness and is displayed on a scale of 0 to 100, with higher numbers indicating brightness. a* value indicates the degree of red-green, a positive number indicates red, a value b* indicates a yellow-blue degree, and a positive number indicates yellow[8]. The ⊿E value refers to the solid distance between the positions of the two colors, and the difference in color is calculated using the distance on the vector of the two colors[7]. If the distance is large, there is a lot of color difference, and if there is almost no difference in distance, it is perceived as a similar color.

In general, if the ⊿E is less than 3.7, there is no difference that can be perceived by the eye[9]. In this experiment, the ⊿E was observed to be 3.7 or higher, indicating that there was a difference in color. Of the three digital cameras, the Galaxy has the lowest ⊿E, showing the most similar color (Table 2). The experimental results showed that the lowest ⊿E was obtained at a color temperature of 4000~4500 °K. Therefore, if the actual dental clinic environment is maintained at a color temperature of 4000~4500 °K, the photograph with the smallest difference from reality can be obtained.

In terms of L* value, DSLRs were significantly lower than smartphone camera. This means that smartphone cameras capture brighter images than DSLRs. Galaxy in particular captures the brightest images, as it has the highest values (Table 3).

The a* value was significantly higher for DSLR cameras than for smartphone cameras. This means that photos taken with a DSLR camera come out redder than those taken with a smartphone camera, and among smartphones, the Galaxy showed more green than the iPhone. However, no significant difference was observed between the Galaxy and the iPhone at 4000°K at the a* value, which is judged to be the effect of the post-definition (Table 4).

In the b* value, DSLRs are significantly lower than smartphone cameras, so DSLRs can be said to have a bluer hue than smartphone cameras. Among smartphones, the iPhone had the highest value and was photographed with the yellowest light (Table 5).

According to other research taken with digital cameras under the color temperature of various external light sources, changes in the external lighting environment did not show any perceptible changes, although there was a statistical difference between the photographs taken with the digital cameras[5]. The results of this study show a difference that can be recognized by both DSLR and smartphone cameras. The reason for the difference from the results of this study seems to be that the E value was derived by using a spectrophotometer to capture the actual color of the resin to establish a reference point.

A limitation of this study is that it is not possible to compare DSLR and smartphone cameras with the same settings. First, in order to shoot at a size similar to that of a DSLR equipped with a macro lens, it is necessary to zoom in on the smartphone camera by 3~4 times. There is also a difference in the pixels of DSLR and smartphone cameras. the iPhone used in this study has 12 million pixels and the DSLR has 24.2 million pixels, so the quality of the photos may also vary accordingly. In addition, since the L*, a*, and b* values of the pixel were derived from a specific point, it may be difficult to obtain a precise value when zoomed in.

Second, the smartphone cameras and internal software perform post-correction to produce results that are similar to the real thing. AI-based post-processing technologies such as image denoising, deblurring, HDR reconstruction, and UDC image restoration support this process[10,11]. In addition, deep learning models are used to enhance camera scene detection on the smartphone itself, which automatically adjusts camera settings based on the detected scene to provide optimal photograph quality[12]. Galaxy had the lowest ⊿E value, followed by iPhone and DSLR (Table 2). This means that the Galaxy had the most similar hue. This result is believed to be due to the fact that AI-based post-processing technology was introduced to Galaxy first. The smartphone's built-in AI performs post-correction tasks that affect the photo's output, resulting in a photo that is better than the actual image. Therefore, when taking color tones with a smartphone, the impact of these AI-based post-processing technologies should be considered.

Despite these limitations, this study confirmed how differences in color temperature of external light sources affect digital photography and what differences occur depending on the shooting device. However, various other factors such as aperture, shutter speed, white balance, etc., which can be set and adjusted by the DSLR itself, also affect the photograpgh[13]. Additional research appears necessary based on these various factors.

V. Conclusion

In this study, since the ⊿E values are all greater than 3.7, there is a difference between the actual color tone and the digital camera and the smartphone camera, and the first null hypothesis was rejected. Statistically, the Galaxy is the most realistic photograph, with the Galaxy being the brightest and greenest, and the iPhone being the most yellowish. Therefore, the second null hypothesis of this study was rejected.

Since the color temperature of the external light source has a significant effect on the photo result, it is recommended to maintain a constant environment as much as possible when taking pictures of the premises, and when shooting under a color temperature of 4000~4500°K, it was possible to obtain a picture with the least difference from the actual one.

Since each imaging device shows different results, it is necessary to identify and refer to the characteristics of each imaging device when shooting in order to obtain color tone in clinical practice.

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