Original Article

Validity and reliability of tooth color selection by smartphone photography and software applications

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Abstract

Aim: This study assessed the validity and reliability of color selection by smartphone photography using two smartphone applications and Adobe Photoshop software.

Settings and Design: In vitro comparative study.

Materials and Methods: The validity and reliability of dental tooth shade recognition (DTSR), Chromatcher, and Adobe Photoshop were evaluated for color selection of shade tabs. The iPhone 7 camera in automatic mode was used for photography. Images were captured using Smile Lite with/without polarized filter and with camera flash. To assess the reliability, nine Vita Lumin Vacuum shade tabs were chosen and each was photographed for 10 times using Smile Lite. The reliability of DTSR, Chromatcher, and Photoshop in shade-taking was calculated. To assess their validity, 16 shade tabs of Vita Lumin Vacuum and 26 shade tabs of Vita 3D Master were photographed using the aforementioned lighting conditions. The color of photographs was calibrated and shade-taking was performed and compared with the shade suggested by SpectroShade as reference.

Statistical Analysis Used: Data were analyzed using Two-way analysis of variance and Bonferroni post hoc test.

Results: The reliability of Photoshop, DTSR, and Chromatcher was 98.88%, 63.3%, and 100%, respectively. The validity of Photoshop was significantly higher than other software programs ($P < 0.05$). Chromatcher had higher validity than DTSR ($P < 0.05$).

Conclusion: Shade-taking by calibrated smartphone pictures and Adobe Photoshop has high validity and reliability.

Keywords: Color calibration, dental applications, digital imaging, polarization filter, Smile Lite, tooth color selection

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BACKGROUND

Achieving a perfect color match between a dental restoration and adjacent teeth is a challenging topic in operative dentistry. Restoration esthetics depends on its proper design and morphology, topography, translucency, and color. However, from the patient's point of view,

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tooth color and color match of anterior restorations with the adjacent teeth play the most important roles in smile esthetics.[1-4]

Micro-abrasion and tooth bleaching are among the treatment modalities used for the correction of tooth color. However, in some cases, teeth need to be restored using restorative materials or prosthetic crowns. In such cases, a correct color match between the restoration and adjacent teeth is imperative to achieve smile esthetics.[5]

Evidence shows around 50% of failure in correct determination of tooth color.[6] To eliminate human errors in shade-taking and data transfer to the laboratory, digital colorimeters such as spectrophotometers were introduced to the market.[7] Considering the increased demand of patients for dental esthetics and complexity of colorimeters, studies on alternative techniques for shade-taking are on the rise.[8] Spectrophotometers and colorimeters have shortcomings such as small field of view, light loss at the edges of teeth due to higher translucency, high cost, high technical sensitivity, and reporting the mean color values. Moreover, these tools have been designed to analyze smooth surfaces while the tooth surface is convex.[9]

Digital photographs are now commonly used for diagnosis, treatment planning, documentation, instruction and research purposes, and data acquisition.[10] Digital cameras are also used for color selection of teeth. This technique allows easy and error-free transfer of clinical data to the lab wirelessly. The surface topography of the teeth is easily transferred to the lab as such, enabling more accurate color selection. However, the shortcomings of this technique include high cost of software programs and digital cameras and time-consuming nature. Moreover, some other factors such as lighting condition and background color also play a role in image quality.[2,9,11]

With advances in technology and increasing popularity of smartphones and related software programs, shade-taking has been simplified by the use of smartphones, which is low cost and fast.[4,9] Tooth properties can be more accurately and easily transferred to the lab as such, enabling more accurate fabrication of restoration. This technique enables reproducible color determination of several teeth or different areas of one tooth.

Considering the shortcomings and limitations of old-fashioned shade-taking techniques, this study aimed to assess the validity and reliability of shade-taking by smartphone photography using dental tooth shade recognition (DTSR) and Chromatcher applications and Adobe Photoshop software.

METHODS

The study was approved by institutional review board. This *in vitro*, experimental study evaluated nine A and B shade tabs of Vita Lumin Vacuum (Vita, Germany) color shade guide for the assessment of reliability and 16 samples of Vita Lumin Vacuum (Vita, Germany) shade guide and 26 shade tabs of Vita 3D Master (Vita, Germany) for assessment of validity of shade-taking with a smartphone.

First, the reliability of photographs taken of shade tabs with a smartphone was evaluated using DTSR version 1.0.0 and Chromatcher version 1.0 applications in an iPhone 7 and Adobe Photoshop CC 2014 on windows under Smile Lite (Smile Line SA, Switzerland) lighting condition. Next, the validity of the aforementioned software programs was evaluated under Smile Lite, Smile Lite plus polarization filter, and the smartphone camera flash as follows.

Assessment of reliability

Nine A and B shade tabs of vita lumen vacuum shade guide were used for this assessment. First, the shade tab was outlined on a Styrofoam and fixed in place using a white fit checker. Next, the tip of a SpectroShade was outlined on the Styrofoam. An index was fabricated of the shade tab surface using a warmed plastic sheet, and a circle with 4 mm diameter was created at the center of it. The shade tab was fixed in front of the smartphone camera. The distance between the camera and shade tab in the calibration box was 8 cm (smile capture). Next, all shade tabs were subjected to colorimetry using a SpectroShade (MHT, Niederhasli, Switzerland) and their CIE L * a*b* color parameters were measured and recorded as reference (control). The SpectroShade was calibrated before use according to the manufacturer's instructions. Apple iPhone 7 (Apple, USA) with factory default setting was then used to take photographs of the samples. The iPhone camera was set in automatic mode. Using Smile Lite, 10 photographs were taken of the shade tabs in the calibration box and saved in JPEG format. The photographs were analyzed using DTSR, Chromatcher, and Adobe Photoshop at the created window and the color parameters were recorded. The output data of DTSR and Chromatcher included the name of vita classic shade tab, while the output data of Adobe Photoshop were in the form of CIE L * a*b* color parameters.

Next, the percentage of similarity of output data of DTSR and Chromatcher was calculated. For Adobe Photoshop, the color difference (ΔE) of the software data and

SpectroShade data was calculated. For each shade tab, data with >1.9-unit difference were separately reported and the similarity percentage was calculated.

Assessment of validity

Sixteen shade tabs of Vita Lumin Vacuum and 26 shade tabs of Vita 3D Master were used for assessment of validity. The shade tabs were outlined in a Styrofoam as explained earlier and the color coordinates of shade tabs were first recorded using a SpectroShade as explained earlier. Apple iPhone 7 was set in default factory setting. The iPhone camera was set in automatic mode and photographs were taken under three lighting conditions: (i) using Smile Lite in the calibration box, (ii) using Smile Lite with polarized filter in the calibration box, and (iii) using camera flash in the calibration box. The images were saved in JPEG format.

The photographs were calibrated using SpectroShade color coordinate data and Adobe Photoshop software such that the mean CIE L * a*b* difference of Photoshop data and SpectroShade data was calculated and applied for all photographs using Photoshop software. The photographs were analyzed using DTSR, Chromatcher, and Adobe Photoshop in the created window and their color coordinates were recorded. The DTSR output was the name of vita classic and Vita 3D Master shade tabs and Chromatcher output was the name of vita classic shade tabs. Thus, considering the CIE L * a*b* data provided by SpectroShade for each shade tab and the name of shade tabs reported by the aforementioned two applications, ΔE of each shade tab was calculated (since Chromatcher does not report data according to Vita 3D Master shade guide, we had to compare the data of this shade tab with the data of vita classic calculated by the SpectroShade). The Δ E of shade tabs in Adobe Photoshop was also compared with the CIE L * a*b* data provided by the SpectroShade.

Statistical analysis

The homogeneity of variances was first evaluated using Levene's test. One-way and two-way randomized block ANOVA were then applied followed by Bonferroni *post hoc* test to analyze statistical differences between the groups. The validity of Δ E data was reported as frequency percentage. For assessment of reliability, the frequency percentage of data was also reported. All statistical analyses were carried out using SPSS version 21 (SPSS Inc., IL, USA).

RESULTS

Reliability

Assessment of the reliability of the two applications and Photoshop revealed that DTSR had 63.3% reliability for the two colors reported for each shade tab, which was within the acceptable range. Chromatcher showed 100% reliability. Photoshop had 98.88% reliability under Smile Lite. Table 1 presents the reliability (ΔE of Photoshop with SpectroShade) under Smile Lite.

Validity

In all three lighting conditions, Photoshop, DTSR, and Chromatcher had 72.66%, 9.33%, and 15.66% validity, respectively (ΔE <4.2). The three lighting conditions were not significantly different ($P > 0.05$). The effect of Smile Lite, polarization filter, and flash on the validity of results was not significant ($P > 0.05$). Their interaction effects were not significant either ($P > 0.05$). Table 2 shows the validity (mean Δ E) of different subgroups.

Two-way randomized block ANOVA showed that the effect of shade tab and software program on validity of results was significant ($P = 0.000$). The effect of light on the validity of results was not significant ($P = 0.055$). The interaction effect of light and software was not significant either ($P = 0.288$). Table 3 shows a pairwise comparison of Photoshop, DTSR, and Chromatcher. Table 4 shows the validity of Photoshop, DTSR, and Chromatcher under different lighting conditions. Figure 1 shows the perceivable Δ E in different subgroups.

DISCUSSION

Assessment of the reliability of Photoshop, DTSR, and Chromatcher revealed that DTSR had 63.3% reliability for the two colors reported for each shade tab, which was within the acceptable range. Chromatcher had 100% reliability. Photoshop had 98.88% reliability under Smile Lite. Previous studies have reported the reliability of Photoshop to be 50%–75%.[12,13] We repeated each measurement for 10 times to assess reliability. Previous studies repeated the tests for 2,[14] 3,[12] or 10 times.[15]

Assessment of validity of the results revealed that the three lighting conditions were not significantly different ($P > 0.05$). Previous studies have used different light sources such as natural daylight,[7,16] different light-correcting devices,[3,16,17] flashes of digital cameras,[13,14,18] and polarized filter.[3,17] According to them, adjusted light would increase the accuracy of color shade selection, while the polarized filter cannot significantly enhance the color selection.

Our findings indicated that Photoshop was superior to the other two and Chromatcher was superior to DTSR. Cal *et al*.,[13] Jarad *et al*.,[19] Wee *et al*.,[12] Schropp[20] Tam

Table 1: Reliability (ΔE of Photoshop with SpectroShade) under Smile Lite

SampleΔE	A1	A2	A3	A3.5	A4	B1	B2	B3	B4
Mean	24.34	24.47	24.01	26.52	20.55	22.84	23.18	25.59	22.86
Median	24.14	24.47	23.91	26.51	20.41	23.15	23.03	25.62	22.88
SD	0.423	0.570	0.316	0.111	1.16134	0.50889	0.30452	0.04441	0.05270
Minimum	24.11	23.90	23.83	26.35	19.24	22.16	23.03	25.54	22.72
Maximum	25.15	25.05	24.90	26.71	23.70	23.28	24.02	25.63	22.88

SD: Standard deviation

Table 2: Validity (meanΔE) of different subgroups

Group	Mean	SE	95% CI	
			Lower bound	Upper bound
Photoshop-filter	2.820	0.382	2.069	3.571
Photoshop-Smile Lite	2.956	0.382	2.204	3.707
Photoshop-flash	4.259	0.382	3.508	5.011
Chromatcher-Smile Lite	6.379	0.382	5.628	7.130
DTSR-Smile Lite	8.483	0.382	7.732	9.234
Chromatcher-filter	7.012	0.382	6.261	7.764
Chromatcher-flash	7.059	0.382	6.308	7.811
DTSR-filter	8.355	0.382	7.603	9.106
DTSR-flash	8.620	0.382	7.868	9.371

SE: Standard error, CI: Confidence interval, DTSR: Dental tooth shade recognition

and Lee[18] Gotfredsen *et al*.,[2] and Kiran *et al*.[7] evaluated the validity of digital camera photography by visual observation and spectrophotometry. They showed that digital camera photography has adequate validity. All the above-mentioned studies used Adobe Photoshop to analyze the photographs.[7,13,19] Tam and Lee[9] used the camera of iPhone 6 Plus. Our study showed that with correct calculations, this method has adequate validity. Photoshop had significant differences with the two applications under all three lighting conditions ($P < 0.05$) and yielded more reliable results. However, no significant difference was noted among the three lighting conditions. DTSR and Chromatcher were not significantly different under camera flash and polarized filter, but Chromatcher yielded more acceptable results under Smile Lite ($P < 0.05$). Overall, in all three lighting conditions, Photoshop, DTSR, and Chromatcher had 72.66%, 9.33%, and 15.66% validity, respectively (ΔE <4.2). In general, review of the literature shows that the reliability of SpectroShade is 80%–100% and its validity is 54%–96.9%.[15,21,22]

In the present study, due to inherent limitations of iPhone camera, absence of optical zoom, and different focal length compared to that of digital camera, we could not change the distance from the camera to the shade tab. In the majority of previous studies, the distance between the camera and shade tab was 20–40 cm.[7,13,19,20]

In the present study, Smile Lite was adjusted at 2, 4, 6, and 8 cm distance from the A1, A2, A3, A3.5, A4, B1, B2, B3, and B4 shade tabs and five photographs were taken. The L*, a *, and b * color parameters were then measured on

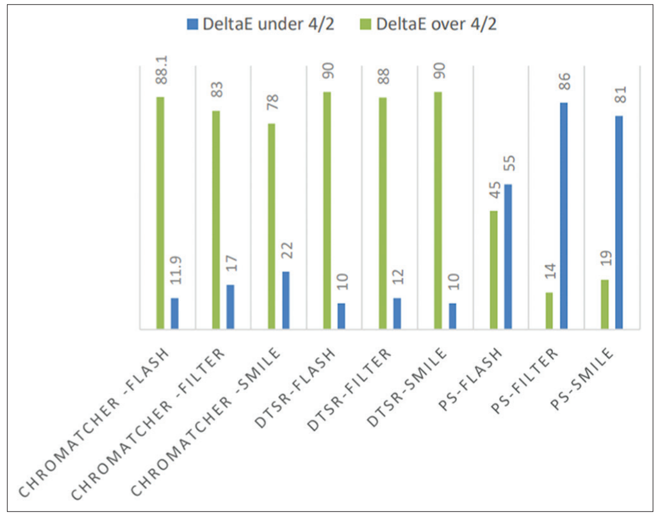

Figure 1: Perceivable ΔE in different subgroups

photographs using Photoshop software. The best result was obtained when the distance between the shade tab and light source was equal in the calibration box. In previous studies, the distance from the camera and light source to the sample was the same and in some cases, the light source had a 45° angle relative to the sample or two light sources were used.[12,19] In some other studies, the light source was at the same level as the sample and one light source was used.[7,18]

We also used putty impression material and cardboard to specify the assessment area. However, due to their diameter, shadow was created during photography. Thus, we used black acrylic resin to overcome this problem. However, passage of light through the acrylic darkened the photographs. The use of white markers also affected the color of shade tab and was not suitable. The use of adhesive and shield decreased the validity and reliability of assessment because it was hard to create a reproducible position for color assessment. Eventually, we decided to use a white Styrofoam in the background and a shield adapted to a tooth was used to specify the area to be tested.

Previous studies used black,[13] white,[13] and gray[20] backgrounds. We used white, gray, and black colors in the background. Gray cardboard created a more realistic color compared to the use of black cardboard but had no significant difference with white cardboard. White

Table 3: Pairwise comparison of the software programs

Software (I)	Software (J)	Mean difference (I−J)	SE	Significant	95% CI for differenceb	
					Lower bound	Upper bound
Photoshop	DTSR	−5.141*	0.312	0.000	−5.891	−4.390
	Chromatcher	−3.472*	0.312	0.000	−4.222	−2.721
DTSR	Ps	5.141*	0.312	0.000	4.390	5.891
	Chromatcher	1.669*	0.312	0.000	0.919	2.420
Chromatcher	Ps	3.472*	0.312	0.000	2.721	4.222
	DTSR	−1.669*	0.312	0.000	−2.420	−0.919

SE: Standard error, CI: Confidence interval, DTSR: Dental tooth shade recognition, *The mean difference is significant at the .05 level

Table 4: Validity of different software programs and lighting conditions*

Dependent variable: Delta E	Pairwise comparisons	Photoshop -Smile Lite	Photoshop -filter	Photoshop-flash	DTSR -Smile Lite	DTSR -filter	DTSR -flash	Chromatcher –Smile Lite	Chromatcher -filter	Chromatcher -flash
Photoshop-Smile Lite	Mean difference		0.136	−1.304	−5.527	−5.399	−5.664	−3.423	−4.057	−4.104
	Significant		1.000	0.589	0.000	0.000	0.000	0.000	0.000	0.000
Photoshop-filter	Mean difference	−0.136		−1.439	−5.663	−5.535	−5.800	−3.559	−4.192	−4.239
	Significant	1.000		0.291	0.000	0.000	0.000	0.000	0.000	0.000
Photoshop-flash	Mean difference	1.304	1.439		−4.224	−4.095	−4.360	−2.120	−2.753	−2.800
	Significant	0.589	0.291		0.000	0.000	0.000	0.004	0.000	0.000
DTSR-Smile Lite	Mean difference	5.527	5.663	4.224		0.128	−0.137	2.104	1.471	1.424
	Significant	0.000	0.000	0.000		1.000	1.000	0.004	0.246	0.317
DTSR-filter	Mean difference	5.399	5.535	4.095	−0.128		−0.265	1.976	1.343	1.296
	Significant	0.000	0.000	0.000	1.000		1.000	0.011	0.484	0.613
DTSR-flash	Mean difference	5.664	5.800	4.360	0.137	0.265		2.241	1.608	1.561
	Significant	0.000	0.000	0.000	1.000	1.000		0.002	0.113	0.148
Chromatcher-Smile Lite	Mean difference	3.423	3.559	2.120	−2.104	−1.976	−2.241		−0.633	−0.680
	Significant	0.000	0.000	0.004	0.004	0.011	0.002		1.000	1.000
Chromatcher-filter	Mean difference	4.057	4.192	2.753	−1.471	−1.343	−1.608	0.633		−0.047
	Significant	0.000	0.000	0.000	0.246	0.484	0.113	1.000		1.000
Chromatcher-flash	Mean difference	4.104	4.239	2.800	−1.424	−1.296	−1.561	0.680	0.047	
	Significant	0.000	0.000	0.000	0.317	0.613	0.148	1.000	1.000	

DTSR: Dental tooth shade recognition, *The mean difference is significant at the .05 level

Styrofoam had no significant difference with the white cardboard.

Previous studies attempted to fix the teeth or shade tabs by a gingival matrix,[15] yellow putty silicon impression material,[7] or using a phantom head.[19] We used putty and black acrylic resin to fix the shade tabs. However, the main drawback of using putty and black acrylic resin was that the background affected the results in photography with a digital camera, but only the acrylic resin and putty had a significant effect on the results when using SpectroShade and the background had no effect on the results of SpectroShade. In previous studies, the assessment area was specified on the software and thus, errors could occur in a reproducible selection of an area.[7,21]

In our study, the photographs were saved in JPEG format. Most previous studies used digital cameras and saved pictures in tagged image file format format.[7,12,13] Studies that used calibrated software programs saved the photographs in RAW format.[22]

The middle third of the shade tabs was used for assessment in our study to allow reproducible color measurement. Most previous studies either evaluated the entire surface of samples for color selection[12,13,19] or the middle third region[7,15,21] by the software. The incisal region is highly translucent and is greatly affected by the background color. The gingival region is also affected by the light reflected from the gingiva and often has higher chroma. Thus, the middle third seems to be more suitable for color selection.[2,3]

It should be noted that color selection software programs for the Android operating system and IOS are limited and the majority of them do not have adequate efficacy since they do not provide quantitative data. A program should be designed to automatically calibrate the pictures taken with smartphones. Future studies are recommended to assess the efficacy of different methods for calibration of pictures and cameras. Furthermore, similar studies are required using several different smartphones.

CONCLUSION

Photography with a smartphone camera has acceptable accuracy and validity for shade-taking, given that the photographs are calibrated. The lighting conditions tested in this study had no superiority to each other. The Photoshop software was superior to the other two and Chromatcher had superior performance compared to DTSR. Adobe Photoshop confirmed its optimal validity and reliability for color selection of shade tabs. DTSR and Chromatcher did not have optimal validity but their reliability was favorable.

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Conflicts of interest

There are no conflicts of interest.

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