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Comparison of different digital shade selection methodologies in terms of accuracy

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PURPOSE. This study aims to evaluate the accuracy of different shade selection techniques and determine the matching success of crown restorations fabricated using digital shade selection techniques. **MATERIALS AND METHODS.** Teeth numbers 11 and 21 were prepared on a typodont model. For the #11 tooth, six different crowns were fabricated with randomly selected colors and set as the target crowns. The following four test groups were established: Group C, where the visual shade selection was performed using the Vita 3D Master Shade Guide and the group served as the control; Group Ph, where the shade selection was performed under the guidance of dental photography; Group S, where the shade selection was performed by measuring the target tooth color using a spectrophotometer; and Group I, where the shade selection was performed by scanning the test specimens and target crowns using an intraoral scanner. Based on the test groups, 24 crowns were fabricated using different shade selection techniques. The ΔE values were calculated according to the CIEDE2000 (2:1:1) formula. The collected data were analyzed by means of a one-way analysis of variance. **RESULTS.** For the four test groups (Groups C, Ph, S, and I), the following mean ΔE values were obtained: 2.74, 3.62, 2.13, and 3.5, respectively. No significant differences were found among the test groups. **CONCLUSION.** Although there was no statistically significant difference among the shade selection techniques, Group S had relatively lower ΔE values. Moreover, according to the test results, the spectrophotometer shade selection technique may provide more successful clinical results. [J Adv Prosthodont 2024;16:38-47]

KEYWORDS
Dental photography; Esthetics; Visual; Zirconium oxide

INTRODUCTION

In terms of restorative treatments, one of the most important expectations of both dentists and patients is esthetic restorations mimicking natural teeth, and the satisfaction of this expectation mainly depends on mimicking the

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natural color of teeth.[1] From the perspective of dentists and dental technicians, accurate shade selection is necessary to meet patients' demands in this regard. Indeed, accurate shade matching is a crucial factor in the clinical success of anterior restorations. The shade selection must be performed properly and accurately, and afterwards, the obtained color information should be objectively transferred to the dental technician. Simply put, the perception of color may vary depending on the intensity of the light, the observer, and factors associated with the surface of the object.[2,3] Thus, clinicians must be aware of the concept of color, the components of color, and the effects of different factors on color detection.

Shade selection can be performed using various techniques. Conventional shade selection techniques entail using shade guides and visual inspections, whereas digital techniques rely on tools such as spectrophotometers, colorimeters, and intraoral scanner (IOS) devices.[4] The use of digital technologies and instrumental shade selection approaches has become increasingly popular in dental practice. Spectrophotometers and colorimeters are devices that measure the amount of reflectance or transmittance curve light reflected from the object. Digital cameras can be used to communicate data such as tooth color, morphology, surface texture, and color distribution. IOS devices accompanied by software can perform photographic color measurements.[5] In this way, these devices can transfer color information and can be used for both color determination and communication with dental prosthesis technicians.[6]

Shade selection can be affected by a number of factors related to both the clinician and the patient. The surrounding ambient light, background color, and experience of the clinician are the most commonly reported factors in the literature.[7-10] Digital tools such as spectrophotometers, colorimeters, digital cameras, and some IOS devices (TRIOS 3, TRIOS 4 (3Shape, Copenhagen, Denmark), CEREC Omnicam, CEREC Primescan (Sirona Dental Systems, Bensheim, Germany), etc) are more objective.[5,11] However, the main disadvantage of digital color selection devices is their high price.[12] As a consequence, prior studies have compared the success of visual color selection and digital techniques.[13-15] For instance, Liberato *et al*.[16] compared the reliability of different visual and instrumental methods (Trios 3 Shape [T-3S], VITA Easyshade Advance 4.0) for dental shade matching, and they found the most successful shade selection technique is the intraoral scanner configured for the 3D MASTER scale. Hampé-Kautz *et al*.[17] reported that while there was no significant difference between the two tested spectrophotometers (VITA EasyShade V and Rayplicker), the IOS devices (Trios 3 Shape [T-3S] and CEREC Omnicam), and the visual shade selection, the IOS devices were found to be the least successful group. Moreover, numerous studies have performed comparisons among the available digital techniques.[18,19] The measurement accuracy of digital devices (VITA Easyshade, SpectroShad, ShadeVisio) was examined in repeated measurements and, under standardized conditions, repeatability of all three devices was very good, except for ShadeVision with Vita Classical.[20]

Although previous studies mainly focused on the effects of the accuracy of different shade selection techniques, a few studies evaluated the success of new digital technologies. In addition, a few studies evaluated the accuracy of IOS devices with regard to shade determination. Therefore, the present *in vitro* study sought to determine whether different shade selection techniques, including new technologies, affect the accuracy of the shade selection. The null hypothesis of the study was that there would be no significant differences between the visual and digital shade selection techniques and that the color difference values would be below the 50:50% acceptability threshold range for all the techniques ($\Delta E_{00} < 2.7$).

MATERIALS AND METHODS

In this *in vitro* study, the clinical accuracy of different shade selection techniques (both visual and digital) was evaluated.

Six different patient scenarios were identified, and six target crowns designed to meet the relevant demands were fabricated to allow for a comparison of the shade selection accuracy of the test specimens. Full crown preparation was performed on the right and left maxillary central teeth of an artificial jaw model (Frasaco, Tettnang, Germany) for each scenario. Digital impressions were obtained using an IOS

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(Medit i500, Seoul, South Korea) to create the patient scenarios by producing full-crown restorations for tooth #11. The obtained digital impression data were transferred to the laboratory in the stereolithography file (.stl) format using Medit Link Software. The .stl data were then loaded into the computer-aided design (CAD) software (EXOCAD, GmbH, Darmstadt, Germany). The restorations were designed according to the cut-back technique, and they were finished via the layering technique using nano-fluorapatite glass-ceramic (IPS e-max Ceram, Ivoclar Vivadent, Schaan, Liechtenstein). The randomized staining techniques and glazing were performed after leveling. In this way, full crowns with six different colors were obtained (Fig. 1). All the processes were completed by the same dental technician.

The visual shade selection was performed by an experienced clinician using the Vita 3D Master Shade Guide (3D; Vita Zahnfabrik, Bad Säckingen, Germany) (Fig. 2). Prior to starting the shade selection, the Ishihara Color Blindness Test was performed to test the clinician for red-green color deficiencies. Then, the information contained in the Vita 3D Master Shade Guide user manual was transferred to the clinician. According to this user manual first determining the lightness, second selecting the chroma, and finally determining the hue are done. For hue, if the target crown is more yellow choose ''L'' or, if redder ''R''. For the purpose of shade selection, a black background product tent with a light source (D65) with a temperature of 6500 °K was used, which was in accordance with International Organization for Standardization (ISO) /TR 28642. After the shade selection was adjusted to allow for a distance of 25 - 30 cm between the scale and the clinician, the visual shade selection was completed. First, the value selection was performed, then the chroma selection, and finally, the hue selection for the target crown.[21] Prior to each shade selection, the clinician rested for 20 minutes to avoid mistakes caused by eye strain.[22] Shade selection data obtained from 3 different areas of each target crown (cervical, middle, incisal) were saved to an Excel file and shared with the dental technician. The restorations manufactured using this shade selection technique served as the control test specimens (Group C).

Photo guided shade selection was performed under the guidance of dental photography. Canon 80D camera, macro lens (100 mm), ring flash and polarizing filter were used for shade selection with the camera. The aperture value used in the camera was set to f 22, shutter speed: 1/125, and ISO value set to 100. To ensure standardization in photography, a mechanism was prepared that ensures that the model and scale samples are perpendicular to the machine plane. The camera was fixed at a distance of 37 cm from the crowns with the help of a tripod. In each scenario for tooth #11 (6 different patient scenarios), crowns and 3 colors (incisal, middle, cervical) selected by the same clinician from the Vita 3D Master color scale were photographed together (Fig. 3). The photo data were collected, and the total .jpeg files were organized into 6 separate folders with a specific name for each target

Fig. 1. Target crowns.

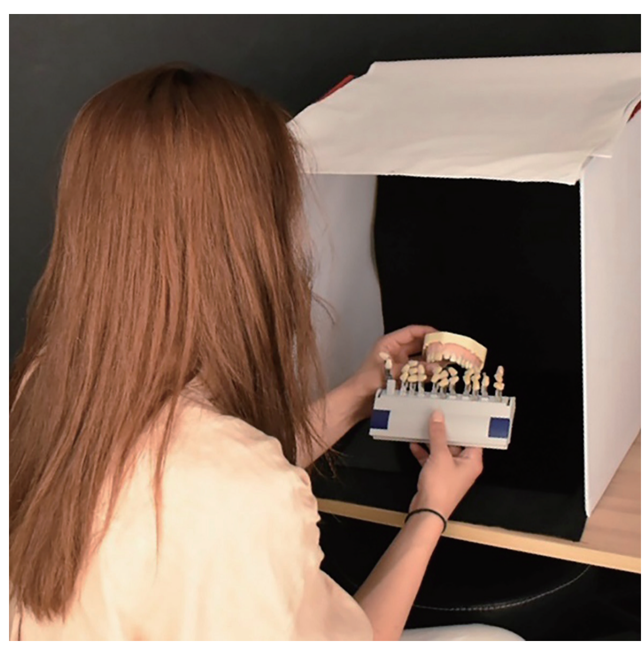

Fig. 2. Visual shade selection.

Fig. 3. Shade selection from 3 different regions by photography.

crown, no further processes were applied to images to get the color coordinates and transferred by e-mail to the dental prosthesis technician. The photo data were collected and sent only to give information to the dental technician to understand which shade was selected by the clinician and give chance to analyze the color grades on the target crowns so there was no further process applied to get the color coordinates.

The restorations fabricated using this shade selection technique served as a test group (Group Ph).

SpectroShade Micro™ (MHT, Verona, Italy) device was used for shade selection by spectrophotometer and measuring the target tooth color. Calibration was performed using white and green calibration plates before each measurement in accordance with the manufacturer's instructions. To ensure standardization, a silicon index compatible with the optical measuring tip, where the samples can be placed exactly, was prepared. The SpectroShade optical measuring tip was placed at a 90° angle with the target crowns in the prepared silicone index. All procedures were repeated 3 times for each sample and all measurements were made by the same clinician. The device settings were adjusted according to the Vita 3D Master color scale and to measure the color of 3 different parts of the crown (incisal, middle, cervical). Color measurements were completed and the obtained data was saved in the memory card of the device and transferred by e-mail to the dental technician (Fig. 4). The restorations fabricated using this shade selection technique served as a test group (Group S).

TRIOS 3 (3Shape, Copenhagen, Denmark) intraoral scanning device was used for shade selection with an intraoral scanner and for color measurements of target crowns on the upper jaw artificial jaw model using

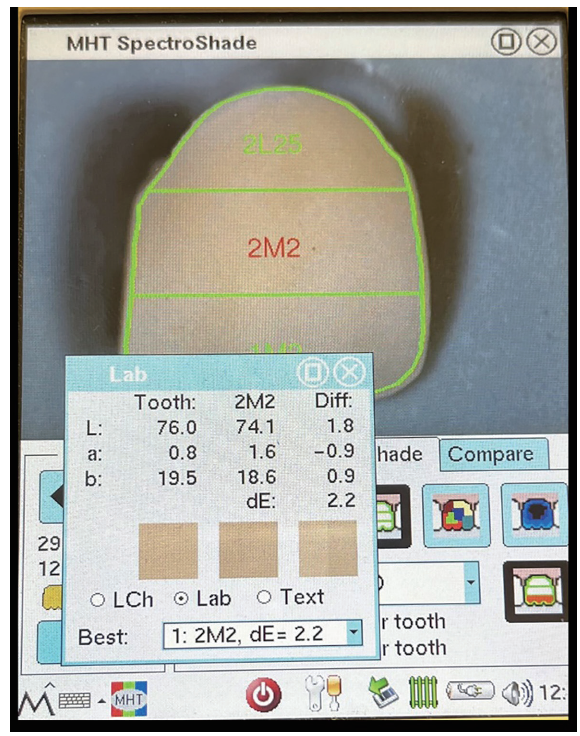

Fig. 4. Shade selection with the spectrophotometer.

an intraoral scanner. A new patient record has been created for the screening process. Then, full arch scanning of the maxilla was completed by the same clinician in accordance with the scanning instructions of the manufacturer. Three different regions (incisal, middle, cervical) were selected for shade selection on the system. Color data were determined according to the Vita 3D Master and Vita Classical color scale. Care was taken to ensure that the shade selection was on the midline of the tooth and the tooth area was divided into three equal parts gingivo-incisally (Fig. 5). The scanning process was repeated in the same way

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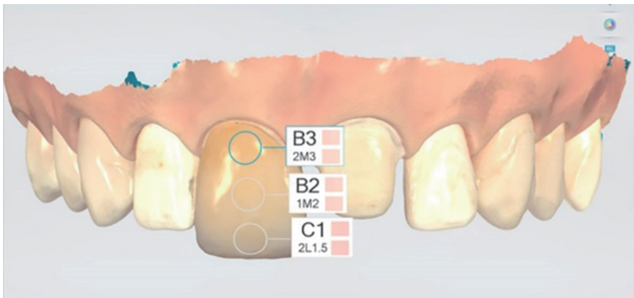

Fig. 5. Shade selection with the intraoral scanner.

for each sample. Digital color measurement data obtained with the help of software (Software 1.18.2.6, Trios 3, 3-Shape, Copenhagen, Denmark) were transferred to the dental prosthesis technician. The restorations fabricated using this shade selection technique served as a test group (Group I).

24 cut-back crown restorations for tooth #21 were produced from the same zirconium-oxide block (Upcera, Shenzhen Upcera Innovatuve Materials CO., Shenzhen, China) using the grinding method in a milling unit. In line with the data obtained for each patient scenario, the conventional layering technique was using nano fluorapatite glass-ceramic (IPS e.max Ceram, Ivoclar Vivadent, Schaan, Liechtenstein) by the same dental prosthesis technician. After layering processes, staining techniques and glazing were performed according to the target crown data, and 24 full crowns were obtained according to previously obtained colors.

Measurements were made using a spectrophotometer (SpectroShade Micro™) device from the middle region of each target crown and test specimens. L, a*, and b* values were recorded.

ΔL, ΔC, ΔH values were calculated according to the CIEDE2000 (2:1:1) formula, assuming the L, a*, and b* values of the target crowns as L^1, a^1, and b^1 and those of the test samples as L^2, a^2, and b^2. kL, kC and kH parameters were accepted as 2, 1, 1, respectively.

$$\Delta E_{00} = \left[\left(\frac{\Delta L'}{K_L S_L}\right)^2 + \left(\frac{\Delta C'}{K_C S_C}\right)^2 + \left(\frac{\Delta H'}{K_H S_H}\right)^2 + R_T\left(\frac{\Delta C'}{K_C S_C}\right)\left(\frac{\Delta H'}{K_H S_H}\right)\right]^{1/2}$$

Obtained data were analyzed with IBM SPSS V23. The test data were evaluated with the Shapiro-Wilk test for conformity to normal distribution. One-way analysis of variance was used to compare ΔE values according to groups. Analysis results were presented as mean ± standard deviation and median (minimum - maximum). Significance level was taken as $P < .05$. The research workflow diagram is shown below (Fig. 6).

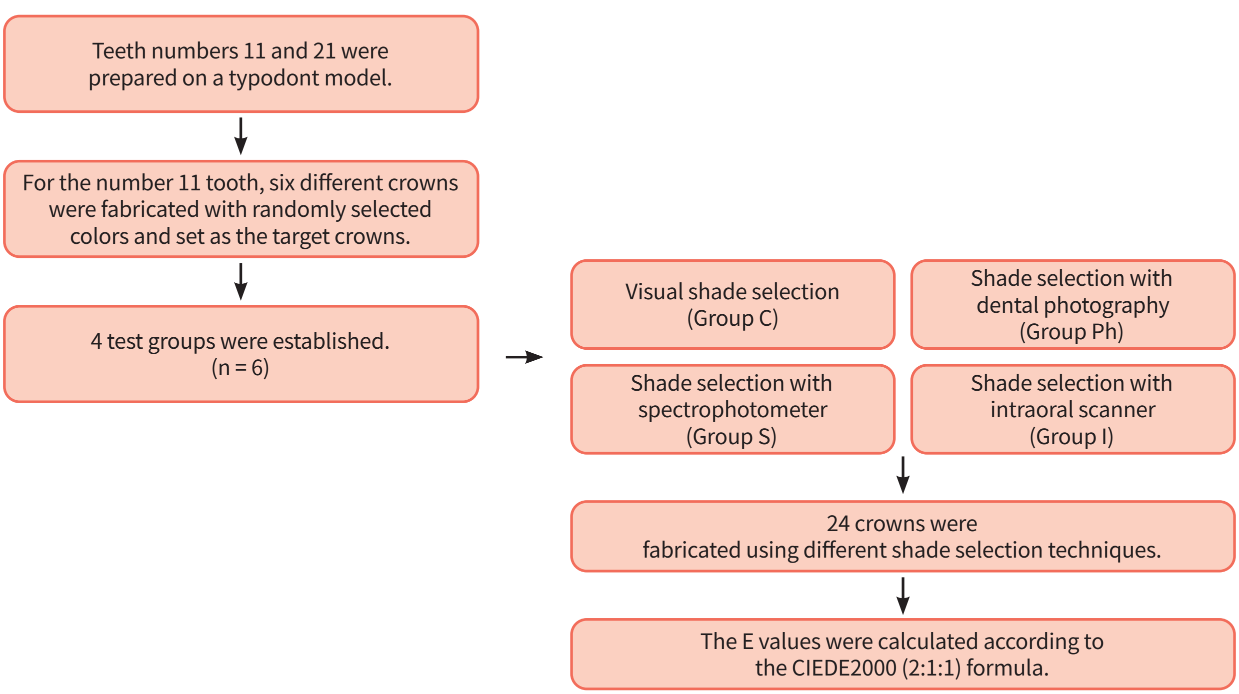

Fig. 6. The research workflow diagram.

RESULTS

The L, a*, and b* values were obtained in the measurements made with the spectrophotometer (SpectroShade Micro™) from the middle ⅓ region of the target crowns.

The color difference between target crowns and test samples was calculated according to the CIEDE 2000 (2:1:1) color difference formula.

In the test groups in which visual, digital camera, spectrophotometer, intraoral scanner shade selection techniques were performed the mean ΔE test values were obtained (2.74 ± 1.53, 3.62 ± 1.01, 2.13 ± 0.45, 3.50 ± 0.64, respectively). Even though the groups showed different test values, there was no significant differences (P = .057). All the mean test values and standard deviations were listed at Table 1.

Among the test groups, the lowest ΔE values were obtained in the Group S while the highest was found in Group Ph. The ΔE values of the crowns fabricated by spectrophotometer and visual shade selection were below the clinically acceptable color difference threshold value (ΔE < 2.7); other techniques showed values above the threshold. There was no significant difference between visual shade selection (2.74 ± 1.53) and digital shade selection techniques (3.08 ± 0.7) (P < .05). Among the digital shade selection techniques compared, no significant difference was found among the digital shade selection techniques.

DISCUSSION

Based on the results detailed above, the null hypothesis that there would be no significant differences between the visual and digital shade selection techniques when determining the color of a full crown restoration for the maxillary incisor region or no significant differences among the different digital color measurement techniques can be accepted.

When the related literature is examined, many prior studies have compared visual shade selection techniques and the devices used to perform shade selection; however, there is no consensus regarding the ideal shade selection technique.[22-24] Although visual shade selection remains the preferred technique in a clinical setting, its outcomes are influenced by environmental factors as well as patient- and clinician-related factors.[25-27] Hence, this *in vitro* study first sought to compare the accuracy of different digital and visual color selection techniques.

Visual shade selection is a subjective process, as its outcomes may differ according to the color perception of the personal and/or environmental conditions. Many studies have examined the factors that affect visual shade selection. For instance, Ivan *et al*. evaluated the relationship between shade selection success and education by comparing the visual color selection of 174 students at the beginning of their course and after they had received training in shade selection.[10] According to their test results, a significant difference could be observed between the different levels of training, prompting the conclusion that color perception can be improved through clinical experience.[25,28] It has been argued that one of the factors affecting shade selection is gender,[29] although some studies have found that gender is not effective in this regard.[10,30] In the present study, to avoid confounding results during the visual color selection, the tests were performed under identical conditions by the same experienced clinician. Mehl *et al*.[31] performed an *in vivo* study to evaluate the success of the visual (dentist and technician) and spectrophotom-

Table 1. Statistical analysis table of the color difference (ΔE) values of shade selection techniques

Test Groups	Color Difference (ΔE) Mean	Color Difference (ΔE) Std. Deviation	F	P
Group C	2.74[a]	± 1.53	F = 2.952	.057
Group Ph	3.62[a]	± 1.01		
Group S	2.13[a]	± 0.45		
Group I	3.50[a]	± 0.64		

No significant differences were found between groups with same letter (P > .05).

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eter (EasyShade [ES], EasyShade Advance, SpectroShade [SS Micro], and intraoral scanner [T-3S]) shade selection techniques. While no significant difference was found among the techniques, the SS Micro device provided the most consistent and reproducible results. In other studies comparing the visual and digital shade selection techniques, visual shade selection was found to be less successful than digital shade selection.[32,33]

Digital shade selection can be performed using various devices and software, including spectrophotometers, colorimeters, and IOS software. In recent years, digital images have also been used to convey accurate and objective color information to dental technicians. These digital images can be used with different shade guides, allowing the technician to observe the color grading on the natural tooth. Another technique involves using digital images with special software that can analyze the color and provide relevant mathematical formulas to the technician.

The most preferred digital technique in a modern clinical setting involves using an external shade selection device. In this regard, spectrophotometers are frequently preferred by clinicians. These devices are very practical and light. They illuminate the surface of the teeth with a 6500 K light and measure the amount of light reflected from the surface. The resulting analysis provides a report for use in shade selection. The surface properties and environmental light conditions may be affected by the spectrophotometer. In the *in vivo* study performed by Dozic *et al*., where the success levels of the colorimeter (ShadeEye and Identa-Color II), spectrophotometer (ES), and digital camera (Ikam and ShadeScan) shade selection techniques were compared, the ES device produced the most successful result, whereas the ShadeScan device produced the least successful result. Studies concerning spectrophotometers, both *in vitro* and *in vivo*, recommend the use of digital cameras in relation to *in vitro* studies.[19]

In previously reported results, this *in vitro* study found no significant difference between the control group and the other test groups, although less accurate results were obtained in the IOS test group regarding the test values. The identified differences may be related to technological differences between the spectrophotometer and the IOS. Color selection using an IOS is performed with only image processing methods, and this technique is not very sensitive. Analysis of the light reflected from the surface of the teeth using a spectrophotometer has been reported to be a more sensitive approach.[34,35]

Shade selection with the help of a digital camera and provision of the selected shade information to the dental technician seems to be an effective technique. However, according to the present test results, this technique does not show accurate results when compared with the other test groups. This could be due to the lack of photograph standardization. Moreover, the images obtained from the camera may be perceived differently on different screens. Thus, digital images should be standardized using cross-polarizing filters and image processing software. As a result of these drawbacks, technicians may become confused during staining or cut-back processes. The relatively lower success level of this technique could be related to this factor. In terms of studies comparing digital techniques, Lazar *et al*. compared the Spectroshade (SS) and photography and shade selection (with/without a polarizing filter) techniques. While they did not find a significant difference between the groups that were photographed using a polarizing filter and the SS, they concluded that those groups were still more successful than the other group. However, color differences (ΔE) calculated between the parameters recorded with the dental spectrophotometer and polarized photography were below or at the level of the 50:50% acceptability threshold of 2.7 in 23% of the cases. We think that the reason for this low ratio is due to the ΔE formula used to calculate color difference. In addition, as the brightness value increased in the samples, the success of the photographic shade selection technique decreased,[36] as was also the case in the present study. In another study comparing the same groups, no significant differences were found among the study groups, but when the brightness value was low, the use of a shade selection technique with a photograph taken using a polarizing filter or spectrophotometer was suggested.[37]

The repeatability of the shade selection is also an important factor in a clinic setting. In some situations, as well as during discussions with the patient, the clinician needs a repeatable shade selection technique. Hence, objective and repeatable techniques are advantageous for clinicians. Although this factor is not the core focus of the present study, previous studies reported that instrumental shade selection techniques provide similar and accurate results with regard to repeated shade selection.[38,39]

The CIEDE2000 (ΔE00) and ΔE*ab are formulas used to calculate color differences. However, the ΔE00 formula better reflects the color difference value perceptible to the human eye.[9,40] While the kL, kC, and kH parameters are accepted as 1 in the CIEDE2000 (1:1:1) formula, kL = 2 is assumed as kC = kH = 1 in the CIEDE2000 (2:1:1) formula.[41] The CIEDE2000 (2:1:1) formula provided more precise results than the other color difference formulas in a study from 2020. Regarding this formula, many thresholds can be used. When the prior literature is examined, the acceptable threshold values used in the interpretation of the color difference values include 1.87,[42] 3.7,[43,44] 2,[45] 2.7,[35,46,47] 3.3,[48,49] 5.5,[50] and 6.8.[51,52] In this study, the detectable threshold value was 1.2, while the acceptable threshold value was accepted as 2.7 (ISO/TR 28642).[53] According to these thresholds, the visual selection, dental photography, and IOS techniques provided less accurate results that were below the acceptable threshold value.

It must be acknowledged that this study had a number of limitations. First, *in vitro* conditions cannot accurately reflect *in vivo* conditions. Moreover, in Group Ph, photo standardization, a cross-polarizing filter, and related software were not used. Further studies are planned to evaluate the accuracy of different shade selection techniques involving new technologies, including novel software. Another limitation of this study was that even though the dental technician who fabricated the tested crowns was highly experienced there may be differences between the color data transmitted to the dental technician for different color selection techniques and the test crown color manufactured by the dental technician.

CONCLUSION

With the limitations of this *in vitro* research, following results can be drawn;

Among the digital shade selection techniques, there was no significant difference. However, at IOS and digital photography color selection techniques showed high test values from the acceptable threshold values (< 2.7). The test results obtained from the digital color selection technique with the spectrophotometer were below the acceptable threshold value. Spectrophotometer device can be recommended for routine clinical use due to its easy use and accuracy.

Although the shade selection with digital photography is suitable for communication with dental technician, standardization may be needed; using gray card and cross polarize filter can be recommended. The mean test value obtained from the photography technique showed the highest color difference. Combining visual and instrumental techniques may give more accurate results.

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