Accuracy and Reliability of Smartphone Virtual Shade-Matching Technique: An In Vitro Study

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Purpose: To determine and compare the accuracy and reliability of shade matching using the conventional and smartphone virtual methods. Materials and Methods: A phantom head with both maxillary central incisors removed was set up. A central incisor of various standard shades was inserted into the phantom head. Five undergraduate and five postgraduate students were asked to select the closest shade to match the central incisor using the Vita Classic shade guide. The procedure was then repeated using images taken by a smartphone. Each technique was repeated three times. Differences in accuracy of shade matching between the two techniques for every shade tab and between undergraduate and postgraduate dental students were compared using chi-square statistical analysis. The \( P \) value was set at .001. Differences in intra-rater and inter-rater reliability between the two techniques and among the three sessions were compared using paired \( t \) test and analysis of variance (ANOVA), respectively, with a \( P \) value of .05. The reliability of both techniques was further measured using Cohen kappa statistical test. Results: The smartphone virtual shade-matching technique showed significantly higher accuracy in shade matching with most of the tested shade tabs than the conventional method (\( P < .001 \)), irrespective of observers’ clinical experience. Higher repeatability was found in the virtual technique than the conventional technique, with higher intra-rater and inter-rater reliability observed. Conclusion: Smartphone virtual shade matching showed better accuracy and reliability than the conventional method and could be used as an alternative shade-matching method. Int J Prosthodont 2022 February 22. doi: 10.11607/ijp.7830. Online ahead of print.

Tooth shade matching plays an important role in esthetic dentistry. However, the ability to reproduce the color of a natural tooth on a prosthesis can be challenging, as the natural tooth itself varies greatly in color and surface characteristics. Different color perceptions between clinicians and technicians often lead to a color mismatch in the process of prosthesis fabrication. Hence, a good shade-matching technique is crucial for achieving esthetically pleasing dental prostheses.

At present, conventional visual shade matching remains the standard method for selecting the appropriate color of composite or ceramic for a restoration or prosthesis. However, previous studies have reported that shade-matching outcomes with the conventional technique are inaccurate, unreliable, and affected by various factors,
such as lighting condition, operator experience, and optical properties of the material examined.\(^5\)

In contrast to the conventional shade-matching technique, tooth color could be more objectively measured using spectrophotometers or colorimeters.\(^6\) These devices quantify tooth color by measuring and comparing the spectral data of test samples to the data in a stored database of a dental shade guide. Hence, their reliability is better than the highly subjective visual shade selection method.\(^7\) However, several inherent shortcomings of using these devices have been documented, including a small measuring window, edge-loss effect, the shade measurement being limited to a flat surface, and incomplete recording of color distribution over the whole tooth surface.\(^8\)

With advancements in photography, the use of digital imaging could be an alternative shade-matching approach in dentistry.\(^9\) Digital photographs with high image resolution help to replicate tooth color by recording the full spectrum of tooth color together with special tooth characteristics. This provides better and more effective shade information—sharing between clinicians and dental technicians.\(^10\) Furthermore, the images obtained can be further analyzed using appropriate imaging software to produce tooth color values for shade analysis. Digital Single Lens Reflex (DSLR) cameras have been commonly used in dentistry due to their high-quality images. However, developments in technology have made the smartphone camera a possible useful alternative for producing equally satisfactory images with minimal training. Smartphone cameras have also been increasingly popular in the field of mobile tele-dentistry because of their easy availability and affordability.\(^11\) The built-in flash located close to the lens enables adequate illumination for optimal image documentation.\(^12\) Besides, the intrinsic properties of smartphones would simplify image processing, storage, and transmission.

Previous studies have widely compared shade-matching using different methods.\(^13\) However, data on the applicability of virtual shade matching using images obtained from a smartphone camera are still lacking. Therefore, this in vitro study aimed to assess and compare the accuracy and reliability of using observers’ visual perceptions to match two identical shade tabs using the conventional visual shade-matching technique (CVMT) and the smartphone virtual shade-matching technique (SVMT). The hypothesis was that no significant difference would be found in shade-matching accuracy or reliability between the CVMT and SVMT.

**MATERIALS AND METHODS**

Ten participants (5 preclinical year undergraduate students and 5 postgraduate students) were recruited from The Faculty of Dentistry, The National University of Malaysia, in this study. All participants were screened for color blindness. Informed consent was obtained from all participants after the study approval by the university’s Research Ethics Committee (JEP-2019-639). Full instructions on the shade-matching techniques were given to all participants.

Each participant was required to match 9 (A2, A3, A3.5, B2, B3, B4, C1, C2, and C3) of 16 selected shade tabs using the Vita Classical shade guides (Vita Zahnfabrik) in the CVMT\(^14\) and using digital images of the Vita Classical shade guides in the SVMT. Shade matching of each selected shade tab was repeated 3 times for both techniques. To avoid selection bias, the 9 selected shade tabs were randomly arranged in a different order each time when the participants repeated the shade-matching exercises. A 10-minute break was given between each exercise.

**Preparation of CVMT**

A complete set of typodont teeth (Frasaco) without the two maxillary central incisors was fixed on a phantom head. The shade tab to be tested was placed in the maxillary right central incisor position. During each exercise, an individual participant was given a complete set of Vita Classical shade guides (Vita Zahnfabrik) and asked to choose a shade tab to match the test tab, which had been fixed on the phantom head (Fig 1). All participants were instructed to perform shade matching at eye level. All of the shade-matching exercises were carried out in a single dental simulation clinic with walls of neutral color and four clear, noncolored window panes (268 cm x 248 cm) without curtains during daytime (from 12 pm to 1 pm) under a ceiling daylight fluorescent tube lamp (Phillips, 36 W, 4,000 K).

**Preparation of SVMT**

Digital images of each test tab placed on a phantom head were taken by a single operator using a smartphone (iPhone X, Apple) camera utilizing the automatic capture mode. The smartphone was attached to a tripod and positioned 20 cm from the shade tab.\(^15\) An image of each of the 9 tested shade tabs was captured 3 times—each shade tab was removed from the phantom head and refixed, and then the image was captured again, resulting in 3 identical sets of the 9 test shade tab images. A single digital shade guide was prepared by capturing the images of 16 shade tabs from the Vita Classical shade guides.

All of the digital pictures were then exported to Microsoft PowerPoint for preparation of the virtual shade-matching slides. Three sets of slides for each of the nine test shade tabs were prepared. Each participant was required to move the digital shade tab and match the nine test shade tabs on the computer (Macbook Pro...
Statistical Analysis
The collected data were analyzed using SPSS version 22 (IBM). Chi-square statistical analysis was used to compare the accuracy of shade matching between undergraduate and postgraduate dental students’ performances, as well as for each of the nine selected shade tabs using both methods. The $P$ value was set at .001.

Intra-rater reliability was assessed in each of the three sessions, as well as overall for each method. The most frequently chosen shade tab by each of the 10 observers over three sessions of exercises was used as the reference/denominator for the calculation of intrarater reliability percentage. The mean percentage of agreement...
of all 10 observers was then calculated for each of the three sessions, from which the overall mean was derived. Inter-rater reliability was similarly assessed in each of the three sessions and overall for each method. The most frequently chosen shade tab by all 10 observers over the three sessions of exercises was used as the reference/denominator for calculation of the inter-rater reliability percentage. The mean of agreement percentages of the observers was then calculated for each of the three sessions, from which the overall mean was derived.

Differences in the mean percentage of agreement between each technique and among sessions for intra-rater and inter-rater reliability were compared using paired t test and analysis of variance (ANOVA), respectively, with the P value set at .05. The reliability of CVMT and SVMT was further measured using Cohen kappa statistical test. The correspondence between both kappa values and the strength of agreement were then assessed as poor (≤20%), fair (21%–40%), moderate (41%–60%), good (61%–80%), or very good (81%–100%).

RESULTS

Five undergraduate and five postgraduate dental students who volunteered to participate in this study were enrolled. A total of 540 shade-matching measurements, with 270 measurements for CVMT and SVMT each (3 measurements per each of the 9 shades for each dental student), were recorded in this study.

The percentages of correct shade matching for undergraduate and postgraduate students using CVMT and SVMT are presented in Fig 3. The accuracy of shade matching with both techniques among undergraduate students was comparable to that of postgraduate students. Both groups of students performed significantly better with the SVMT than the CVMT (P < .001). The results of the 9 tested shade tabs using CVMT and SVMT are illustrated in Fig 4. SVMT exhibited superior shade-matching accuracy for 7 out of 9 shade tabs, with significant results shown in the Hue A group (A2, A3.5), the Hue B group (B2, B3) and the Hue C group (C2; P < .001).

Regarding reproducibility, the results of intra-rater reliability and inter-rater reliability for CVMT and SVMT are presented in Tables 1 and 2. SVMT exhibited significantly higher intra-rater and inter-rater reliability than CVMT (P < .05). Cohen kappa scores of both CVMT and SVMT were assessed. SVMT showed a better score with good agreement (0.757), while CVMT exhibited moderate agreement (0.554).

DISCUSSION

This study compared the accuracy and reliability of shade matching using CVMT and SVMT. These results showed that SVMT is significantly more accurate and reliable than CVMT. Hence, the hypothesis of this study was rejected. Although there are various shade guides available on the market, the Vita Classical shade guide was used in the present study because it is not only the most popular one in practice, but also because the shade selection process is simple and its accuracy is shown to be comparable to other shade guides.

Although CVMT is the most common modality used in shade matching, its accuracy is affected by variations in environmental and observer factors. The impact of different light sources with various correlated color temperature...
(CCTs) and color rendering index (CRI) conditions on the shade-matching outcome has been reported in previous studies.\textsuperscript{20,21} The present study closely simulated a clinical setting using fluorescent and natural lighting and demonstrated that the shade tabs were poorly matched using the CVMT. This is in line with another published study with an identical study setting\textsuperscript{22} and supports previous research that ambient lighting in most of the clinical environment is less ideal for shade matching.\textsuperscript{23} The ceiling fluorescent lights used in the present study provided comfortable illumination for the observers\textsuperscript{24}; however, their CCT and CRI of 4,000 K and 85, respectively, might be suboptimal for shade matching. This issue was compounded by the inconsistent external illumination of natural daylight from the windows, which was inadequate to provide an ideal CRI of > 90 for shade-matching purposes, as the CCT of daylight can vary up to 200% due to cloud and weather conditions at any given time.\textsuperscript{23}

On the other hand, in comparison to other studies with shade-matching exercises performed in a viewing box under a color-corrected light source (D65) representing natural daylight with a light temperature of 6,500 K,\textsuperscript{25} favorable results have been demonstrated. This is due to the elimination of an inconsistent natural environment and room lighting sources as confounding factors, which potentially affected the results. Nevertheless, this method is not practical for adoption in daily clinical practice. Although intraoral matching devices offer a better quantitative shade measurement to overcome the subjectivity of CVMT,\textsuperscript{26,27} they are not readily easily accessible due to their high cost.

SVMT is comparable to CVMT in terms of ease of use and cost. In the present study, color determination accuracy was significantly better when the observers matched the corresponding shade tabs using SVMT compared to CVMT. This finding is also consistent with a similar study using images captured by a DSLR camera, which demonstrated that shade-matching assisted by digital photography outperformed CVMT.\textsuperscript{28} A good image is essential for replicating the color of a tooth as closely as possible, and this may be achieved with optimal ISO selection, which was achieved in the present study by using the auto-mode setting of the selected smartphone camera.\textsuperscript{29} In addition, to further enhance the quality of captured images in this study, the smartphone was mounted on a tripod to reduce the risk of suboptimal images due to involuntary fine hand movement.\textsuperscript{30} The photographed images were exported and displayed on a computer screen with optimal resolution (2,560 x 1,600) for the shade-matching procedure. To optimize the shade-matching outcome, all of the observers were allowed to adjust the brightness of the monitor to suit their eye’s comfort level to avoid stressing their eyes throughout the shade-matching procedure.

All SVMT image samples in the present study were captured using the auto-mode setting under similar ambient lighting as for CVMT. To minimize the variations in illumination, all of the tested shade tabs were fixed in the same position on the phantom head during photography, and the shooting distance was fixed at 20 cm. This protocol is in agreement with a study by Tam and Lee, which reported a superior shade categorization

<table>
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<th>Table 1</th>
<th>Intrarater Reliability for the Mean (SD) Percentages of Agreement Over Three Sessions and Between CVMT and SVMT</th>
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<tbody>
<tr>
<td>Methods</td>
<td>Session 1</td>
</tr>
<tr>
<td>CVMT</td>
<td>44 (24)</td>
</tr>
<tr>
<td>SVMT</td>
<td>66 (19)</td>
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</tbody>
</table>

$^a$ANOVA. $^b$Paired t test.
$P < .05$ was considered significant.

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<tr>
<th>Table 2</th>
<th>Interrater Reliability for the Mean (SD) Percentages of Agreement Over Three Sessions and Between CVMT and SVMT</th>
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<tbody>
<tr>
<td>Methods</td>
<td>Session 1</td>
</tr>
<tr>
<td>CVMT</td>
<td>38 (11)</td>
</tr>
<tr>
<td>SVMT</td>
<td>70 (23)</td>
</tr>
</tbody>
</table>

$^a$ANOVA. $^b$Paired t test.
$P < .05$ was considered significant.
when tested images were captured using a smartphone in the same position.\textsuperscript{15} It is of interest to note that the lighter shade tabs (A2, B2, and C2) have been found to be particularly well-matched (> 80%) using SVMT in this study. This might be partly due to the elimination of environmental illumination factors, including background interferences from oral cavities, which have been reported to affect lighter shades more than darker ones.\textsuperscript{31,32}

The importance of clinical experience and knowledge of color science on better shade-matching has been emphasized in some studies,\textsuperscript{21,33} but it is inconclusive.\textsuperscript{34} Hence, the present study was conducted to assess the impact of these factors on the outcomes of tooth shade matching by selecting preclinical undergraduate students with neither formal clinical nor lecture training with shade matching. The present study findings showed that the shade-matching performance of undergraduate students using both techniques is comparable to that of postgraduate students who have a minimum of 7 years of clinical experience in shade matching. Categorical sensitivity to color differences is a complex process; an individual who has better innate color discrimination would have better shade match accuracy,\textsuperscript{35} and this is hardly enhanced through clinical teaching and training.

Overall, less than 60% of the shade tabs in both CVMT and SVMT were accurately matched by the observers. Although the observers’ color discrimination ability was not tested in this study, these results are not surprising, as the normal population was shown to have poor to average color discrimination ability\textsuperscript{26,37} compared to the minority of individuals with superior color discrimination ability who could correctly match more than 85% of shade tabs.\textsuperscript{38} The acceptable threshold of tolerance for shade mismatch\textsuperscript{39} among observers in a real-life clinical scenario is yet to be verified in future studies.

The reliability of different shade-matching techniques evaluated in past studies showed that conventional visual shade matching, independent of the type of shade guide used, was the least reliable technique.\textsuperscript{26,40} Özat et al also carried out a study to investigate the reliability of visual shade selection using the conventional method and concluded that the outcome was suboptimal.\textsuperscript{41} In contrast, a higher shade-matching reliability was reported when using digital photography over the conventional technique.\textsuperscript{13} These results are closely matched with those of the present study. Apart from improved shade-matching accuracy and reliability, SVMT could provide dental technicians with finer tooth details, including shade distribution and surface texture, as compared to the conventional method, which entails additional written prescription and sketching.\textsuperscript{42} Communication between the dentist and dental technician can also be enhanced using pictorial images as per SVMT.\textsuperscript{43} Therefore, the virtual shade-matching technique could potentially be used as an alternative tool in clinical practice.

There are a few other limitations of this study. The tested and reference sets of shade tabs were not measured by a spectrophotometer to ensure shade concordance. In future studies, spectrophotometric color measurement is suggested to be used as objective data to verify the color values (CIELab) of shade tabs obtained from digital images.\textsuperscript{44} A color correction device was not used to ameliorate the effect of inconsistent lighting conditions. Smartphone and computer monitor screens have different color spaces,\textsuperscript{45} which might influence the effective shade communication between clinicians and dental technicians. To address this inherent issue, color calibrations of digital devices would be ideal to optimize visual integration for better shade reproduction in definitive restorations/prostheses.\textsuperscript{46}

**CONCLUSIONS**

Within the limitations of this study, these results have demonstrated higher reliability and accuracy of shade matching of the virtual shade technique using the iPhone X camera compared to the conventional technique. Clinical experience and shade-matching training do not seem to affect the shade-matching outcome, including that of the virtual technique. SVMT has a good potential to be an alternative to CVMT, but more controlled clinical studies are needed.

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**REFERENCES**


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