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# Performance assessment of dental shade guides

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ABSTRACT

*Objectives:* The goal of this study was to evaluate influence of different shade guides and respective shade matching methods on shade matching results and to analyze user satisfaction with these products and methods.

*Methods:* Eighty-eight pre-doctoral dental students completed the study. The color of four target shade tabs was matched using Toothguide 3D-Master (TG), Vitapan Classical (VC), and the prototype of Linearguide 3D-Master (LG). Shade matching was performed using color-corrected light source and 0/45° optical geometry. An intra-oral spectrophotometer was used for color measurements of target tabs and shade guide tabs. Results for the first 10 best matching shade guide tabs were expressed as ranks (best match – 10 points to 10th match – 1 point). Participants also performed subjective evaluation of three shade guides/tab arrangements. Descriptive statistics were calculated. *T*-test and Wilcoxon signed rank test were used for statistical analysis of the data ($\alpha = 0.05$).

*Results:* The best shade matching results were achieved using LG, followed by VC and TG, and the ranks were $9.1 \pm 1.2$, $8.8 \pm 1.9$ and $8.4 \pm 2.8$. Differences in $\Delta E^*$ values for the first 10 matches between TG/LG ($4.5 \pm 1.8$) and VC ($6.2 \pm 2.2$) were found to be statistically significant ($p < 0.001$). Subjective evaluation revealed significant advantage of LG compared to TG and VC.

*Conclusions:* Linearguide 3D-Master enabled better shade matching results compared to Toothguide 3D-Master ($p < 0.05$). Both 3D-Master shade guides exhibited significantly smaller $\Delta E^*$ values for the first 10 matches compared to Vitapan Classical ($p < 0.001$). Linearguide 3D-Master was superior in a subjective evaluation compared to Toothguide 3D-Master and Vitapan Classical ($p < 0.001$).

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## 1. Introduction

Tooth shade matching is most frequently performed visually using dental shade guides; different intra- or extra-oral color measuring devices are used to much less extent.[1] Shade matching is a comparison between the sample (tooth) and multiple standards (shade guide tabs). As an exact match is rarely found, the magnitude and direction of the difference (departure from color equality) between tooth and shade tab should be described.[2]

The first systematic shade guide, Tooth Color Indicator, was created by Clark, and it consisted of 60 ceramic tabs.[3] Although numerous products appeared on the market since then, the breakthrough occurred in mid-1950s, when the Vitapan Classical (VC, Vita Zahnfabrik, Bad Säckingen, Germany) was introduced. VC, with 16 tabs originally arranged

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into four groups based on hue and within the groups according to increasing chroma (also known as A-to-D arrangement), was a gold standard in dentistry for decades and to a large extent it still is, but a history of complaints, primarily related to color range, distribution and user-friendliness, is almost equally long. The most important issues are related to the need for – and lack of – logical and adequate distribution in part of color space encompassed by human teeth.[4,5] In a 1985 survey, the majority of faculty involved in undergraduate and graduate programs concerning the teaching of color science indicated a need for the development of a new and systematic shade guide.[6]

The next step in evolution of dental shade guides occurred in late 1990s, when the Toothguide 3D-Master (TG, Vita Zahnfabrik, Bad Säckingen, Germany) was introduced. As opposed to VC that was designed empirically, the TG more closely utilizes the accepted color perception concepts of hue, lightness and chroma and number (lightness) – letter (hue) – number (chroma) markings. Six different levels of lightness were used to create six groups of tabs, from 0 (the lightest) to 5 (the darkest). There are 3 chroma levels, from 1 (the least chromatic) to 3 (the most chromatic) in each group (except in group 1 that has two chroma levels). Intermediate chroma levels (1.5 and 2.5) in groups 2, 3 and 4 are associated with hue variations—L (less red) and R (more red).

As compared to VC, it was found that TG matches natural teeth better, encompasses wider color range and has more uniform color distribution.[7–14] Despite these advantages, some less experienced dental professionals and those with limited knowledge of color, have difficulty in understanding the shade matching method and implementation of the lightness-chroma-hue concept. In addition, some users find a shade guide with 29 tabs on the same holder somewhat ''busy'' and confusing. New version of TG, Linearguide 3D Master (LG) is a modification of TG. LG contains exactly the same tabs, but with the simplified presentation and a two-step shade matching procedure: TG holders contain only 6 (step 1) and up to 7 (step 2) linearly arranged tabs instead of 29 three-dimensionally arranged tabs presented at the beginning of a three-step procedure with TG. The goal of this study was to evaluate the efficacy of the new simplified guide versus VC and TG shade guides for shade matching and to analyze user satisfaction with these guides. Null hypotheses were that shade matching results and user satisfaction were not influenced by the type of shade guide and shade matching method.

## 2. Materials and methods

Upon obtaining the exempt status from the Committee for Protection of Human Subjects, 100 predoctoral dental students (participants) were recruited for the study. After brief instructions that encompassed the information on the used shade guides and shade matching techniques, groups consisting of 16 participants, allocated in four sub-groups of four completely independent participants, worked simultaneously in 45-min sessions.

Shade matching was performed using table lamps (overhead lights were turned off) with color-corrected light source (BlueMax, Full Spectrum Solutions, Jackson, MI) with correlated color temperature of 5900 K and color rendering index of 96 against neutral-gray background. Optical geometry (illuminant/viewing geometry) was 0/45°.

The color of four target shade tabs (Fig. 1), supplied by manufacturer, was matched using the following shade guides: TG (Fig. 2), value scale of VC (light-to-dark tab arrangement suggested by the manufacturer in VC instruction sheet, Fig. 3), and the prototype of LG (Fig. 4). The final version of LG is shown in Fig. 5. Since TG and LG contained exactly the same 29 tabs, when applicable/related to both shade guides, the abbreviation 3D was used. For TG, the participants were instructed to

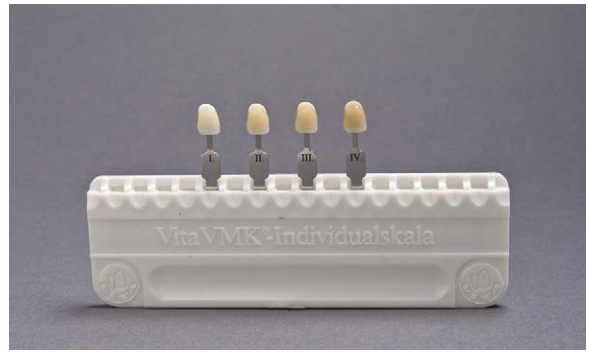


**Fig. 1 – Target shade tabs: target tab I—1M1.5; target tab II—2R2.5; target tab III—A3; and target tab IV—4.5M2.**

**Fig. 2 – Toothguide 3D-Master.**

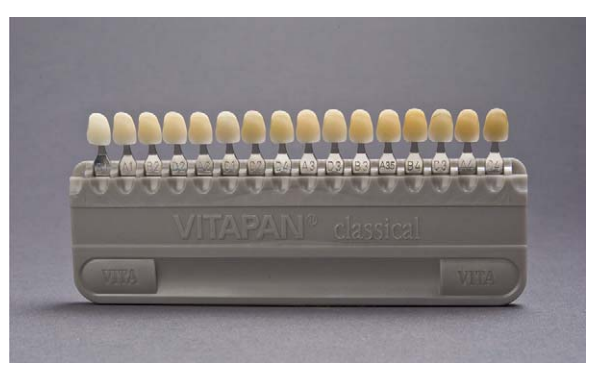


**Fig. 3 – Vitapan Classical, value scale (alternative, light-to-dark tab arrangement, provided by manufacturer).**

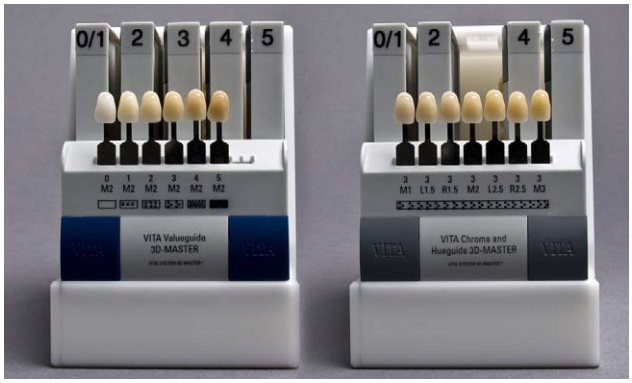


**Fig. 4 – Prototype of Linearguide 3D-Master used in this study. Blue-gray holder contains 6 group representatives (0M2–5M2), whereas gray holder containes all tabs from respective groups (0/1, 2, 3, 4, and 5).**

**Fig. 5 – Final verision of Linearguide 3D-Master.**

first select the group (lightness—achromatic, black to white coordinate), and then to subsequently select chroma (pale to strong) and hue (color name) within the chosen group (if groups 2, 3, and 4 were selected; there were no hue variations in groups 0, 1, and 5). The instructions for the value scale of the VC were to simply select the best match. Instructions for LG were to first select the group (lightness) using the dark-gray holder with 6 group representatives (0M2–5M2). The second step was to select the best match using the light-gray holder with corresponding group number, where less and more chromatic tabs were to the left and right from the group representative (duplicates of corresponding M2 tabs from the dark-gray holder), respectively.

The resulting answer sheets that contained a brief explanation of the study and tasks that should be fulfilled, record on selected shades, and a survey were processed. Due to incomplete or wrongly placed answers, there were a total of 88 valid answer sheets.

A contact-type intra-oral spectrophotometer (Vita Easyshade, Vita Zahnfabrik, Bad Säckingen, Germany) with a spectral range 400–700 nm and a resolution of 25 nm, was used for color measurements of target tabs and shade guide tabs. A custom positioning mold was made provide accurate repositioning and measurement on the middle third of labial tab surface. Light-cured flowable resin was used to attach a clear acrylic cylinder (5 mm in diameter and 5 mm high) to the area to be measured. Clear silicone registration material (ClearBite, Discus Dental, Culver City, CA) was injected around the cylinder and over and around the labial surface of the tab. Upon setting, the mold with a tunnel for placement of the spectrophotometer probe was separated from the cylinder and tab.

CIE[1] $L^*a^*b^*$ color coordinates were recorded from the touchscreen display. Color differences, $\Delta E^*$, were calculated using the following equation[2]:

$$\Delta E^* = [(\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2]^{1/2}, \quad (1)$$

where $\Delta L^*$, $\Delta a^*$ and $\Delta b^*$ denote differences in lightness, green-red coordinate and blue-yellow coordinate, respectively.

Coverage error ($\Delta E_{COV}$) of was calculated as the mean of the best matches of one shade guide to another (3D to VC and vice versa), as follows[15]:

$$\Delta E_{COV} = \frac{\Sigma \Delta E_{MIN}}{n} \quad (2)$$

where the mean color difference of all individual best matches and a number of best matches were denoted as $\Sigma \Delta E_{MIN}$ and $n$, respectively.

Results for the first 10 best matching shade guide tabs were expressed as ranks. Selection of shade guide tab with numerically the smallest color difference ($\Delta E^*$) compared to target shade tab corresponded to 10 points. The second smallest color difference corresponded to 9 points, and so on, up to the 10th match that corresponded to 1 point. The 11th match and subsequent matches corresponded to 0.

Shade matching error was calculated as the number of shade guide tabs between the best matching tab and the selected one when the shade guide tabs were ordered according to increasing color difference (best match to the 10th match) compared to the target tab. For example, the selection of the third best matching tab corresponded to a shade matching error of 2 (10 points minus 8 points).

Participants additionally performed subjective evaluation of three shade guides/tab arrangements. Grades 1, 2, 3, 4, or 5 corresponded to strongly disagree, disagree, not certain, agree, and strongly agree, respectively.

Descriptive statistics were calculated. Differences in $\Delta E^*$ values for the first 10 matches between 3D and VC were compared using paired $t$-test. Differences in shade matching results between shade guides/methods were evaluated using unpaired $t$-test, whereas subjective evaluations were analyzed using Wilcoxon signed rank test (SPSS, Chicago, IL), all at the 0.05 level of significance.

## 3. Results

The 10 closest shades from 3D and VC to each of four target tabs and corresponding ranks are listed in Table 1. Mean color differences between each of the first 10 matches from 3D and

[1] Commission Internationale de L'Eclairage, International Commission on Illumination.

**Table 1 – Ten best matches (ranks and corresponding tabs) from 3D-Master (3D) and Vitapan Classical (VC) compared to each of four target shade tabs (the best match = 10 points, to the tenth match = 1 point).**

| Ranks (points) | Target tab I 1M1 | | Target tab II 2R2.5 | | Target tab III A3 | | Target tab IV 4.5M2 | |
|---|---|---|---|---|---|---|---|---|
| | 3D | VC | 3D | VC | 3D | VC | 3D | VC |
| 10 | 2M1 | A1 | 2R2.5 | A2 | 3M2 | A3 | 4M2 | A4 |
| 9 | 1M1 | B2 | 2M2 | B2 | 3L1.5 | C2 | 5M2 | C4 |
| 8 | 2R1.5 | B1 | 2L1.5 | A3 | 3R1.5 | D4 | 4R2.5 | A3.5 |
| 7 | 1M2 | A2 | 2L2.5 | C2 | 2R2.5 | B3 | 4L2.5 | C3 |
| 6 | 2L1.5 | C1 | 3M2 | B3 | 4L1.5 | A3.5 | 4L1.5 | B4 |
| 5 | 0M3 | D2 | 3R1.5 | D4 | 3R2.5 | B4 | 4R1.5 | D4 |
| 4 | 2M2 | A3 | 2R1.5 | A1 | 4R1.5 | A2 | 5M1 | B3 |
| 3 | 0M2 | C2 | 3L1.5 | C1 | 2L2.5 | C3 | 4M3 | C2 |
| 2 | 2R2.5 | D3 | 2M3 | A3.5 | 4M2 | D3 | 3R2.5 | A3 |
| 1 | 3M1 | D4 | 2M1 | B4 | 2M2 | B2 | 4M1 | D3 |

VC shade guides, and all four target tabs, are presented in Fig. 6. Mean differences in $\Delta E^*$ values for the first 10 matches between 3D ($4.5 \pm 1.8$) and VC ($6.2 \pm 2.2$) were found to statistically significant ($p < 0.001$), with 95%CI $-2.0$ and $-1.4$, respectively.

The best shade matching results were achieved using LG, followed by VC and TG, and the respective ranks (sd) were $9.1 \pm 1.2$, $8.8 \pm 1.9$ and $8.4 \pm 2.8$. Based on the results of unpaired *t*-test (Table 2), the LG enabled significantly better shade matching than TG ($p < 0.05$).

Shade matching error for LG and VC was $1.0 \pm 1.2$ and $1.2 \pm 1.6$ tabs, respectively. This means that the second best matching tab has been selected in average. Corresponding value for TG was $1.6 \pm 2.8$ tabs, which means that there were almost two better matches compared to selected tab.

VC coverage errors to 3D were: $\Delta E^* = 3.5 \pm 2.9$ for all tabs and $2.9 \pm 2.1$ without group 0. 3D coverage error to VC was $1.9 \pm 0.9$.

Subjective evaluation of different shade guides and respective shade matching methods and differences between them (Wilcoxon signed rank test) are presented in Table 3.

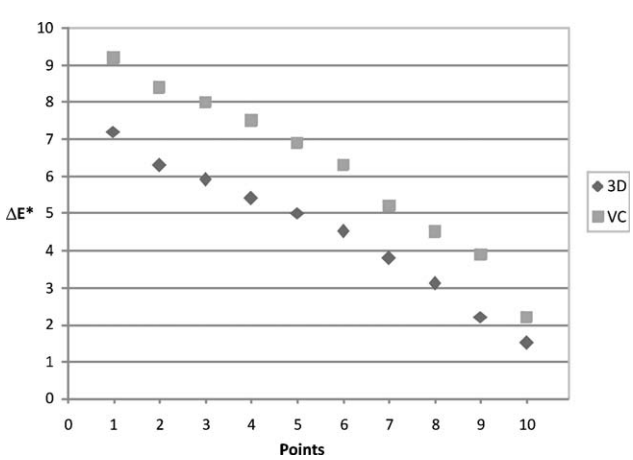


**Fig. 6 – Mean color difference, $\Delta E^*$, between each of the first ten matches (best match = 10; 10th match = 1) from 3D Master (3D) and Vitapan Classical (VC) shade guides, and all four target tabs.**

## 4. Discussion

The results supported the rejection of the null hypothesis for the objective TG–LG comparison (shade matching results), and for subjective comparison (user satisfaction) between all pairs of shade guides.

Quality of dental shade guides is customary assessed through evaluation of coverage error (10–15) and interpreted through perceptibility and acceptability visual judgments.[16–18] Coverage error is an objective and reliable parameter that tells about the mean minimal $\Delta E^*$ value (or corresponding color difference obtained using another color difference formula) between natural teeth and best matching tabs. However, instrumentally determined coverage error is not necessarily the same as visual coverage error,[14] the later one clearly being more clinically relevant. Although this experiment was performed under carefully controlled conditions and using different shade guides/shade matching techniques, none of them enabled selection of the best match. Actually, the second best match was selected with the LG and VC, and the third best match was selected with the TG. This is why it was beneficial to calculate mean $\Delta E^*$ values for the second, third, and subsequent matches. Therefore, instrumental and visual coverage error can be perceived theoretically and practically as the mean of best matches, respectively. A remark that the smallest $\Delta E^*$ is not necessarily visually the best match applies equally to studies on the coverage error and this study, but does not really compromise either of two research methods. The results revealed that the $\Delta E^*$ for the second best match with 3D corresponded to the best match with VC. The $\Delta E^*$ values for the third and fourth best match with 3D were

**Table 2 – Differences in shade matching results for different methods: Toothguide 3D-Master (TG), Vitapan Classical (VD), and Linearguide 3D-Master (LG); unpaired *t*-test.**

| | TG–VC | TG–LG | VC–LG |
|---|---|---|---|
| Mean | −0.5 | −0.7* | −0.2 |
| SE | 0.4 | 0.3 | 0.2 |
| 95%CI | −1.2; 0.3 | −1.3; −0.1 | −0.7; 0.2 |

* $p < 0.05$.

**Table 3 – Subjective evaluation of different shade matching methods: Toothguide 3D-Master (TG), Vitapan Classical (VC), and Linearguide 3D-Master (LG). Differences in subjective evaluation between methods; Wilcoxon signed rank test (standardized scores).**

| Question | TG | VC | LG | TG–VC | TG–LG | VC–LG |
|---|---|---|---|---|---|---|
| The arrangement of shade tabs is logical | 3.3 (1.0) | 3.8 (1.0) | 4.5 (0.6) | −3.3* | −6.4** | −4.3** |
| This color matching method is easy to use | 3.0 (1.2) | 3.9 (1.0) | 4.3 (0.7) | −4.8** | −6.5** | −3.0* |
| I would use this method in my practice | 3.0 (1.1) | 3.7 (1.0) | 4.3 (0.8) | −4.1** | −5.9** | −3.9** |
| I was able to master the task using this method | 3.3 (1.0) | 3.8 (0.9) | 4.3 (0.7) | −3.7** | −5.8** | −3.6** |
| Overall satisfaction with this method | 3.0 (1.1) | 3.6 (1.0) | 4.3 (0.7) | −3.4* | −6.7** | −4.9** |

* $p < 0.01$.
** $p < 0.001$.

smaller than the $\Delta E^*$ for the second match with VC (actual selection), while the 5th, 6th, 7–9th, and 10th 3D match exhibited smaller $\Delta E^*$ than the 3rd, 4th, 5th, and 6th VC match, respectively. This means that chances to select the shade with smaller color difference were much higher with 3D, which is in accordance with findings on coverage errors of these two shade guides.[13,14]

Four sub-groups of four participants were created for each session to enable equal representation of all possible sequences of target tab/method. Each sub-group of four participants had one set of target tabs and all three shade guides that were used interchangeably. Each participant within the one group of 16 and each of four sub-groups had different target tab/method sequence. To give the same chance to each method, only one target tab had the exact match in each 3D (2R 2.5) and VC (A3), while two target tabs with non-conventional shade designations (1M1.5 and 4.5M2) had no exact match in either 3D or VC. The same is true for grading only first 10 matches from each shade guide. This experimental design eliminated the influence of different number of tabs in 3D and VC, falsely high findings originating from the huge number of tabs, impact of severe mismatches on the results, and differences in color ranges between 3D ($24.8 \pm 4.5$) and VC ($15.3 \pm 3.9$).

In the so-called A-to-D arrangement, VC tabs are divided into four groups, with primary group division based on hue. Within the groups, tab arrangement is based on increasing chroma—the more chromatic tabs are marked with higher numbers. The alternative tab arrangement (value scale) does not include group division. As light-to-dark tab arrangement was found to enable better shade matching results than the A-to-D arrangement,[19] value scale was selected to be used for VC in this study.

The TG consists of 29 tabs divided into six groups according to lightness. Within the groups, tabs are arranged according to chroma (vertically) and hue (horizontally). Group 0 has three tabs, group 1 consists of two tabs; groups 2, 3 and 4 have seven tabs each; and the fifth group consists of three tabs. In number-letter-number tab marking, the numbers in front of the letters indicate group number and lightness level (lower number—higher lightness), the letter designates the hue (M—middle, L—less red, and R—redder), while the number after the letter designates chroma level (lower number—lower chroma).

LG shade guide has the same 29 tabs as TG—the difference is in the design and shade matching method. LG has 6 holders. The dark gray holder contains all M2 tabs, while five light gray holders contain all tabs from groups 0 to 1 (merged), 2, 3, 4 and 5. With the TG, both "L" tabs (less and more chromatic than corresponding M2) in groups 2, 3 and 4 are placed to the left of "M" tabs. The same is true for the "R" tabs, placed to the right of "M" tabs. In the LG, both less chromatic tabs (L1.5 and R1.5) are placed to the left, while both more chromatic tabs (L2.5 and R2.5) are placed to the right from the central M2 tab. Shade selection with LG is self-explanatory and simplified. Although the same color principles as in TG were applied, with the LG dental professionals do not necessarily need to know these principles. Initial shade selection with LG is facilitated because: (a) it is fairly easy to perceive large color differences among adjacent M2 tabs; (b) based on both dental practice and physiology of color vision it is easier to work with fewer tabs; and (c) linear tab arrangement is user friendly and dental profession is traditionally familiar with it. The remarks (b) and (c) are applicable to the second and last shade matching step with the LG—a "fine tuning" within the selected group of linearly arranged tabs.

Subjective evaluation is important as it reveals participants' experience with shade guide/shade matching method. Intuitively, dentist and technicians adopt the more appealing methods even if the research results are not so favorable. The best example is more than 50 years of the use of VC worldwide. Fortunately, objective findings for LG supported the subjective perception—both were found to be superior to other evaluated products/methods.

## 5. Conclusions

Within the limitations of this study, the Linearguide 3D-Master enabled significantly better shade matching results than the Toothguide 3D-Master. On average, the second-best match was selected for Linearguide 3D-Master and Vitapan Classical, while the third-best match was selected with Toothguide 3D-Master. Both 3D-Master shade guides exhibited significantly smaller $\Delta E^*$ values for the first 10 matches than the Vitapan Classical. The $\Delta E^*$ value of the second-best match with 3D-Master corresponded to the best match with Vitapan Classical, while the third and fourth match with 3D-Master exhibited smaller $\Delta E^*$ than the second match with Vitapan Classical. Linearguide 3D-Master also was superior to Toothguide 3D-Master and Vitapan Classical in terms of subjective evaluation. These findings support the use of Linearguide 3D-Master in clinical dentistry and dental technology.

## Conflict of interest statement

Linearguide 3D-Master was jointly developed by Dr. Rade D. Paravina and Vita Zahnfabrik. The University of Texas Health Science Center has executed a licensing agreement with VITA Zahnfabrik, dealing with commercialization of VITA Linearguide 3D-Master. Dr. Paravina is a paid consultant for Vita Zahnfabrik.

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