Satisfaction of Dental Students, Faculty, and Patients with Tooth Shade-Matching Using a Spectrophotometer

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Abstract: The aims of this study were to evaluate dental students' clinical shade-matching outcomes (from subjective use of shade guide) with an objective electronic shade-matching tool (spectrophotometer); to assess patients', students', and supervising faculty members' satisfaction with the clinical shade-matching outcomes; and to assess clinicians' support for use of the spectrophotometer to improve esthetic outcomes. A total of 103 volunteer groups, each consisting of patient, dental student, and supervising faculty member at the University of Louisville, were recruited to participate in the study in 2015. Using the spectrophotometer, clinical shade-matching outcome ($\Delta E_{clinical}$) and laboratory shade-matching outcome ($\Delta E_{laboratory}$) were calculated. Two five-point survey items were used to assess the groups' satisfaction with the clinical shade-matching outcome and support for an objective electronic shade-matching tool in the student clinic. The results showed that both $\Delta E_{clinical}$ (6.5±2.4) and $\Delta E_{laboratory}$ (4.3±2.0) were outside the clinical acceptability threshold ΔE values of 2.7, when visual shade-matching method (subjective usage of shade guide) was used to fabricate definitive restorations. Characteristics of the patients, dental students, supervising faculty members, and restorations had minimal to no effect on the $\Delta E_{clinical}$. The patients, dental students, and supervising faculty members generally had positive opinions about the clinical shade-matching outcome, despite the increased $\Delta E_{clinical}$ observed. Overall, clinical shade-matching outcomes in this school need further improvement, but the patients' positive opinions may indicate the need to revisit the acceptability threshold ΔE value of 2.7 in the academic setting.

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The shade guide commonly used to visualize the desired shade of dental restorations and communicate the results to the dental laboratory collects the shade-matching result by visual and subjective means.[1-5] The shade guide is usually designed according to the theory of Munsell's color parameters (hue, value, and chroma), but the use of these parameters varies among commercial systems.[6-8] Shade guides may differ from each other on which of the three parameters should be matched first and in what order.[2,7] Among commercially available products, the Vita 3D and the Vita Classical Shade Guides are most commonly used.[4,9-11]

The subjective nature of the shade guide may allow environmental variants to affect shade-matching outcomes. The shade tabs in the guide appear differently under changing lighting conditions (fluorescent, incandescent, or daylight). Metamerism causes an initially pleasing shade match to look like a mismatch in different lighting.[1] A range of other factors beyond lighting can also affect shade-matching outcomes: for instance, tooth dehydration as result of prolonged procedure[12] and color alternations of shade tabs after chemical disinfection.[13-15] The clinician's age,[16] clinical experience,[17-20] and training[21] have also been found to influence the accuracy of the shade-matching selection. Although color blindness can be a factor, its influence may not be significant.[22] In an academic institution, the presence of a specialist such as a prosthodontist may also alter a patient's opinion about shade-matching.[23] Although there are limitations associated with use of a shade guide, it has been

widely available and accepted by clinicians since the 1950s.[1] The shade guide is also less expensive than other shade-matching tools,[24] and many restorative materials have been developed around it.[1,25] To improve the subjective shade-matching outcomes of the shade guide, researchers recommend using digital photographs to supplement the shade guide-based information, especially for anterior restorations, to provide more detail such as translucence for dental laboratory technicians.[26-28] Objective dental shade-matching instruments such as the colorimeter, spectroradiometer, and spectrophotometer can also produce useful information.[5] Through reflection and absorption of light, the spectrophotometer has been found to outperform other electronic shade-matching instruments and the visual shade-matching method.[21,29-34] Objective dental shade-matching instruments allow for use of an equation established by the International Convention on Illumination as a means to quantify shade-matching communications.[1,5] The equation is shown as $\Delta E^* = \sqrt{(\Delta L^*)^2 + (\Delta a^*)^2 (\Delta b^*)^2}$.[35] ΔE* is the color difference between two objects, ΔL* is the difference in lightness-darkness, Δa* is the difference in green-red coordinate, and Δb* is the difference in blue-yellow coordinate. A recent review article summarized the clinical acceptability threshold, indicating a difference in shade that is clinically acceptable.[35] Although one-third of published studies utilized ΔE* of 3.7 as the acceptability threshold, they all referred to the same source from the late 1980s, before the higher esthetic demands of modern dentistry.[35,36] More recent in vivo studies supported a lowered acceptability threshold at ΔE* of 2.7.[33,37]

Visual shade-match selection with a shade guide is subjective and could be affected by many factors. The aims of this study were to evaluate dental students' clinical shade-matching outcomes (from subjective use of shade guide) with an objective electronic shade-matching tool (spectrophotometer); to assess patients', students', and supervising faculty members' satisfaction with the clinical shade-matching outcomes; and to assess clinicians' support for use of the spectrophotometer to improve esthetic outcomes.

Materials and Methods

Following University of Louisville Institutional Review Board approval (#14.1182), a convenience sample of 103 volunteer groups of patient, dental student, and supervising faculty member were recruited from the University of Louisville School of Dentistry to participate in the study in 2015. We sought to evaluate visual shade-matching performance (VITA classical Shade Guide; VITA North America, Yorba Linda, CA, USA) with an objective electronic shade-matching tool, the spectrophotometer (Easyshade Advance 4.0; VITA North America). The spectrophotometer was used to assess ΔE* in relation to an acceptability threshold (AT) of 2.7.

The volunteer groups received consent forms explaining the benefits, risks, and purpose of the study. Only the patients who fit the following inclusion criteria were recruited. The patient must have received treatment in the form of full coverage, indirect, tooth-colored restorations; have information on the Vita Classic Shade Guide noted in the laboratory authorization form; be able to understand and sign the consent form; and have accepted the functional and esthetic outcomes of the luted restoration with the dental student and supervising faculty member.

Descriptive information such as patients', dental students', and supervising faculty members' gender, specialty, and experience level as well as the restoration location were collected. The laboratory authorization forms were obtained, and the prescription shades (the shade selection the clinician made with the shade guide based on the targeted tooth and communicated to the dental technician for the definitive restoration) were gathered from the laboratory authorizations and noted on the data collection sheet. All the restorations included in this study were fabricated by an outsourced commercial dental laboratory.

Using the spectrophotometer, we recorded the reference shade (the shade of targeted tooth measured by the spectrophotometer, such as adjacent or contralateral tooth, that the clinician intended to match with the shade selection) and the shade of luted definitive restoration (measured by the spectrophotometer intraorally) on the data collection sheet. By using the prescription shade, reference shade, and shade of luted definitive restoration, we calculated two ΔE* values with the spectrophotometer. The first value, $\Delta E_{clinical}$, measured the difference between the reference shade and the shade of luted definitive restoration. The $\Delta E_{clinical}$ represented the clinical objective shade-matching outcome of luted definitive restoration. The second $\Delta E_{laboratory}$ reflected the difference between the prescription shade and the shade of luted definitive restoration. The $\Delta E_{laboratory}$ represented the ability of the dental technician to provide the desired shade for definitive restorations matched to the information on the laboratory authorization.

In addition, we asked the participants to respond to two author-designed, survey questions after completing treatment. The first survey item sought to determine participating patients', dental students', and supervising faculty members' satisfaction with the shade-matching outcome. Response options ranged from 1=extreme dissatisfaction to 5=extreme satisfaction. Patients were given a handheld mirror to view their teeth and luted definitive restoration in the clinic. The second survey item assessed support for an objective electronic shade-matching tool as a way to improve esthetic outcome of the definitive restoration. Response options ranged from 1=strong disagreement to 5=strong agreement. Neither dental students nor supervising faculty members were shown either $\Delta E_{laboratory}$ or $\Delta E_{clinical}$ data points; the surveys were based on their visual assessment only. All surveys were administered verbally and privately. In an effort to reduce potential bias associated with the presence of the interviewer in verbal surveys and to standardize the results, questions were asked in the same order each time the surveys were administered.[38,39]

Descriptive statistics were calculated for characteristics of patients, dental students, supervising faculty members, and restorations. Means and standard deviations were calculated for both $\Delta E_{laboratory}$ and $\Delta E_{clinical}$. The t-test was used to assess whether $\Delta E_{laboratory}$ and $\Delta E_{clinical}$ and were significantly different from the AT value of 2.7, which was defined to determine clinical acceptance.[35] The t-test was also used to assess the difference between $\Delta E_{laboratory}$ and $\Delta E_{clinical}$. The p-values were adjusted for multiple comparisons. Furthermore, means and standard deviations were calculated for $\Delta E_{laboratory}$ and $\Delta E_{clinical}$ by restoration location (anterior vs. posterior). Linear regression model and Tukey pairwise comparison were used to assess the difference between $\Delta E_{laboratory}$ and $\Delta E_{clinical}$ by restoration location.

The survey responses were viewed as a continuous measurement scale, and the Pearson product-moment correlation coefficient was tested to investigate potential relationships between $\Delta E_{clinical}$ and survey responses. The t-test or one-way ANOVA was used to evaluate the effect of characteristics of patients, dental students, supervising faculty members, and the restorations on $\Delta E_{clinical}$. The p-values were adjusted for multiple comparisons. Statistical analysis was performed by a statistician using SAS version 9.4 (SAS Institute, Cary, NC, USA) with statistical significance set at $p<0.05$.

Results

In the 103 patient, dental student, and supervising faculty groups, there were more male patients (56%) than female (44%) (Table 1). Dental students were split nearly identically by gender (47% vs. 53% for males and females, respectively). The dental students were mostly in their fourth year (96%), and the majority did not have previous experience in clinical dentistry (73%). The supervising faculty members were mostly prosthodontists (78%).

Table 1. Characteristics of participating patients, dental students, supervising faculty members, and restorations (N=103)

Characteristic	Number	Percentage
Patients		
Male	58	56.3%
Female	45	43.7%
Dental students		
Gender		
Male	48	46.6%
Female	55	53.4%
Dental background		
No prior experience before dental school	75	72.8%
Prior experience before dental school	28	27.2%
Year in dental school		
Third	4	3.9%
Fourth	99	96.1%
Supervising faculty members		
General dentists	23	22.3%
Prosthodontists	80	77.7%
Restorations		
Location		
Anterior	32	31.1%
Posterior	71	68.9%
Supporting structure		
Implant	49	47.6%
Natural dentition	54	52.4%
Type of restoration		
Metal-ceramic	92	89.3%
All-ceramic	11	10.7%
Restorative material		
Base-metal alloy	8	7.8%
Noble metal alloy	83	80.6%
High noble metal alloy	1	1.0%
Lithium disilicate	9	8.7%
Zirconia	2	1.9%

Of the 103 definitive restorations, 32 (31%) were performed on anterior teeth (incisors and canines) (Table 1). The restorations were split 52% vs. 48% on natural dentition vs. implant, respectively. While metal-ceramic material was used for the majority of the restorations (89%), noble metal-alloy was the most common choice of substructure material for the metal-ceramic restorations (81%).

$\Delta E_{clinical}$ and $\Delta E_{laboratory}$ values were normally distributed. Overall $\Delta E_{clinical}$ (6.5±2.4) and $\Delta E_{laboratory}$(4.3±2.0) were both significantly higher than the AT ΔE value of 2.7 ($p<0.0001$) (Table 2). The overall $\Delta E_{clinical}$ (6.5±2.4) was significantly higher than the overall mean $\Delta E_{laboratory}$ (4.3±2.0) ($p<0.001$). The shade differences (ΔE*) were also analyzed based on the restoration locations (Table 3). $\Delta E_{clinical}$ and $\Delta E_{laboratory}$ in all restoration locations ($\Delta E_{clincal\_Anterior}$, $\Delta E_{clincal\_Posterior}$, $\Delta E_{laboratory\_Anterior}$, and $\Delta E_{laboratory\_Posterior}$) were significantly higher than the AT ΔE value of 2.7 ($p<0.0001$). The difference between $\Delta E_{clinical}$ and $\Delta E_{laboratory}$ was not evident in the anterior area ($\Delta E_{clincal\_Anterior}$: 5.6±2.5 vs. $\Delta E_{laboratory\_Anterior}$: 4.6±2.0, $p=0.08$). In the posterior area, the difference between $\Delta E_{clinical}$ and $\Delta E_{laboratory}$ was statistically significant ($\Delta E_{clincal\_Posterior}$: 6.9±2.3 vs. $\Delta E_{laboratory\_Posterior}$: 4.2±1.9, $p<0.001$).

Table 2. Shade differences (ΔE*)

	Mean (SD)	p-value[a]	p-value[b]
$\Delta E_{clinical}$	6.5 (2.4)	<0.0001	<0.001
$\Delta E_{laboratory}$	4.3 (2.0)	<0.0001	

[a]Difference of mean values from 2.7
[b]Difference of mean values between $\Delta E_{clinical}$ and $\Delta E_{laboratory}$

Note: The Bonferroni correction was used to control family-wise error rate for multiple comparisons and adjust the p-values. All p-values were statistically significance at p≤0.05.

The first survey question was used to assess the participants' satisfaction with the shade-matching outcome (Table 4). Despite the $\Delta E_{clinical}$ and $\Delta E_{laboratory}$ discrepancies, the majority of the patients (94.2%), dental students (82.5%), and faculty members (58.3%) were satisfied or extremely satisfied. The patients had higher levels of satisfaction than the dental students and faculty members.

The second survey question was used to assess if the supervising faculty members and dental students supported use of an objective electronic shade-matching tool as a way to improve esthetic outcome (Table 4). Generally, both the students (77.7%) and faculty members (60.2%) agreed or strongly agreed with its use to improve esthetic outcome. However, the dental students tended to agree more strongly with this statement than the faculty members did.

The effects of characteristics of the patients, dental students, faculty members, and the restorations on the $\Delta E_{clinical}$ were also analyzed (Table 5). In general, there were no effects of participants' characteristics on the clinical shade-matching outcome ($\Delta E_{clinical}$). However, supporting structure (implant vs. natural dentition) ($p=0.0496$) had effects on the clinical shade-matching outcome ($\Delta E_{clinical}$). $\Delta E_{clinical}$ tended to be higher on the implant restorations.

There was no significant correlation between the patients' and students' satisfaction and the clinical shade-matching outcome ($\Delta E_{clinical}$) ($r=-0.06$, $p=0.55$; $r=-0.06$, $p=0.57$, respectively) (Table 6). There was a significant negative correlation between the supervising faculty members' satisfaction and the clinical shade-matching outcome ($\Delta E_{clinical}$) ($r=-0.45$, $p<0.001$). The higher the shade difference, the less likely the faculty member was to be satisfied with the matching. Additionally, the faculty member was most likely to agree with use of the objective shade-matching equipment if $\Delta E_{clinical}$ was high ($r=0.35$, $p<0.001$).

Table 3. Shade differences (ΔE*) based on restoration location

	Anterior			Posterior		
	Mean (SD)	p-value[a]	p-value[b]	Mean (SD)	p-value[a]	p-value[b]
$\Delta E_{clinical}$	5.6 (2.5)	<0.0001*	0.08	6.9 (2.3)	<0.0001*	<0.001*
$\Delta E_{laboratory}$	4.6 (2.0)	<0.0001*		4.2 (1.9)	<0.0001*	

[a]Difference of mean values from 2.7
[b]Difference of mean value between $\Delta E_{clinical}$ and $\Delta E_{laboratory}$ in various restoration locations (such as $\Delta E_{clinical\_Anterior}$ vs. $\Delta E_{laboratory\_Anterior}$ with p-value of 0.08).

*Statistically significant at $p<0.05$

Table 4. All participants' satisfaction with shade-matching outcome and dental students' and faculty members' support of effectiveness of objective electronic shade-matching tool

	Question 1: Satisfaction		Question 2: Effectiveness
Patients	Number (Percentage)		Number (Percentage)
Extremely dissatisfied	1 (1.0%)		
Somewhat dissatisfied	0		
Neutral	5 (4.9%)		
Satisfied	21 (20.4%)		
Extremely satisfied	76 (73.8%)		
Median (IQR)	5 (1.0%)		
Mean (SD)	4.7 (0.7%)		
Dental students		Dental students	
Extremely dissatisfied	1 (1.0%)	Strongly disagree	3 (2.9%)
Somewhat dissatisfied	0	Disagree	5 (4.9%)
Neutral	17 (16.5%)	Neutral	15 (14.6%)
Satisfied	59 (57.3%)	Agree	32 (31.1%)
Extremely satisfied	26 (25.2%)	Strongly agree	48 (46.6%)
Median (IQR)	4 (1.0%)	Median (IQR)	4 (1.0%)
Mean (SD)	4 (0.7%)	Mean (SD)	4.1 (1.0%)
Faculty members		Faculty members	
Extremely dissatisfied	0	Strongly disagree	0
Somewhat dissatisfied	9 (8.7%)	Disagree	12 (11.7%)
Neutral	34.0 (33.0%)	Neutral	29 (28.2%)
Satisfied	45 (43.7%)	Agree	53 (51.5%)
Extremely satisfied	15 (14.6%)	Strongly agree	9 (8.7%)
Median (IQR)	4 (1.0%)	Median (IQR)	4 (1.0%)
Mean (SD)	3.6 (0.8%)	Mean (SD)	3.6 (0.8%)

Note: Question 1 was worded: How satisfied are you with the shade-matching outcome? Question 2 was worded: The use of an electronic objective shade-matching tool may improve the esthetic outcome in this treatment provided to the patient.

Discussion

Shade-matching with the visual shade guide has previously been found to be subjective, potentially leading to discrepancies in the shade match.[1-5,30] Our study sought to objectively evaluate the shade-matching outcomes resulting from visual subjective shade selection with a shade guide and to assess patients', dental students', and supervising faculty members' satisfaction with those outcomes and supports for the shade-matching tool.

The mean $\Delta E_{clinical}$ in our study was significantly above 2.7, the acceptability threshold recommended in previous studies.[33,35,37] The $\Delta E_{clinical}$ represented the clinical objective shade-matching outcomes. From clinicians' perspective, the clinical experience has been found to lead to greater shade-matching success.[17-20] The results of our study could possibly contribute to dental students' lower level of clinical experiences. In addition, Burki et al. found that dental students tended to spend more time in clinical procedures to allow for verification from the supervising faculty, potentially allowing tooth dehydration to lead to differences in color parameters that make up E equation.[12] Furthermore, Khashayar et al. reported that the majority of studies that contribute to current knowledge of acceptability/perceptibility thresholds were in vitro-based, potentially excluding the clinical environment.[35] For reasons such as these, in conjunction with the high patient satisfaction ratings, it may be useful to re-evaluate stringent E thresholds.

In our study, the $\Delta E_{laboratory}$ represented the ability of dental technicians to provide the desired shade for definitive restorations matching information on the laboratory authorization, and the mean $\Delta E_{laboratory}$ value was also above the clinical acceptability threshold value of 2.7.[33,37] The $\Delta E_{laboratory}$ value was statistically lower than the $\Delta E_{clinical}$ value. This result

Table 5. Effects of participants' and restorations' characteristics on clinical shade-matching outcome ($\Delta E_{clinical}$)

	$\Delta E_{clinical}$		
Characteristic	Estimate	Std Err	p-value
Patients			
Gender (male vs. female)[a]	0.07	0.48	0.88
Dental students			
Gender (male vs. female)[a]	-0.32	0.47	0.50
Dental background (none vs. some)[a]	0.68	0.53	0.20
Year in dental school (third vs. fourth)[a]	-2.20	1.20	0.07
Supervising faculty members			
Prosthodontist vs. general dentist[a]	1.03	0.31	0.10
Restorations			
Supporting structure (implant vs. natural dentition)[a]	0.92	0.46	0.0496*
Types of restoration (metal-ceramic vs. all-ceramic)[a]	-0.16	0.71	0.82
Restorative materials[b]			0.74

[a]The t-test and [b]one-way ANOVA were used to evaluate effects of participants' and restorations' characteristics on clinical shade-matching outcome. Restorative materials were base-metal, noble-metal, high noble alloy, lithium disilicate, and zirconia.

*Statistically significant at $p<0.05$

Table 6. Correlations between clinical shade-matching outcome ($\Delta E_{clinical}$) and participants' satisfaction with shade-matching outcome and support for objective shade-matching tool

	$\Delta E_{clinical}$	
	Correlation Coefficient (r)	p-value
Satisfaction with shade-matching outcome		
Patients	-0.06	0.55
Dental students	-0.06	0.57
Supervising faculty members	-0.45	<0.001*
Support for objective electronic shade-matching tool		
Dental students	0.11	0.27
Supervising faculty members	0.35	<0.001*

Note: The Pearson Correlation test was used to test correlation between clinical shade-matching outcome ($\Delta E_{clinical}$) and survey outcomes.

*Statistically significant at $p<0.05$

is reasonable, since the $\Delta E_{clinical}$ is the combined reflection of the clinician's ability to select the desired shade and the $\Delta E_{laboratory}$ dental technician's ability to duplicate laboratory authorization. One noteworthy finding is that most of the laboratory authorizations included in this study did not provide clinical photographs. Previous studies support the use of digital photographs since that additional information is helpful in communicating between the clinician and dental technician.[26-28] The laboratory authorizations also showed that the majority of these dental students did not include the dentin shade selection for all-ceramic restorations. Without this information, the laboratory may not be able to adequately incorporate the hue of the underlying tooth structure to create an accurate shade-match outcome, thus adversely affecting both $\Delta E_{clinical}$ and $\Delta E_{laboratory}$.[8]

The functional and esthetic outcomes of the definitive restoration were confirmed by both clinicians and patients as clinically acceptable, indicating some initial level of satisfaction with the shade match. The satisfaction survey showed that 94.2% of the patients were at least satisfied or extremely satisfied with the clinical shade-matching outcome,

despite significant $\Delta E_{clinical}$ discrepancies. The patients frequently mentioned the desire to whiten their teeth after receiving restorations during this study. Patient satisfaction may have been influenced by the lightness of the restoration shade—whether or not restoration shade and target shade truly matched. In addition, Al-Wahadni et al. found that patients tended to rate restorations more favorably when the restoration was received in an academic institution.[23] Those researchers noted that the patients' pride in the school or positive relationship with the dental student may have elevated his or her opinion of the care received.

Considering the statistically significant level of discrepancy in $\Delta E_{clinical}$, it would be expected that at least the dental students and supervising faculty members would have been able to detect the shade mismatch. However, the majority of dental students (82.5%) and supervising faculty members (58.3%) reported being at least satisfied or extremely satisfied with the shade-matching outcome. The students' favorable rating may be attributed to lack of experience.[16,17,19] It is also possible that the students and faculty members tailored the laboratory authorizations to the patients' request for a lighter restoration shade despite the actual shade match, leading to a satisfied patient, therefore satisfied clinicians, but a contradicting shade match with higher ΔE. While these faculty members were generally satisfied with the shade-matching outcomes (58.3%), a significant correlation between $\Delta E_{clinical}$ and faculty satisfaction was observed. As $\Delta E_{clinical}$ decreased, the faculty members were more satisfied. Clinical experience is important to shade-matching accuracy, and it is possible that the faculty members realized that students were not experienced and therefore tolerated some flexibility.[16-19,33]

Despite these satisfaction ratings, both the dental students (77.7%) and supervising faculty members (60.2%) agreed or strongly agreed with use of an objective electronic shade-matching tool to improve esthetic outcome. Overall, the dental students were generally supportive of the need for an objective electronic shade-matching tool. Dental students may not be confident in their ability, due to their lower level of experience, to perform accurate shade-matching with a shade guide. The idea of removing doubt from subjective selection with an objective electronic tool could be a welcoming concept for students. The supervising faculty members' agreement with the objective electronic shade-matching tool correlated with $\Delta E_{clinical}$ ($r=0.35$; $p<0.001$) significantly. The faculty members never saw the actual $\Delta E_{clinical}$ value; this correlation came from strictly visual assessment. In other words, the faculty members were more able to discern visual inaccuracies in shade without knowledge of any quantitative markers than the students. Da Silva et al. had similar findings when they created two sets of crowns, evaluated the accuracy of the crowns, and then had experienced faculty members choose the most accurate shade-match through visual mean only.[33] In their study, the experienced clinicians consistently chose the group with the lower ΔE.

The patients included in our study reported high satisfaction ratings, indicating that subjective visual shade-matching selection with a shade guide can still be a viable option to produce definitive restoration with clinically acceptable esthetic outcome. Previous studies explored issues associated with visual shade matching[2,7,11,13-15] and the efficacy of the spectrophotometer extensively.[16,30-34] Our study explored different components of the shade-matching outcome from subjective visual shade-matching selection with a shade guide and can potentially provide future direction of shade-matching education in dental schools.

A limitation of our study was the unknown reliability and validity of the author-developed survey items. Future research should be conducted to confirm the reliability of the survey items and to validate their use. Another limitation of our study is that the objective electronic shade-matching devices can vary in their reliability and accuracy to produce color measurements. Kim-Pusateri et al. found that most devices showed similar high reliability (over 96%) but more variability in accuracy among devices (67-93%).[34] More laboratory and clinical studies should be conducted to investigate the reliability and accuracy of the objective electronic shade-matching devices and to predict their performance in the clinical setting. In future research, study participants can be screened for color blindness or other color vision deficiency to eliminate any potential influence to shade-matching outcome, as called for by Chu et al. and Poljak-Guberina et al.[1,22] Further research can also focus on the clinical control trial to revisit clinical acceptability threshold with different patient populations, effect of training programs on the improvement of clinical esthetic outcomes with subjective visual shade-matching method, or cost-benefit analysis of implementation of an objective electronic shade-matching tool with a clinical study.

Conclusion

In this study, shade discrepancy outside the clinical acceptability threshold value of 2.7 was noted in both $\Delta E_{clinical}$ and $\Delta E_{laboratory}$, when subjective visual shade-matching method was used with a shade guide to fabricate definitive restorations. Characteristics of the patients, dental students, supervising faculty members, and the restorations had none to minimal effect on the clinical shade-matching outcome ($\Delta E_{clinical}$). The majority of patients, dental students, and faculty members reported being satisfied with the shade-match outcome resulting from the subjective visual shade-matching method, despite the increased mean value of 6.5. The generally accepted clinical acceptability threshold value of 2.7 may need to be revisited based on different patient populations and clinical environments (in vitro vs. clinical; academia vs. private practice). The dental students and faculty members in our study were supportive of objective electronic shade-matching tool as a way to improve shade-matching outcome. $\Delta E_{clinical}$ correlated significantly with faculty satisfaction as well as agreement of the need for objective shade measurement, indicating experienced clinicians' higher ability to discern shade discrepancy.

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