In Vivo and In Vitro Assessment of an Intraoral Dental Colorimeter

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Abstract

Purpose: The purpose of this study was to assess the performance of an intraoral dental colorimeter.
Materials and Methods: In vivo repeatability of an intraoral colorimeter was assessed by performing color measurements of 30 individuals' right maxillary central incisor. Three consecutive measurements from each individual were made. In the in vitro part of the study, 25 metal-ceramic and 25 all-ceramic specimens were prepared. Five shades of metal-ceramic and all-ceramic specimens were selected for color determination. A widely recognized in vitro colorimeter was used as the control group for the in vitro performance assessment of the in vivo colorimeter. The color differentiation capability of two colorimeters was compared with the readings obtained from ceramic specimens. ΔE values between shade groups of ceramic specimens were calculated and statistically analyzed with Student's *t*-test. The repeatability of the intraoral instrument was evaluated statistically with Intraclass correlation coefficient.
Results: The in vivo evaluation results showed that the overall repeatability coefficient values of L*, a*, and b* notations of the intraoral colorimeter were "excellent." The color differences (ΔE) calculated between the colorimeters were significant only between shades A_1-B_1 for metal-ceramic specimens ($p = 0.002$); however, from 5 of 10 shade couples of all-ceramic specimens, the color differences obtained from the readings of the in vivo colorimeter were significantly different from that of the in vitro colorimeter ($p < 0.001$). For all specimens, the differences between ΔE values were within clinically acceptable limits (<3.5).
Conclusions: Within the limitations of this study, the intraoral colorimeter exhibited successful in vivo repeatability; however, the color difference detection performance of the device varied depending on the translucency of the specimens.

The demand for an enhanced appearance through cosmetic restorative dental procedures is critical to today's esthetics-conscious patient. Due to these high demands, it is obligatory that dental laboratories fabricate restorations that are near perfect in shade match; however, shade matching is a very complicated task.[1] Although the human eye is capable of detecting even slight differences in color between two objects, visual color determination is considered highly subjective,[2] and the ability to communicate color alterations in terms of magnitude and nature of difference is limited.[3]

Colorimeters provide a means to improve the evaluation of tooth color.[2] Instrumental measurements with colorimeters enable communication to be more precise. Moreover, colorimetric measurement allows quantification of color using CIELab coordinates. The color difference between two objects can be analyzed mathematically with these three coordinates, which represent the changes in brightness (L*), chroma along the red-green axis (a*), and chroma along the yellow-blue axis (b*).[4,5]

Development of advanced instruments has increased their use in dental research.[6-11] Tristumulus colorimeters have been found to have both precision and accuracy for the in vitro assessment of monochromatic opaque porcelain specimens,[12] and Minolta CR-321 is a widely used device for objective measurement of color in vitro.[13] Its use has been confirmed for evaluation and specification of dental porcelain color.[3] Its massive size limits intraoral use, and it may not be possible to make color determination without very incommodious templates;[3,14,15] however,

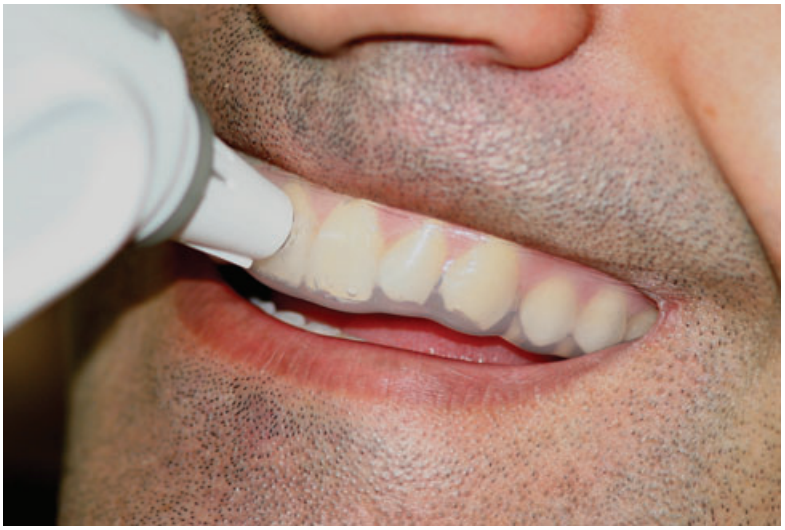

Figure 1 Intraoral dental colorimeter.

recently developed intraoral colorimeters allow easy color measurements for both the dentist and the patient.[16] A relatively new colorimeter (ShadeEye NCC, Shofu, Menlo Park, CA) has been introduced on the market as a suitable device for intraoral color measurements. The device is a contact probe-type colorimeter with a circular 0/0 measuring geometry that uses a pulse xenon flash to illuminate the tooth surface. Once the device is calibrated, the tooth number to be measured is selected from the menu, and the measurement process begins. Three to five measurements are made and averaged to determine the measured shade. The data is transmitted to the docking unit by an infrared signal; therefore, the handheld device is not tethered. The readout generated by the instrument from the measurement gives a tooth identifying number, the closest single Vitapan Classical shade guide designation, and simple opaque, body, and enamel mixture ratios that the technician can apply. The device was specifically developed to work in conjunction with the Vintage Halo porcelain system, but it has additional references for other popular porcelain systems.[17]

The precision of the color-measuring instruments can be evaluated by means of repeatability. Repeatability is the closeness of agreement between the results of successive measurements of the same test specimen, or of test specimens taken at random from a homogenous supply, carried out in a single laboratory, by the same method of measurement, operator, and measuring instrument, with repetition over a specified period of time.[18]

The aim of this study was to evaluate the in vivo and in vitro performance of an intraoral colorimeter compared with a relatively recognized colorimeter. The null hypothesis of this study was that the recently developed intraoral colorimeter will exhibit successful repeatability and color-differentiation results when compared with a widely recognized and used in vitro colorimeter.

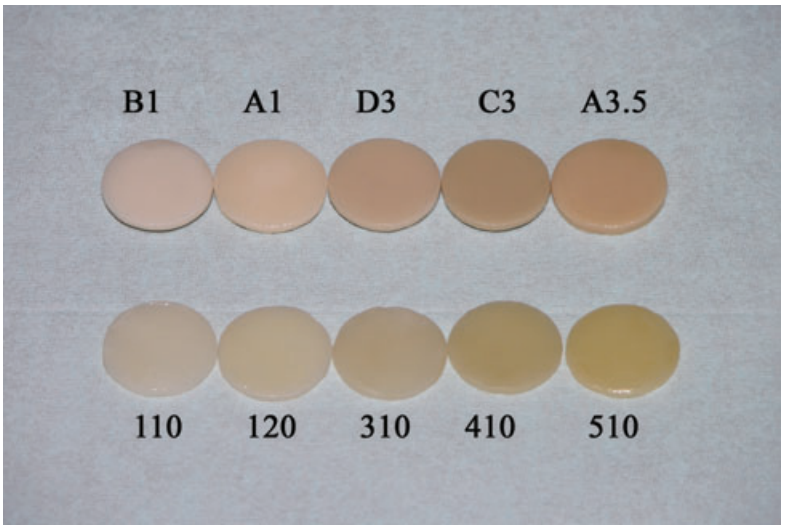

Figure 2 Metal-ceramic (upper row) and all-ceramic (lower row) specimens.

Materials and methods

In vivo evaluation

The shade determination procedures were performed on 30 research assistants at Ankara University, Faculty of Dentistry (13 women and 17 men, 22–30 years). The right maxillary central incisor was used for color determination as performed in previous studies.[2,16,19] The inclusion criteria for teeth were as follows: teeth without restorations, carious lesions, stains, gingivitis, periodontitis, with no history of orthodontic therapy or tooth bleaching. The teeth were without endodontic treatment and adjacent natural dentition was present. The subjects were given instruction concerning oral hygiene and told to abstain from smoking and tooth-bleaching procedures during the experimental period.

An impression of the maxillary arch of each subject was made with an irreversible hydrocolloid impression material (Cavex CA37, Cavex Holland BV, Haarlem, The Netherlands). The impression was poured, and stabilization splints were fabricated on each cast. The splints were perforated in the middle third region of each right maxillary incisor to the exact diameter of the probe of the intraoral colorimeter to maintain the repeatable fit of the tip of the probe to the tooth's exact surface. The teeth were cleaned with pumice and air-spray dried. A 3 m^2 room with standardized illumination (D65, Sylvania, Raleigh, NC) was used as the test area. The color of 30 subjects' right maxillary central incisors was measured with the intraoral colorimeter (ShadeEye NCC) by an experienced observer. The elastic tip of the instrument contacted the tooth through the perforation on the splint, and the first measurement was performed in the "analyze" mode, which provides L*, a*, and b* coordinates of the measured subjects (Fig 1). Three consecutive measurements were performed with 1-minute intervals, and readings in terms of L*, a*, and b* coordinates were recorded. Measurements were made with replacement of the instrument. The instrument was removed from the tooth surface, placed into and taken out of its box, and repetitive measurements were performed in the "analyze" mode. The instrument was calibrated according to the manufacturer's instructions before each measurement session.

In vitro evaluation

For the in vitro part of the study, twenty-five disk-shaped wax patterns (10-mm diameter, 1-mm thick) were prepared with the use of a Teflon template for metal-ceramic specimens. After investment, the metal substructure of the specimens was cast from a base metal alloy (Wirobond C, BEGO, Bremen, Germany). The opaque porcelain (0.1 mm) and dentin porcelain (1 mm) (Vita Omega, Vita Zahnfabrik, Bad Sackingen, Germany) were layered in five shades of Vita Lumin Vacuum (Vita Zahnfabrik) shade guide (A_1, $A_{3.5,}$ B_1, C_3, D_3). Five specimens were prepared from each shade. The metal substructure, opaque, and dentin porcelain thicknesses of the specimens were controlled with a micrometer (Praecimeter S. 0.01 mm, Renfert GmbH, Hilzingen, Germany) at four points. All porcelain surfaces were flattened with a diamond cutting instrument to prevent surface texture variations, and airborne-particle abraded with 25-μm aluminum oxide (Basic Classic, Renfert GmbH) before glaze application. The porcelain surfaces were glazed according to the manufacturer's instructions.

Twenty-five disk-shaped wax patterns (10-mm diameter, 1-mm thick) were prepared with the same Teflon template used for the metal-ceramic specimens for the preparation of all-ceramic specimens (IPS Empress 2, Ivoclar Vivadent, Schaan, Liechtenstein). The wax patterns were invested and pressed according to the manufacturer's instructions using 110 (Ivoclar Vivadent) shade ingot. Five shades of Chromascope shade guide (Ivoclar Vivadent) (110, 120, 420, 310, 510) were selected, and five specimens of each shade were prepared with staining technique. The disks were glazed according to the manufacturers' instructions (Fig 2).

The in vitro (Minolta CR-321, Minolta Inc, Osaka, Japan) and the in vivo colorimeter (ShadeEye NCC) were used for shade determination. The in vitro (M) colorimeter was placed on a Teflon positioning apparatus, which contained a socket. The specimens were firmly fit for shade determination, and the colorimeter was calibrated before each shade determination session according to the manufacturers' instructions. The color of 25 randomly arranged metal-ceramic and 25 randomly arranged all-ceramic specimens were measured with the instrument with replacement. Shade determination of specimens with the in vivo colorimeter (S) was performed in the same sequence by the same experienced observer. The device was calibrated before each measurement session. As the translucency of all-ceramics should be considered an important factor for objective color determination results,[3] the measurements of the all-ceramic specimens were standardized with a neutral gray background during the shade determination sessions with both colorimeters.

L*, a*, b* notations for all specimens were recorded, and the color differences between the results of the two colorimeters were calculated with the following equation:[12,20]

$$\Delta E_{(L,a,b)} = [(L_1 - L_2)]^2 + (a_1 - a_2)^2 + (b_1 - b_2)^2]^{1/2}.$$

A ΔE greater than 1 was used as a baseline of visual significance. ΔE difference >1 was considered perceivable by human eye in the present study. O'Brien reported a clinical color-matching tolerance table (Table 1).[21] The table was considered during the calculated color-difference interpretation. The color differences (ΔE) calculated with the data obtained from two colorimeters were statistically analyzed with Student's *t*-test. Bonferroni correction was applied for multiple comparisons. The repeatability of the L*, a*, b* values was calculated using the Intraclass correlation coefficient (ICC). A repeatability coefficient of 1 would be indicative of perfect agreement, 0 of no agreement; negative values are theoretical. Values of the lower bound of the ICC 95% confidence interval (95% CI) of

Table 1 Clinical color-matching tolerance

Color difference ΔE	Clinical color match
0	Perfect
0.5–1	Excellent
1–2	Good
2–3.5	Clinically acceptable
>3.5	Mismatch

Table 2 Mean L*, a*, b* values and standard deviations of selected shades of metal-ceramic specimens obtained from two colorimeters. All L*, a*, b* values are statistically significantly different ($p = 0.043$)

	L*		a*		b*	
	S	M	S	M	S	M
D_3	73.66 ± 1.9	97.84 ± 5.25	0.83 ± 0.16	5.29 ± 0.25	13.22 ± 0.87	3.54 ± 1.18
A_1	77.54 ± 1.25	100.21 ± 2.76	0.06 ± 0.13	5.98 ± 0.27	12.94 ± 0.13	2.12 ± 0.25
C_3	71.28 ± 2.74	97.14 ± 4.36	0.96 ± 0.05	5.13 ± 0.23	13.42 ± 1.85	4.84 ± 2.54
B_1	78.94 ± 0.47	102.9 ± 2.08	0.69 ± 0.1	6.62 ± 0.12	10.6 ± 0.35	0.14 ± 0.15
$A_{3.5}$	70.75 ± 2.3	94.13 ± 3.97	2.62 ± 0.22	−3.7 ± 0.17	16.72 ± 1.83	7.96 ± 2.73

S = in vivo colorimeter (ShadeEye NCC). M = in vitro colorimeter (Minolta CR-321).

$0.4 < \text{ICC} \leq 0.75$ were judged as acceptable and $\text{ICC} > 0.75$ as excellent.[22,23]

Results

The L*, a*, b* notations of each specimen were measured (Tables 2, 3). The differences between data (L*, a*, b*) obtained from two colorimeters were significantly different ($p = 0.043$). The color differences of the selected shades (ΔE) were calculated with the values obtained from both colorimeters. The color difference values (ΔE) between shades of metal-ceramic specimens were calculated, and the values of in vivo colorimeter (S) were smaller than the in vitro colorimeter (M) in 8 of 10 values (Table 4). The color-difference result obtained from the readings of the in vivo colorimeter (S) between A_1 and B_1 shades was significantly different ($p = 0.002$) from the color difference result obtained from the readings of the in vitro colorimeter (M). The color difference values (ΔE) between shades of all-ceramic specimens were calculated, and the values of the in vivo colorimeter (S) were smaller for each (Table 5). The color differences (ΔE) calculated with the readings obtained from two distinct colorimeters were significantly different for some shades of all-ceramic specimens (Table 5). The color difference calculated with the readings of the in vivo colorimeter between shade 110–510 ($p = 0.003$), 110–310 ($p < 0.001$), 120–310 ($p < 0.001$), 120–410 ($p < 0.001$), and 120–510 ($p = 0.001$) were significantly different than the color difference calculated from the readings of the in vitro colorimeter. The in vivo reliability results of the in vivo colorimeter are displayed in Table 6. The repeatability results were "excellent" (>0.75).

Discussion

Colorimeters developed in recent years are used extensively for in vitro and in vivo studies.[7,12,15,16] Okubo et al[8] compared visual and colorimetric shade matching and stated that the colorimeter performed only slightly better than visual detection. Paul et al[2] reported 83% reproducibility for spectrophotometric measurements, whereas only 27% reproducibility was calculated for three human observers in the same study. Although the repeatability of the colorimeters and comparison of the human eye with instruments were evaluated in previous studies,[2,3,6,16,20] the number of studies that evaluate an in vivo colorimeter in comparison with an in vitro colorimeter is limited.[10]

Shade determination with colorimetric instruments is technique sensitive and requires exact lighting conditions and repeatable placement to produce consistent measurements.[20] Therefore, an alignment device was used for the in vitro colorimeter (M) to prevent positioning errors, which also prevents the effect of external illumination on the measurement surface. Although the advanced colorimeters make intraoral use possible,[16] the routine clinical use of these devices with a positioning apparatus is not practical. In the present study, the measurements with the in vivo colorimeter were performed by an experienced investigator with only the use of silicone splints, which ensure the measurement of exactly the same area on the

Table 3 Mean L*, a*, b* values and standard deviations of selected shades of all-ceramic specimens obtained from two colorimeters. All L*, a*, b* values are statistically significantly different ($p = 0.043$)

	L*		a*		b*	
	S	M	S	M	S	M
110	78.16 ± 2.08	98.71 ± 1.57	2.02 ± 0.27	5.07 ± 0.18	12.44 ± 2.34	4.21 ± 1.98
120	77.36 ± 1.87	99.26 ± 2.24	1.92 ± 0.11	5.35 ± 0.34	15.88 ± 1.33	7.98 ± 1.62
310	71.00 ± 0.87	91.40 ± 0.94	1.07 ± 0.22	5.16 ± 0.21	29.57 ± 1.10	23.88 ± 1.22
410	71.26 ± 1.65	91.31 ± 2.51	0.98 ± 0.12	4.03 ± 0.38	16.76 ± 1.22	9.81 ± 1.74
510	70.72 ± 1.34	90.87 ± 1.33	1.07 ± 0.15	4.50 ± 0.14	24.14 ± 0.34	17.53 ± 1.11

S = in vivo colorimeter (ShadeEye NCC). M = in vitro colorimeter (Minolta CR-321).

Table 4 Mean ΔE values and standard deviations between selected shades of metal-ceramic specimens and clinical interpretation

ΔE	S	M	*p*	ΔES-ΔEM	Clinical acceptability
D_3-A_1	4.13 ± 2.01	4.45 ± 4.29	0.739	0.32	Perfect
D_3-B_1	6.15 ± 1.76	6.73 ± 4.61	0.566	0.58	Excellent
D_3-$A_{3.5}$	6.50 ± 2.34	8.02 ± 3.71	0.091	1.52	Good
D_3-C_3	3.60 ± 2.30	5.36 ± 4.22	0.074	1.76	Good
A_1-B_1	3.05 ± 0.62	4.29 ± 1.72	0.002*	1.24	Good
A_1-$A_{3.5}$	8.34 ± 2.61	8.85 ± 4.26	0.610	0.49	Perfect
A_1-C_3	6.57 ± 2.79	5.44 ± 3.90	0.245	1.13	Good
B_1-$A_{3.5}$	10.80 ± 2.53	12.33 ± 4.17	0.124	1.53	Good
B_1-C_3	8.38 ± 2.90	7.88 ± 4.49	0.640	0.5	Excellent
$A_{3.5}$-C_3	5.06 ± 2.05	6.73 ± 3.90	0.067	167	Good

*Significantly different.

S = in vivo colorimeter (ShadeEye NCC). M = in vitro colorimeter (Minolta CR-321).

tooth. The in vivo performance of the colorimeter without the use of a splint might be investigated in future research.

Dental plaque and saliva have an important role in color inconsistency. Plaque may interfere with underlying tooth structure, while saliva may change the reflective index of the tooth surface, causing inaccurate measurement results.[16] Therefore, although rehydrating the tooth surface would better simulate the clinical conditions, the teeth were pumiced and air-spray dried prior to each session to prevent measurement errors.

Wang et al[10] compared the color of porcelain-fused-to-metal specimens with five color-measuring instruments. The color data for the same specimens measured on different instruments were correlated, although there were statistical differences among the data. In the present study, the measured L^*, a^*, b^* data on the same specimens between two colorimeters were also statistically different. The statistical differences may be attributed to the different calibration of devices.

A previous study indicated that measurements made on translucent porcelain are less accurate than on opaque specimens.[20] From the repeatability standpoint, the intraoral colorimeter performed successful repeatability results on maxillary central incisors, which are translucent in nature; however, repeatability is the closeness of agreement for a defined measurement procedure and is not accuracy.[18] The results of the present study gave the opportunity to disclose the quality control of the manufacturing process. An accuracy test of the devices in general is not possible, as there is no gold standard for the color of both types of specimens assessed. Therefore, the color differences of selected shades were calculated by the values obtained from the two colorimeters, and these values were compared to evaluate the color-differentiation capability of both colorimeters.

Tung et al[16] investigated and reported the repeatability and reliability of an in vivo colorimeter (ShadeEye-Ex). The reliability of the device was evaluated with Cronbach's α coefficient. The α values were obtained from the color determination results of two examiners. The reliability coefficient for the first examiner with the colorimeter was 0.99 for chroma, 0.95 for value, and 0.96 for hue. The second examiner's coefficients were 0.99 for chroma, 0.93 for value, and 0.97 for hue. The repeatability of the instrument was 82% after in vivo shade determinations. Yilmaz and Karaagaclioglu[19] compared the repeatability of ShadeEye NCC and visual shade determination in a previous study, and the authors concluded that in vivo

Table 5 Mean ΔE values and standard deviations between selected shades of all-ceramic specimens and clinical interpretation

ΔE	S	M	*p*	ΔES-ΔEM	Clinical acceptability
120–310	15.25 ± 5.37	17.40 ± 1.78	<0.001*	2.15	Clinically acceptable
120–510	10.84 ± 1.21	12.97 ± 1.64	<0.001*	2.13	Clinically acceptable
120–110	4.58 ± 1.93	4.62 ± 2.17	0.947	0.04	Perfect
120–410	6.54 ± 1.97	8.60 ± 2.90	0.005*	2.06	Clinically acceptable
310–510	5.61 ± 1.08	6.58 ± 1.47	0.012	0.97	Excellent
310–110	18.75 ± 1.82	21.08 ± 1.69	<0.001*	2.33	Clinically acceptable
310–410	12.92 ± 1.51	14.31 ± 2.01	0.008	1.39	Good
510–110	14.16 ± 1.42	15.63 ± 1.53	0.001*	1.47	Good
410–510	7.65 ± 1.15	8.12 ± 2.03	0.317	0.47	Perfect
410–110	8.75 ± 1.47	9.74 ± 2.28	0.076	0.99	Excellent

*Significantly different. S = in vivo colorimeter (ShadeEye NCC). M = in vitro colorimeter (Minolta CR-321).

Table 6 ICC coefficients of L*, a*, b* values obtained from in vivo shade determination of ShadeEye NCC colorimeter

Instrumental shade determination (S)	L*	a*	b*
Repeatability coefficient	0.926	0.910	0.941

[1]Intraoral dental colorimeter (ShadeEye NCC).
[2]Metal ceramic (B1, A1, D3, C3, A3.5) and all-ceramic (110, 120, 310, 410, 510) specimens.

repeatability of both colorimeter and visual shade determination was acceptable. The in vivo shade determination was performed on 10 objects, which is a smaller sample size than used in the present study. The repeatability of both methods was evaluated with Cronbach's α repeatability, and the repeatability results for L*, a*, b* coordinates were 0.74, 0.80, and 0.85, respectively. In the present study, the repeatability coefficient (ICC) for L*, a*, b* coordinates obtained from ShadeEye NCC were 0.92, 0.91, and 0.94, respectively. These results are deemed "excellent" and successful.

When the instruments with a small aperture for both illumination and collection of light are used, the amount of reflected light is reduced, causing an inadequate reading of lightness.[8] Therefore, the contact colorimeter devices are very susceptible to changes in translucency. This is particularly true of the L* value, which shows the greatest changes. The translucent all-ceramic and opaque metal-ceramic specimens were used to observe the effect of the material's translucency on both colorimeters. Therefore, the diameter of the specimens was greater than the diameter of the measurement tip of the colorimeters, to minimize the possible effects of "edge loss"[5] that is usually related to the color near the edge of a translucent material, such as porcelain.[7] The readings from the all-ceramics and the maxillary central incisors might have been influenced by the translucent structure of these objects. The differences between the color difference values (ΔE) were calculated, and the results were explicated in terms of clinical acceptability values by O'Brien.[21] It was found that the interpretations on differences between metal-ceramic specimens were mostly "perfect," "excellent," or "good," whereas they were mostly "clinically acceptable" for all-ceramic specimens; however, the concern may not be of particular importance for the opaque and dentin porcelain applied to the metal specimens used in the present study.

The color differences calculated with two distinct colorimeters were only statistically significant for one shade couple (A_1–B_1) of metal-ceramic specimens; however, when the color difference results were calculated between the shades of the all-ceramic specimens, color differences between 5 of 10 shade couples obtained from the readings of two colorimeters were significantly different ($p < 0.001$). This may be attributed to the translucent structure of the all-ceramic specimens, which may lead to inaccurate measurements of the small aperture colorimeters due to the "edge-loss" effect. Therefore, in accordance with the results obtained from the present study, it might be stated that the color measurements of the device on translucent teeth and direct composite restorations might be inaccurate; however, when the numerical differences between color differences (ΔE) were evaluated, it was found that none of them were above the clinically acceptable limit (3.5 units).

The surface form of the material is also an important factor for correct measurements by the instruments. The curved surfaces may negatively impact the uniform reflectance of light to the colorimeter.[11] Therefore, flat measurement surfaces were created on the metal-ceramic and all-ceramic specimens; however, the ideal surface is often missing in vivo. There are a limited number of teeth with a flat surface large enough to accommodate the diameter of the measurement tips of the colorimeter. Therefore, maxillary central incisors were chosen as the objects the colorimetric measurements are performed on. The elastic structure of the measurement tip of the intraoral colorimeter might have been considered as an advantage, particularly when the successful repeatability results were evaluated.

The results of the present study may be limited when compared with the results obtained under different experimental conditions. The performance of the intraoral colorimeter on the curved surfaces, such as the labial surface of the canine, should also be evaluated. The absence of a gold standard limits the authors' claim regarding the exact accuracy of the performance of the device. Therefore, evaluation of precision and accuracy of the ShadeEye NCC colorimeter in intraoral conditions might be an area of future investigation.

Conclusions

Within the limitations of this study, it may be concluded that:

1. The in vivo colorimeter demonstrated excellent repeatability.
2. For color-difference detection, the performance of the intraoral colorimeter varied depending on the translucency of the specimens.

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