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Spectrophotometric Analysis of All-ceramic Materials and Their Interaction with Luting Agents and Different Backgrounds

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Abstract — In this study, two All-Ceramic (AC) materials—Empress 2 (EMP) (Ivoclar Vivadent AG, Schaan, Liechtenstein) and In-Ceram ALUMINA (ICA) (Vita Zahnfabrik, Bad Säckingen, Germany)—were analyzed, along with the effects of 3 luting agents—*viz*. Zinc Phosphate cement (ZNPO, PhospaCEM PL, Ivoclar Vivadent AG, Schaan, Liechtenstein), Glass Ionomer Cement (GIC, Ketac-Cem Radiopaque, ESPE Dental AG, Seefeld, Germany), and Compolute (COMP, ESPE Dental AG, Seefeld, Germany)—on the final color, using the CIELab system. Color differences (DeltaL, Deltaa, Deltab, and DeltaE) were calculated for samples with luting agents and for samples without luting agents with standard white and black backgrounds, with the use of a spectrophotometer, Luci 100 (Dr. Lange, Berlin, Germany). One-way ANOVA for DeltaL, Deltaa, Deltab, and DeltaE within both the AC systems, with and without luting agents, showed significant contributions of the background ($p < 0.05$). EMP was seen to be more translucent than ICA. Darker ceramics showed less color variation. Luting agents altered the final color of the restoration. ZNPO was least translucent, followed by GIC and COMP. Marginal increases in thicknesses of ICA samples (0.4 mm) do not show a statistically significant color difference. No method exists to predict the outcome of an AC restoration based on consideration of the luting agent and the background color.

Introduction

The dental profession has long been concerned with the problem of matching the appearance of the ceramic restorations with a patient's natural dentition (Seghi *et al*., 1986). As far as the appearance of a tooth-colored restoration is concerned, the color of a metal ceramic or all-ceramic (AC) dental restoration is decisive. AC restorations without a metal substructure allow for greater light transmission within the restoration, thereby improving the color and translucency of the restoration, but still a perfect esthetic tooth-colored restoration cannot be ensured (Wee *et al*., 2002). It has been suggested that color training for dentists should be a part of the course in prosthetic dentistry (Huang *et al*., 1989). The CIELab color system (Commission Internationale de l'Éclairage) was first published in 1976 (CIE, 1976). This system facilitates color space presentation (Fig. 1).

The background color of the esthetic all-ceramic restoration is controlled primarily by the thickness of the material and the background color (Jorgenson and Goodkind, 1979). If the color of an esthetic dental material of any thickness with any background color could be precisely predicted, shade selection could be optimized.

All-porcelain veneers provide a masking effect for the background shade when luted to the substrate with a luting agent (Davis *et al*., 1992). The shade is determined not only by the color of the porcelain, but also by the thickness of the porcelain, the thickness and the color of the luting agent, and the color of the underlying tooth structure (Vichi *et al*., 2000). The ceramics are translucent at clinically relevant thicknesses (Heffernan *et al*., 2002), and with different core materials, the translucencies vary within the ceramics.

The primary purpose of this study is to investigate the effects of background color and luting agents on the final color in AC samples.

Materials & Methods

In this study, 2 AC materials—IPS Empress 2 (EMP) (Ivoclar Vivadent AG, Schaan, Liechtenstein), a heat-pressed glass ceramic which has lithium disilicate as the core material, and VITA In-ceram Alumina (ICA) (Vita Zahnfabrik, Bad Säckingen, Germany), which has aluminum oxide as the core material—were studied. For the study, 15 ceramic sample discs for each group, 16 mm in diameter, were prepared by the manufacturer. Three shades were arbitrarily selected, visually, to represent a cross-section of various degrees of pigmented porcelain.

For Empress 2 (EMP, n = 45), the combinations we used were: 100-110-S1 (EMP1, n = 15), 300-320-S2 (EMP2, n = 15), 500-520-S3 (EMP3, n = 15), with 100, 300, and 500 being the core, 110, 320, and 520 the dentin, and S1, S2, and S3 the enamel (Fig. 2).

For In-Ceram ALUMINA (ICA, n = 90), the combinations we used were: al1-b1-EN1 (ICA1, Th. 1.00, n = 15 and 1.40 mm, n = 15), al2-b3-EN2 (ICA2, Th. 1.00, n = 15 and 1.40 mm, n = 15), al4-b4-EN3 (ICA3, Th. 1.00, n = 15 and 1.40 mm, n = 15), with al1, al2, and al4 being the core, b1, b3, and b4 being the dentin, and EN1, EN2, and EN3, the enamel (Fig. 2). The thickness (Th) was measured 3X, and the mean of the 3 measurements was recorded.

The luting agents (CEM) used as an intermediate layer, when luted to the inner (core—non-glazed) surface, were: Zinc Phosphate cement (ZNPO), shade Neutral (PhospaCEM PL, Ivoclar Vivadent AG, Schaan, Liechtenstein); Glass Ionomer Cement (GIC), shade Universal (Ketac-Cem Radiopaque, ESPE Dental AG, Seefeld, Germany); and Compolute Aplicap (COMP), shade A3, a Resin Luting Agent (ESPE Dental AG, Seefeld, Germany). The luting agents were pressed onto the inner (non-glazed) surface of the ceramic sample by means of a micrometer (Mitutoyo, Neuss, Germany), with a glass slide

Key Words

Ceramics, dental cements, luting agents, color, colorimetry.

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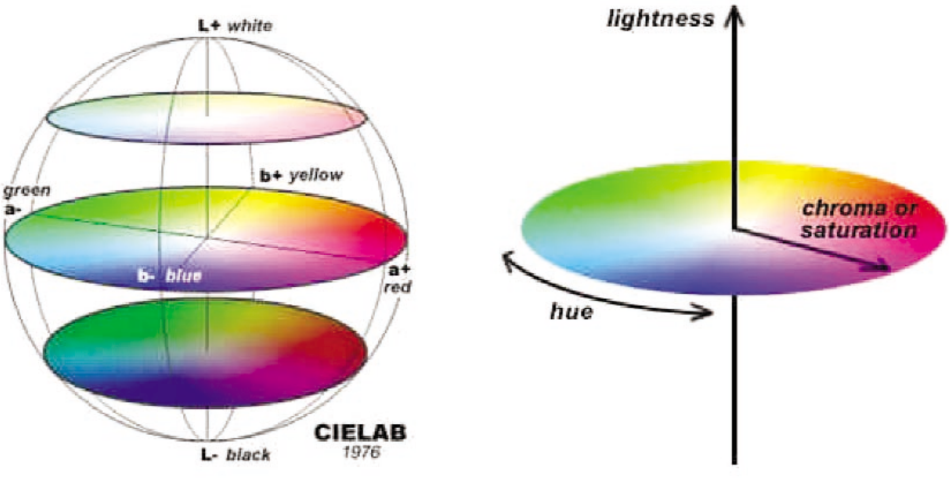

Fig. 1 — Framework of the CIELAB color model. Kindly provided by http://www.handprint.com/. L - 0 (black) to 100 (white); a - -80 (green) to +80 (red); b - -80 (blue) to +80 (yellow); C - difference of a specific color in relation to gray color of the same lightness. H : H = 0 red, H = 90 yellow, H = 180 green, H = 270 blue.

used as an intermediate layer between the micrometer and the "All Ceramic Luting agent" (ACLA) unit, to press the luting agent onto its non-glazed surface, to produce a thickness of 0.08 to 0.18 mm with various (arbitrary) pressures.

Spectrophotometric evaluation

The colorimeter we used for the measurements was LUCI 100 (Dr. Bruno Lange GmbH, Berlin, Germany), a spectral two-beam spectrophotometer with mobile measuring head. The measurements were recorded on a PC equipped with LUCIQC software (Dr. Bruno Lange GmbH, Berlin, Germany). The spectral range of the colorimeter was between 380 and 720 nm. Distance between two measured points was 10 nm, and the measuring geometry was d/8° according to DIN (Deutsches Institut für Normung) 5033.

The black-and-white standard discs were used for calibration of the spectrophotometer and then served as the standard backgrounds for the sample discs during the CIELab measurements before and after application of the luting agents to the surfaces of the ceramic samples.

We determined the difference between two colors by comparing the differences between respective coordinate values for each coordinate, as shown by the following equation:

$$\Delta E = (\Delta L^2 + \Delta a^2 + \Delta b^2)^{½}$$

(Eq. 1)

ΔE ("Empfindung" = sensation [in German]), the total color difference, and ΔL (also represents translucency of the material), Δa (redness-greenness), and Δb (yellowness-blueness) are:

$$\Delta L = L_w - L_b \qquad \text{(Eq. 2)}$$
$$\Delta a = a_w - a_b \qquad \text{(Eq. 3)}$$
$$\Delta b = b_w - b_b \qquad \text{(Eq. 4)}$$

Here, "w" represents the white background and "b" represents the black background due to different luting agents as the intermediate layer, with standard backgrounds, respectively.

ΔE values were calculated for the samples with black and white backgrounds (ΔEWB) for the 3 sample groups of each product (n = 15). The samples were then divided into 3 subgroups; luting agent was applied to the non-glazed surface, and ΔE (ΔEWCBC) values were calculated for the samples with different luting agents as the intermediate layer (n = 5), with white and black backgrounds. We calculated this to see the effect of the background on the final color. To see the effects of the luting agents on the final color, we calculated the ΔE values for samples with the same background, with and without luting agents (ΔEWWC-with white background and ΔEBBC-with black background).

Last, we calculated ΔE values for the individual luting agent samples (n = 10) with standard black and white backgrounds.

Statistical analysis

The significance of the results was tested by one-way ANOVA, followed by Duncan's (DUN) multiple comparison at the 0.05 level. Pearson's correlation coefficient was used for evaluation of correlation of translucency (ΔLBW) with the color change (ΔEWCBC) due to background, thickness of the luting agent (CTh), and the effects of luting agents on the final color (ΔEWWC and ΔEBBC).

Results

The mean thickness (STh) and standard deviation (SD) of the EMP samples and ICA sample groups, without luting agents, and the mean thickness and standard deviation of luting agents on the samples (CTh) are shown in Table 1.

The mean ΔE, ΔL, Δa, and Δb values, according to Eqs. 1-4, with and without luting agents, with standard black and white backgrounds, respectively, are shown in Table 2. The ΔL values show translucency. A reduction in translucency is seen as the shade darkened from EMP1 to EMP3 and ICA1 to ICA3, respectively. Additionally, the translucency decreased from samples with COMP to samples with ZNPO. This showed the ZNPO to be the least translucent luting agent, COMP the most, and GIC intermediate. The ICA samples at the same thickness were less translucent than the EMP samples. ICA samples with an increase of 0.40 mm showed a reduction in translucency. The Δa values showed a shift toward red. The Δa values increased with an increase in the darkness of the sample and a decrease in translucency. For the EMP2 and ICA2 samples, Δa values showed the maximum shift toward red (maximum with COMP and minimum with ZNPO), as shown in Fig. 3. Δb values shifted toward yellow upon placement of the white background. The

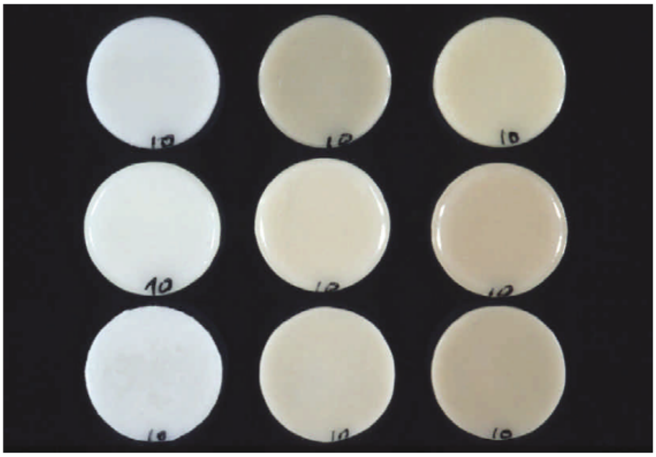

Fig. 2 — Ceramic samples (left to right). First row: In-Ceram ALUMINA (1.0 mm), ICA1, ICA2, ICA3. Second row: In-Ceram ALUMINA (1.4 mm), ICA1, ICA2, ICA3. Third row: IPS Empress 2 (1.4 mm), EMP1, EMP2, EMP3.

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Δb values decreased with the increase in the darkness of the samples and a decrease in translucency. Overall, the ΔE values varied from highest in the EMP1 group, with the most translucent luting agent, COMP, to the least in the ICA3, with the least translucent ZNPO. A *post hoc* Duncan test showed that the 12 groups formed were significantly different from each other (Table 2).

Table 3 shows the ΔL, Δa, Δb, and ΔE values for the samples with and without luting agents but with the same background. The overall color change in cases of black and white background with and without luting agents (ΔEBBC and ΔEWWC) was highest with ZNPO (least translucent) and least with COMP (most translucent). In general, as the shade of the ceramic became darker and the thickness increased, the ΔE value decreased. It also decreased with the increase in the translucency of the luting agent. *Post hoc* Duncan tests for ΔEBBC and ΔEWWC showed that 11 groups and 5 groups were formed, respectively.

The correlation of ΔLBW and ΔEBCWC (translucency with color change due to background) was significant for ZNPO (Table 4a), due to different backgrounds. With a black background (Table 4b), the thicknesses of ZNPO and GIC had a statistically significant effect on color change. With a white background (Table 4c), the thickness of ZNPO also had a statistically significant effect on color change.

The box plots for the ΔL, Δa, Δb, and ΔE values of the differences between the samples with black and white backgrounds for EMP, with and without luting agents as intermediate layers, are shown in Fig. 3; in the other groups of ICA samples, the same pattern was followed.

The luting agents were also analyzed without the AC samples, *i.e.*, so that the translucency of the materials could be studied separately. The ΔL and thus the ΔE values are highest for the COMP and least for ZNPO, thus showing that COMP is the most translucent material and ZNPO the least (detailed CIELab values not shown).

TABLE 1 — Mean Thickness ± SD of Samples without Luting Agents (STh) and with Luting Agents (CTh) (in mm)

AC	N	STh	SD	Cem	N	Cth	SD
EMP1	15	1.43	0.03	Comp	5	0.08	0.03
				GIC	5	0.14	0.04
				ZNPO	5	0.08	0.03
EMP2	15	1.43	0.03	Comp	5	0.07	0.02
				GIC	5	0.12	0.01
				ZNPO	5	0.1	0.02
EMP3	15	1.4	0.04	Comp	5	0.17	0.03
				GIC	5	0.13	0.02
				ZNPO	5	0.08	0.02
ICA11	15	1	0.04	Comp	5	0.15	0.02
				GIC	5	0.14	0.03
				ZNPO	5	0.18	0.03
ICA12	15	1.02	0.02	Comp	5	0.1	0.01
				GIC	5	0.13	0.02
				ZNPO	5	0.15	0.02
ICA13	15	1.02	0.02	Comp	5	0.13	0.04
				GIC	5	0.1	0.03
				ZNPO	5	0.16	0.02
ICA21	15	1.4	0.01	Comp	5	0.11	0.01
				GIC	5	0.11	0.02
				ZNPO	5	0.12	0.03
ICA22	15	1.4	0.02	Comp	5	0.09	0.02
				GIC	5	0.1	0.02
				ZNPO	5	0.14	0.03
ICA23	15	1.41	0.01	Comp	5	0.11	0.02
				GIC	5	0.08	0.01
				ZNPO	5	0.1	0.01

Discussion

This study simulated a clinical situation where the samples are not individual layers of the components of the ceramics—for example, core, dentin, and enamel—but rather a complete unit, with the dentin and enamel layers fired onto the core layer. The application of luting agents onto the samples was done to simulate a clinical situation, resulting in different thicknesses of luting agents (Morando *et al.*, 1995).

The development of the CIELab color system has been a cornerstone for the measurement and evaluation of color differences by dental materials scientists. Over the years,

TABLE 2 — ΔL, Δa, Δb, and ΔE Values between the Samples without Luting Agents and Those with Luting Agents, with Standard Black and White Backgrounds

AC	N	TH	ΔLWB	SD	ΔaWB	SD	ΔbWB	SD	ΔEWB	SD	CEM	N	ΔLWCBC	SD	ΔaWCBC	SD	ΔbWCBC	SD	ΔEWCBC	SD	DUN
EMP1	15	1.4	10	1.22	1.29	0.18	8.88	1.07	13.44	1.61	COMP	5	11.57	1.25	1.62	0.09	10.95	0.96	16.01	1.55	l
											GIC	5	5.14	0.45	1.42	0.13	5.25	0.37	7.49	0.57	i
											ZNPO	5	2.79	0.37	1.72	0.04	3.75	0.41	4.99	0.51	de
EMP2	15	1.4	4.66	0.33	3.44	0.31	6.49	0.44	8.7	0.6	COMP	5	5.05	0.54	3.85	0.28	6.94	0.71	9.41	0.91	j
											GIC	5	2.77	0.13	2.28	0.22	3.82	0.28	5.25	0.34	jkl
											ZNPO	5	1.16	0.29	1.6	0.23	1.85	0.43	2.71	0.55b	c
EMP3	15	1.4	4.03	1.19	2.39	0.68	5	1.4	6.86	1.91	COMP	5	3.84	0.85	2.73	0.24	5.22	0.46	7.04	0.83h	i
											GIC	5	2.82	0.27	1.99	0.29	3.58	0.36	4.98	0.48	de
											ZNPO	5	1.63	0.61	1.45	0.09	2.06	0.2	3.03	0.43	c
INC1	15	1	8.57	0.9	0.99	0.18	7.49	0.38	11.43	0.91	COMP	5	7.89	1.63	1.31	0.05	6.85	0.8	10.54	1.73	k
											GIC	5	5.39	0.61	1.39	0.09	5.34	0.39	7.72	0.69	i
											ZNPO	5	1.32	0.42	1.39	0.19	1.91	0.55	2.72	0.67	bc
INC2	15	1	6.9	0.93	2.57	0.23	7.36	0.65	10.42	1.03	COMP	5	7.38	3.63	2.44	1.01	4.78	4.29	10.27	2.17	jk
											GIC	5	3.73	0.87	2.12	0.82	4.57	0.48	6.34	0.73	fgh
											ZNPO	5	0.97	0.2	1.4	0.17	1.56	0.37	2.32	0.43	abc
INC3	15	1	4.8	0.87	2.29	0.12	5.27	0.68	7.5	1	COMP	5	4.28	0.68	2.46	0.14	4.73	0.58	6.84	0.87	ghi
											GIC	5	3.13	0.6	2	0.1	3.71	0.63	5.26	0.83	def
											ZNPO	5	0.69	0.3	1.13	0.15	1.03	0.26	1.69	0.33	ab
INC1	15	1.4	5.15	0.47	1.46	0.25	5.71	0.47	7.83	0.6	COMP	5	4.35	0.57	1.66	0.08	4.93	0.19	6.79	0.49	ghi
											GIC	5	3.65	0.48	1.3	0.11	4.23	0.5	5.73	0.69	efg
											ZNPO	5	1.08	0.3	1.3	0.16	1.72	0.49	2.42	0.55	abc
INC2	15	1.4	3.2	0.75	2.26	0.24	3.91	1.4	5.62	1.27	COMP	5	2.44	0.77	2.04	0.12	2.83	0.42	4.28	0.68	d
											GIC	5	2.45	0.25	1.95	0.06	3.29	0.23	4.54	0.31	d
											ZNPO	5	0.71	0.11	1.15	0.1	1.09	0.17	1.73	0.22	ab
INC3	15	1.4	1.77	0.28	1.75	0.16	2.32	0.39	3.4	0.49	COMP	5	1.24	0.34	1.62	0.15	1.87	0.19	2.77	0.35	bc
											GIC	5	1.36	0.09	1.47	0.06	1.82	0.12	2.71	0.16	bc
											ZNPO	5	0.52	0.39	0.91	0.15	0.98	0.18	1.49	0.18	a

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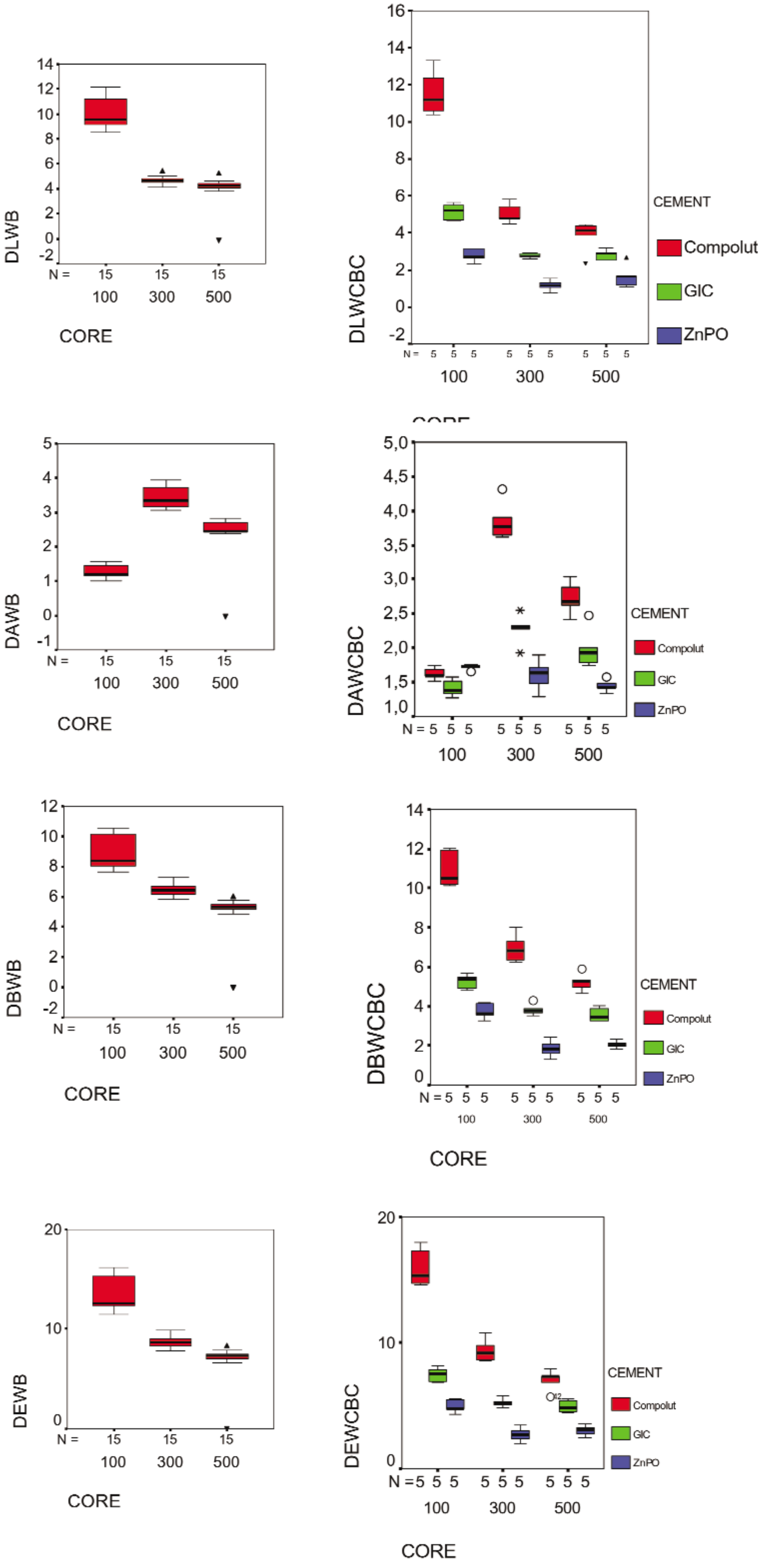

Fig. 3 — Box plots showing ΔL, Δa, Δb, and ΔE values between the samples without and with luting agents with standard black and white backgrounds for Empress, 100, 300, and 500 being the core shades.

CIELab has been an accepted method for color measurement, since each color occupies a unique location in the three-dimensional CIELab color space (CIE, 1976) (Fig. 1). CIELab color space gives the actual visualization of the color but not the color properties of the material. The ΔE values are graded as follows (Kuehni, 1976; Johnston and Kao, 1989; O'Brien *et al.*, 1991; Touati and Miara, 1993):

$\Delta E > 3.7$ = very poor match
$\Delta E > 2$ = clinically unacceptable
$\Delta E \leq 2$ = clinically acceptable
$\Delta E < 1$ = not appreciable

For our purposes, we consider $\Delta E > 2$ as clinically unacceptable (Tables 2,3).

We clearly demonstrated that the color of the luting agent does play a significant role in the final color in cases of translucent AC materials. The EMP samples are seen to be more translucent than the INC samples, due to the more translucent lithium disilicate core material in EMP as compared with the less translucent aluminum oxide core material in INC samples (Carossa *et al.*, 2001; Heffernan *et al.*, 2002). As the darkness of the samples increases from EMP1 to EMP3 and ICA1 to ICA3, the translucency decreases, and a similar pattern is also observed when luting agents are placed (ΔL values in Table 2). This is due to the increase in pigments in the ceramics to make them darker, thus reducing translucency. For EMP2 and INC2, with the high Δa value and its shift toward red, *i.e.*, when a standard black background is used, the color coordinates move markedly toward red. This unexpected change altered the end ΔE values significantly and needs to be explained by studying the reflection curve of the materials according to the Kubelka-Munk (KM) theory (Cook and McAree, 1985). This theory gives information about scattering and absorption of incident light, and has been used to predict with accuracy the colors of AC systems with several backgrounds (Miyagawa and Powers, 1983; Cook and McAree, 1985; Davis *et al.*, 1994). The clinically acceptable ΔE values are seen only with dark shades—EMP3 and INC3—with opaque luting agent ZNPO, which is only 11% of all cases. This supports the fact that translucency (ΔLBW) had a statistically significant correlation to color change (ΔEWCBC) in dark shades only in cases of ZNPO.

In Table 3, when the ΔL values for the most translucent agent COMP with a black background are compared with those for COMP with a white background, the final color with black background is further darkened. This means that, when the most translucent agent used in this study (COMP with black background) was placed, the shade of the final restoration was further darkened. This unexpected shift with the black background needs further explanation by study of the reflectance curve and application of KM theory. GIC shows the

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least change in ΔL values with white and black backgrounds, fraught within the limitations of experimental errors, making the color brighter. Thus, ZNPO has the maximum effect on translucency, making the highest shift in ΔL values with white and black backgrounds. ΔL decreases with the increase in the thickness and the darkness of the samples. The influence of the cement on the final color is dependent on the translucency of the core material (Heffernan *et al.*, 2002).

With a black background, in the case of ZNPO, the ΔE is highest, which is due to the fact that it is less translucent than the GIC and COMP. Over half of the samples, 52%, with luting agents show clinically relevant results which are exclusively due to GIC and ZNPO, as also seen statistically, thus proving that translucent luting agents have less effect on color change with dark background colors. The color of the background—with the black background, clinically, for example, where the background could be a discolored tooth, metal post or core, etc.—is the dominant color with translucent luting agents. With a white background, 33% of the samples show clinically relevant results (ΔEWWC, clinically unacceptable), which are due to all three luting agents, *i.e.*, clinically relevant color differences are observed with all luting agents, whereas, statistically, only ZNPO has showed to have a significant effect (Table4c). The color of the luting agent is clinically relevant in determining the final color of the restoration, in the case of light background colors—for example, in the case of dentin, dentin-colored esthetic posts and cores (Vichi *et al.*, 2000). The EMP samples with GIC show unexpectedly large ΔE values. This is seen with both white and black backgrounds. This could possibly be due to variations in mixing conditions, since the thickness factor can be ruled out because of low deviation in the thicknesses of GIC in samples (Table 1). Overall, the less translucent AC (*e.g.*, INC) when compared with the more translucent ones (*e.g.*, EMP) show less color change due to luting agents and background color (Carossa *et al.*, 2001; Heffernan *et al.*, 2002). A 0.4-mm increase in the thickness of INC samples does not significantly affect the color properties and does not significantly improve shade matching, as shown in the study and also proven earlier (Carossa *et al.*, 2001).

TABLE 4 — Pearson's Correlations

Luting agent	r	p
(a) ΔLBW and ΔEBCWC		
ZNPO	0.82	0.00
GIC	0.05	0.76
COMP	0.13	0.38
(b) ΔEBBC and CTh		
ZNPO	0.43	0.03
GIC	0.37	0.01
COMP	0.15	0.34
(c) ΔEWWC and CTh		
ZNPO	0.66	0.00
GIC	0.26	0.80
COMP	0.27	0.27

Conclusion

(1) EMP is more translucent than ICA. When AC restorations are used, the darker shades are less translucent than the lighter shades, and therefore the color properties of the luting agents and the background color must be considered.
(2) Luting agents, in combination with the background shade, influence the final color of the restoration.
(3) A more opaque luting agent cannot be used to mask the color of a darker background color, because of the predominance of the background color. Background shade can be masked only in cases where dark ceramics and opaque luting agents are used. With light background color, luting agents also have a clinically relevant effect on the final restoration of the ceramics.
(4) With a marginal increase in ceramic thickness (0.4 mm, in the case of INC), the color properties do not statistically significantly differ but are clinically relevant.
(5) Color cannot be predicted accurately with differing AC thicknesses, differing luting agent thicknesses and colors, and different background shades.

TABLE 3 — ΔL, Δa, Δb, and ΔE Values between the Samples without Luting Agents and Those with Luting Agents, with the Same Backgrounds

AC	TH	CEM	N	ΔLBBC	SD	ΔaBBC	SD	ΔbABBC	SD	ΔEBBC	SD	DUN	ΔLWWC	SD	ΔaWWC	SD	ΔbWWC	SD	ΔEWWC	SD	DUN
EMP1	1.4	COMP	5	-0.87	0.92	-0.16	0.14	-0.91	0.94	1.29	1.3	ab	-0.86	0.35	-0.05	0.02	-0.27	0.18	0.91	0.37	ab
		GIC	5	3.48	0.49	0.34	0.06	2.25	0.25	4.17	0.54	gh	-0.72	0.74	0.61	0.26	-0.61	0.6	1.31	0.64	abc
		ZNPO	5	4.72	0.42	0.98	0.15	4.32	0.38	6.48	0.46	jk	-1.59	0.35	1.5	0.13	-0.17	0.23	2.2	0.34	abcde
EMP2	1.4	COMP	5	-0.48	0.46	-0.22	0.24	-0.82	0.54	0.99	0.71	ab	-0.29	0.13	-0.18	0.11	-0.69	0.2	0.78	0.24	a
		GIC	5	0.75	2.14	0.91	0.33	0.95	1.85	2.91	0.6	def	-1.12	2.14	-0.05	0.54	-1.63	2.08	2.09	2.94	abcde
		ZNPO	5	3.01	0.3	2.1	0.27	3.19	0.59	4.87	0.67	hi	-0.3	0.27	0.46	0.12	-1.2	0.09	1.35	0.1	abc
EMP3	1.4	COMP	5	-0.46	0.16	-0.29	0.2	-0.76	0.44	0.95	0.48	ab	-0.9	1.02	-0.32	0.16	-0.95	0.52	1.38	1.1	abc
		GIC	5	2.66	2.18	0.81	0.23	2.11	1.57	3.5	2.67	efg	1.9	2.74	0.84	0.99	1.34	2.64	3.05	3.39	cde
		ZNPO	5	2.03	0.88	1.41	0.19	2.43	0.43	3.54	0.59	efg	-0.58	0.5	0.42	0.1	-0.75	0.18	1.1	0.32	abc
INC1	1	COMP	5	-1.23	1.19	0.03	0.04	-0.36	0.43	1.29	1.26	ab	-1.84	0.27	0.27	0.12	-0.99	0.36	2.13	0.3	abcde
		GIC	5	1.88	0.62	0.16	0.05	1.79	0.36	2.61	0.69	cde	-1.59	0.4	0.57	0.2	-0.48	0.35	1.79	0.42	abc
		ZNPO	5	3.97	0.76	1.16	0.23	4.49	0.64	6.11	0.98	j	-3.06	0.33	1.63	0.26	-0.97	0.22	3.61	0.35	de
INC2	1	COMP	5	-1.36	0.73	-0.26	0.12	-0.87	0.3	1.68	0.67	ab	0.08	3.32	-0.55	1.11	-2.77	4.54	3.81	4.97	e
		GIC	5	2.1	0.23	0.75	0.18	2.42	0.35	3.29	0.44	efg	-1.08	1.1	0.25	0.85	-0.37	0.4	1.42	1.13	abc
		ZNPO	5	4.48	0.2	2.11	0.1	5.28	0.17	7.24	0.23	k	-2.41	0.22	1.16	0.15	-1.19	0.23	2.94	0.18	bcde
INC3	1	COMP	5	-1.7	0.48	-0.02	0.19	0.68	0.51	1.92	0.37	bcd	-1.44	0.14	0.12	0.09	0.79	0.15	1.66	0.09	abcd
		GIC	5	0.75	0.28	0.75	0.09	2.86	0.18	3.06	0.22	efg	-1.02	0.18	0.4	0.11	1.16	0.13	1.6	0.15	abcd
		ZNPO	5	3.18	0.28	1.89	0.33	4.25	1.18	5.66	1.11	ij	-1.63	0.58	0.81	0.34	-0.5	0.85	2.08	0.42	abcde
INC1	1.4	COMP	5	-0.77	1.07	0.05	0.31	-0.29	0.12	1.07	0.82	ab	-0.99	0.6	-0.01	0.02	-0.49	0.09	1.12	0.57	abc
		GIC	5	1.2	0.33	0.14	0.07	1.23	0.43	1.73	0.54	abc	-0.61	0.28	0.16	0.08	-0.52	0.18	0.83	0.28	ab
		ZNPO	5	2.48	0.52	0.92	0.24	3.06	0.6	4.05	0.82	fgh	-1.86	0.18	0.85	0.15	-1.23	0.18	2.39	0.19	abcde
INC2	1.4	COMP	5	-0.39	0.58	-0.16	0.14	-0.37	0.37	0.66	0.59	a	-0.21	0.07	-0.1	0.13	0.15	1.34	0.92	0.92	ab
		GIC	5	0.72	0.17	0.43	0.07	0.83	0.18	1.18	0.23	ab	-0.48	0.19	0	0.1	-0.53	0.19	0.73	0.23	a
		ZNPO	5	1.85	0.23	1.56	0.13	2.6	0.33	3.56	0.38	efg	-1.15	0.21	0.28	0.05	-1.07	0.1	1.6	0.19	abcd
INC3	1.4	COMP	5	-0.13	0.32	-0.14	0.08	-0.44	0.1	0.56	0.14	a	-0.34	0.36	-0.13	0.1	-0.45	0.19	0.63	0.3	a
		GIC	5	0.63	0.09	0.33	0.08	0.24	0.11	0.75	0.13	ab	0.06	0.11	-0.03	0.07	-0.46	0.08	0.48	0.08	a
		ZNPO	5	1.12	0.1	0.91	0.1	0.95	0.25	1.74	0.21	abc	-0.28	0.46	0.01	0.14	-0.62	0.17	0.8	0.2	a

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Future Work

Due to the absence of standard methods of color matching and color prediction in clinical dentistry for "all-ceramic luting agent" units for specified backgrounds—which could be a post, core, a discolored tooth, or dentin—an *in silico* model for color matching, prediction, and simulation will be developed, taking into account the background shade and the shade of the luting agent, based on the Kubelka-Munk (KM) theory and Parallel Evolutionary Programming (PEP) of Artificial Neural Networks (ANN) (Angeline *et al.*, 1997).

A database with the color properties of the materials will be developed, along with an algorithm for calculation of color properties of dental restorative materials and final color predictions with various combinations and various background colors. The algorithm will be programmed in Java^{TM} (Java Sun Microsystems), mainly due to its portability. Thickness and mixing conditions will be ignored in the first instance for simplicity reasons.

The main purpose of this would be to eliminate traditional color matching and color prescription, thereby eliminating errors in human eye-color matching and prescription (Yap *et al.*, 1999). A visualization tool will also be developed so that clinicians can see the outcome of the restoration *in silico*.

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