

Color changes of esthetic elastomeric ligatures evaluated with the Commission Internationale d'Éclairage color system

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ABSTRACT

Objective: The aim of this study was to assess and compare color changes in esthetic elastomeric ligatures after 30 days *in situ* using a spectrophotometer and the Commission Internationale d'Éclairage (CIE) color system. **Materials and Methods:** The sample comprised elastomeric ligatures of four color groups ($n = 42$): blue pearl (BP); colorless; white pearl (WP); and pearl. Four samples from each group were allocated in for quadrants of seven patients in a split-mouth model. Color measurements were performed with a spectrophotometer in the elastomeric ligatures as received (T0) and after 30 days *in situ* (T1). Variables L^* , a^* , and b^* were compared between times (T1–T0) with Wilcoxon paired ranks; color changes were compared between groups with Kruskal–Wallis test; Dunn's test was used for multiple comparisons. Spearman's correlation was applied between CIELAB and CIEDE2000 calculations. **Results:** All groups showed color changes (T1–T0) in a^* and b^* , but only the Group BP had a change in L^* ($P < 0.01$). Group C showed the greatest lightness decrease ($\Delta L = -2.49 \pm 0.47$) ($P < 0.05$), the smallest yellowing ($\Delta b = 3.17 \pm 0.88$) ($P < 0.05$), and the smallest total color change ($\Delta E_{2000} = 3.19 \pm 0.85$), which had no statistical difference from Group WP ($\Delta E_{2000} = 3.36 \pm 0.53$). Correlation between ΔE_{ab} and ΔE_{2000} was moderate ($r = 0.59$; $P < 0.01$). **Conclusions:** Esthetic elastomeric ligatures became yellowish after 30 days *in situ*, and there were color differences between them.

Key words: Elastomeric ligatures, esthetics, orthodontic appliances, pigmentation

INTRODUCTION

Esthetic orthodontic appliances are a primary demand of adult patients. Due to this, the dental industry has been engaged in the development of more esthetic and less visible appliances. Polycarbonate brackets and polycrystalline/monocrystalline ceramic brackets have improved the esthetics

preserving the biomechanical features of the fixed appliances. Clear elastomeric ligatures complete a translucent look.^[1-3] However, the orthodontic esthetic set fails when the elastomeric ligatures

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stain due to dyes in the diet and conditions of the oral environment.^[3-9]

Visual color perception results from physiological and psychological responses to the wavelengths of light stimulation on cell receptors of the human eye.^[10] In dentistry, color determinations are routinely performed using visual matching to the VITA shade guide.^[11,12] However, the use of a spectrophotometer on color evaluation eliminates the influence of viewing conditions, observer's experience, and eye fatigue. Color assessments are more predictable and reliable using a spectrophotometer than the shade guide.^[13,14] The spectrophotometer identifies light wavelengths as numerical values in three coordinates (lightness, green-red, and blue-yellow) resembling the human eye visual system.^[15] Color calculation derives from mathematical formulas defined by the International Commission Internationale d'Éclairage (CIE). Original CIELAB formula evolved to CIEDE2000 color-difference equation with lightness, chroma, and hue weighting functions improving the performance for blue and gray colors. Currently, CIEDE2000 is the best color evaluation method in dentistry.^[16-21]

Only *in vitro* studies used spectrophotometers and the CIE color system to quantify staining of elastomeric ligatures. Clinical studies assessed pigmentation by means of qualitative scores. Until now, no *in situ* studies evaluated the color changes of esthetic elastomeric ligatures using a spectrophotometer. CIELAB and CIEDE2000 equations could distinguish color changes in three coordinates, elucidating the problem of elastomeric ligature pigmentation during the interval between consultations. Therefore, the aim

of this study was to assess and compare *in situ* color changes of different esthetic elastomeric ligatures using a spectrophotometer and the CIE color system. The null hypothesis was that there is no color difference related to the oral exposure and to the elastomeric ligatures types. The alternative hypothesis was that there are color differences in the three coordinates in all elastomeric ligatures types.

MATERIALS AND METHODS

The Ethics Committee of the Pontifical Catholic University approved this *in situ* study. The subjects' rights were preserved, and an informed consent was obtained from all participants. Esthetic elastomeric ligatures of two dental companies were allocated in four color groups ($n = 42$) [Table 1]. Four elastomeric ligatures from each group were randomly allocated in four quadrants of seven patients in a split-mouth model. Sample size calculation indicated the need of 33 elastomeric ligatures per group to detect a bilateral difference of 0.5 units in the total color change (ΔE_{ab}), with a power of 80% and significance level of 5% (Statistical Solutions, LLC Systems, Cottage Grove, WI, USA). The sample of 42 elastomeric ligatures per group considered 25% follow-up loss. The eligibility criteria for participation in the study were adult patients undergoing orthodontic treatment with fixed appliances, in good general and oral health conditions, with no congenital malformations and presenting at least four teeth per hemiarch both in the maxilla and in the mandible. Seven patients (three males, four females; mean age: 35.5 years) from a private orthodontic clinic met criteria and signed an informed consent form agreeing with their participation in the study.

The esthetic elastomeric ligatures were placed in ceramic brackets (Radiance, American Orthodontics) with the aid of a Mathieu plier, avoiding overstretching. Patients were instructed on proper oral hygiene using dental floss, toothbrush, and dye-free toothpaste. No recommendation was made regarding the daily diet. The next consultations were scheduled after a 30-day

Table 1: Esthetic elastomeric ligatures tested in the study

Group	n	Color	Manufacturer
BP	42	Blue pearl	Ortho Technology, Tampa, FL, USA
C	42	Colorless	American Orthodontics, Sheboygan, WI, USA
WP	42	White pearl	American Orthodontics
P	42	Pearl	Ortho Technology

Table 2: Descriptive statistics of variables L*, a*, b* (T1-T0)

Group	n	L*		a*		b*	
		Mean±SD	P	Mean±SD	P	Mean±SD	P
BP	41	-1.96±0.59	0.01*	0.58±0.39	<0.001*	4.52±0.61	<0.001*
C	34	-2.49±0.47	0.94	0.72±0.61	<0.001*	3.17±0.88	<0.001*
WP	36	-2.08±0.52	0.28	0.50±0.43	<0.001*	3.76±0.66	<0.001*
P	34	-1.93±0.66	0.87	0.83±0.45	<0.001*	4.08±1.1	<0.001*

Wilcoxon test (T1-T0), * indicates statistical significance; L*, lightness; a*, green-red chromaticity; b*, blue-yellow chromaticity; and SD, standard deviation

interval when patients underwent to professional toothbrushing. Duplicated samples of elastomeric ligatures were removed using a dental probe and stored in sealed 96-well microplates, to protection against heat, light, and moisture until to color evaluation within 24 h.

Color measurements

Quantitative and qualitative color assessments were carried out in the elastomeric ligatures as received (T0) and after 30 days *in situ* (T1). Color measurements were carried out using a portable spectrophotometer (SP60 X-Rite, Grand Rapids, MI, USA) in white background, under the same lighting, in a blind random sequence [Figure 1]. The spectrophotometer recorded numeric values in the coordinates L^* , a^* , and b^* according to the CIE color system. Coordinate L^* determines a lightness level from 0 (completely

black) to 100 (pure white). Coordinate a^* identifies chromaticity in the green-red axis, where positive values indicate red color and negative values mean a green shade. Coordinate b^* defines chromaticity in the blue-yellow axis, where yellow is positive and blue is negative.^[14,15] Differences in L^* , a^* , and b^* measures between the evaluation times (T1–T0) in each group (blue pearl [BP], colorless, white pearl [WP], and pearl) indicated a color variation in three coordinates (ΔL , Δa , and Δb). Calculation of total color change of esthetic elastomeric ligatures was performed using the CIELAB (ΔE_{ab}) and the CIEDE2000 (ΔE_{2000}) equations.^[16] Reproducibility testing was carried out on repeated measures taken by one observer in 20 samples that were randomly selected, after a 7-day interval. Visual evaluations of color were performed in a 1366 × 768 pixel screen, which displayed samples from the four elastomeric ligatures groups as received (T0) and after 30 days *in situ* (T1) [Figure 2]. Twelve observers (four orthodontists, four graduate orthodontic students, and four undergraduate students) ranked the elastomeric ligature groups in a one to four sequence, where the smallest color change was the rank one and the greatest color change was rank four.

Statistical analysis

Data were analyzed with SPSS 20.0 software (IBM, Armonk, NY, USA). Intraobserver reproducibility was tested with intraclass correlation coefficient (ICC). The Shapiro–Wilk test attested that the data were not normally distributed for all dependent variables (L^* , a^* , b^* , ΔL , Δa , Δb , ΔE_{ab} , and ΔE_{2000}). Variables L^* , a^* , and b^* were compared between times (T1–T0) with Wilcoxon paired ranks; color changes (ΔL , Δa , Δb , ΔE_{ab} , and ΔE_{2000}) were compared between groups (BP, C, WP,



Figure 1: (a) Portable spectrophotometer (SP60 X-Rite, Grand Rapids, MI, USA); (b) Selection of a white background; (c) A sample of elastomeric ligature placed for color assessment

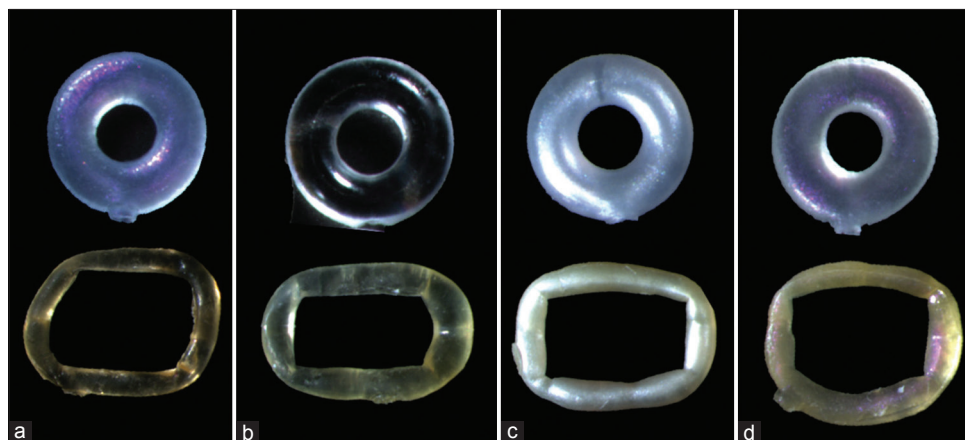


Figure 2: Esthetic elastomeric ligatures as received from the manufacturer and after 30 days *in situ*. (a) Group BP, blue pearl; (b) Group C, colorless; (c) Group WP, white pearl; and (d) Group P, pearl

and P) with the Kruskal–Wallis test; Dunn’s test was used for multiple comparisons. Spearman’s correlation was applied between CIELAB and CIEDE2000 calculations. Visual ranks of color changes were analyzed through Kendall’s coefficient. Results were significant at the 95% confidence level ($P < 0.05$).

RESULTS

Twenty-three samples were lost throughout the study (14%); intraclass coefficient showed excellent agreement between repeated measures of L^* , a^* , and b^* (ICC = 0.99). Under naked eye, all groups of esthetic elastomeric ligatures underwent pigmentation after 30 days *in situ* [Figure 2].

Table 2 reveals that all groups of elastomeric ligatures showed statistically significant chromaticity change both in the green-red axis (a^*) and in the blue-yellow axis (b^*) ($P < 0.001$). Only the Group BP presented a change in lightness level (L^*) with statistical significance ($P = 0.01$). In all groups, mean changes were negative for L^* (–1.93 to –2.49), slightly positive for a^* (0.50–0.83), and positive for b^* (3.17–4.52).

Table 3 shows the elastomeric ligatures of Group C had the greatest lightness decrease ($\Delta L = -2.49 \pm 0.47$) and the smallest yellowing ($\Delta b = 3.17 \pm 0.88$) ($P < 0.05$). Yellowing of elastomeric ligatures from Group BP was statistically greater ($\Delta b = 4.52 \pm 0.61$) than that of Group WP ($\Delta b = 3.76 \pm 0.66$) ($P < 0.05$). Only red color change of statistical significance was between Groups P ($\Delta b = 0.83 \pm 0.45$) and WP ($\Delta b = 0.50 \pm 0.43$) ($P < 0.05$).

Table 4 reveals that the smallest total color change was in the Group C ($\Delta E_{2000} = 3.19 \pm 0.85$), which showed statistical difference compared to Groups P ($\Delta E_{2000} = 3.74 \pm 0.91$) and BP ($\Delta E_{2000} = 4.11 \pm 0.54$, $P < 0.05$), and no difference compared to Group WP ($\Delta E_{2000} = 3.36 \pm 0.53$). Visual evaluations indicated a smaller color change in the Group WP, followed by Groups C, P, and BP ($W = 0.903$; $P < 0.001$). Correlation between ΔE_{ab} and ΔE_{2000} was moderate ($r = 0.59$; $P < 0.01$); only CIEDE2000 detected statistically significant color differences between elastomeric ligature groups.

DISCUSSION

The null hypothesis was rejected as the esthetic elastomeric ligatures showed color changes after 30 days *in situ* with statistical difference between elastomeric ligatures types. The alternative hypothesis was partially accepted because all groups presented a statistically significant color change in the coordinates a^* and b^* , but only the Group BP presented a significant change in the coordinate L^* .

Esthetic elastomeric ligatures remained *in situ* for 30 days, which is ordinary time interval between consultations during the orthodontic treatment of adults. All tested elastomeric ligatures were made with injection molding to prevent that material intrinsic features could influence color evaluations.^[2,5] The spectrophotometer and the CIE color system allowed numeric and accurate color difference evaluations that overcame limited source of information from visual evaluations.

Table 3: Descriptive statistics of three parameters of color change

Group	n	ΔL			Δa			Δb		
		Mean \pm SD	Minimum	Maximum	Mean \pm SD	Minimum	Maximum	Mean \pm SD	Minimum	Maximum
BP	41	–1.96 \pm 0.59 ^A	–3.38	–0.77	0.58 \pm 0.39 ^{AB}	–0.21	1.22	4.52 \pm 0.61 ^C	3.19	5.83
C	34	–2.49 \pm 0.47 ^B	–3.25	–1.46	0.72 \pm 0.61 ^{AB}	–0.36	2.69	3.17 \pm 0.88 ^A	1.99	4.81
WP	36	–2.08 \pm 0.52 ^A	–3.42	–1.31	0.50 \pm 0.43 ^A	–0.17	1.31	3.76 \pm 0.66 ^B	2.17	4.98
P	34	–1.93 \pm 0.66 ^A	–3.13	1.1	0.83 \pm 0.45 ^B	0.05	1.92	4.08 \pm 1.1 ^{BC}	0.57	6.03

Kruskal–Wallis test ($P < 0.05$) and Dunn’s multiple comparisons test. Different letters indicate statistical significance by columns. ΔL : Lightness variation, Δa : Variation in the green-red axis, Δb : Variation in the blue-yellow axis, SD: Standard deviation, BP: Blue pearl, C: Colorless, WP: White pearl, P: Pearl

Table 4: Descriptive statistics of total color changes

Group	n	ΔE_{ab}			ΔE_{2000}			Visual	
		Mean \pm SD	Minimum	Maximum	Mean \pm SD	Minimum	Maximum	Mean rank	W
BP	41	5.00 \pm 0.68	3.73	6.44	4.11 \pm 0.54 ^C	3.00	5.22	4	0.903*
C	34	4.15 \pm 0.91	2.62	6.37	3.19 \pm 0.85 ^A	1.98	5.58	1.58	
WP	36	4.37 \pm 0.71	3.03	5.79	3.36 \pm 0.53 ^{AB}	2.20	4.31	1.42	
P	34	4.65 \pm 1.11	1.24	6.87	3.74 \pm 0.91 ^{BC}	0.83	5.27	3	

Kruskal–Wallis test ($P < 0.05$) and Dunn’s multiple comparisons test; different letters indicate statistical significance by columns. Kendall’s tau coefficient (W) ($P < 0.05$); *Statistical significance, rank 1–4, smaller to greater color change. ΔE_{ab} : CIELAB, ΔE_{2000} : CIEDE2000, SD: Standard deviation, BP: Blue pearl, C: Colorless, WP: White pearl, P: Pearl

Pigmentation on esthetic elastomeric ligatures was evident under naked eye, what is in line with other clinical studies with the same evaluation time.^[3,4] Calculations of total color changes using CIELAB and CIEDE2000 equations surpassed the perception threshold of the human eye. A systematic review on color differences in Dentistry found that a ΔE_{ab} equal to 1 is perceptible for most observers in 50% of the times. Thresholds of acceptable ΔE_{ab} varied between 2 and 3.7 units.^[22] Another study using the CIEDE2000 equation reported the thresholds of 0.8 for perceptibility and 1.8 for acceptability of total color change.^[23] In the current study, total color changes were above ΔE_{ab} 3.7 in 83% of the sample and above two units of ΔE_{2000} in 98%. Visual rank of color changes reflected the numeric total color change. In both evaluations, the Groups C and WP showed less total color change, followed by the Groups P and BP.

Decreases in lightness level (negative ΔL) would be perceptible to the human eye whereas red color changes (positive Δa) would not. On the other hand, color changes to yellow (positive Δb) surpassed the acceptable limits. Studies *in vitro* already reported that clear elastomeric ligatures are more susceptible to color change in the blue-yellow axis than in the other coordinates of the CIE system.^[1,5] In the present study, the elastomeric ligatures from Group C showed both the smallest yellowing and the greatest decrease in lightness. One says that C elastomeric ligatures are not suitable for patients consuming large amounts of coffee, whereas they are adequate for who follows a daily diet with yellow-colored foods.^[5] The present study enriches the current knowledge on pigmentation of esthetic elastomeric ligatures by quantifying the color changes in the three coordinates of the CIE system. Raw data analysis revealed that a color change to yellow was responsible for 60%–83% of total color change, while a lightness decrease had an influence between 16% and 37%. Red color change showed a weight of <3%cent in total color change in all elastomeric ligatures groups. Yellowing is a weakness of the esthetic elastomeric ligatures that manufacturers need overcome as soon as possible.

Correlation between CIELAB and CIEDE2000 equations is well established.^[24,25] However, material intrinsic features may influence in the equation performance.^[18] CIEDE2000 enabled detect statistical significance in small color differences among groups and showed a better performance than CIELAB in color evaluation of elastomeric ligatures.^[19,20] Moderate correlation ($r = 0.591$) between CIELAB

and CIEDE2000 in the present study reinforces the importance of weighting lightness, chroma, and hue in the calculation of total color change of esthetic elastomeric ligatures.

Because all the esthetic elastomeric ligatures tested in the current study showed color changes above acceptable thresholds, the differences among groups were of limited clinical implication. A predictable pigmentation on esthetic elastomeric ligatures should be emphasized to patients before treatment as a shorter interval between consultations might be necessary to work around the pigmentation problem. The discoloration has been concern of research in dental materials.^[26] Further studies on staining of elastomeric ligatures might be helpful on the improvement of these materials.^[27]

CONCLUSIONS

All elastomeric ligatures showed color changes after 30 days *in situ* and became yellowish, overall. Colorless elastomeric ligatures (Group C) showed the smallest yellowing but also the greatest lightness decrease. The total color change was less in the Groups C and WP than in the Groups P and BP.

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Conflicts of interest

There are no conflicts of interest.

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