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ORIGINAL ARTICLE

Color differences of canines and incisors in a comparative long-term clinical trial of three bleaching systems

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Abstract This study was a long-term clinical trial of home and in-office LED and laser bleaching systems comparing for the first time interdental color differences (differences between the central labial surfaces of the canine and the central incisor). A total of 90 patients were divided into three groups of 30 each. One group received day guard vital bleaching, and the other two groups received one bleaching session for 20 min accelerated by a diode laser for 30 s per tooth or a blue LED for 3 min per tooth, and both groups received additionally day guard for 7 days. A total of four color measurements were carried out during the study period of 3 months and 3 weeks. The group treated with the LED tended to show the highest degree of equalization of lightness, chroma and hue. A significantly stronger overall increase in lightness was observed for canines after treatment when compared with incisors resulting in more homogeneous lightness values.

Keywords Vital tooth bleaching · Spectrophotometer · Hydrogen peroxide · LCH color space · Lightness · Chroma · Hue

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Introduction

To have whiter teeth is nowadays a very frequent and common desire of patients and esthetic dentistry has turned its attention to this appeal developing a series of techniques and materials for this purpose. Basically it is possible to divide these techniques into home-applied and in-office procedures. Home-applied procedures depend generally on some bleaching agent that liberates low levels of hydrogen peroxide (HP), mostly around 3% HP, whereas in-office procedures use much higher levels of HP (around 35%) that may be combined with some activator such as a heat or light source [1, 2]. These techniques, using coherent [3] or incoherent [4] light sources, have the advantage of being quick and convenient, and even have some beneficial effects on sensitivity. Among the newer irradiation devices are light emitting diodes (LEDs) [5], especially blue LEDs and diode lasers. Both are extremely compact devices when compared with plasma arc lamps, and are very efficient and therefore need no moving, noisy parts such as ventilators or refrigeration pumps [6]. Diode lasers emit coherent, well-collimated light, whereas the light emitted by LEDs is more difficult to collimate and they usually have a lower output power. Nowadays, there is a strong trend towards the LED devices for bleaching applications because their much lower price and sufficiently high output power (almost 1 W/cm^2) makes it possible, using a broad area device, to irradiate all the teeth at once, considerably reducing the time needed for one whitening procedure.

A significant goal of tooth whitening research has been the development of a portable tooth color measuring system that gives reliable in vivo measurements. Recent technological advances have generated a series of compact and easy to handle color measurement devices such as colorimeters and digital imaging equipment [7]. Most of these

devices permit specification of color in a way similar to the human color response [8] by using an appropriate color space. A milestone in this effort is the CIE L*a*b* color system [9] (CIELAB for short). In this system the distance between any two similar colors within the color solid approximately equals the apparent dissimilarity between them. The L* value in the CIELAB system is a measure of lightness (also called brightness), a* is a measure of the red–green contrast, and b* is a measure of the yellow–blue contrast. The a* and b* values can be used to derive the hue angle ($h^* = \tan^{-1}(b/a)$); 0° is red and 90° is yellow) and chroma ($C^* = (a^2 + b^2)^{0.5}$) that may be interpreted as colorfulness as defined by CIE 1986 [9]. Using color attribute charts for VITAPAN classical shade guides [10], a change from B4 to B3 corresponds to an increase in lightness of approximately 2 units, a change from B4 to D4 corresponds simultaneously to a chroma decrease of approximately 4 units and a hue increase of approximately 5 units.

Although tooth color is well documented, its spatial distribution amongst the patient's different teeth is not. In a recent review about tooth color [11] with 97 citations on this subject, there are only four citations concerning the color differences *amongst* labial teeth. Generally there is a color difference between upper and lower labial teeth, the maxillary teeth being generally slightly higher in the value of L* [12]. There is also a difference between central incisors, lateral incisors and canines, generally accompanied by progressive darkening of tooth color towards the canines [13, 14]. Additionally there is a spatial distribution of color on each tooth [15] between the center that has the highest value and the edges of approximately 4 units and 9 units when compared with the cervical and incisal edge, respectively [13, 14]. Similar differences have been observed by O'Brien et al. [16]. The strong decrease in value between the tooth center and the incisal edge is mainly attributed to the increased translucency of the incisal edges. For the same reason a color difference between the proximal and central anterior surfaces can also be observed [15].

This study was a long-term clinical trial of home and in-office LED and laser bleaching systems, comparing for the first time interdental color differences (differences between the central labial surfaces of the canine and the central incisor) during the bleaching procedure. The objective of the study was to determine whether different bleaching techniques can achieve approximately similar color attributes of the incisors and canines.

Materials and methods

A total of 90 subjects were enrolled, 58 women and 32 men. Their ages ranged from 18 to 45 years, with 65 subjects (72%) between 18 and 29 years and 25 subjects above 29 years. After written and verbal informed consent had been obtained, the subjects were submitted to a clinical inspection and radiographic analysis in order to verify the condition of the right and left upper central incisors and right and left upper canines. Although tooth color was not an entrance criterion, subjects with a history of tooth bleaching, current tooth sensitivity, or anterior restorations were excluded from the study. All subjects received a prophylactic treatment consisting of ultrasonic and bicarbonate jet (Profi II Ceramic, Dabi Atlante, Brazil) and brushing (Robinson brush and prophylactic toothpaste with fluoride) with the purpose of removing superficial debris before each tooth color evaluation. Tooth color was measured always on the same upper central incisor and canine using a portable spectrometer (PS4, Imbotec, New York, NY). Although the spectrometer has its own light source, care was taken to reproduce the same environmental lighting conditions and the same mouth aperture (approximately 1 mm between central upper and lower incisors). The spectrometer was positioned perpendicular and in contact with the tooth surface, centered on the incisal surface as shown in Fig. 1. As the colorimeter is very sensitive to holding position, ambient light and mouth aperture, color measurements were not performed in a blinded fashion and, in order to minimize measurement errors, it was found to be essential that the same qualified and trained researcher performed all the measurements. Different evaluators introduce different systematic errors. In order to minimize this kind of error one needs several evaluators per patient, which was logistically not practical in this study. If the same evaluator performs all the measurements, resulting in the same systematic error in all the data, more accurate comparisons between the data are possible.

After the first tooth color measurement (baseline measurement), all patients had their tooth impressions taken. The whitening tray fabrication followed the usual steps of alginate impression of the arches, pouring the impression and trimming the cast, making appropriate

Fig. 1 Color measurement of the central incisor

reservoirs on the labial surfaces to receive the whitening gel and vacuum-forming the soft tray material onto the dry cast, exceeding the cervical margins by 1 mm.

Treatment groups were balanced with respect to the following demographic characteristics: daily consumption of tooth staining food and beverage (admitted by 75 subjects), and smokers (6 subjects).The subjects were allocated to the following groups:

Laser group: laser and 35% hydrogen peroxide +7 days home bleaching
LED group: LED and 35% hydrogen peroxide +7 days home bleaching
Tray group: home bleaching for 14 days

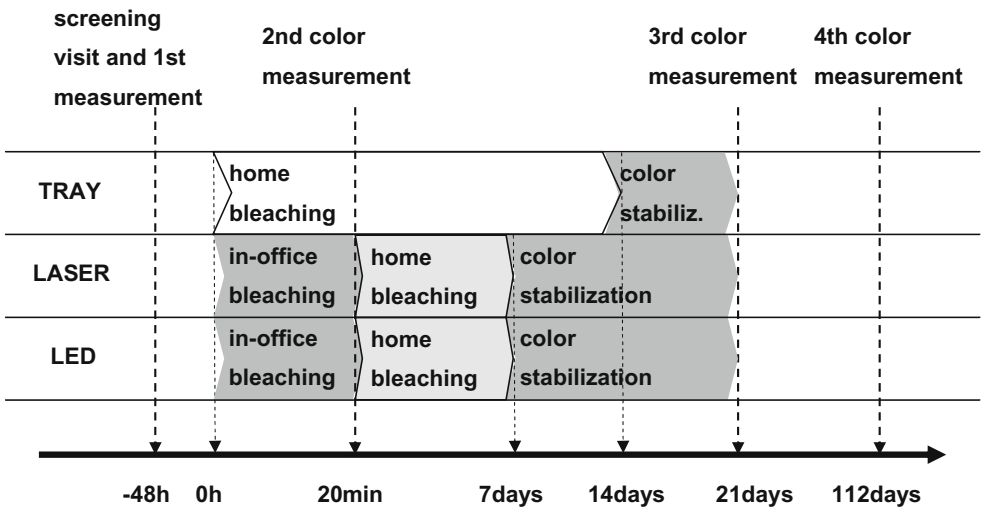
The LED equipment (Bright LEC II; MM Optics, São Carlos, SP, Brazil; λ=470 nm, P=250 mW) has an acrylic tip that covers three teeth simultaneously (area 2.4 cm^2) and was applied for 3 min to each group of three teeth (fluence 19 J/cm^2) over the dental arch from left to right canine. The 808-nm diode laser (SoftLase; Zap Lasers, Pleasant Hill, CA) was applied in a scanning motion for 30 s to each tooth (fluence 30 J/cm^2, assuming an irradiated tooth area of 1 cm^2) with 1-W output power using a 600-μm fiber delivery. Before each session, the output power of the light sources was checked with a power meter (Molectron Powermax 600) by trained staff. Home bleaching was performed for 1 h per day using 10% carbamide peroxide.

Two days after the screening visit, all subjects returned to receive their test products (bleaching syringes and custom trays), and instructions on product application and removal. Each custom-made bleaching tray was adjusted to ensure no gingival impingement. Additionally, the LED and laser groups received LED or laser irradiation (see Table 1). In both these groups the procedure was as follows. Subjects received protective eye-wear (goggles), labial moisturizer, a plastic retractor and a gingival margin dam. A 0.5 to 1-mm thick layer of whitening gel (Whiteness HP, FGM, Brazil; 35% hydrogen peroxide) was applied and rapidly agitated (approximately 3 s) with an ultrasound probe (Profi II Ceramic, Dabi Atlante, Brazil) without cooling in order to achieve a good chemical contact with the tooth surface. This gel was left in place prior to irradiation for approximately 5 to 7 min after which a second layer of whitening gel was applied, mixed with the first layer and immediately irradiated with the light source. The final layer had an overall thickness of approximately 2 mm. Altogether, the bleaching gel remained in contact with the tooth surface for exactly 20 min, after which the remaining layer was removed with a high-speed suction system and a water jet was applied, followed by the removal of the dam. A second color measurement was taken immediately after the in-office bleaching.

All subjects in the three groups had no treatment for at least 7 days before the next clinical visit and color evaluation in order to allow for color stabilization, which was carried out 2 days from the beginning of the effective treatment (Table 1). After another 3 months (total of 112 days from the beginning of the effective treatment) the subjects returned for a follow-up and last color evaluation visit. Overall, there were four color evaluations with the exception of the tray group that did not have measurement 2 (after in-office bleaching). Color values were obtained in RGB color space and transformed into CIE L*C*h*.

All data was analyzed individually with respect to normality of distribution and homogeneity of variances using the Shapiro-Wilk and Brown-Forsyth tests, respectively. Since all the data (differences between canines and incisors and normalized data) turned out to have normal distributions, only parametric tests were applied. Two groups were compared using the *t*-test or paired *t*-test,

Table 1 Study timeline



depending on whether the groups were independent or dependent, respectively. For more than two independent groups with normal distributions and equal initial conditions the ANOVA test was used or, in cases of different initial conditions (Fig. 3b), the ANCOVA test and, for dependent groups, the repeated measures ANOVA test was used.

Results

Two patients abandoned the treatment, one in the tray group and one in the laser group. Another four patients did not attend for the last color evaluation (tray group one subject, laser group one subject, LED group two subjects) and were excluded from the evaluation. Three patients in the tray group and two patients each in the laser and LED groups used their tray sometimes for more than 1 h per day. We also recorded side effects. Hypersensitivity was reported by a total of six subjects (two in each group, five women, and one man in the LED group). Two subjects in the laser group reported mild sensitivity, two subjects in the LED group reported sensitivity (one intense and one mild), and two subjects in the tray group reported moderate sensitivity. The chi-squared test was applied to these binomial, independent data, but revealed no statistically significant difference in terms of hypersensitivity between the three groups ($p>0.05$).

Comparing the normalized lightness of the central incisor and the canine between the three groups (Fig. 2a), there was a general tendency for a greater increase in whiteness of the canines, with a statistically significant difference ($p<0.05$) in the LED and laser groups at the end of the treatment. After the bleaching procedures (21 days) there was a tendency for a greater lightness regression in the incisors than in the canines. The final difference in lightness was statistically the same for all three treatments (Fig. 2b) and the overall lightness difference (mean difference for all treatments together) showed a statistically significant decrease ($p<0.05$) until the end of the treatment (Fig. 2c) by 1.2 units or 16%, resulting in an effective increase in lightness homogeneity of the teeth. Before treatment the incisors showed a mean lightness value 8 units higher than the canines. The LED group showed the strongest decrease (Fig. 2b) in lightness difference and also a statistically significant decrease after only 21 days (Fig. 2a; individual lightness measurements in the LED group are shown in Table 2 for comparison).

Comparing the normalized chroma values (Fig. 3a), only the LED group showed a statistically significant decrease ($p<0.05$) in chroma between the incisor and canine (approximately 1.5 units or 73%, Fig. 3b). In general, chroma values were very close to zero (Fig. 3b) and visible changes due to the bleaching procedures were faint.

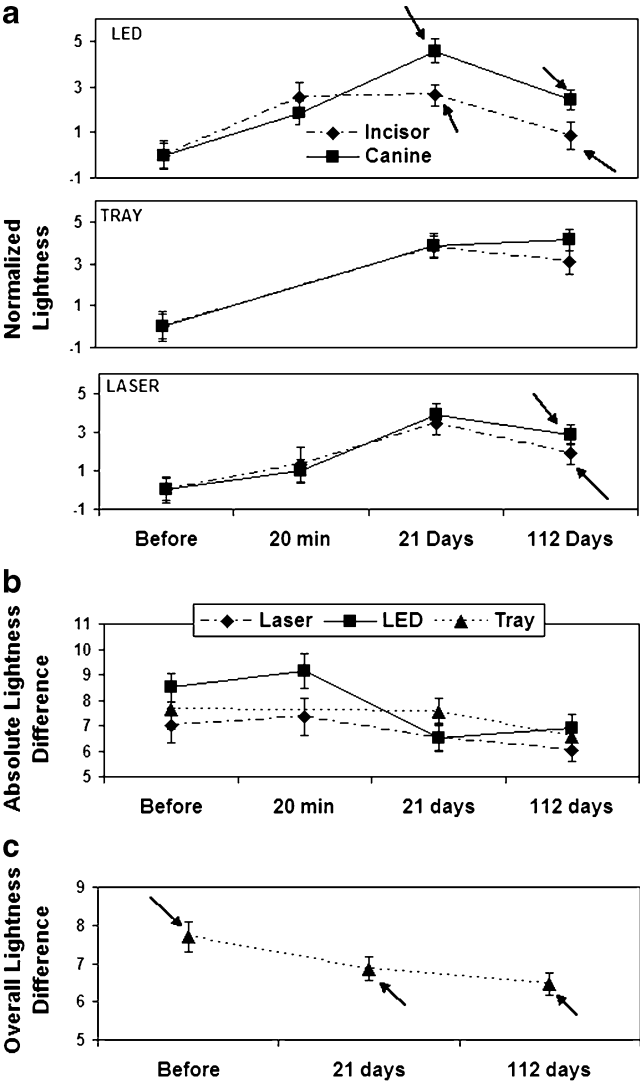


Fig. 2 Lightness differences. **a** Baseline normalized lightness increase of the canines and incisors separately for each of the three treatments; **b** Absolute differences (incisor–canine) for all treatments; **c** Overall mean difference. Opposing arrows indicate statistically significant differences ($p<0.05$)

Comparing the normalized hue values (Fig. 4a), there was a general red shift (negative values) that was stronger for the canines than for the incisors, this difference being statistically significant ($p<0.05$) for the LED and laser groups at the end of the treatment. The absolute differences at the end of all treatments were statistically the same (Fig. 4b) and showed a statistically significantly increase ($p<0.05$) contrary to what may be expected (Fig. 4c). Of all the groups, the LED group showed the smallest increase in difference in hue value of the canines and incisors (Fig. 4b).

The subjects' subjective responses were assessed by a satisfaction survey at the end of the treatment. Seven subjects were not satisfied with the results, one in the laser group (smoker, female, more than 29 years of age), four in

Table 2 Individual lightness differences (incisor–canine) in the LED group including the mean values and standard errors

Patients (LED group)	Before treatment	After treatment		
		20 min	21 days	112 days
1	10.5	11.40	6.4	2.7
2	4.5	0.4	3.3	0.8
3	6.2	4.2	5.5	5.1
4	5.2	5.2	4.2	2.0
5	10.0	7.3	6.3	9.3
6	6.4	12.4	7.8	6.9
7	8.0	10.0	5.2	13.8
8	7.0	8.5	5.6	6.3
9	6.2	6.1	0.9	4.8
10	8.2	3.8	5.8	5.6
11	12.4	11.3	6.5	6.4
12	6.9	11.3	-0.1	4.9
13	9.3	6.8	7.8	5.3
14	12.3	16.4	9.0	8.4
15	4.3	11.7	4.0	4.9
16	15.0	13.6	11.7	9.3
17	9.8	13.8	6.2	10.5
18	12.0	9.9	9.3	10.5
19	11.0	5.9	10.5	11.2
20	5.0	4.4	5.7	6.8
21	12.0	13.2	7.4	7.7
22	8.9	9.8	6.8	8.6
23	4.8	9.6	8.5	6.7
24	7.8	11.8	11.1	3.7
25	11.4	10.2	10.5	8.5
26	6.6	9.3	1.3	4.7
27	9.9	8.0	7.8	10.4
28	6.2	9.7	8.0	7.1
Mean	8.49	9.15	6.53	6.89
Standard error	0.54	0.68	0.56	0.56

the LED group (two females, one more than and one less than 29 years of age, and two males less than 28 years of age), and two in the TRAY group (both female, more than 29 years of age, one a smoker). The chi-squared test, showed no statistically significant differences in satisfaction between the three groups ($p>0.05$).

Discussion

Tooth whitening involves a series of complex color changes that alter a set of separate color parameters of which L* is generally regarded as the primary one and also the most used to assess the effectiveness of a bleaching procedure. Nevertheless, the patient's subjective response to whiteness is connected to hue, chroma and also to intra- and interdental homogeneity. These changes are directly related to the tooth site and also to the type of tooth (incisor and canine).

Translucency, opacity, iridescence, surface gloss and fluorescence are secondary optical properties of the teeth, and lightness, hue and chroma are the main ones [14, 17,18]. The most demanding tooth region regarding bleaching is the cervical area which has been shown to have the lowest translucency [14]. The middle site of teeth is considered the site that best represents the color, because the incisal site is most often translucent and is affected by its background and because the cervical color is modified by scattered light from the surrounding soft tissues in the mouth [12, 14, 16, 18]. The anterior dentin begins to dominate tooth shade as a result of normal wear, and thus the dentin chroma is more saturated leading to a lower overall tooth value [8]. The measurement of tooth color is possible using several methods including visual assessment with shade guides, colorimetry, spectrophotometry and analysis of digital images on the computer. These methods have successfully been used to measure longitudinal color changes of teeth that have undergone whitening procedures [19–23].

Upper anterior teeth are known to be slightly more yellow than lower anterior teeth [12] and the upper central incisors show a higher value than the lateral incisors and canines [14, 16, 24]. Hasegawa et al. [13] and O'Brien et al.

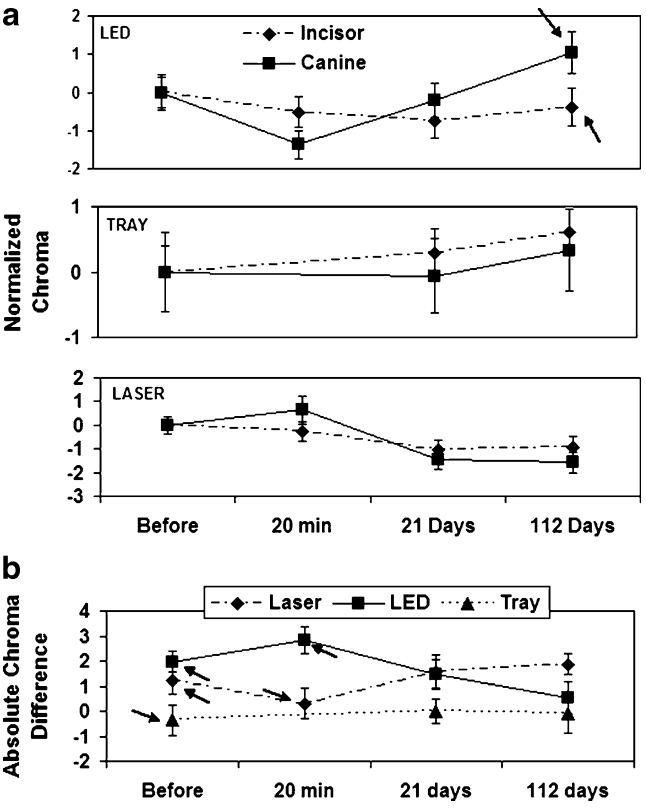


Fig. 3 Chroma differences. **a** Baseline normalized chroma variation of the canines and incisors separately for each of the three treatments. **b** Absolute differences (incisor–canine) for all treatments. Opposing arrows indicate statistically significant differences ($p<0.05$)

[16] found significant variations in L* a* b* values along the axis. In terms of L* the center was the lightest portion while in the cervical and incisal areas the value was significantly lower. The highest values a* and b* were found in the cervical area with a gradual and significant reduction towards the incisal edge where the value of b* was lower than the value of a*.

Table 2 shows that the outcome of the procedures varied strongly from patient to patient. The degree of success depended on baseline demographics such as type of stain, initial tooth color and patient age [8]. In vivo measurements also have much larger variability than in vitro measurements and therefore require much larger numbers per group.

The fact that the overall lightness difference (Fig. 2c) decreased, indicates that bleaching procedures do homogenize the whiteness of teeth, because the relative bleaching effect is generally higher with darker teeth as demonstrated in this study (Fig. 2a) and elsewhere [25]. In the last observation period, from 21 days to 3 months, the lightness of the teeth regressed as expected [26], and this effect was more pronounced for the incisors, contrary to what one may expect [27]. The red shift of both incisors and canines has been observed before [28] and might be linked to the higher transparency of the teeth after the bleaching procedure which influences the color measurements and makes them more background-dependent [15] reflecting predominantly the red color from the oral soft tissues [16, 18]. It should be noted that hue is not a primary variable and also must be seen in context with color saturation. Because of the low levels of color saturation associated with teeth [29, 30], also shown in our study (Fig. 3b), the effect of the change in hue is slight.

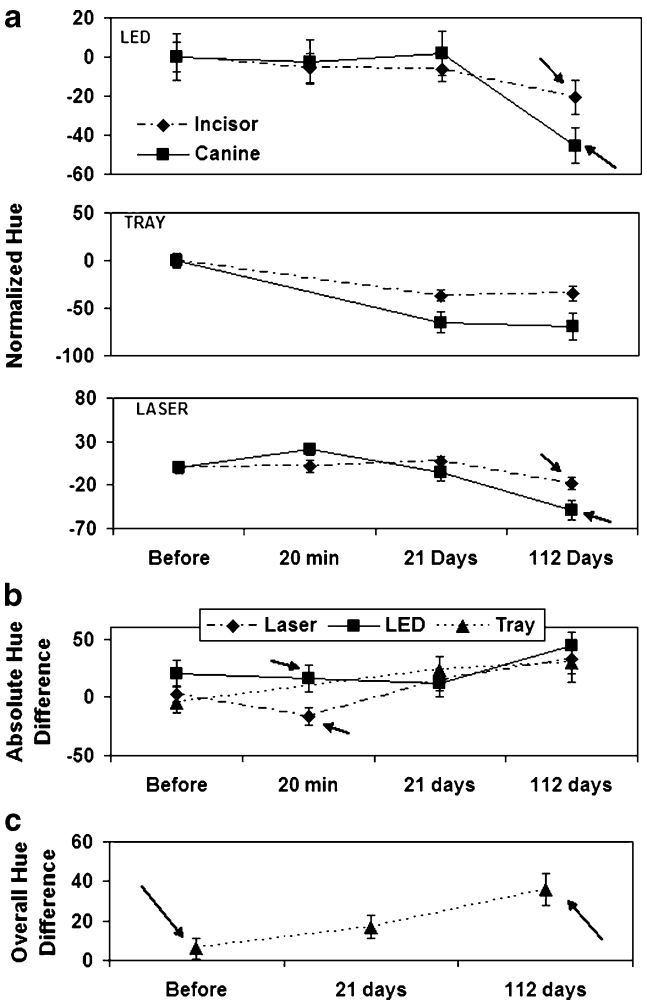


Fig. 4 Hue differences. **a** Baseline normalized hue decreases of the canines and incisors separately for each of the three treatments (negative numbers indicate red shift). **b** Absolute differences (incisor–canine) for all treatments; **c** Overall mean differences. Opposing arrows indicate statistically significant difference ($p<0.05$)

In our study the LED treatment showed the strongest trend in equalizing the whiteness, chroma and hue values of canines and incisors whereas the laser and tray treatments showed a similar behavior throughout. Only one session of in-office bleaching was applied in the LED and LASER group. Although the TRAY group tended to show better results in terms of interdental color homogenization, future studies would benefit from the use of additional in-office bleaching sessions and may demonstrate more clearly which technique is the most appropriate for this purpose.

It is important to note that although there are a considerable number of publications that report *absolute* values of L*C*h* for different bleaching procedures showing different outcomes, only *relative* changes (interdental differences) between incisors and canines were evaluated in this study. If the objective is to decrease the differences between canines and incisors, our study shows that LED, laser and home bleaching procedures have end-results that do not differ significantly in any of the three color attributes, as shown in Figs. 2b, 3b and 4b.

Conclusion

Interdental color differences are an important issue in the patient's subjective response to the whitening procedure. All procedures evaluated in this study were effective in decreasing the color differences in terms of lightness (L*), the primary variable. Comparing the color differences of the central labial surfaces of the central incisor and the canine of all treatments together, a statistically significant decrease in the difference in lightness was observed. Also, a statistically significant increase in the difference in hue values was observed. The group treated with the LED tended to show better equalization of lightness and color saturation (C*) and also showed the smallest differences in hue (h*) compared with the groups receiving the other two treatments, which were not significantly different. There were no

statistically significant differences between the three groups in terms of patient satisfaction or hypersensitivity.

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