A randomized CIE L*a*b* evaluation of external bleaching therapy effects on fluorotic enamel stains

Michael Knösel, Dr Med Dent[1]/Rengin Attin, Dr Med Dent[2]/
Klaus Becker[3]/Thomas Attin, Dr Med Dent[4]

Objective: To evaluate the effect of external bleaching on the color and luminosity of fluorotic stains and adjacent, normally mineralized enamel areas by means of CIE L*a*b* colorimetry. **Method and Materials:** Eighteen adolescents with mild to moderate fluorotic stains were randomly assigned to either bleaching group A (n = 9) or control group B. Eligibility criteria were fluorotic stained maxillary incisors or canines and the informed consent of the participants and their guardians. Using a colorimeter, CIE L*a*b* values of maxillary incisors and canines were assessed at baseline (T1) in the center of the fluorotic stained area (F1) and at adjacent, normally mineralized enamel areas (F2). Then, external bleaching with Illuminé office (30% hydrogen peroxide, Dentsply DeTrey) was performed for 60 minutes, followed by color reassessment (T2). After 14 days (T3), a 2-week home bleaching period with a daily bleaching time of 1 hour with Illuminé home (15% carbamide peroxide, Dentsply DeTrey) was conducted with subsequent color determination (T4). **Results:** After completion of bleaching therapy, 96.0% of all fluorotic areas (F1) and 100% of normal enamel areas (F2) showed a significant change within group A, compared to 29.4% in control group B. Comparing the collective ΔE (L*, a*, b*) of F1 and F2, 60.0% of all areas showed significant differences after completion of bleaching therapy, compared to 88.0% initially. Of group B sites, 82.4% showed color differences in the beginning (T1) and 88.2% at the end (T4). **Conclusion:** Whereas a single 1-hour session of in-office bleaching with 30% hydrogen peroxide does not significantly affect the color and luminosity of fluorotic teeth, a 14-day period of home bleaching leads to an assimilation of the color of the fluorotic stain with the color of surrounding enamel areas due to different responses of sound and fluorotic enamel to the bleaching regime. *(Quintessence Int 2008;39:391–399)*

Key words: CIE L*a*b* colorimetry, external bleaching, fluorotic stains

The nature of fluorosis, its genesis and pathology, as well as the histologic properties of fluorosed dental enamel, has been the focus of many studies.[1–4] Depending on the fluoride levels of drinking water, a prevalence of up to 54% of dental fluorosis seems to be evident.[5] However, mild to moderate fluorotic mottling in contemporary literature is considered a primarily esthetic problem.[6–8] McKnight et al[7] provided evidence that dental fluorosis is perceived more as an esthetic concern than other enamel opacities. Also, literature on oral health–related quality of life[9] and psychosocial aspects of fluorotic stains[6] points out that there is an esthetic treatment need in cases of dental fluorosis. Thus, many publications have been dedicated to the esthetic correction of fluorotic stains. Besides veneering and crowning to correct incisor esthetics as a field-

[1]Assistant Professor, Department of Orthodontics and Dentofacial Orthopedics, Center of Dentistry, Georg-August-University, Göttingen, Germany.

[2]Consultant, Zürich, Switzerland.

[3]Research Assistant, Clinic for Preventive Dentistry, Periodontology, and Cariology, University of Zürich, Zürich, Switzerland.

[4]Professor and Head, Clinic for Preventive Dentistry, Periodontology, and Cariology, University of Zürich, Zürich, Switzerland.

Correspondence: Dr Michael Knösel, Department of Orthodontics and Dentofacial Orthopedics, Center of Dentistry, Georg-August-University, Robert-Koch-Str. 40, Göttingen, Germany 37099. E-mail: mknoesel@yahoo.de

tested solution for severe fluorotic stains,[3] 2 main alternative approaches have been established to treat fluorosis-stained teeth; first, the microabrasive method,[10–12] and second, changing the perception of the stains by bleaching,[13,14] as well as combinations of both methods.[15,16]

Welbury and Shaw[17] suggest a paste of hydrochloric acid and pumice as the treatment of choice in cases of fluorotic stained teeth. Comparing an acid-bleach combination technique for treating fluorotic incisors to a singular acid technique, Wong[15] reported no clinical differences in either treatment time or esthetic results. Later, Train et al[10] recommended the abrasive technique as definitive treatment only for teeth with mild fluorosis, because of enamel-surface alteration mostly in severe and moderate cases. Similarly, Akpata[3] suggested that the choice among bleaching, abrasive, or restorative correction be based on the severity of fluorosis. Using a 35% hydrogen peroxide bleaching, Bussadori et al[14] succeeded in providing a more uniform appearance to incisors affected by fluorosis, since the color of the fluorotic areas matched better with the remaining tooth surface after the bleaching process.

CIE L*a*b* colorimetry has been established as a method for assessing color changes and efficacy of color-changing agents.[18–23]

Whereas Chen et al[24] showed in a scanning electron microscopic study the effect of bleaching solutions on fluorotic stained enamel, Giambro et al[25] were the first to evaluate the character of mottled human enamel by means of CIE L*a*b* colorimetry.

These days, the esthetic treatment of bleaching fluorotic stains is common practice. Given the vast assortment of different bleaching agents currently available, CIE L*a*b* evaluation seems instrumental in making the effects of different bleaching agents or microabrasive methods on fluorotic stains comparable.

However, there is a lack of information about how much the objective color parameters of the CIE L*a*b* system might be altered in fluorotic and adjacent nonfluorotic enamel by bleaching. Since no CIE L*a*b* evaluation of color changes in bleaching dental fluorosis has been conducted yet, this study aims at providing a basis for comparing the efficiency of different bleaching agents or methods in the treatment of fluorotic stains.

The objective of the present study was to evaluate the change in fluorotic stains and surrounding, nonfluorotic enamel areas under the effect of external bleaching by means of CIE L*a*b* colorimetry and, furthermore, to appraise patient perception of the esthetic appearance of stains after a single bleaching therapy. The null hypothesis was that the percentage of collective ΔE (L*a*b*) of fluorotic stains and surrounding enamel surfaces does not decrease after completion of the presented bleaching regime compared to baseline.

METHOD AND MATERIALS

During a period of 6 months, every patient in the Department of Orthodontics, Göttingen University, who met the eligibility criteria was informed about the present study design; of the 584 patients, 20 Caucasian subjects met the criteria, 2 of whom refused to participate. The remaining 18 subjects (7 males, 11 females; mean age 18.4 years, SD 4.3 years) were randomly assigned by lot to either bleaching group A (n = 9) or control group B (n = 9).

This study was approved by the ethics committee of Göttingen University. Eligibility criteria were mild to moderate fluorotic stained maxillary incisors or canines and the informed consent of the subjects and their guardians for participating in the study. Exclusion criteria were hypersensitivities, proximal caries, insufficient restorations, younger than 14 years, and gingival diseases. The total enamel surfaces eligible for assessment were 25 in group A and 17 in group B.

The setup of the study is presented in Fig 1. All measurements were performed in the Department of Orthodontics at the Göttingen University Hospital. For baseline examination (T1) of both groups, color determination of carefully wetted maxillary incisors and canines was performed chairside in well-lit,

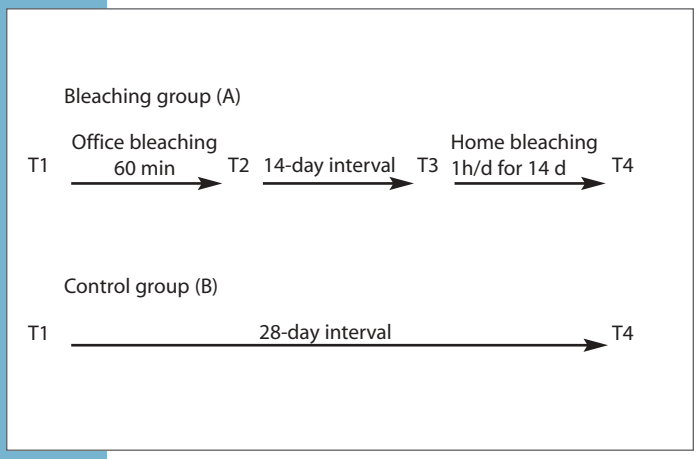

Fig 1 Setup of the study. Color assessments were conducted at T1 to T4.

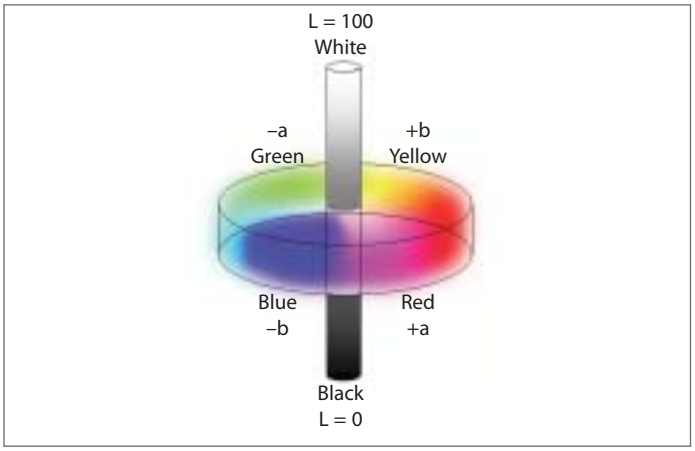

Fig 2 The CIE L*a*b* coordinate system for chrominance and luminance. Parameter L* corresponds to the degree of lightness in the Munsell system, while the a* and the b* values give the position on the red or green axis (+a* = red, –a* = green) and yellow or blue axis (+b* = yellow, –b* = blue), respectively.

standardized, ambient conditions (ie, the same chair position and assessment field illumination were maintained throughout all assessments) using a colorimeter (ShadeEye, Shofu) recording CIE L*a*b* values.

The CIE L*a*b* system includes 3 channels. The first of these channels describes the object's luminance (parameter L*), while the 2 other channels mark the chrominance (axis of value a* reaching from green to red; axis of b* from blue to yellow) (Fig 2). Th same operator performed all CIE L*a*b* determinations. The colorimeter was used according to the manufacturer's instructions. In pre-series assessments of maxillary enamel surfaces of 3 subjects performed at a 3-day interval, no relevant differences were detected among the respective measurements.

With group A, baseline color determinations (T1) were performed immediately before initiation of the in-office bleaching session in the area of the initial lesions (F1) and at adjacent, normally developed enamel areas (F2) by placing the nozzle of the colorimeter on these areas. The localization of F2 for every site was noted so that it could be retrieved in the subsequent color determinations (Fig 3).

Then, Illuminé office bleaching gel (30% hydrogen peroxide, Dentsply DeTrey) was applied using a tray 1 time for 60 minutes onto the anterior maxillary teeth. Per the manufacturer's instructions, neither heat nor light activation of the bleaching gel was performed. After the 60-minute treatment, the color determination was repeated (T2). After an interval of 2 weeks and reassessment (T3), a 14-day home-bleaching regimen for group A was begun for 1 hour per day with Illuminé home (15% carbamide peroxide, Dentsply DeTrey). After 14 days, color determinations were repeated (T4).

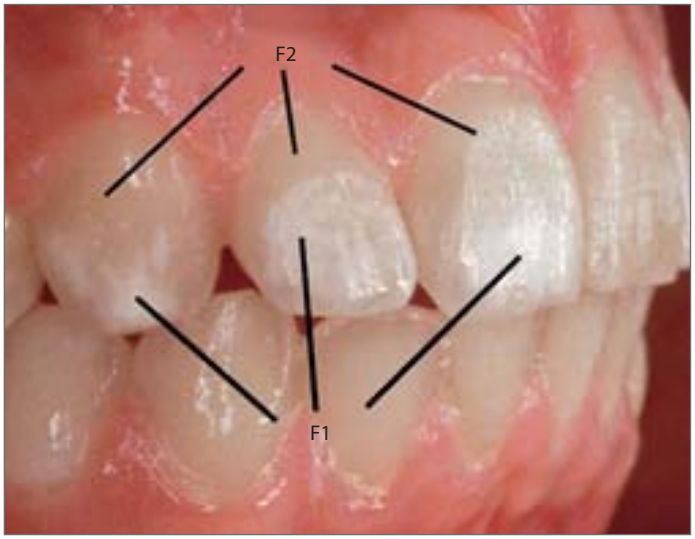

Fig 3 Color determinations were performed at the center of the fluorotic stained areas (F1) and at adjacent, normally mineralized enamel areas (F2).

Questionnaire: Expectation, Outcome, and Side Effects of Bleaching Therapy

To what extent is fluorotic mottling bothering you?

1 2 3 4 5 6 7 8 9 10

1 = not at all 10 = strongly

Satisfaction with outcome after office bleach session

1 2 3 4 5 6 7 8 9 10

1 = discontented, expectations not fulfilled 10 = complete satisfaction

Satisfaction with outcome after home bleaching

1 2 3 4 5 6 7 8 9 10

1 = discontented, expectations not fulfilled 10 = complete satisfaction

Side effects: Hypersensitive teeth during or after bleaching

1 2 3 4 5 6 7 8 9 10

1 = not acceptable 10 = no side effects

Side effects: Rough enamel surface after bleaching

1 2 3 4 5 6 7 8 9 10

1 = not acceptable 10 = no side effects

Side effects: Gingival (gums) problems during or after bleaching

1 2 3 4 5 6 7 8 9 10

1 = not acceptable 10 = no side effects

Expenditure of time

1 2 3 4 5 6 7 8 9 10

1 = not appropriate 10 = appropriate

Would you recommend this kind of bleaching therapy to your best friend?

YES NO

Thank you for your cooperation!

Fig 4 The questionnaire used for evaluation of adverse effects and patient satisfaction.

In group B, color was assessed at baseline (T1) and then repeated after a 4-week interval (T4) (see Fig 1).

Evaluation of patient satisfaction

With the help of a questionnaire, patients' subjective satisfaction concerning the outcome of the bleaching therapy was evaluated (scale 1 to 10), as was the occurrence of adverse effects during bleaching (Fig 4).

Statistical analysis of color change

Color determinations at F1 and F2 were performed 4 times (T1 to T4) in both groups. Statistical analysis was performed using the Statistica program (StatSoft). Mann-Whitney *U* test and Fisher exact test ($P = .05$) were applied for calculating the significance of the differences in groups A and B at any time point (T1 to T4). Paired *t* tests ($P = .05$) were used to compare the changes between F1 and F2 at time points T1 to T4.

Table 1a No. and percentages of sites with DE > 3.0 or > 3.7 units in the areas F1 vs F2 in bleaching group A

	T1		T2		T3		T4	
F1 – F2	n	%	n	%	n	%	n	%
DE > 3.0 units	22	88.0	20	80.0	15	60.0	15	60.0
DE > 3.7 units	22	88.0	20	80.0	12	48.0	13	52.0

$DE_{(F1T1 - F2T1)} = [(L_{F1T1} - L_{F2T1})^2 + (a_{F1T1} - a_{F2T1})^2 + (b_{F1T1} - b_{F2T1})^2]^{1/2}$ gives the color difference between reference area (F2) and WSL (white spot lesion) area (F1) at baseline (T1).
$DE_{(F1T2 - F2T1)} = [(L_{F1T2} - L_{F2T2})^2 + (a_{F1T2} - a_{F2T2})^2 + (b_{F1T2} - b_{F2T2})^2]^{1/2}$ gives the color difference between F2 and F1 after completion of the office session (T2).
$DE_{(F1T3 - F2T3)} = [(L_{F1T3} - L_{F2T3})^2 + (a_{F1T3} - a_{F2T3})^2 + (b_{F1T3} - b_{F2T3})^2]^{1/2}$ gives the color difference between F2 and F1 after the 14-day interval (T3).
$DE_{(F1T4 - F2T4)} = [(L_{F1T4} - L_{F2T4})^2 + (a_{F1T4} - a_{F2T4})^2 + (b_{F1T4} - b_{F2T4})^2]^{1/2}$ gives the color difference between F2 and F1 after completion of office and home sessions (T4).

Table 1b No. and percentages of sites with DE > 3.0 or > 3.7 units in the areas F1 vs F2 in control group B

	T1		T4	
F1 – F2	n	%	n	%
DE > 3.0 units	14	82.4	15	88.2
DE > 3.7 units	12	70.6	13	76.5

$DE_{(F1T1 - F2T1)} = [(L_{F1T1} - L_{F2T1})^2 + (a_{F1T1} - a_{F2T1})^2 + (b_{F1T1} - b_{F2T1})^2]^{1/2}$ gives the color difference between reference area (F2) and WSL area (F1) at baseline (T1).
$DE_{(F1T4 - F2T4)} = [(L_{F1T4} - L_{F2T4})^2 + (a_{F1T4} - a_{F2T4})^2 + (b_{F1T4} - b_{F2T4})^2]^{1/2}$ gives the color difference between F2 and F1 after the 28-day control interval (T4).

Determination of clinical visibility: Analysis of CIE (L*a*b*) values

Although a ΔE difference of 3 units is sometimes regarded as an indicator for mismatching colors, according to most studies concerning color stability, a color change is said to be clinically visible in any site with ΔE data higher than 3.7 units.[19] Therefore, thresholds of 3.0 and 3.7 units were established for CIE L*a*b* ΔE.

The collective ΔE data of areas F1 and F2 before bleaching (T1), after completion of the office session (T2), after the rest interval (T3), and after completion of home bleaching therapy (T4), were evaluated on the basis of the following equation[18]:

$$\Delta E_{(Fx,\,Tx-Fy,Ty)} = [(L_{Fx,\,Tx} - L_{Fy,\,Ty})^2 + (a_{Fx,\,Tx} - a_{Fy,\,Ty})^2 + (b_{Fx,\,Tx} - b_{Fy,\,Ty})^2]^{1/2}$$

F1 and F2 data were then individually examined at T2, T3, and T4.

RESULTS

Collective ΔE (L*a*b*)

According to trial power analysis, at least 15 sites were needed to reveal relevant ΔE (L*a*b*) differences of at least 3.0 units in our trial; 25 sites in group A and 17 in group B were assessed. Comparing the collective ΔE (L*a*b*) of F1 and F2, 52.0% of all areas showed significant differences after completion of bleaching therapy, compared to 88.0% initially, indicating a better color matching of these 2 areas compared to baseline (Table 1a). Of group B sites, 82.4% showed color differences in the beginning (T1) and 88.2% at the end (T4) (Table 1b). Under the premise of 3.0 units as the threshold for ΔE (L*a*b*), 96.0% of all fluorotic areas (F1) and 100% of area F2 showed a significant change after completion of bleaching therapy, compared to 29.4% in control group B (F1 and F2) (Tables 2a, 2b, 3a, and 3b).

Table 2a No. and percentages of sites with DE > 3.0 or > 3.7 units in area F1 in bleaching group A

	T2		T3		T4	
F1	n	%	n	%	n	%
DE > 3.0 units	16	64.0	15	60.0	24	96.0
DE > 3.7 units	14	56.0	12	48.0	20	80.0

$DE_{(F1T1 - F1T2)} = [(L_{F1T1} - L_{F1T2})^2 + (a_{F1T1} - a_{F1T2})^2 + (b_{F1T1} - b_{F1T2})^2]^{1/2}$ gives the color changes of F1 after completion of the office session (T2).
$DE_{(F1T1 - F1T3)} = [(L_{F1T1} - L_{F1T3})^2 + (a_{F1T1} - a_{F1T3})^2 + (b_{F1T1} - b_{F1T3})^2]^{1/2}$ gives the color changes of F1 after the 14-day interval (T3).
$DE_{(F1T1 - F1T4)} = [(L_{F1T1} - L_{F1T4})^2 + (a_{F1T1} - a_{F1T4})^2 + (b_{F1T1} - b_{F1T4})^2]^{1/2}$ gives the color changes of F1 after completion of the office and home sessions (T4).

Table 2b No. and percentages of sites with DE > 3.0 or > 3.7 units in area F1 in control group B

	T4	
F1	n	%
DE > 3.0 units	5	29.4
DE > 3.7 units	5	29.4

$DE_{(F1T1 - F1T4)} = [(L_{F1T1} - L_{F1T4})^2 + (a_{F1T1} - a_{F1T4})^2 + (b_{F1T1} - b_{F1T4})^2]^{1/2}$ gives the color changes of F1 after the 28-day control interval (T4).

Table 3a No. and percentages of sites with DE > 3.0 or > 3.7 units in area F2 in bleaching group A

	T2		T3		T4	
F2	n	%	n	%	n	%
DE > 3.0 units	12	48.0	17	68.0	25	100.0
DE > 3.7 units	10	40.0	17	68.0	24	96.0

$DE_{(F2T1 - F2T2)} = [(L_{F2T1} - L_{F2T2})^2 + (a_{F2T1} - a_{F2T2})^2 + (b_{F2T1} - b_{F2T2})^2]^{1/2}$ gives the color changes of F2 after completion of the office session (T2).
$DE_{(F2T1 - F2T3)} = [(L_{F2T1} - L_{F2T3})^2 + (a_{F2T1} - a_{F2T3})^2 + (b_{F2T1} - b_{F2T3})^2]^{1/2}$ gives the color changes of F2 after the 14-day interval (T3).
$DE_{(F2T1-F2T4)} = [(L_{F2T1} - L_{F2T4})^2 + (a_{F2T1} - a_{F2T4})^2 + (b_{F2T1} - b_{F2T4})^2]^{1/2}$ gives the color changes of F2 after completion of the office and home sessions (T4).

Table 3b No. and percentages of sites with DE > 3.0 or > 3.7 units in area F2 in control group B

	T4	
F2	n	%
DE > 3.0 units	5	29.4
DE > 3.7 units	4	23.5

$DE_{(F2T1 - F2T4)} = [(L_{F2T1} - L_{F2T4})^2 + (a_{F2T1} - a_{F2T4})^2 + (b_{F2T1} - b_{F2T4})^2]^{1/2}$ gives the color changes of reference area (F2) after the 28-day control interval (T4).

Color development during therapy: Segregated ΔE data of (L*), (a*), (b*)

Beyond analysis of collective CIE (L*a*b*) ΔE data, the segregated (L*a*b*) values were regarded at each time point T1 to T4 to judge the color development during bleaching therapy.

CIE L data.* In group A, there was no significant change after office bleaching (T2), in either F1 or in F2, and no significant change after the 14-day inactive interval (T3). At T4, there was a significant increase of L* value in F1 (α = .005) and in F2 (α = .002), indicating that lightness of both areas increased significantly compared to baseline (T1).

In control group B, there were no significant changes either in F1 or in F2 at any time point.

CIE a data.* In group A, as well as in control group B, there were no significant changes at the time points T2 and T3 compared to baseline, at either F1 or F2 sites. At T4, there was a significant decrease of a* value in the fluorotic areas F1, but not in F2 or the control group.

CIE b data.* In group A, there was no significant change after office bleaching in either F1 or F2. After the 14-day interval (T3), a significant decrease (α = .0003) compared to baseline was noted at T3, as well as at T4 (α = .000001), indicating a change of color coordinates from yellow to blue domain. In control group B, no significant changes (F1, F2) were noted (T1, T2, T3, T4).

The mean CIE (L*a*b*) data for all measurements are presented in Table 4.

Analysis of questionnaire

All patients of group A were satisfied with the outcome of the bleaching therapy and would recommend this kind of bleaching therapy to a friend. After finishing the home bleaching period, they subjectively felt the fluorotic stains were less visible than before bleaching. In control group B, patients did not judge fluorotic stains as less visible after the 4-week period than at baseline. With the exception of slight hypersensitivities (minor grade 8 on our adverse effect scale from 1 to 10 (where

Table 4 Mean values (SD) of L*, a*, b* in groups A and B at the respective time points

		T1		T2		T3		T4	
	Area	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Group A (n = 25)									
L	F1	75.39	5.19	76.77	4.99	77.01	4.09	79.77	4.44
a	F1	−0.29	1.07	−0.6	0.74	−0.85	1.25	−1.04	0.89
b	F1	10.59	6.33	8.27	3.97	7.65	2.98	4.62	3.43
L	F2	75.18	5.48	77.33	5.28	78.12	4.70	80.32	4.61
a	F2	−0.22	0.97	−0.32	0.90	0.31	1.57	−0.42	1.30
b	F2	15.42	4.07	13.4	4.52	10.56	3.60	8.6	3.10
Group B (n = 17)									
L	F1	78.46	4.30	—	—	—	—	78.6	4.21
a	F1	−0.82	0.98	—	—	—	—	−0.58	1.00
b	F1	11.56	4.49	—	—	—	—	10.79	4.92
L	F2	79.25	5.21	—	—	—	—	79.29	5.22
a	F2	−0.67	1.12	—	—	—	—	−0.61	1.25
b	F2	14.21	4.86	—	—	—	—	13.49	5.86

grade 10 indicated no hypersensitivities at all; see Fig 4), patients did not report any adverse effects or discomfort.

DISCUSSION

According to Johnston and Kao,[19] color differences are clinically visible to the naked eye in cases with ΔE (L*a*b*) exceeding 3.7 units. Of the bleached sites (F1, F2), 88% exceeded the 3.7-unit threshold before bleaching (T1), as did 52% in the end (T4). The respective ΔE (L*a*b*) values were significant according to Fisher exact test (P = .01). Thus, the null hypothesis was rejected. In control group B, no significant changes were noted, which leads to the assumption that single bleaching therapy provides a more uniform, esthetic appearance to enamel surfaces of fluorotic stained teeth.

On closer look at segregated ΔE (L*), (a*), (b*) values at the distinct time points T1 to T4, no significant changes in F1 or in F2 after the initial hour of in-office bleaching (T2) with 30% hydrogen peroxide were noticeable, and the color differences between the 2 sites (F1, F2) were not significantly reduced, which was in accordance with the patients' recorded self-perception.

Collective ΔE data of area F1 (bleaching group A) was not significantly increased between T2 and T3 (see Table 2a), but did increase in area F2 from 48% at T2 to 68% at T3 (ΔE T2 to T3; see Table 3a). On closer look, it is most likely due to the significant decrease of b* value in F2 (α = .0003) compared to baseline, which seems to be responsible for significantly reduced collective ΔE between F1 and F2 at T3 (see Table 1a): There were no significant changes regarding L* or a* data at T3. A decrease of b* value is equivalent to a color change from yellow to blue direction (see Fig 2). According to the colorimeter manufacturer's description, the measuring unit digitally analyzes the shades along with hue, value, and chroma without being affected by lighting conditions. Although we attempted with extraordinary diligence to provide identical ambient illumination, completely reproducible conditions on convex enamel surfaces can hardly be achieved in vivo. For example, a slightly different head position may alter the refraction of the ambient light within the enamel surface. The manual positioning of the colorimeter's nozzle on the teeth may also mark a source of potential imprecision, as its incline is likely to affect the shades recorded by the sensor. Therefore, we cannot exclude the possibility

that value b* with in vivo assessments is more affected by lighting conditions and adjustment of the colorimeter's nozzle on the convex enamel surfaces than is warranted by the manufacturer.

After bleaching, collective ΔE (F1 versus F2) was reduced significantly, which is due to a significant change of all segregated ΔE (L*a*b*) data (group A), except from a* value in area F2. Since a lower value a* means a color change on the axis from red/brownish to green, it might be assumed that small stains of a more brownish color within the fluorotic area F1 (and lacking in F2) were removed.

According to power analysis, at least 15 sites were needed to reveal relevant ΔE (L*a*b*) differences of at least 3.0 units in our trial. Since 25 sites in group A and 17 in group B were assessed, it is assumed that the trial findings can be generalized. However, all participants were Caucasian and from a single geographic location (Göttingen, Germany). Presuming there are no differences in the reaction of fluorotic teeth in different populations, it is likely that the results obtained would also apply to cases with mild to moderate fluorosis in other geographic locations. Considering the number of assessed sites, it is hypothesized that overall evidence is provided. However, because the results in this study were obtained from a sample of 18 subjects, further research concerning routine CIE (L*a*b*) evaluation on new samples would be useful to corroborate the results in this study.

A pronounced increase of patient contentment was registered at the end of the home bleaching session (T4). Perceived adverse effects remained in the area of the expectations, which was about 30%.[26]

CONCLUSIONS

1. A single 1-hour session of in-office bleaching with 30% hydrogen peroxide does not significantly affect the color and luminosity of fluorotic teeth.
2. After 14 days of home bleaching with 15% carbamide peroxide, the color of moderate fluorotic stains assimilates with surrounding, normally developed enamel areas due to different responses of sound and fluorotic enamel to the bleaching regime.
3. According to patient statements, the single bleaching therapy seems to be a satisfying nonabrasive approach in cases of mild or moderate fluorosis.
4. Further research concerning routine CIE L*a*b* evaluation on new samples would be useful to corroborate the results in this study.

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