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ORIGINAL ARTICLE

Clinical and patient reported outcomes of bleaching effectiveness

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ABSTRACT

Objective: The objective of this study is to evaluate clinical and patient reported outcomes of different bleaching products.

Materials and methods: Thirty participants were randomly divided into three bleaching groups ($n = 10$). Bleaching was performed with high concentrations of hydrogen peroxide (HP) – Boost (40%) and Dash (30%), and with prefabricated splints Bite&White (6% HP). Tooth colour was measured before, immediately after, and 1 and 6 months after the bleaching by using classical shade guide and spectrophotometer. Tooth hypersensitivity was self-rated by patients on the Wong-Baker's face scale. Patient satisfaction was evaluated on a 7-point Likert-type scales that measured perceived performance and importance of different characteristics of bleaching treatment.

Results: All products were effective in teeth colour change ($\Delta E > 3.3$), which was significantly higher for Boost ($p = .016$) and Dash ($p = .024$) than Bite&White treatment. Perception of hypersensitivity was the highest in Boost group, followed by Dash and Bite&White treatment. Most of the patients were satisfied with final tooth colour, length and comfort during treatment, but were dissatisfied with the stability of bleached tooth colour.

Conclusion: Materials with the higher concentrations of bleaching agent demonstrated greater bleaching effectiveness than at-home bleaching product, but also a greater hypersensitivity. Lengthening the treatment process, but achieving a more stable tooth colour may improve the perceived value of a bleaching service.

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Introduction

Unsatisfactory tooth colour is a major factor in motivating patients for dental aesthetic treatment [1]. Permanent teeth often become darker over time, losing their natural whiteness due to the changes in enamel and dentin [2]. Tooth discolouration is classified based on its aetiology. Intrinsic factors, which are incorporated into tooth structure, can be congenital or acquired, and cause more complicated discolouration which requires more aggressive bleaching procedures than extrinsic tooth discolouration [3]. Extrinsic discolouration is an outcome of accumulated stains on the tooth surface. Exposure to outside influences, such as pigments from food, bacterial byproducts, soda/carbonated drinks, red wine, tea, smoking and cationic substances such as chlorhexidine, may result in additional deposition of chromophore that is responsible for tooth discolouration [4,5].

To improve the colour of their teeth, patients often decide on a cosmetic teeth-bleaching treatment. Bleaching is an oxidation reaction where an agent combines with the chromophores to decolourize or solubilize them [6]. Bleaching agents are usually based on hydrogen peroxide (HP), sodium perborate or carbamide peroxide, and can be used with or without an additional light activation. Tooth-bleaching effectiveness, or the extent to which bleaching agent achieves its intended purpose (such as increased tooth lightness and reduced tooth yellowness), mostly depends on the concentration and application time of peroxide [6,7]. There are different types of vital teeth-bleaching procedures including in-office bleaching using high concentrations of bleaching agents with adequate soft tissue protection and at-home bleaching procedures with lower concentration of bleaching agents which are used without dentist supervision [6,8].

Since the tooth bleaching has become a common procedure, there are concerns about the side effects of bleaching agents, such as tooth sensitivity and gingival irritation. Sensitivity is usually related to the small microscopic enamel and dentin defects and subsurface pores, where bleaching agent can penetrate into the pulp because of its small molecular mass [9]. It directly activates nerve endings that cause pain and lead to a mild reversible pulpitis [10]. Pulp damage can produce an inflammatory response which results with the release of cell-derived factors such as adenosine triphosphate [11] neuropeptides and prostaglandins, which excite or sensitize pulpal nociceptors [12,13].

Current literature lacks the comprehensive evaluation of a bleaching treatment. Most studies have been focused on

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physical properties of different bleaching treatments, such as bleaching effectiveness measured in CIELab colour space, but ignored the perceptions of patients themselves. Tooth colour is considered a critical factor in influencing patient satisfaction with bleaching treatment; however, only a limited number of studies examined patient satisfaction with different aspects of a bleaching treatment [14,15]. Bleaching efficacy and patient satisfaction with the treatment are not necessarily related [16]. This study adds to the literature by comparing the clinical outcomes, defined herein as objective clinical conditions or results used to assess the efficacy of bleaching treatment [17] (e.g. overall change in tooth colour, change in tooth lightness, yellowness, etc.), with the perceptions of patients themselves. Different bleaching procedures and concentrations of bleaching agent were used: two in-office bleaching treatments with high concentrations of HP, namely Boost (40% HP) and Dash (30% HP), and at-home Bite&White treatment with lower concentration of HP (6%). We investigated the medium-term effects of bleaching, up to 6 months after the bleaching treatment. The tooth colour was not expected to be stable in this period of time after the treatment. As eating, drinking and smoking habits may confound the effects of bleaching (i.e. the stability of tooth colour) [5], our study examined those factors as well.

The aim of this study was to examine the following outcomes of a bleaching treatment: the longitudinal change in tooth colour and intensity of hypersensitivity across different types of bleaching treatment, patient satisfaction with different characteristics of a bleaching treatment and relationship of patient satisfaction with the change in tooth colour and intensity of hypersensitivity. The following hypotheses were tested: (I) patient satisfaction is not related to clinical outcomes of a bleaching process, (II) there is no difference in bleaching effectiveness between different treatments, (III) there is no difference in colour stability between different treatments and (IV) there is no difference in postoperative sensitivity between different treatments.

Materials and methods

Patients were eligible for the study if they had good oral hygiene with healthy teeth and without any periodontal disease, gingival irritation, cervical lesions or prosthodontics treatment. Pregnant or nursing patients, patients with severely stained teeth (tetracycline stains, fluorosis and endodontic treatment) and those who had previously undergone any tooth whitening treatments were not included in the study. Thirty patients voluntarily agreed to participate in the study, and gave their informed consent. The institutional Ethics Committee approved the study.

Bleaching procedure

Patients were randomly divided into three bleaching groups ($n = 10$) (Figure 1). In each group, different bleaching procedure and/or different bleaching agent was used: in-office 40% HP Opalesence Boost (Ultradent Products, South Jordan, UT), in-office 30% HP Dash (Philips, Andover, MA) or at-home 6% HP Cavex Bite&White Ready 2 Use (Cavex, Haarlem, Netherlands). In-office bleaching treatments were performed in the morning at the Department of Endodontics and Restorative Dentistry at the School of Dental Medicine, University of Zagreb, Croatia. Before the bleaching treatment, calculus and stains were removed using a sonic instrument SONICflex (Dentsply, York, PA) and followed by polishing the teeth with prophylactic paste Proxyt (Ivoclar Vivadent, Schaan, Liechtenstein). The bleaching procedure was conducted according to the manufacturer's instructions. Retractor was set in place, the teeth were dried by air stream and the gingival soft tissues were isolated by protective Opaldam gel (Ultradent, South Jordan, UT) or Liquidam (Philips, Andover, MA), which were illuminated by the polymerization unit Bluephase Style (Ivoclar-Vivadent, Liechtenstein). Labial surfaces of the teeth 14–24 and 34–44 were then covered with whitening gel in about 1–2 mm thick layer using the original manufacturer brush. After each bleaching treatment, the gel was removed by Heidemann Instrument (Carl Martin, Germany) and a cotton pellet. This treatment was repeated three times for 15 min each. Three well-trained operators performed the treatments. At-home bleaching treatment was performed by patients themselves. After good oral hygiene (brushing with toothpaste for at least 2 min, and using dental floss afterwards), patients were instructed to use whitening trays according to the manufacturer's instructions: for one hour daily during six days in a row.

Tooth colour measurements

In this study, both methods were used: tooth colour was measured using VITA classical shade guide (Vita Zahnfabrik, Säckingen, Germany) and spectrophotometer Vita Easyshade Advance 4.0 with accuracy of 93.75% (Vita Zahnfabrik, Säckingen, Germany) [18]. The spectrophotometer was operated according to the manufacturer's instructions. Before each measurement, nylon protection was set at the top of the apparatus sensor to prevent cross infection. The patients were instructed to place their heads against the headrest of the dental chair and to keep their mouths slightly open during measurement. Also, they were instructed to keep the tongue in a relaxed position away from the maxillary teeth during measurement to prevent potential false measurements. Operators in this study were well trained in colour assessment and handling of the dental shade-matching device under standardized test conditions. Before any measurement, the device was calibrated on its own white ceramic block and it was used in 'single tooth' mode. The measured values were recorded in the units of CIELab colour space. CIE L^* parameter shows the degree of lightness, a^* is indicative of redness/greenness ($-a^* = \text{green}, +a^* = \text{red}$), and b^* indicates yellowness/blueness ($-b^* = \text{blue}, +b^* = \text{yellow}$). The tooth colour was measured before treatment, immediately after (i.e. after 3×15 min of bleaching for Boost and Dash, and at the end of six days of treatment for Bite&White), and 1 and 6 months after the bleaching treatment. Overall colour change was calculated using the following equation:

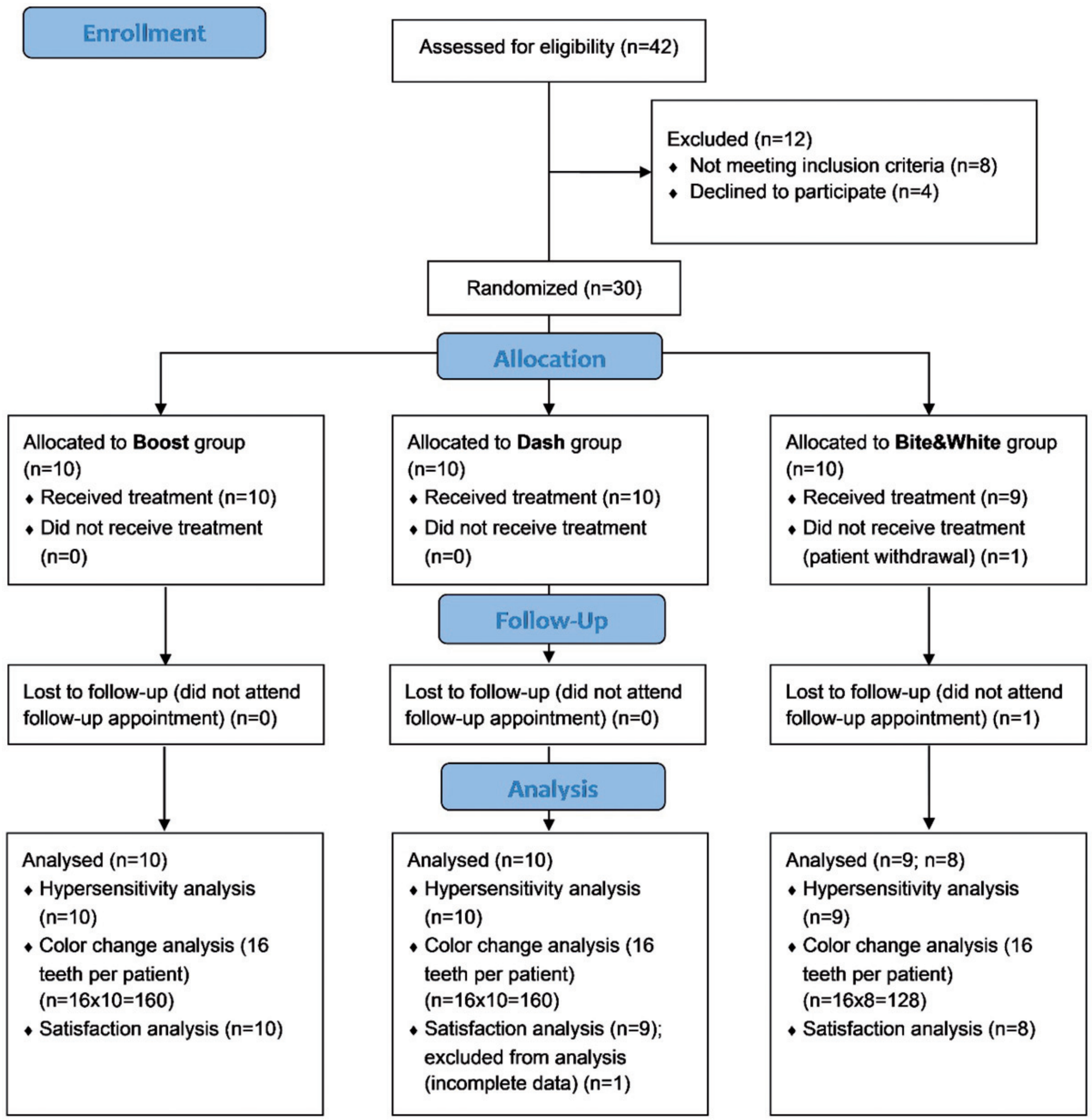

Figure 1. Study flow chart.

$\Delta E = [(L_1 - L_0)^2 + (a_1 - a_0)^2 + (b_1 - b_0)^2]^{1/2}$. L_0 denotes the values of L^* recorded at the baseline (i.e. before bleaching treatment) and L_1 the values recorded after the bleaching. The same coding applies to a^* and b^* values.

All recordings were made in the same room under D65 daylight fluorescent tubes with a luminescence intensity of between 1200 and 1600 lux. The central region of the labial surface of each bleached teeth (14–24 and 34–44) was used for colour measurement. Therefore, 16 measurements were made per patient (or 480 in total) at each observation point (before, immediately after, and one and six months after the treatment). Due to respondent attrition (as two patients did not complete all follow-ups), 448 observations were used in the analysis.

Dietary data

For each patient, dietary data were collected at the beginning of the study. Collection of dietary data was based on a self-reported food/drink frequency questionnaire. Patients were asked to indicate the frequency of consumption of various types of green vegetables (Swiss chard, spinach, collard greens, broccoli and beet), drinks (coca cola, red juices, tea, red wine and coffee), and the frequency of smoking on a four point scale (0 = 'Never', 1 = 'Seldom', 2 = 'Sometimes' and 3 = 'Often'). Similar measures were used in other studies on dietary behaviour [19].

Evaluation of postoperative sensitivity

Pain is a sensory experience usually interfering with physiological, psychological and socio-cultural factors. Due to the impossibility of an objective measure of the degree of pain, it is generally assessed through "subjective" self-reported measures [20]. A number of scales rely on the patient's subjective impression of pain, and the Wong–Baker's face scale was used in this study. The scale shows a series of faces ranging from a happy face at 0 ("No hurt") to a crying face at 10 ("Hurts worst"). The patient had to choose the face that best describes how they were feeling. All patients had no preoperative sensitivity, which was ascertained by a light air jet over the labial surface of the teeth in the root region for 3 s at the distance of 2–3 mm. The intensity of postoperative sensitivity was evaluated immediately after, and 6, 12 and 24 h after the bleaching treatment.

Evaluation of patient satisfaction

A dominant conceptual model in evaluating customer satisfaction, disconfirmation-of-expectations model, considers satisfaction as a function of customers' perceptions of service performance and their expectations or comparison standards [21]. In this context, performance is defined as customers' perceived value of service attributes or delivered outcomes [22]. Once the service has been experienced, outcomes are compared against expectations. A customer is either satisfied or dissatisfied as a result of positive or negative difference between expectations and perceptions of delivered outcomes [21]. This framework therefore requires separate data on customers' expectations and perceived performance of service attributes.

At the end of the study (6 months after the bleaching treatment), the questionnaire was given to the patients to assess their satisfaction with bleaching treatment. Multi-item measure of satisfaction was used to evaluate patients' perceptions of importance (often used as a proxy for customers' expectations) and performance of four characteristics of a bleaching treatment – final tooth colour, colour stability, length of treatment and comfort during treatment. Patients were asked to rate the perceived importance of each characteristic on a 7-point Likert scale anchored by 1 = 'Not at all important' and 7 = 'Very important'. The perceived performance of each characteristic was assessed on a scale anchored by 1 = 'Very bad' and 7 = 'Excellent'. Difference between performance and importance scores of individual service characteristics was then calculated to form a third variable, the gap score, which was used as an indicator of patient satisfaction. On one hand, non-negative gap score implies that perceived performance is equal to or greater than patients' expectations (i.e. expectation confirmation or positive disconfirmation), and signals that patients are satisfied with specific characteristic of a bleaching treatment. On the other hand, a negative gap score (negative disconfirmation) indicates that patients are dissatisfied.

The overall satisfaction of patients with the bleaching service was measured separately on a 7-point scale anchored by 1 = 'Not at all satisfied' and 7 = 'Very satisfied'. The final part of the questionnaire asked patients about their intention of having the same treatment again and of recommending such bleaching treatment to their family and friends (i.e. of positive word-of-mouth).

Statistical analysis

Repeated-measures analysis of variance (ANOVA) models were used to assess the changes in tooth colour (ΔE, ΔL^*, Δa^* and Δb^*) across different bleaching systems during a 6-month study period. Measures of skewness and kurtosis indicated that measurements were approximately normally distributed. A compound symmetry covariance structure was used to account for clustering of observations because of multiple measurements taken on each patient (i.e. 16 teeth evaluated per patient). Arithmetic means and corresponding 95% confidence intervals were used in reporting the results.

Chi-square test was used to compare the recorded colour of teeth measured by VITA classical shade guide across different bleaching groups. Patients' perception of pain was compared across treatment groups by using Wilcoxon Rank Sum test due to the ordinal nature of rating scale used to evaluate the pain. When analyzing patient satisfaction, discrepancy between performance and importance scores of specific characteristic of bleaching treatment was tested by the means of non-parametric Wilcoxon-Signed Rank test. Medians and interquartile ranges (IQRs) were used as summary and dispersion measures for satisfaction data. Spearman correlation coefficient (r_s) was used to test the relationship between bleaching effectiveness and patient satisfaction.

The size of the population for sample selection was substantially constrained by the study requirements and longitudinal nature of the study. Sample size for the analysis of colour change ($n = 448$) within and between bleaching groups was large enough to capture the medium to small effects according to Cohen's effect size conventions [23], i.e. Cohen's $d \sim 0.3$, with a statistical power of 80%. Sample size for the analysis of patient satisfaction ($n = 27$) was large enough to capture the medium standardized effect size, i.e. Cohen's $d \sim 0.5$, with a statistical power of 80%; therefore, the statistical power was somewhat lower compared to the analysis of colour change, but still considered satisfactory. On the contrary, between-group comparisons of patient satisfaction, dietary habits and hypersensitivity had low statistical power (<50%) to detect even large differences (measured by the Cohen's large effect size) between the groups. These results were, therefore, largely omitted from the analysis, and reported ones should be treated with caution. The level of statistical significance was set at .05. p Values were adjusted for multiple comparisons according to the Bonferroni–Holm method. The data analysis was performed in SAS System (SAS Institute Inc., Cary, NC), and power analysis in G*Power (Heinrich-Heine-University Düsseldorf, Germany).

Results

Respondents were on average 25 years old (SD = 6.2). Most of them were females (71%). Their eating, drinking and smoking habits are summarized in Table 1. Large differences in the frequency of eating green vegetables, drinking coloured beverages and smoking were not detected among three bleaching groups (i.e. Boost, Dash and Bite&White). Spectrophotometer measurements in CIELAB colour space demonstrated that baseline values of L^*, a^* and b^* were not significantly correlated with eating and drinking habits of patients. Variable representing eating habits was calculated as the sum of stated frequencies ('Never' = 0, 'Seldom' = 1,

Table 1. Eating, drinking and smoking habits of respondents.

		Green vegetables					Drinks					
Bleaching system	Frequency of consuming	Swiss chard	Spinach	Collard greens	Broccoli	Beet	Coca cola	Red juice	Tea	Red wine	Coffee	Smoking
Boost ($n = 10$)	Never	.	.	50%	20%	50%	40%	40%	.	.	10%	60%
	Seldom	40%	50%	20%	40%	30%	60%	50%	20%	50%	10%	10%
	Sometimes	40%	30%	20%	30%	10%	.	10%	40%	50%	20%	.
	Often	20%	20%	10%	10%	10%	.	.	40%	.	60%	30%
Dash ($n = 10$)	Never	20%	20%	90%	10%	60%	30%	20%	30%	20%	10%	56%
	Seldom	20%	10%	10%	40%	30%	60%	80%	.	30%	.	22%
	Sometimes	50%	70%	.	40%	10%	.	.	40%	30%	10%	11%
	Often	10%	.	.	10%	.	10%	.	30%	20%	80%	11%
Bite&White ($n = 9$)	Never	.	.	56%	.	78%	22%	22%	.	11%	.	67%
	Seldom	56%	44%	33%	56%	22%	67%	56%	33%	67%	11%	.
	Sometimes	33%	56%	.	44%	.	.	22%	56%	11%	22%	11%
	Often	11%	.	11%	.	.	11%	.	11%	11%	67%	22%
Total ($n = 29$)	Never	7%	7%	66%	10%	62%	31%	28%	10%	10%	7%	61%
	Seldom	38%	34%	21%	45%	28%	62%	62%	17%	48%	7%	11%
	Sometimes	41%	52%	7%	38%	7%	.	10%	45%	31%	17%	7%
	Often	14%	7%	7%	7%	3%	7%	.	28%	10%	69%	21%

Table 2. Tooth shades measured by VITA shade guide.

	Boost ($n = 160$)				Dash ($n = 160$)				Bite&White ($n = 128$)			
Tooth shade	Base	Bleach	Bleach 30	Bleach 180	Base	Bleach	Bleach 30	Bleach 180	Base	Bleach	Bleach 30	Bleach 180
A1	18.1%	20.0%	40.0%	39.4%	18.1%	25.0%	37.5%	32.5%	16.4%	28.1%	26.6%	24.2%
A2	20.6%	26.3%	21.3%	21.9%	22.5%	29.4%	16.9%	22.5%	24.2%	21.9%	25.0%	21.9%
A3	6.9%	8.8%	2.5%	4.4%	6.9%	3.1%	10.6%	4.4%	7.0%	14.1%	10.2%	14.1%
A3,5	8.1%	1.9%	.	.	15.0%	9.4%	1.3%	.	7.0%	.	.	.
A4	.	0.6%	.	.	0.6%	.	.	1.9%	1.6%	.	.	.
B1	0.6%	3.1%	13.1%	10.6%	.	1.3%	5.0%	5.6%	3.1%	8.6%	9.4%	7.8%
B2	13.1%	17.5%	18.8%	20.0%	12.5%	13.1%	20.0%	19.4%	11.7%	13.3%	12.5%	14.8%
B3	31.3%	21.3%	1.9%	1.3%	24.4%	18.1%	6.3%	5.0%	26.6%	10.2%	14.1%	12.5%
B4	.	.	.	.	.	0.6%	1.3%	0.6%	.	.	.	.
C1	.	0.6%	1.9%	.	.	.	0.6%	1.3%	.	0.8%	.	0.8%
C2	.	.	.	.	.	.	.	0.6%	.	1.6%	2.3%	3.1%
C3	1.3%	.	.	.	.	.	.	3.1%	0.8%	0.8%	.	0.8%
D2	.	.	0.6%	1.9%	.	.	0.6%	1.3%	.	.	.	.
D3	.	.	.	0.6%	.	.	.	.	1.6%	0.8%	.	.
D4	.	.	.	.	.	.	.	1.9%	.	.	.	.

Base: Baseline; Bleach: Immediately after bleaching; Bleach 30: One month after bleaching; Bleach 180: Six months after bleaching.

'Sometimes' = 2, 'Often' = 3) of consumption of different types of green vegetables, and variable for drinking habits was calculated as the sum of stated frequencies of drinking different beverages. Spearman's correlation coefficients between eating habits and respondent-averaged baseline values of L^* ($r_s = -0.08$, $p = .706$), a^* ($r_s = 0.10$, $p = .603$) and b^* ($r_s = 0.15$, $p = .463$) were low, as well as correlations between drinking habits and respondent-averaged baseline values of L^* ($r_s = 0.295$, $p = .135$), a^* ($r_s = -0.08$, $p = .683$) and b^* ($r_s = 0.07$, $p = .744$).

Colour change

Tooth shades ($n = 448$) recorded before and after the bleaching treatment by using the VITA classical shade guide are presented in Table 2. Baseline tooth shades were not significantly different across three bleaching groups (Chi-square test; $p = .701$). A clinically significant change in tooth colour ($\Delta E > 3.3$) was recorded after all bleaching treatments (Table 3). The average change in tooth colour recorded 1 month after the bleaching compared to baseline colour was significantly larger for Boost ($p = .016$) and Dash ($p = .024$) than Bite&White treatment. For all types of bleaching treatments and throughout the whole study period the average values of a^* component of CIELAB colour space remained around zero, in the interval between -1 and $+1$. Measurements within this range do not have significant impact on visible colour of tooth; therefore, the analysis of bleaching effectiveness was focused on changes in L^* and b^* components. The average changes in L^* values throughout the whole study period were similar across the three bleaching groups (Table 3). In comparison with Bite&White treatment, the decrease in b^* values recorded 1 and 6 months after the treatment (Δb_{30_0} and Δb_{180_0}) was significantly larger for Boost ($p_{\Delta b30\_0} = 0.008$ and $p_{\Delta b180\_0} = 0.005$) and Dash ($p_{\Delta b30\_0} = 0.013$ and $p_{\Delta b180\_0} = 0.005$) treatments.

Postoperative sensitivity

Immediately after the bleaching process, there was no statistically significant difference in the pain perception across three bleaching groups (Kruskal–Wallis test; $p = .368$). However, the pain perception measured 6, 12 and 24 h after the bleaching treatment was generally higher in the Boost group than in Dash (Wilcoxon Rank Sum test: $p_{6h} = 0.017$, $p_{12h} = 0.006$ and $p_{24h} = 0.087$) and Bite&White (Wilcoxon

Table 3. Summary of longitudinal changes in tooth colour (spectrophotometer measurements).

Effect[a]	Boost Mean difference[b]	Boost 95% CI Lower	Boost 95% CI Upper	Dash Mean difference[b]	Dash 95% CI Lower	Dash 95% CI Upper	Bite&White Mean difference[b]	Bite&White 95% CI Lower	Bite&White 95% CI Upper
ΔE_{30_0}	7.1*** A	6.0	8.2	6.9*** A	5.8	8.0	4.7*** B	3.5	5.9
ΔE_{180_0}	7.3*** A	6.2	8.4	6.8*** A	5.7	7.9	4.7*** B	3.5	5.9
ΔE_{180_30}	3.9*** A	3.0	4.7	4.0*** A	3.1	4.9	3.7*** A	2.7	4.6
ΔL_{30_0}	2.4*** A	1.1	3.7	2.5*** A	1.2	3.7	1.6** A	0.2	3.0
ΔL_{180_0}	1.6 A	−0.5	3.7	1.0 A	−1.1	3.1	0.8 A	−1.5	3.2
ΔL_{180_30}	−0.8 A	−2.4	0.8	−1.5* A	−3.0	0.1	−0.7 A	−2.5	1.0
Δb_{30_0}	−5.0*** A	−6.0	−3.9	−4.6*** A	−5.7	−3.6	−2.4*** B	−3.6	−1.2
Δb_{180_0}	−4.7*** A	−5.6	−3.9	−4.8*** A	−5.6	−3.9	−2.5*** B	−3.5	−1.6
Δb_{180_30}	0.2 A	−0.3	0.7	−0.1 A	−0.6	0.3	−0.2 A	−0.7	0.4

$n = 448$.

[a]Subscript denotes which two measurement points are compared: $_{30\_0}$ = 'Difference between the measurement recorded one month after the treatment and baseline measurement'; $_{180\_0}$ = 'Difference between the measurement recorded six months after the treatment and baseline measurement'; $_{180\_30}$ = 'Difference between the measurements recorded 6 months after the treatment and 1 month after the treatment'.

[b]Asterisks indicate significant differences between two measurement points (specified in 1st column): *significant at 10% level, **significant at 5% level, and ***significant at 1% level; different letters (A and B) in the same row indicate significant differences between two bleaching systems.

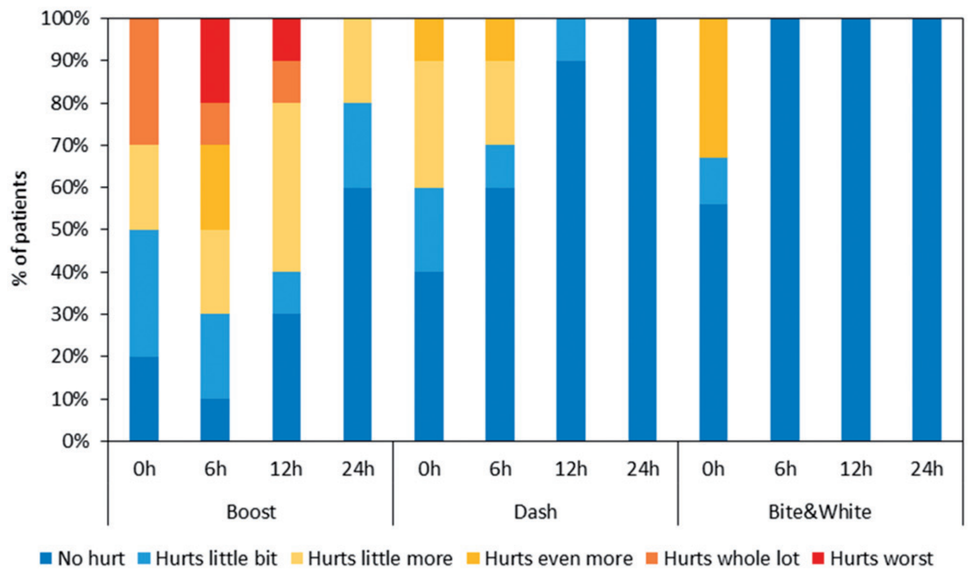

Figure 2. Perception of pain on Wong-Baker's face scale (0h = 'During bleaching treatment' to 24h = '24 h after the bleaching treatment').

Rank Sum test: $p_{6h}<0.001$, $p_{12h}=0.003$ and $p_{24h}=0.087$) groups. Six hours after the treatment, postoperative sensitivity was not present in Bite&White group; however, it was felt among patients who received Boost (90%) or Dash (40%) treatments (Figure 2). Twelve hours after the bleaching the pain decreased in both groups, and 24 h after the bleaching, it was still felt among some subjects in the Boost group.

Patient satisfaction

Internal consistency of satisfaction items was acceptable with Cronbach's alpha coefficient of 0.70. Patient satisfaction was measured by calculating the gap score or the difference between performance and importance scores assigned to specific treatment characteristic (Table 4). Overall gap analysis indicated that most of the patients were satisfied with final tooth colour, length of treatment and comfort during treatment. Length of treatment significantly exceeded their expectations (Wilcoxon Signed Rank test; $p = .004$). The critical aspects of a bleaching treatment were the final tooth colour and colour stability – the majority of patients rated these attributes with the highest importance score on a 7-point Likert scale. However, on one hand, the patients were generally not satisfied with the stability of tooth colour after the bleaching (Wilcoxon Signed Rank test; $p < .001$), as indicated by the median gap score of −1.0. Patients in different bleaching groups gave similar scores when evaluating the performance of specific treatment characteristics. They were quite satisfied with the overall bleaching treatment. The median score of overall patient satisfaction was 6.0 (IQR = 1.0) on a 7-point Likert scale, and was equal in all bleaching groups. Overall patient satisfaction was moderately and positively correlated with the average change in tooth lightness ΔL_{30_0} ($r_s = 0.57$; $p = .002$) and ΔL_{180_0} ($r_s = 0.42$; $p = .033$). On the other hand, patient satisfaction with final tooth colour was moderately and positively correlated with the overall change in tooth colour after bleaching ΔE_{30_0} ($r_s = 0.49$; $p = .014$), and negatively correlated with the change in yellowness Δb_{30_0} ($r_s = -0.52$; $p = .008$) and Δb_{180_0} ($r_s = -0.45$; $p = .023$). Satisfaction with the stability of tooth colour was positively correlated with the

Table 4. Patient satisfaction with characteristics of bleaching treatment.

Bleaching system	Measure[a]	Characteristics of bleaching treatment: Final tooth colour Median (IQR)	Colour stability Median (IQR)	Length of treatment Median (IQR)	Comfort during treatment Median (IQR)
Boost ($n=10$)	Performance (P)	6.0 (1.0)	6.0 (1.0)	5.5 (2.0)	6.0 (1.0)
	Importance (I)	7.0 (1.0)	7.0 (1.0)	4.0 (1.0)	6.0 (1.0)
	Gap score (P–I)	0.0 (0.0)	−1.0 (2.0)	1.5 (2.0)	0.0 (1.0)
Dash ($n=9$)	Performance (P)	6.0 (1.0)	5.0 (1.0)	6.0 (1.0)	6.0 (1.0)
	Importance (I)	6.0 (2.0)	7.0 (2.0)	5.0 (2.0)	5.0 (2.0)
	Gap score (P–I)	0.0 (1.0)	−1.0 (2.0)	0.0 (3.0)	1.0 (2.0)
Bite&White ($n=8$)	Performance (P)	6.0 (2.0)	5.0 (2.0)	6.0 (2.0)	5.5 (2.0)
	Importance (I)	6.5 (1.5)	6.5 (2.0)	5.0 (3.0)	6.5 (2.5)
	Gap score (P–I)	−0.5 (1.0)	−0.5 (2.5)	0.0 (3.0)	−1.0 (2.5)

IQR: Interquartile range.
[a]Patients were asked to rate the perceived performance (P) of each characteristic on a 7-point Likert scale anchored by 1= 'Very bad' and 7= 'Excellent'. The perceived importance (I) of each characteristic was assessed on a 7-point Likert scale anchored by 1= 'Not at all important' and 7= 'Very important'. Gap score (P–I) is the median difference between performance and importance scores. A negative gap score indicates that patient's expectations were not met, while non-negative value indicates that patient was satisfied with the specific characteristic of bleaching treatment.

increase in tooth lightness ΔL_{30_0} ($r_s=0.45$; $p=.024$) and ΔL_{180_0} ($r_s=0.51$; $p=.010$).

Most of the patients (70%) would surely be willing to repeat the same bleaching treatment. They also indicated positive word-of-mouth – 85% would certainly recommend the same bleaching treatment to their family or friends. The highest share of those who were not sure was recorded for Bite&White treatment (38%), followed by Boost (10%), while all patients who received Dash treatment indicated that they would certainly recommend it.

Discussion

Despite the inherent subjectivity in valuing outcomes of a bleaching treatment, most studies have been focused on the physical properties and effectiveness of bleaching process, and ignored the perceptions of patients. However, the bleaching effectiveness is not necessarily a perfect or even a good indicator of patient satisfaction. Conversely, Heinisch et al. [16] did not find positive correlation between bleaching efficacy and patient satisfaction with the treatment. In our study, the hypothesis that patient satisfaction is not related to clinical outcomes of a bleaching process was rejected. Clinical studies suggest that after the bleaching, most changes in tooth colour can be observed on L^* and b^* dimensions, with minor changes on a^* dimension [24–26], which was also supported in our study. Furthermore, the change in the value of b^* (yellowness) was a better indicator of patient satisfaction with the tooth colour after the bleaching treatment than the change in L^* dimension, thereby supporting the findings of Bengel [27] that the changes in b^* values are the best for the assessment of colour change. On the other hand, Karpinia et al. [25] and Trakyali et al. [26] found that L^* dimension of CIELab colour space is the most important parameter in the detection of tooth bleaching effectiveness and that human eye can easier detect the change in lightness compared to other dimensions (a^* and b^*). Our findings revealed that the change in the value of L^* (lightness) was a better indicator of patient satisfaction with the stability of tooth colour. Therefore, both L^* and b^* dimensions may be equally important indicators of tooth bleaching effectiveness, as both the final tooth colour and the colour stability were identified as equally important and critical aspects of bleaching treatment.

The patients' high expectations regarding the different attributes of bleaching treatment were not always satisfied. For most of the patients, the expectations about colour stability were not fulfilled. These results support the findings of Gupta and Saxena [28] who evaluated patient satisfaction with the bleaching treatment of traumatized discoloured teeth and concluded that the unpredictability of final shade and lack of colour stability were the most concerning aspects of a bleaching process. In contrast to colour stability, the length of a treatment exceeded patient expectations, indicating that they would be willing to have a somewhat longer treatment. This suggests that lengthening the treatment process, but achieving a more stable tooth colour might increase the patient satisfaction. Using bleaching agents with lower concentration of hydrogen or carbamide peroxide may provide such an outcome – more stable colour, but at the expense of longer treatment appointments.

Tooth colour can be determined by using subjective visual methods (e.g. shade guides), or objective methods (e.g. spectrophotometer or digital photography analysis) [27]. The latter are considered as more reliable [24,29]. Clinically significant changes in tooth colour ($\Delta E > 3.3$) were observed following the bleaching process with Boost, Dash or Bite&White system. Conversely, in some cases the overall change in tooth colour (ΔE) from spectrophotometer readings was higher when measured 1 month after than immediately after the bleaching process. This finding was supported by the recorded distribution of tooth shades observed manually by using the VITA classical shade guide, and can be explained by the dehydration of hard dental tissues caused by high concentrations of hydrogen peroxide which can prolong the effects of bleaching [30,31]. As the primary outcome of interest was the medium-term effects of bleaching, the measurements recorded immediately after the treatment was not included in the analysis. Although some studies found no difference between in-office and at-home bleaching treatments [25,32,33], in our study, at-home Bite&White treatment had lower bleaching effectiveness than Boost and Dash treatments, and should be used for a longer period than 6 d to produce the similar outcomes. The hypothesis that there is no difference in bleaching effectiveness between different treatments was therefore rejected. The average change in L^* and b^* values in the period from one to six months after the treatment did not differ significantly across different bleaching groups. Therefore, the hypothesis of no between-treatment differences in colour stability could not be rejected.

Postoperative tooth sensitivity is a post-treatment complication of unknown origin and is often associated with caries removal, cavity preparation or filling placement. Tooth sensitivity during bleaching is usually related to rapid transenamel and transdentinal diffusion of hydrogen peroxide to the pulp or other toxic components released with the degradation of the bleaching gels [34–36]. At-home Bite&White treatment generally led to lower postoperative sensitivity than in-office Boost and Dash treatments which used higher concentrations of bleaching agent. The hypothesis of no differences in postoperative sensitivity across different bleaching treatments was, therefore, rejected. Other studies also demonstrated that higher concentration of active bleaching agent causes greater hypersensitivity [29,37–39]. Benetti et al. reported, in an *in vitro* study, that the amount of peroxide which can penetrate to the pulp is proportional to the concentration of hydrogen peroxide, so the appearance and intensity of pain might be proportional to the concentration (i.e. potency) of bleaching agent [40]. Except concentration, higher postoperative sensitivity can be related to lower pH of a bleaching agent [41,42]. Lower pH causes microscopic and subsurface enamel defects and can also decrease microhardness [43–45]. These defects can cause faster and greater diffusion of bleaching agent toward the pulp, causing inflammatory reaction [46]. Bite&White used in our study had pH value between 6.0 and 8.5, while Dash had pH between 4.8 and 5.2 and Boost almost alkaline pH. Despite favourable pH value of Boost agent, hypersensitivity in this group was greater, indicating that the concentration of hydrogen peroxide in bleaching agent is more important for development of postoperative pain than its pH value.

Limitation of this study is relatively small sample size, so some of the between-group comparisons should be treated with caution due to the low statistical power. A larger sample size would increase the reliability of results; however, this was an exploratory study and the inclusion of colour stability variable, in our opinion, outweighed the negative aspects of having a smaller sample size, which was in part driven by the longitudinal nature of experiment. This variable was identified as a critical characteristic of bleaching treatment. Longitudinal studies with larger number of participants should be conducted in the future to support our findings.

Conclusion

Materials for professional in-office bleaching caused greater change of colour in comparison with at-home agent, but also a greater hypersensitivity. The change in tooth yellowness was a better indicator of patient satisfaction with the tooth colour after the bleaching treatment, while the change in lightness was a better indicator of perceived colour stability. The instability of tooth colour was identified as the most critical aspect of bleaching treatment. Lengthening the treatment process, but achieving a more stable tooth colour could be beneficial for improving the perceived value of a bleaching service.

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Disclosure statement

The authors report no conflicts of interest.

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