



Review article

Is at-home bleaching more effective on the upper arch than the lower arch? A prospective cohort study

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ABSTRACT

Objective: Teeth bleaching is one of the most popular aesthetic dental treatments, uses to address both extrinsic and intrinsic tooth discoloration. However, variations in bleaching efficacy between the upper and lower dental arches are commonly observed. Sublingual salivary glands may play a role in these differences by increasing saliva contamination of bleaching trays, which accelerates the degradation of bleaching gel and may reduce its effectiveness in the lower arch. This study aims to evaluate and compare the effectiveness of bleaching treatments in the upper and lower arches.

Methods: This study employed a prospective observational cohort design with a split-mouth approach. Thirty-two participants completed a three-week bleaching regimen using 16 % carbamide peroxide. Color changes were assessed using the CIELAB, CIEDE2000, and Whiteness Index for Dentistry (WID) formulas, with spectrophotometric measurements taken at baseline and weekly intervals.

Results: No statistically significant differences ($p > 0.05$) in bleaching efficacy for incisors between the two arches. However, upper canines demonstrated significantly greater bleaching effectiveness than lower canines by the second and third weeks ($p < 0.05$), as indicated by the CIELAB and CIEDE2000 formulas. No significant differences ($p > 0.05$) were observed using the WID formula.

Conclusion: While the lower canines exhibited slightly reduced bleaching effectiveness, these differences were not clinically noticeable, affirming the overall efficacy of the treatment for both arches.

Clinical significance: At-home bleaching treatment demonstrates equivalent effectiveness in both dental arches. While the lower canines may achieve a slightly reduced degree of bleaching, these differences are not clinically noticeable. Consequently, extending the duration of the bleaching treatment for the lower arch is unnecessary.

1. Introduction

Teeth bleaching is one of the most requested treatments in esthetic dentistry to solve extrinsic and intrinsic tooth discolorations [1–4]. There are two main techniques (in-office and at-home) and many products available for bleaching vital teeth, but the most used procedure is at-home bleaching with individualized trays and low concentrations of carbamide peroxide (CP) or hydrogen peroxide (HP) [5–7]. European

legislation allows at-home bleaching products with concentrations of 0.1–6 % HP and 0.3–17 % CP [8].

Studies have demonstrated the general efficacy of bleaching gels, with most authors noting that the color remains stable for 1 to 2.5 years [9]. However, the degree of bleaching may differ between the two arches at the end of the bleaching treatment. The presence of sublingual salivary glands increases tray contamination with saliva, leading to faster degradation of the bleaching gel [10–12]. For this reason, the

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bleaching effect may be slower in the lower arch compared to the upper arch [12].

For the objective evaluation of color changes, the most commonly used formulas are CIELAB (ΔE^*ab) and CIEDE2000 ($\Delta E00$) [13,14]. The CIELAB formula is based on three color coordinates: lightness (L^*); the a^* coordinate, which represents the chromatic value on red/purple to green/blue axis, and the b^* coordinate, which represents the chromatic value on blue/purple to yellow axis. The CIEDE2000 formula, introduced in 2001 as an enhancement of the CIELAB color difference formula, offers greater complexity and precision. It is the preferred method for calculating color differences in clinical interpretation, as it was specifically designed to address the non-uniformity of the CIELAB color space and mitigate discrepancies between instrumental color measurement and human visual perception. The formula incorporates lightness, chroma, and hue weighting functions, along with an interactive term between chroma and hue differences to improve accuracy for blue colors. Additionally, it includes a scaling factor for the CIELAB a^* axis to enhance performance in the assessment of gray colors [15–17]. Recently, it has been introduced the Whiteness Index for Dentistry (WID) obtained from CIELAB chromatic coordinates [18]. It is a method to calculate the whiteness differences (ΔWID) in bleaching treatments based on correlations with visual perception of tooth shaped shade tabs and dental materials. High positive WID values mean higher whiteness values and low values, including negative ones, mean lower whiteness values [18].

Even though objective color assessment is essential, human eye perception is also important [19]. To provide clinical relevance to these color assessments, visual thresholds for color differences have been established: the acceptability threshold (AT) and the perceptibility threshold (PT) [20–23]. These thresholds help ensure quality control and assist both patients and professionals in addressing aesthetic concerns [22,23].

The objective of this cohort study is to determine whether the degree of bleaching in the lower arch is less than that of the upper arch. To achieve this, the relationship between the degree of bleaching from the first visit to the end of the treatment for both the upper and lower arches (incisors and canines) will be analyzed using the CIELAB, CIEDE2000, and WID formulas, along with the analysis of the L^* , a^* , and b^* parameters. The null hypothesis was that there is no difference in bleaching efficacy between the upper and lower arches in both incisors and canines.

2. Material and methods

2.1. Ethical considerations

This cohort study was approved by the Galician Research Ethics Committee of SERGAS with registration code 2022/491. The study was designed and conducted following the recommendations of the Strengthening the Reporting of Observational studies in Epidemiology (STROBE) guideline and in accordance with The Code of Ethics of the World Medical Association (Declaration of Helsinki). All participants were provided an information sheet and a written informed consent.

2.2. Study design

This is a prospective observational cohort study with a split-mouth design. The upper dental arch will be considered as an unexposed cohort, while the lower dental arch will be considered as an exposed cohort. Tooth color will be measured at the baseline and in the first, second and third week of bleaching treatment. The main target of the present investigation is to evaluate the effectiveness of bleaching treatments in the lower and upper arch. The study was carried out in the Faculty of Dentistry of Santiago de Compostela, Spain

2.3. Sample selection

All patients who requested at-home bleaching treatment at the faculty clinic during the study period were invited to participate. Patients had to fulfill a series of criteria, represented in Table 1.

2.4. Sample size

The sample size was determined based on the acceptability threshold for $\Delta E00$ (AT) and a mean difference greater than 1.8 to detect potential color mismatches between upper and lower teeth. The calculation was performed automatically using the !Nsize.sps microdata developed for statistical software packages (IBM SPSS Statistics, v29.0; IBM Corp). Considering an increase of $>1.8 \Delta E00$ in the lower teeth, an alpha risk of 5 %, a power of 80 %, and the inclusion of a 20 % buffer for potential participant losses, 64 teeth were required. A split-mouth design was employed, involving 32 patients and 64 teeth. We decided to analyze 128 teeth, 64 central incisors and 64 canines.

2.5. Bleaching procedure

All patients underwent a complete oral examination, both visual and radiographic, to check the presence of caries, any pathology or alteration. A dental prophylaxis was performed before the start of bleaching treatment to remove extrinsic stains. Alginate impressions of both arches were taken (Orthoprint; Zhermack), and these impressions were cast in plaster (Elite Model; Zhermack). Individualized 1-mm soft upper and lower bleaching trays without reservoirs were fabricated for each patient using a vacuum plasticizer (Econo-Vac; Dental Buffalo). The trays were trimmed 1 mm above the gingival margin.

Each patient received their personalized bleaching trays and one syringe of bleaching agent (Opalescence 16 % PF; Ultradent Products Inc). The trays fit to the arch was checked. To standardize oral hygiene protocols during the study, participants were provided with a toothbrush and toothpaste (Colgate Total Toothpaste; Colgate Oral Pharmaceuticals). All patients were instructed in proper hygiene techniques. They were instructed to brush their teeth before starting the treatment and to place a drop (size-size) of bleaching gel on each tooth from premolar to premolar, wearing the bleaching tray overnight, approximately 6 h, following manufacturer's instructions. This process was to be repeated daily for three weeks. Written instructions of the process and cleaning recommendations for the bleaching trays were given to all patients. At each weekly control visit, patients were provided with a new syringe of bleaching agent.

2.6. Color assessments

Two trained evaluators were in charge of measuring the tooth shades with a dental spectrophotometer (Easysshade V; VITA Zahnfabrik). The spectrophotometer was calibrated before the evaluation of each participant, the parameters were recorded three times per each tooth, and average values were used for statistical analysis.

The maxillary and mandibular canines and central incisors on the right side were used as a reference. To ensure a standardized

Table 1
Inclusion and exclusion criteria.

Inclusion criteria	Exclusion criteria
- Over 18 years	- Adhesive restorations or prostheses in the anterior region
- No oral or systemic pathology	- Active orthodontic treatment
- Periodontally healthy	- Enamel or dentin alterations
- No gingival recession or dentin exposure	- Prior hypersensitivity
- No cavities	- Smokers
- Tooth Shade A2 or darker	- Pregnant women
	- Prior bleaching treatment

measurement on each visit, a custom position-finder was created using a 4-mm thick transparent plastic sheet (Mouthguard 150; Dentaflux) [24]. To ensure accurate parallel measurements with the spectrophotometer, an access window was created at the mid-cervical point (2 mm from the cervical margin) of each tooth to be studied with a 6 mm diameter trephine.

The parameters L* (lightness of the color measured from black to white), a* (the shade along the red/purple to green/blue axis), b* (the shade along the blue/purple to yellow axis), C* (chroma, which is the quality of a color's purity, intensity or saturation), and h° (hue angle, the degree to which a resembles or differs from colors described as red, orange, yellow, green, blue, or purple and is represented on a scale from 0 to 360° in the CIELAB system) were recorded [15–17,25].

Color measurements were taken at different times of the bleaching treatment. D0- Before the bleaching treatment, baseline; D1–7 days after the start of the bleaching treatment; D2- 14 days after the start of the bleaching treatment; D3- 21 days after the start of the bleaching treatment, end of the treatment.

The ΔL*, Δa*, and Δb* before (D0) and after treatment (D1, D2, and D3) were evaluated. To determine the color change between D0 and the evaluations at D1, D2, and D3, the ΔE*ab, the ΔE00 and ΔWID were calculated for each tooth type (upper central incisor – UCI, lower central incisor – LCI, upper canine – UC, lower canine – LC).

The CIELAB color differences (ΔE*ab) were calculated using the following equation [15]:

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

Where ΔL*, Δa*, and Δb* represent the color differences in each parameter for a pair of sample [15]:

The CIEDE2000 color differences (ΔE00) were calculated using the following equation [15,16]:

$$\Delta E_{00} = \sqrt{\left(\frac{\Delta L'}{K_L S_L}\right)^2 + \left(\frac{\Delta C'}{K_C S_C}\right)^2 + \left(\frac{\Delta H'}{K_H S_H}\right)^2} + R_T \left(\frac{\Delta C'}{K_C S_C}\right) \left(\frac{\Delta H'}{K_H S_H}\right)$$

Where ΔL', ΔC' and ΔH' represent the color differences in each parameter for a pair of samples. The weighing functions (SL, SC, and SH) adjust the total color difference based on the position of the color difference pair in L*, a*, and b* coordinates. The parametric factors (KL, KC, and KH) serve as correction terms for experimental conditions. In this study the parametric factors were set to 1. And the rotation function (RT) represents how chroma and hue angle differences interact, especially in the blue region [15,16].

The WI_D was calculated with de follow equation [14,18]:

$$WI_D = 0.511L^* - 2.324a^* - 1.100b^*$$

The 50:50 % perceptibility (PT) and 50:50 % acceptability (AT) thresholds values were used to evaluate the color differences obtained [13,22,26].

2.7. Statistical analysis

To determine if the sample followed a normal distribution, the Kolmogorov-Smirnov test was performed (sample >50 teeth). Means and standard deviations of color change (ΔL*, Δa*, Δb*, ΔC*, Δh°, ΔE*ab, ΔE00, ΔWI_D) between baseline (D0) and assessment times (D1, D2, and D3), color coordinates (L*, a*, b*), and WI_D had a normal distribution. The ΔL*, Δa*, Δb*, ΔC*, Δh°, ΔE*ab, ΔE00, ΔWI_D of each tooth types (Central Incisors and Canines) of upper and lower teeth were compared at different assessment times. An intergroup comparison using Student's T-test for independent samples was made. The level of significance was 5 % for all statistical tests. All comparisons were performed using IBM SPSS (SPSS Inc., Chicago, IL, USA) for Mac, v29.0.

3. Results

Initially, 57 volunteers were evaluated and 25 were excluded since they did not meet the eligibility criteria (Table 1). A total of 32 participants were included in the study, with a sample size consisting of 64 teeth (canines and incisors). All participants attended and completed all the phases of the study. The baseline characteristics of participants are represented in Table 2. mean age in years was 30 ± 10.75, and 68,75 % of the participants were woman. No statistically significant differences were found between the groups in terms of age, sex, baseline color coordinates (L*, a*, b*, C*, h°) and WID. All scales utilized for color change evaluation exhibited significant bleaching effectiveness.

3.1. Incisors

The means and standard deviation of color change coordinates (ΔL*, Δa*, Δb*, ΔC*, Δh°), color differences (ΔE*ab and ΔE00), and whiteness index for dentistry (ΔWI_D) between baseline (D0) and the different assessment times (D1, D2, and D3) for UCI and LCI are represented in Table 3. There were no statistically significant differences (p > 0.5) between groups for CI in color changes coordinates (ΔL*, Δa*, Δb*, ΔC*, Δh°), color differences (ΔE*ab and ΔE00) and whiteness index for dentistry (ΔWI_D).

All median ΔE*ab and ΔE00 values for all the evaluation times compared with the baseline (D1-D0, D2-D0,D3-D0) were above the 50 %:50 % perceptibility threshold (PT ΔE*ab = 1.22; PT ΔE00 = 0.81) [22] and the 50 %:50 % acceptability threshold (AT ΔE*ab = 2.66; AT ΔE00 = 1.77) [22] for all incisors (UCI, LCI). All median ΔWI_D values were also above the 50 %:50 % perceptibility threshold (WPT = 0.72) and the 50 %:50 % acceptability threshold (WAT = 2.60) [27].

3.2. Canines

In Table 4, the means and standard deviation of color change coordinates (ΔL*, Δa*, Δb*, ΔC*, Δh°), color differences (ΔE*ab and ΔE00), and whiteness index for dentistry (ΔWI_D) between baseline (D0) and the different assessment times (D1, D2, and D3) for UC and LC is represented. UC showed statistically significant higher L* (p < 0.05) and a lower a* value (p < 0.5) at D2-D0 than LC. UC showed statistically significant (p < 0.05) higher h* values in all periods (D1-D0, D2-D0, D3-D0). Statistically significant color changes for ΔE*ab were found between UC and LC at D2-D0 and D3-D0 (p < 0.05) and for ΔE00 at D3-D0 (p < 0.5). Color change was higher in UC than in LC. No statistically significant differences in ΔWI_D (p > 0.5) were found between groups, but UC had higher WID values than LC.

All median ΔE*ab, ΔE00 and ΔWI_D values for all the evaluation times compared with the baseline (D1-D0, D2-D0,D3-D0) were above the 50 %:50 % perceptibility threshold (PT ΔE*ab = 1.22; PT ΔE00 = 0.81; WPT = 0.72) [22,27] and the 50 %:50 % acceptability threshold

Table 2
Baseline characteristics of the participants.

	Upper Arch (n = 16)	Lower Arch (n = 16)	
INCISORS	L*	79.88 ± 5.04	78.62 ± 6.58
	a*	-1.50 ± 1.46	-0.69 ± 1.85
	b*	18.28 ± 5.64	18.25 ± 5.90
	C*	18.39 ± 5.63	18.31 ± 5.76
	h°	95.77 ± 4.43	93.53 ± 5.49
	WID	24.19 ± 10.98	21.68 ± 12.48
CANINES	L*	73.80 ± 5.62	76.59 ± 4.20
	a*	1.04 ± 1.80	.85 ± 2.55
	b*	27.04 ± 6.11	28.16 ± 6.30
	C*	26.79 ± 6.33	28.23 ± 6.51
	h°	88.32 ± 3.51	88.87 ± 3.45
	WID	5.54 ± 11.09	6.18 ± 14.01
Sex (female; %)	22 (68,75 %)		
Average age (years)	30 ± 10.75		

Table 3

Means and standard deviation of color change coordinates (ΔL^* , Δa^* , Δb^* , ΔC^* , Δh°), color differences (ΔE^*ab and $\Delta E00$), and whiteness index for dentistry (ΔWI_D) between baseline (D0) and the different assessment times (D1-D0, D2-D0, D3-D0) for upper and lower incisors.

Color evaluation	Assessment times	Group	Mean difference (95 % CI)	p-value ^a
INCISORS				
ΔL^*	D1-D0	Upper	4.34 ± 2.65	.03 (−1.49 to 1.56)
		Lower	4.30 ± 3.42	
	D2-D0	6.31 ± 2.58	−0.19 (−1.72 to 1.34)	.804
Δa^*	D1-D0	Upper	8.09 ± 2.73	−0.12 (−0.93 to 0.69)
		Lower	8.24 ± 3.71	
	D2-D0	−0.93 ± 1.97	.30 (−0.19 to 0.79)	.229
Δb^*	D1-D0	Upper	−0.66 ± 3.79	.38 (−0.16 to 0.93)
		Lower	−1.04 ± 4.23	
	D2-D0	−0.59 ± 2.24	.60 (−0.59 to 1.60)	.317
ΔC^*	D1-D0	Upper	−6.89 ± 2.55	−0.74 (−2.22 to 0.75)
		Lower	−6.16 ± 3.33	
	D2-D0	−4.91 ± 2.35	.58 (−0.58 to 1.74)	.321
Δh°	D1-D0	Upper	−6.76 ± 2.51	−0.75 (−2.19 to −0.70)
		Lower	−6.01 ± 3.24	
	D2-D0	4.35 ± 2.97	−1.10 (−2.83 to 0.64)	.212
ΔE^*ab	D1-D0	Upper	6.84 ± 3.13	.58 (−1.76 to 2.91)
		Lower	6.26 ± 5.77	
	D2-D0	6.45 ± 2.87	−0.34 (−1.83 to 1.15)	.653
$\Delta E00$	D1-D0	Upper	8.36 ± 2.83	−0.68 (−2.25 to 0.88)
		Lower	9.04 ± 3.41	
	D2-D0	10.92 ± 2.96	−0.06 (−1.69 to 1.56)	.937
ΔWI_D	D1-D0	Upper	4.09 ± 1.72	−0.20 (−1.14 to 0.74)
		Lower	4.29 ± 2.03	
	D2-D0	5.42 ± 1.89	−0.23 (−1.33 to 0.86)	.672
	D1-D0	Upper	6.96 ± 1.74	−0.04 (−1.12 to 1.04)
		Lower	7.00 ± 2.51	
	D2-D0	6.96 ± 4.40	−0.04 (−1.12 to 1.12)	.936
	D1-D0	Upper	13.26 ± 4.94	−0.18 (−3.09 to 2.72)
		Lower	8.75 ± 5.35	
	D2-D0	10.10 ± 4.40	−1.45 (−4.03 to 1.12)	.263
	D1-D0	Upper	13.26 ± 4.94	−0.16 (−3.11 to 2.80)
		Lower	13.42 ± 6.73	
	D2-D0	13.26 ± 4.94	−0.16 (−3.11 to 2.80)	.916

CI, confidence interval.

^a Student's T-test.

(AT ΔE^*ab = 2.66; AT $\Delta E00$ = 1.77; WAT = 2.60) for all canines (UC, LC) [22,27]

4. Discussion

Dental bleaching is an aesthetic treatment aimed at achieving a whiter and more uniform smile. Ensuring a comparable level of bleaching between the upper and lower arches is crucial for patient satisfaction. However, most studies on at-home and in-office bleaching have primarily focused on analyzing the color change on the upper arch, often neglecting the lower arch. There is higher concentration of active bleaching agent in the upper arch and the increased likelihood of salivary contamination in the lower trays due to sublingual salivary glands. Such contamination accelerates the degradation of the bleaching agent

Table 4

Means and standard deviation of color change coordinates (ΔL^* , Δa^* , Δb^* , ΔC^* , Δh°), color differences (ΔE^*ab and $\Delta E00$), and whiteness index for dentistry (ΔWI_D) between baseline (D0) and the different assessment times (D1-D0, D2-D0, D3-D0) for upper and lower canines.

Color evaluation	Assessment times	Group	Mean difference (95 % CI)	p-value ^a
CANINES				
ΔL^*	D1-D0	Upper	6.90 ± 3.22	.88 (−0.68 to 2.44)
		Lower	6.02 ± 3.03	
	D2-D0	9.73 ± 3.36	1.55 (0.02 to 3.08)	.047 ^b
Δa^*	D1-D0	Upper	10.15 ± 13.48	−0.15 (−5.03 to 4.73)
		Lower	10.30 ± 2.99	
	D2-D0	−2.49 ± .84	−0.44 (−1.99 to 1.02)	.124
Δb^*	D1-D0	Upper	−2.76 ± .94	−0.52 (−0.99 to −0.04)
		Lower	−2.24 ± .98	
	D2-D0	−3.08 ± 1.18	−0.56 (−1.21 to 0.09)	.092
ΔC^*	D1-D0	Upper	−6.24 ± 3.80	−0.48 (−1.99 to 1.02)
		Lower	−5.76 ± 1.92	
	D2-D0	−8.28 ± 4.20	−0.70 (−2.41 to 1.02)	.417
Δh°	D1-D0	Upper	−10.96 ± 3.98	−1.21 (−2.76 to 0.34)
		Lower	−9.77 ± 1.86	
	D2-D0	−5.93 ± 3.74	−0.17 (−1.67 to 1.33)	.823
ΔE^*ab	D1-D0	Upper	−7.92 ± 4.30	−0.38 (−2.12 to 1.35)
		Lower	−7.53 ± 2.37	
	D2-D0	4.30 ± 10.52	−0.83 (−2.39 to 0.74)	.293
$\Delta E00$	D1-D0	Upper	6.35 ± 2.49	1.67 (0.64 to 2.70)
		Lower	4.68 ± 1.52	
	D2-D0	7.75 ± 2.87	2.02 (0.75 to 3.28)	.002 ^b
ΔWI_D	D1-D0	Upper	9.91 ± 3.31	2.56 (1.14 to 3.98)
		Lower	7.35 ± 2.27	
	D2-D0	10.40 ± 3.11	1.41 (−0.05 to 2.86)	.058
	D1-D0	Upper	13.75 ± 8.76	2.11 (0.58 to 3.63)
		Lower	11.65 ± 3.03	
	D2-D0	18.74 ± 8.76	4.15 (0.88 to 7.43)	.014 ^b
	D1-D0	Upper	6.32 ± 2.29	.76 (−0.33 to 1.84)
		Lower	5.56 ± 2.03	
	D2-D0	8.48 ± 3.14	1.33 (−0.12 to 2.77)	.071
	D1-D0	Upper	10.82 ± 2.86	1.75 (0.37 to 3.12)
		Lower	9.08 ± 2.63	
	D2-D0	10.82 ± 5.66	1.75 (0.37 to 4.72)	.014 ^b
	D1-D0	Upper	16.18 ± 5.66	1.36 (−0.70 to 4.72)
		Lower	14.17 ± 5.17	
	D2-D0	20.50 ± 6.48	2.77 (−0.05 to 5.59)	.054
	D1-D0	Upper	24.41 ± 9.72	2.54 (−1.41 to 6.50)
		Lower	21.87 ± 5.55	
	D2-D0	24.41 ± 9.72	2.54 (−1.41 to 6.50)	.203

CI, confidence interval.

^a Student's T-test.

^b Statistically significant.

in the lower arch, potentially reducing its efficacy [12]. Therefore, it may be necessary to extend the bleaching treatment time for the lower arch to achieve similar results in both arches.

This study aimed to address this fact by comparing the bleaching effectiveness of both arches, making it the first to evaluate individual differences between upper and lower incisors and canines in at-home bleaching.

The effectiveness of dental bleaching was evaluated using three different color change formulas whether they yield varying results. The CIELAB formula, the most widely used, is closely related to human color perception, encompassing all three dimensions of the color space. Equal distances in the CIELAB color space represents approximately equally perceived steps the most used [28]. The CIEDE2000 formula

incorporates improvements and corrections over the CIELAB formula and has been preferred for identifying clinically relevant color differences [29]. The White Index for Dentistry (WID), derived from the CIELAB chromatic coordinates, is a method used to assess color changes and has been incorporated into recent randomized clinical trials [26, 30–32]. It calculates whiteness differences in bleaching treatments by correlating visual perceptions with tooth-shaped shade tabs and dental materials, offering additional insights into the direction and effectiveness of bleaching. High positive WID values indicate greater whiteness, while low or negative values signify reduced whiteness [18].

Color perceptibility (PT) and acceptability thresholds (AT) are essential tools in color research, particularly for assessing tooth bleaching effectiveness [23,27]. The perceptibility threshold (PT) represents the smallest color difference detectable by the human eye, while the acceptability threshold defines the point at which a difference becomes clinically acceptable. In practice, supra-threshold values-differences exceeding PT-are often used, transitioning from just-noticeable differences to acceptable color variations known as color acceptability thresholds (AT) or color tolerances [33–35].

To explore potential differences, incisors and canines were selected for color assessment. This approach allowed for a more detailed analysis of how tooth type influences bleaching efficacy between arches. Some authors state that there are no significant differences between the two types [36]. Most of studies focus solely on canines over incisors due to their darker initial color and greater discoloration, which enhances the visibility of bleaching effects and simplifies patient recruitment [26,37].

The results obtained do not allow for the rejection of the null hypothesis, as no statistically significant relationship was found to demonstrate that bleaching effectiveness is consistently greater in the upper arch than in the lower arch.

For incisors, no statistically significant differences in color change coordinates or color change differences were observed between the upper and lower arches. The higher permeability of central mandibular incisors, which facilitates greater hydrogen peroxide penetration, likely compensates for the reduced active agent in the lower arch, thereby equalizing the bleaching effect between arches [38–40].

In contrast, notable statistically differences were observed when analyzing canines. Human eyes perceive color differences in two ways: quantitatively, through variations in lightness and/or chroma, and qualitatively, through differences in hue angle [41]. Statistically significant differences in lightness (L^*) were detected during the second week of bleaching (D2-D0), with upper canines exhibiting greater lightness. Additionally, lower canines showed higher a^* values indicating a shift toward red tones and away from green. Upper canines also demonstrated consistently higher h° values across all assessment periods. Observers typically associate color with hue angle and do not perceive differences in lightness and/or chroma as changes in color [33]. When the tooth color travels in an optimal hue direction, the same amount of color change will result in greater change in whiteness perception than traveling in other hue directions. The most effective tooth bleaching occurs when the color moves toward the greenish-blue hue direction [25]. No differences in chroma were found between arches, which also plays an important role in color perception [41–43].

At the end of bleaching treatment (D3-D0), if we analyze color change in canines, the CIELab and the CIEDE2000 formula revealed significant differences between arches, indicating superior bleaching in the upper arch. However, no statistically significant differences were found when using the WID formula. This finding suggests variations in the sensitivity of the used formulas.

The observed differences in bleaching effectiveness between incisors and canines can be attributed to variations in dental permeability, enamel thickness, and the presence of saliva. The diffusion capacity of the bleaching agent is inversely proportional to the thickness of the tooth groups [44]. There is a clear difference in enamel thickness between upper and lower central incisors. Lower central incisors, which have greater permeability and thinner enamel, allow deeper peroxide

penetration [44], compensating for the reduced active agent in the lower arch and resulting in similar bleaching outcomes across upper and lower arches.

Canines have a more chromatic substrate due to their greater dentin volume and thicker enamel, which results in lower permeability and limited peroxide penetration [19]. Although there are no significant anatomical differences between upper and lower canines, the presence of saliva in the lower arch promotes greater contamination of the lower tray and reduces the amount of active bleaching agent available, leading to consistently greater bleaching effectiveness in the upper arch.

The perceptibility and acceptability thresholds were applied to ΔE^*ab , $\Delta E00$, and ΔWID . The data indicate that tooth bleaching was satisfactory for both tooth types (incisors and canines) and both groups (upper and lower), as the values exceeded the acceptability thresholds reported in the literature (AT $\Delta E^*ab = 2.66$; AT $\Delta E00 = 1.77$; WAT = 2.60) [22,27]. This confirms that at-home tooth bleaching is an effective procedure, regardless of the arch in which the treatment is performed.

The primary limitation of this study is that the sample predominantly consisted of young adults, which might have affected the observed bleaching efficacy [45]. Tooth color is influenced by dentin characteristics, which change as people age. In older individuals, the enamel becomes less permeable due to increased deposition of hydroxyapatite crystals, potentially reducing its response to bleaching treatments [46, 47]. These age-related differences in the structure of enamel and dentin properties could lead to variations in treatment outcomes across different age groups. Therefore, in older individuals, we might observe more noticeable differences between the upper and lower arches in both incisors and canines. Further studies including older age ranges are necessary to determine whether significant differences between arches truly exist.

5. Conclusion

This study highlights the need to evaluate bleaching effectiveness in both dental arches, as most research has focused on the upper arch. Our results confirm that 16 % carbamide peroxide at-home bleaching is effective for both incisors and canines, regardless of arch placement. While bleaching responses differed between tooth types, all treatment outcomes exceeded perceptibility and acceptability thresholds (ΔE^*ab , $\Delta E00$, and ΔWID), affirming its clinical efficacy. However, variations in color difference formulas highlight the need for standardized assessment protocols to ensure consistent evaluations.

Conflict of interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

CRedit authorship contribution statement

Patricia Pereira-Lores: Writing – original draft, Visualization, Project administration, Methodology, Conceptualization. **Tania Gancedo-Gancedo:** Writing – original draft, Resources, Investigation, Formal analysis, Data curation. **Benjamín Martín-Biedma:** Writing – review & editing, Visualization, Supervision. **Iván Varela-Aneiros:** Software, Resources, Data curation. **Ana Belén Dablanca-Blanco:** Software, Resources, Data curation. **Carolina Villasenín-Sánchez:** Writing – original draft, Validation, Supervision, Investigation, Data curation. **Jenifer Martín-González:** Writing – review & editing, Supervision. **Víctor Alonso de la Peña:** Writing – review & editing, Validation, Supervision, Investigation. **Pablo Castelo-Baz:** Writing – review & editing, Supervision, Project administration, Methodology.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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