Received: 19 March 2020 | Revised: 25 May 2020 | Accepted: 31 May 2020

DOI: 10.1111/jerd.12612

RESEARCH ARTICLE

WILEY

Clinical effects of dehydration on tooth color: How much and how long?

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Abstract

Objective: To evaluate effects of dehydration on tooth color determine whether color returns to baseline after 30 min or 24 h.

Materials and methods: Thirty participants with intact maxillary central and lateral incisors were recruited for the study. Color measurements were performed with a spectrophotometer (SpectroShade Micro) at baseline and at 10, 20, and 30 min of dehydration, as well as 30 min and 24 h of rehydration. CIEDE2000 color parameters were used to calculate color difference. The data were analyzed for color changes over time by repeated-measures analysis of variance (ANOVA), and the Bonferroni-Tukey test was used for post-ANOVA comparisons ($P < .05$).

Results: After 30 min of dehydration, all the tested teeth were above the perceptibility threshold ($\Delta E_{00} = 0.8$), and 85% of the teeth were above the acceptability threshold ($\Delta E_{00} = 1.8$). After 30 min of rehydration, 78.3% of the tested teeth were above the perceptibility threshold, and 31.6% of the teeth were above the acceptability threshold. After 24 h of rehydration, 99.2% of the teeth were below the acceptability threshold, and 90% of the values were below the perceptibility threshold.

Conclusions: Thirty-minute tooth dehydration can result in a clinically significant color change. After a 24-h rehydration period, reliable color assessment can be performed.

Clinical significance: Tooth dehydration causes significant color change, thus assessment of final color or clinical success should be considered after tooth rehydration for esthetic restorations and tooth bleaching.

KEYWORDS

color change, in office tooth whitening, tooth color, tooth dehydration, tooth isolation

1 | INTRODUCTION

Dental restorations should mimic sound tooth structures in terms of color and optical properties, especially in the anterior region. However, closely matching natural teeth with a restoration can be one of the most challenging procedures in restorative dentistry. Shade matching includes color determination, color communication with the dental laboratory and color reproduction with dental restoration for indirect techniques. Furthermore, it can involve color determination and selection of the appropriate material and application method when using direct techniques. Therefore, color selection is the first critical step in restoration procedures, and it should be carried out properly.

Shade guides, spectrophotometers, colorimeters, spectroradiometers, and digital image analysis are used for color determination.[1] Visual shade selection with a shade guide is a quick and cost-effective method, but it is considered inconsistent and subjective. Many factors may influence visual shade selection, including proper lighting, color acuity, and eye fatique.[2] Using sophisticated tools may help overcome these undesirable conditions. However, even if the latest technology is used, when sufficient attention is not paid to the fundamental principles of color selection, dissatisfactory results can occur at the end of the restoration.

Color determination must be carried out before any restorative procedure, isolation or impression is conducted.[2-4] Most dental procedures cause dehydration and increase the opacity of the enamel, such that teeth appear whiter. Normally, the enamel layer is translucent because inter-prism spaces are filled with water and light can scatter among the crystals, while the dentin is rich in hue and chroma.[1] During a dehydration period, as a result of water loss, the inter-prism spaces fill with air instead of water.[5] When the transmitting medium changes, light will refract differently, resulting in decreased enamel translucency and increased luminosity. Under these circumstances, the dentin color is masked and teeth appear lighter.[6]

In addition to the misleading effect on the color of restorations, tooth dehydration may give rise to false assessment of the color change and inflate the whitening effect attributed to the bleaching procedure.[7] Teeth are isolated for a period of time, and some light activation units produce heat during office bleaching. Partial color rebound has been reported 1 week after bleaching as a result of tooth dehydration.[8]

Given the considerations outlined above, color determination or shade selection must be performed before the tooth dehydrates, and the rebound effect after tooth rehydration in the office bleaching process should be kept in mind. Few clinical and in vitro studies have evaluated the degree of color change after dehydration[3,4,9,10] and rehydration periods.[3,4,10] Moreover, there are inconsistencies between studies in terms of the color change degree and duration of return to appreciable values. The aims of the present study were to evaluate the degree of color change over a 30-min dehydration period of the teeth and to determine if color returned to baseline after 30 min or 24 h. The null hypotheses of this unblinded, prospective clinical study are as follows:

- There is no perceptible difference after tooth dehydration; and

- Tooth color will not return to baseline values after a 30-min or 24-h rehydration period.

2 | MATERIALS AND METHODS

2.1 | Participant selection

The study protocol of this single-center clinical study was approved by the Human Ethics in Clinical Research Committee of the Tokat Gaziosmanpasa University Faculty of Medicine (No. 19-KAEK-076). The aim of the trial, clinical procedures and possible study-related risks were explained to the patients prior to inclusion. All participants signed written informed consent forms.

Thirty participants were recruited according to the following inclusion or exclusion criteria:

Inclusion criteria

- Age range of 18 to 45 years;
- Upper central and lateral incisors in good periodontal condition and sound with no wear, restorations or internal or external discoloration;

Exclusion criteria

- Recent fixed orthodontic appliance;
- Vital tooth bleaching in the last year; and
- Medication affecting salivary flow or complaint of dry mouth.

2.2 | Color measurements

All participants were asked for brushing teeth without toothpaste for 2 min before the measurements. Color measurements were carried out in a dental clinic, while participants sitting on reclined same dental unit chair, under fluorescent lightning to minimize the possible change in light conditions. There was no natural light and dental reflector light was kept turned off. Each color measurement was performed with a spectrophotometer (SpectroShade Micro, MHT Optic Research AG, Niederhasli, Switzerland) on upper centrals and laterals by taking polarized images by the same experienced dentist. Spectrophotometric images, including the entire tooth surface, were obtained one by one for each tooth, for three times, under standard light conditions with the aim of minimizing possibly inaccurate readings. Spectrophotometric images were analyzed according to manufacturer's instructions. First, tooth shape was drawn on the screen of the spectrophotometer and by clicking shade button overall shade of the tooth was determined. After that, tooth was displayed in three parts (gingival, middle, and incisal) by clicking parts button. The spectrophotometer was calibrated and used according to the manufacturer's instructions before each set of measurements. All participants were asked not to breathe by mouth during the color measurements.

2.3 | Dehydration procedure

Spectrophotometric color measurements were performed at the study inception, and baseline color parameters were recorded. Lips were retracted using a lip and cheek retractor (Optiview, Kerr Hawe, Bioggio, Switzerland) that was placed within 10 s. Upper central and lateral incisors were isolated with cotton rolls and air dried for 5 s. Excess saliva was removed with saliva ejector during the dehydration period, and participants kept their mouths half open with the help of silicone mouth bite blocks. Spectrophotometric measurements were carried out three times during 30 min at 10-min intervals during the dehydration period for each test tooth.

2.4 | Rehydration procedure

At the end of the dehydration procedure, the lip retractor and cotton rolls were removed and full-mouth rinse with water was carried out for 30 s. The tooth rehydration process was started when the test teeth were in contact with saliva. Participants were asked to drink a glass of water (200 ml) and close their mouth for 30 min. They were then asked to return to routine daily activity but avoid consuming staining beverages for 24 h, such as coffee or red wine. The tooth rehydration process was started when the test teeth were in contact with saliva. Spectrophotometric measurements were carried out at 30 min and 24 h of rehydration.

Commission Internationale de l'eclairage (CIEDE2000) system color parameters (*L*, *C*, *H*) were used to calculate color differences (ΔE_{00}). Primarily color difference between the baseline and dehydration and rehydration periods determined separately for each tooth. Secondarily, color change of the gingival, middle and incisal thirds were calculated. The color difference was determined by using an equation[11,12];

$$\Delta E_{00} = \sqrt{\left(\frac{\Delta L'}{k_L S_L}\right)^2 + \left(\frac{\Delta C'}{k_C S_c}\right)^2 + \left(\frac{\Delta H'}{k_H S_H}\right)^2 + R_T \frac{\Delta C'}{k_c S_C}\frac{\Delta H'}{k_H S_H}}$$

ΔE_{00} values were compared with threshold values of acceptability (ΔE_{00} = 1.8) and perceptibility (ΔE_{00} = 0.8).[13] The color difference and color parameters at 30 min and 24 h after dehydration were compared with the baseline color parameters. In addition, CIELAB color parameters (L^*, a^*, b^*) were recorded to compare the results with previous studies.

2.5 | Statistical analysis

The data were analyzed for color changes over time via repeated-measures analysis of variance (ANOVA; $P < .05$). The Bonferroni test was used for post-ANOVA contrasts between baseline and each measurement time (baseline; 10, 20, and 30 min of dehydration; and 30 min and 24 h of rehydration; $P < .05$).

3 | RESULTS

Demographic and clinical characteristics of the participants are presented in Table 1. Data are expressed in CIEDE2000 coordinates, and the values for the mean and standard deviations of the *L*, *C*, *H*, and ΔE_{00} color differences at baseline; 10-, 20-, and 30-min intervals of dehydration; and 30 min and 24 h of rehydration are shown in Tables 2–3. CIE $L^*a^*b^*$ values are shown in Figure 1. The ΔE_{00} values increased with time during the dehydration period, and the main color change was seen in the first 10 min of dehydration. After 10 min of dehydration, color change of 95.8% of the teeth (115 teeth) were above the perceptibility threshold (ΔE_{00} = 0.8), and 54.1% were (65 teeth) above the acceptability threshold (ΔE_{00} = 1.8). After 30 min of dehydration, all the tested teeth were above the perceptibility threshold, and 85% of the teeth (102 teeth) were above the acceptability threshold. After 30 min of dehydration, while a definite increase of mean L^* (2.5) and definite decrease of mean C^*_{ab} values (–3.01) were observed, only slight changes of mean h_{ab} values (–0.5) were measured.

TABLE 1 Demographic and clinical characteristics of the population sample

Age (mean/range)	27.4/19-37
Gender (female/male)	16/14
Baseline tooth color	A1: 20 (16.7%) B2: 3 (2.5%) D2: 7 (5.8%) A2: 56 (46.7%) C1: 8 (6.7%) C2: 4 (3.3%) A3: 22 (18.3%)
Region of enrollment	Turkey/30 participants

It was observed at the 30-min and 24-h rehydration points that the color parameters tended to return the baseline values during rehydration. A partial return to baseline values for all color parameters was observed after 30 min of rehydration; however, 78.3% of the tested teeth (98 teeth) were above the perceptibility threshold, and 31.6% of the teeth (38 teeth) were above the acceptability threshold. After 24 h of rehydration, all the color parameters came closer to the baseline values. The mean color difference from the baseline of the 99.2% teeth (119 teeth) were below the acceptability threshold, and 90% of the values (108 teeth) were below the perceptibility threshold.

When thirds of the teeth were considered, the mean color changes were above the acceptability threshold after 30 min of dehydration (Table 4). The gingival and middle thirds showed similar color changes. However, the incisal third showed a significantly higher color change than the other parts did after 30 min of dehydration ($P < .001$). After 30 min of rehydration, the mean color change values for gingival and middle thirds were below the acceptability threshold, however mean color change of incisal third (1.96 ± 1.10) was above the acceptability threshold. After 24 h of rehydration, the mean color change values were below the perceptibility threshold.

When centrals and laterals are are compared, it was observed that the lateral teeth exhibited more color change after 30 min of dehydration (2.64 ± 0.85) than the central incisors did (2.99 ± 1.07). However, there was no difference between central and lateral incisors at 10 min, 20 min, and 30 min of dehydration ($P > .05$). During rehydration, the incisor teeth regained color similarly; there was no difference at 30 min and 24 h of rehydration between the central and lateral incisors ($P > .05$).

4 | DISCUSSION

Proper selection of tooth color is an important and sometimes difficult step of an anterior restoration from an esthetic perspective.[2] Color change as a result of tooth dehydration is a crucial phenomenon that may directly affect the results of direct and indirect restorations permanently or unrestored adjacent teeth temporarily. Tooth dehydration also contributes to an immediate posttreatment color change in office bleaching, and this rebound effect may lead to patients' loss of confidence. Therefore, patients should be informed about this transient situation after restoration placement or bleaching applications.

The degree of color change of the teeth in 30 min during the dehydration period and the color recovery effect of rehydration after 30 min or 24 h were evaluated in the present study. It was revealed that there was significant color change, above the acceptable threshold, after 30 min of dehydration. After 30 min of rehydration, the tooth color had not returned to baseline; however, after 24 h of rehydration, the color parameters were close to the baseline values, and the color difference was below the perceptible threshold. Therefore, both null hypotheses were rejected.

The effects of dehydration on tooth color have been evaluated in limited studies in the literature. In an in vitro study, color change of extracted human central incisors was evaluated after 2 and 4 h.[9] Color change was evaluated after 15 min of dehydration with different intervals in two studies[3,10] and 30 min after dehydration in one study.[4] Although the studies mentioned that more than 15 min[3] and

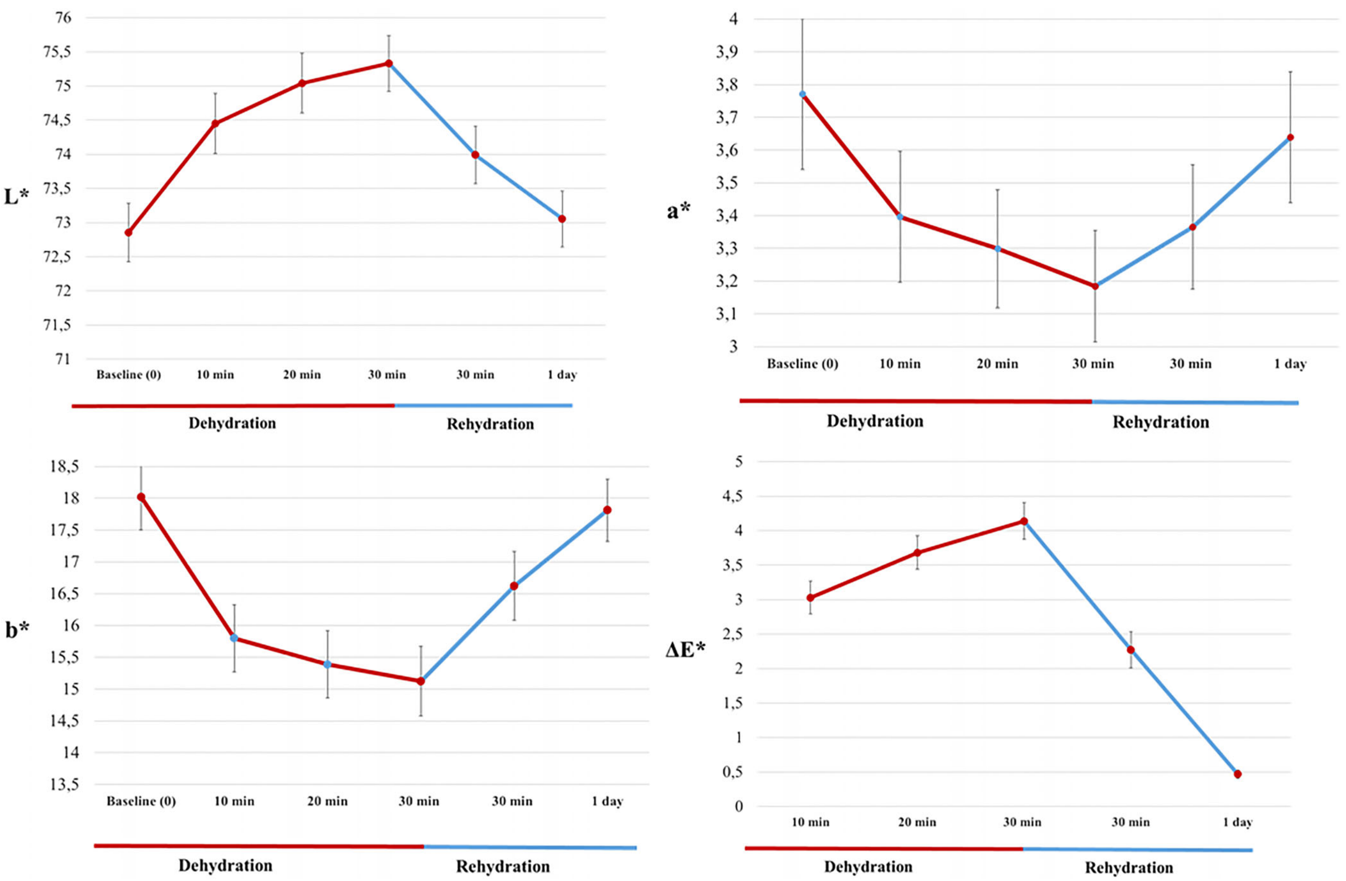

FIGURE 1 Change in color parameters (L^*, a^*, b^* CIELAB ΔE values) and 95% confidence interval with dehydration and rehydration

TABLE 2 Mean ± SD of color parameters and color change to baseline (ΔE_{00} and ΔE_{ab}) of central and lateral incisors

	Time					
	Baseline	Dehydration			Rehydration	
Color parameters	0	10 min	20 min	30 min	30 min	24 h
CIE L^*	72.85 ± 2.39	74.45 ± 2.48	75.04 ± 2.44	75.33 ± 2.34	73.99 ± 2.38	73.05 ± 2.30
CIE C^*_{ab}	18.92 ± 3.08	16.65 ± 3.05	16.22 ± 3.00	15.91 ± 3.08	17.42 ± 3.09	18.66 ± 2.87
CIE h_{ab}	72.89 ± 4.44	72.18 ± 5.19	72.12 ± 5.22	72.38 ± 5.28	73.18 ± 5.10	73.18 ± 4.37
ΔE_{00}	–	2.02 ± 0.85[a]	2.53 ± 0.89[b]	2.81 ± 0.86[c]	1.50 ± 0.86[d]	0.38 ± 0.31[e]
ΔE_{ab}	–	3.03 ± 1.33[a]	3.68 ± 1.36[b]	4.14 ± 1.49[c]	2.27 ± 1.47[d]	0.47 ± 0.36[e]

Note: Means with different superscript letters are significantly different ($p < .001$).

TABLE 3 Mean ± SD color difference (Δ*E*) of incisor teeth and centrals—laterals separately with mean difference and 95% confidence interval

	Color change to baseline (ΔE_{00})			Teeth groups					
				Centrals	Laterals				
Time	Mean ± SD	Lower 95% CI for Mean	Upper 95% CI for Mean	Mean ± SD	Mean ± SD	Mean Difference (Cental-Lateral)	Lower 95% CI	Upper 95% CI	*p* values
10′ (dehydration)	2.02 ± 0.85	1.87	2.17	1.91 ± 0.79[a]	2.14 ± 0.89[a]	−0.230	−0.535	0.074	0.137
20′ (dehydration)	2.53 ± 0.89	2.37	2.69	2.38 ± 0.83[b]	2.67 ± 0.93[b]	−0.289	−0.608	0,031	0,076
30′ (dehydration)	2.81 ± 0.86	2.66	2.96	2.64 ± 0.85[c]	2.99 ± 1.07[c]	−0.346	−0.695	0,004	0.053
30′ (rehydration)	1.50 ± 0.86	1.35	1.65	1.37 ± 0.81[d]	1.62 ± 0.88[d]	−0.245	−0.553	0.062	0.117
24 h (rehydration)	0.38 ± 0.31	0.33	0.44	0.33 ± 0.22[e]	0.43 ± 0.37[e]	−0.105	−0.215	0.005	0.062

Note: Means with different superscript letters are significantly different. (a,b,c): different superscript letters in columns mean statistically difference.

TABLE 4 Mean ± SD color difference to baseline (Δ*E*) of gingival, middle, and incisal parts with mean difference and 95% confidence interval

	Tooth parts								
Color change (ΔE_{00})	Gingival Mean ± SD	Middle Mean ± SD	Incisal Mean ± SD	Mean Difference (Gingival-Middle)	Lower 95% CI/ Upper 95% CI	Mean Difference (Gingival-Incisal)	Lower 95% CI/ Upper 95% CI	Mean Difference (Middle-İncisal)	Lower 95% CI/ Upper 95% CI
ΔE_{00} 0-30′ (dehydration)	2.52 ± 1.15[a,m]	2.63 ± 1.05[a,m]	3.59 ± 1.24[a,n]	−0.108	−0.466/0.249	−1.071	−1.429/−0.713	−0.963	−1.321/−0.605
ΔE_{00} 0-30′ (rehydration)	1.47 ± 0.88[b,m]	1.54 ± 1.01[b,m]	1.96 ± 1.10[b,n]	−0.059	−0.371/0.253	−0.480	−0.792/−0.168	−0.421	−0.733/−0.109
ΔE_{00} 0-24 h (rehydration)	0.38 ± 0.31[c,m]	0.38 ± 0.47[c,m]	0.48 ± 0.37[c,m]	0.001	−0.121/0.123	−0.099	−0.222/0.023	−0.100	−0.223/0.022

Note: Means with different superscript letters are significantly different. (a,b,c): different superscript letters in columns mean statistically difference. (m,n): different superscript letters in rows mean statistically difference ($P < .001$).

30 min[4] of rehydration is required to regain the baseline color, longer periods for tooth rehydration have not been investigated up to now.

The dehydration time of the study was based on the mean clinical time required for isolation, cavity preparation, and restoration placement. Color measurements were carried out using a handheld imaging spectrophotometer in this study. The importance of positioning the spectrophotometer in the same position for repeated measurement intervals was stated in a previous study.[4] SpectroShade has a flashing grid on a screen for correct positioning and presents an advantage for accuracy. It enables color evaluation of the whole tooth surface or gingival, medial and incisal thirds by taking cross-polarized images. However, the color of the background has an essential effect during tooth color measurements. In this study, color measurements were performed in the dehydration and rehydration periods. For this reason, a rubber dam could not be used, and patients were asked to keep the mouth open during spectrophotometric imaging.

A VITA Easyshade (VITA Zahnfabrik, Bad Sackingen, Germany) was used for color measurements in previous studies.[3,4,10] The repeatability of the VITA Easyshade was reported to be 96.4%, while that of the SpectroShade was 96.9%; the accuracy rates of these spectrophotometers were found to be 92.6% and 80.2%, respectively, in an in vitro study.[14] However, in a clinical study, the SpectroShade was found to exhibit better repeatability compared with the VITA Easyshade.[15] In addition, the SpectroShade allows outlining the tooth on the image and displaying the color parameters for the whole tooth surface or in the gingival, middle and incisal thirds. Consequently, the use of the SpectroShade was preferred in this study.

The CIE $L^*a^*b^*$ (CIELAB) color notation system is frequently used in clinical and in vitro dental researches.[16] However, to provide uniformity to color differences of CIELAB and improve the correlation with visual assessment, CIEDE2000 color-difference formula was developed.[1,17] A color difference between two objects or color change with time is expressed as ΔE_{00} in CIEDE2000; a higher ΔE_{00} value means a bigger difference that is more perceptible by the eye. Paravina et al[13] reported that ΔE_{00} = 0.8 was used as a threshold of perceptibility in half the studies on color change, with ΔE_{00} = 1.8 referred to as the acceptability threshold at which 50% of the observers accepted the color difference. Like in previous studies,[3,4] the evaluated teeth in the present study exhibited significant color change after 10 min of dehydration, and 95.8% of the color change was above the perceptibility threshold. These findings support the literature knowledge with quantitative data, suggesting that color measurements should be carried out before any of the restorative procedures.[2-4,18] In the present study, during the dehydration periods, the color change gradually increased. After 30 min of dehydration, all the teeth were above the perceptibility threshold, 85% of the teeth were above the acceptability threshold and the mean color change was ΔE_{00} = 2.81 ± 0.86. Therefore, it was taken into consideration that color match or color assessment would be incorrect immediately after a direct anterior restoration, cementation of crown or laminate restoration or office bleaching. In their clinical study, Russell et al indicated that the teeth regained the baseline values in 30 min after 15 min of rubber dam isolation.[10] Conversely, the color differences were significant after 15 min or 30 min of rehydration in teeth exposed to 15-min[3] and 30-min[4] dehydration period. The latter findings agree with the results of the current study. However, there is no knowledge in the literature regarding how long a wait period should be adopted for correct color matching after dehydration. The mean color difference between baseline and after 24 h of dehydration was below the perceptibility threshold (ΔE_{00} = 0.38 ± 0.31) in this study. It can be concluded that color assessment can be performed after 24 h of rehydration for the anterior teeth.

As a result of tooth dehydration, the tooth appears lighter and enamel translucency decreases.[5,19] Proving the latter, the L^* values significantly increased during the dehydration and decreased in the rehydration period in this study. The nominal white point in the CIELAB color system is L^* = 100, a^* = 0, and b^* = 0.[16] Hence, with the increase in the L^* value, a decrease in a^* and b^* values indicates that the tooth became whiter. In this way, after 30 min of dehydration, a significant decrease was observed in mean a^* and b^* values, and during rehydration, the a^* and b^* values increased up to the baseline level in the present study. In addition, the main increase was observed in the mean L^* (2.5 ± 1.17) and b^* (−2.9 ± 1.67) values, whereas the increase in the mean a^* (−0.58 ± 0.73) values was less important. Similar to our results, the main change was observed in L^* values after 15 min of dehydration by Russel et al,[10] and there was less change in the a^* and b^* values. However, in a more recent study,[4] besides an increase in the mean L^* values (3.2) and change in b^* values (1.2) towards zero, a significant change was observed in the mean b^* values (from 14.4 ± 3.6 to 21.5 ± 4.5). This means that, in the previously mentioned study, the teeth became yellower. However, it was observed clinically in this study that teeth become whiter as a result of dehydration.

Suliman et al[3] reported significant color change of the central incisors after 15 min of dehyration period (ΔE_{00} = 5.11 ± 2.39). However, after 30 min of dehydration, lower mean color change (ΔE_{00} = 2.81 ± 0.86) was observed in previous study. Tooth color change related to dehydration is the result of water loss.[5] Thus, factors affecting water content of the teeth can be reasons of the difference and mean age of the participants is one of them.[20]

Significantly higher color change was observed in the incisal third of the teeth, and the mean color changes of the gingival and middle thirds were similar. Burki et al[4] reported similar patterns and degrees of color change in the cervical, middle and incisal regions due to dehydration; however, they performed color measurements with Vita Easyshade, which has a round and small (5 mm in diameter) probe surface, and their measurement was only taken from the middle third of the tested teeth. After 24 h of rehydration, the highest mean color difference from the baseline was observed in the incisal third of the teeth. The thick enamel layer and thin dentin layer in the incisal third of the teeth may be the cause of this finding. As there have been no data concerning color change after 24 h of rehydration of the incisal part of the tooth, it is not possible to compare the results with those of other studies.

When baseline color of central and lateral incisors was considered separately, with the absence of clinically perceptible difference, centrals were higher in value and laterals were more chromatic. The mean color change after 30 min of dehydration was higher but not significant for the lateral incisors. Lower baseline L^* values had a significant effect on the higher color change of the lateral teeth. However, the lateral and central incisors exhibited similar color changes after 30 min and 24 h of rehydration to baseline.

According to the results of this study, the color change of the teeth varies depending on the duration of dehydration. Determination of the color match between a restoration and sound adjacent teeth can be performed approximately 24 h after the restoration placement or longer based on the dehydration time. A potential limitation of the present study was that the tooth color will be different among different age groups, tooth types and localizations[21] and mineral contents,[22] and these differences can affect the level of dehydration and duration of rehydration.

5 | CONCLUSION

Within the limitations of this study, just 10 min of dehydration can result in a clinically significant color change of the teeth, and the degree of color change increases by 30 min. After 30 min of dehydration, a 30-min rehydration period is not sufficient for precise color assessment. After a 24-h rehydration period, reliable color assessment can be performed. The incisal part of the teeth exhibits more color change after 30 min of dehydration, and the color difference is higher than that of the gingival and middle thirds after 24 h of rehydration.

ACKNOWLEDGMENTS AND DISCLOSURE

This clinical study was supported by the Tokat Gaziosmanpasa Üniversitesi Scientific Research Projects Commission (Project No: 2019-46). The authors are very thankful to Dr Osman Demir for his statistical support.

The authors do not have any financial interest in the companies whose materials are included in this article.

ETHICAL APPROVAL

All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

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How to cite this article: Hatırlı H , Karaarslan EŞ , Yaşa B , Kılıç E , Yaylacı A . Clinical effects of dehydration on tooth color: How much and how long? *J Esthet Restor Dent*. 2021;33:364–370. https://doi.org/10.1111/jerd.12612