



## Effects of Orthodontic Adhesives on Dental Enamel Color Alteration Using Chemically Cured and Light-Cured Composites

Amir Houman Sadr Haghighi<sup>1</sup>, Mohammad Emami<sup>2</sup>, Elaheh Fakhri<sup>2\*</sup>, Yashar Rezaei<sup>3</sup>

1. Department of Orthodontics, Faculty of Dentistry, Tabriz University of Medical Sciences, Tabriz, Iran
2. Dental and Periodontal Research Center, Dentistry Faculty, Tabriz University of Medical Sciences, Tabriz, Iran
3. Department of Dental Biomaterials, Faculty of Dentistry, Tabriz University of Medical Sciences, Tabriz, Iran

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### \* Corresponding author:

Dental and Periodontal Research Center,  
Dentistry Faculty, Tabriz University of  
Medical Sciences, Tabriz, Iran

Email: Fakhrielaheh@yahoo.com

### ABSTRACT

**Objectives:** The purpose of this investigation was to evaluate the color alteration of dental enamel following the use of light-cured and chemically cured composites for bonding of metal brackets.

**Materials and Methods:** Sixty extracted human premolars divided into five groups (n=12) were included in this study. Metal brackets were bonded using chemically cured (System 1+ and Unite) and light-cured (Transbond XT and Grengloo) composites. The control group remained untreated. After 72 hours of immersion in a staining solution and 24 hours of photoaging, the brackets were debonded, and adhesive remnants were cleaned using a 12-blade tungsten carbide bur and polished with Sof-Lex discs. The color was assessed at the baseline and after cleaning procedures in accordance with the CIE L\*a\*b (lightness, red/green, blue/yellow) color system. Statistical analyses were performed using paired sample t-test and one-way analysis of variance (ANOVA).

**Results:** The L\*, a\*, and b\* parameters showed a significant increase in all adhesive groups (P<0.001). The experimental groups showed significant color changes (P<0.05), and the mean ΔE ranged from 2.46 to 3.15 units. No significant difference was found between the ΔE of the adhesive groups (P>0.05).

**Conclusion:** The enamel color change is influenced by bonding and debonding procedures. Chemically cured and light-cured composites have similar effects on dental enamel color alterations.

**Keywords:** Adhesives; Dental Enamel; Tooth Discoloration

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### INTRODUCTION

Although there is considerable evidence regarding the adverse effects of orthodontic treatment on enamel surfaces [1,2], tooth color alteration has remained a major complication that concerns orthodontists. There are several causes of tooth discoloration

during treatment and retention phases. The acid-etching process is associated with enamel loss, surface roughness [2], and slight enamel discoloration [3]. Also, bracket debonding techniques and adhesive removal with various rotary instruments might lead to enamel loss [2], microcracks [1], enamel tearouts [4], and

color alterations [5]. Previous works have reported that enamel loss during debonding procedures can vary from 44.9 to 297.8  $\mu\text{m}$  [6]. The observed tooth color is associated with the scattering properties of dental structures. Since the alteration of enamel surface topography can change the scattering properties of teeth, bonding and debonding procedures seem to have a massive impact on dental enamel color [7].

Aside from the above-mentioned reasons, enamel discoloration might occur due to the irreversible resin penetration up to the depth of 50  $\mu\text{m}$  into the enamel structure [8,9]. In the long term, the accumulation of plaque on adhesive residues and absorption of food pigments lead to external discoloration [10,11]. Internal discolorations are related to physicochemical reactions in the subsurface and inner parts of the material and are induced by visible and ultraviolet (UV) irradiations, thermal stress, and humidity [12].

Various color-measuring implements, such as spectrophotometers, colorimeters, and image analysis devices, have been introduced to the field of dentistry. Formerly, acrylic resin shade guides were used for subjective visual comparison but recently, objective analysis of color alterations according to the CIE  $L^* a^* b^*$  system is preferred.

Orthodontic composites have been evaluated through the years due to several refinements in their properties. Some previous clinical studies have observed visible enamel color changes during fixed orthodontic treatment or retention phase [5,13,14]. Karamouzou et al [14] revealed that chemically cured composites are associated with higher discoloration rates than light-cured resins. In agreement with this study, in an in-vitro study, Ye et al [15] found the highest color change in the chemically cured composite group. However, some in-vitro studies have reported different extents of color alterations among different types of orthodontic adhesives [16,17]. Conflicting findings concerning inevitable enamel color alteration caused by bonding and debonding procedures compelled us to investigate new types of

orthodontic composites.

Therefore, the purpose of this investigation was to evaluate the color alteration of dental enamel following the use of light-cured and chemically cured composites for bonding orthodontic brackets

## MATERIALS AND METHODS

The design of this study has been approved by the Research Ethics Committee of Tabriz University of Medical Sciences (code: 312). The sample size required for this study was calculated to be 9 with  $\alpha=0.05$  and power=80% (G\*Power, version 3.0.1, Germany). Considering possible specimen exclusion during the procedure, 12 teeth were assigned to each group.

### *Specimen preparation:*

Sixty caries-free premolars extracted for orthodontic reasons were collected from patients aged 12-30 years. The teeth did not have any obvious cracks, decalcifications, previous endodontic treatment, discolorations, or restorations. Dental calculi and soft tissue remnants were removed using a periodontal curette (Hu-Friedy, Chicago, IL, USA).

Then, the teeth were stored in distilled water at room temperature until required. Before the color assessment, the teeth were polished with non-fluoridated and oil-free pumice using a low-speed handpiece and a rubber cup. They were then rinsed and dried. The SpectroShade Micro device (Spectro Micro Shade, MTH, Verona, Italy) was used to assess tooth color alterations according to the manufacturer's recommendations. The handpiece of the device was positioned at a right angle relative to the buccal surface of the specimens, and the color was measured from a standardized rectangular area at the middle third of the buccal surface of the teeth. All the measurements were made by the same researcher (M.E) under normal dental unit light three times to minimize possible errors. The specimens were randomly divided into four experimental groups and a control group ( $n=12$ ).

The middle third of the buccal surface of the experimental samples was etched with 37%

phosphoric acid (Scotchbond Etching Gel, 3M Dental Products Division, St. Paul, MN, USA) for 15 seconds and rinsed for 20 seconds with air-water spray and dried. The control samples remained untreated. Premolar stainless steel brackets (Equilibrium 2, Dentaaurum, Germany) were bonded using light-cured adhesives, namely Transbond XT (3M Unitek, Monrovia, CA, USA) and Grengloo (Ormco Corp., Glendora, CA, USA). After the positioning of the brackets, the excess adhesive was removed, and the samples were light-cured using a visible light-curing unit (Litex 680, Dentamerica, USA) for 40 seconds from both mesial and distal edges of the brackets. Chemically cured adhesives, namely Unite (3M Unitek, Monrovia, CA, USA) and System 1+ (Ormco Corp., Glendora, CA, USA), were used in groups 3 and 4, respectively. All specimens were stored in distilled water at room temperature for 48 hours and then immersed in a tea solution for 72 hours to induce external discoloration.

#### *Photoaging procedure:*

Accelerated photoaging chambers allow the samples to be subjected to UV radiation, which results in internal discoloration. The device comprises an enclosure with three lamps that emit UV light at a wavelength of 400 nm. The total power was set at 50,000 kJ/m<sup>2</sup>. Photoaging was applied for 24 hours, which is equivalent to exposure to sun irradiation in Central Europe for one month (Atlas Suntest Bulletin, 1998).

#### *Bracket debonding and adhesive removal:*

The brackets were removed using debonding pliers (Ormco Corp., Glendora, CA, USA). Adhesive residues were cleaned with low-speed 12-blade tungsten carbide burs. Then, the buccal surfaces were polished with Sof-Lex discs (3M Dental Products, St. Paul, MN, USA). A new bur was used for each tooth. The dried enamel surfaces were evaluated under loupe magnification (×3) to ensure the elimination of adhesive residues. After the cleanup procedures, a second enamel colorimetric measurement was carried out in accordance with the CIE L\*a\*b (lightness, red/green, blue/yellow) color system, and the color parameters were recorded.

Then, the total color difference ( $\Delta E$ ) was calculated using the following equation:

$$\Delta E^* = [(L1^* - L2^*)^2 + (a1^* - a2^*)^2 + (b1^* - b2^*)^2]^{1/2}$$

#### *Statistical analysis:*

The normal distribution of the variables was verified by the Kolmogorov-Smirnov normality test ( $P > 0.05$ ). The paired sample t-test was used for the evaluation of the changes in the L\*, a\*, and b\* parameters after the cleaning procedures. One-way analysis of variance (ANOVA) was used for the intergroup comparison of the  $\Delta E$ . The Games-Howell pairwise comparison test was used to determine the differences between each pair of groups. To determine whether the color changes are clinically acceptable, color differences were compared to a clinically detectable standard value ( $\Delta E = 3.7$ ). The chi-square test was used to further compare the distribution of tooth color change values as clinically acceptable or unacceptable among the groups.  $P < 0.05$  was considered to be statistically significant in this study.

## RESULTS

The results of the Kolmogorov-Smirnov test showed that all variables had a normal distribution (P value was 0.055, 0.264 and 0.207 for L, a and b parameters, respectively). According to the paired sample t-test, the color of the specimens showed significant changes in all color parameters (L\*, a\*, and b\*) as shown in Table 1. It was determined that in the light-cured adhesive groups, the mean L\*, a\*, and b\* increased by 2.028  $\Delta L^*$  units, 1.059  $\Delta a^*$  units, and 0.979  $\Delta b^*$  units, respectively ( $P < 0.001$ ). Also, in the chemically cured adhesive groups, the mean L\*, a\*, and b\* increased by 2.669  $\Delta L^*$  units, 1.084  $\Delta a^*$  units, and 0.978  $\Delta b^*$  units, respectively ( $P < 0.001$ ). After the intervention, the mean a\* and b\* did not show any significant difference between the light-cured and chemically cured groups ( $P = 0.460$  and  $0.450$ , respectively) but the mean L\* showed a significant difference ( $P < 0.001$ ). Also, there was a statistically significant difference between the  $\Delta L^*$  of chemically cured and light-cured groups ( $P < 0.05$ ) but the differences between the  $\Delta a^*$  and  $\Delta b^*$  of the mentioned groups were insignificant ( $P > 0.05$ ).

**Table 1.** Mean± Standard Deviation CIE parameters (L, a, and b) of all groups before bonding and after debonding

Adhesive		N	(I) Before bonding	(J) After debonding	Difference (I-J)	P-value
<b>Grengloo</b>	L	12	45.217±4.237	47.015±4.122	1.798±0.827	< 0.001
	a	12	15.827±1.029	17.008±1.111	1.181±0.515	< 0.001
	b	12	15.979±1.985	17.104±1.955	1.125±0.398	< 0.001
<b>Transbond XT</b>	L	12	47.400±2.773	49.658±2.906	2.258±0.765	< 0.001
	a	12	15.687±2.424	16.624±2.431	0.938±0.394	< 0.001
	b	12	15.725±2.451	16.558±2.589	0.833±0.368	< 0.001
<b>Light-cured</b>	L	24	46.308±3.675	48.337±3.740	2.028±0.813	< 0.001
	a	24	15.757±1.822	16.816±1.859	1.059±0.465	< 0.001
	b	24	15.852±2.185	16.831±2.261	0.979±0.403	< 0.001
<b>Unite</b>	L	12	58.408±2.795	61.190±2.789	2.782±0.281	< 0.001
	a	12	15.242±1.882	16.358±1.920	1.117±0.233	< 0.001
	b	12	15.579±1.035	16.522±0.964	0.943±0.248	< 0.001
<b>System 1</b>	L	12	48.858±2.783	51.415±3.173	2.557±0.739	< 0.001
	a	12	15.445±1.594	16.497±1.635	1.052±0.248	< 0.001
	b	12	16.525±2.605	17.537±2.668	1.012±0.352	< 0.001
<b>Chemically cured</b>	L	24	53.633±5.589	56.303±5.784	2.669±0.559	< 0.001
	a	24	15.343±1.709	16.428±1.745	1.084±0.238	< 0.001
	b	24	16.052±1.998	17.030±2.029	0.978±0.300	< 0.001
<b>Control</b>	L	12	52.85±6.28	52.95±6.33	0.098±0.078	0.083
	a	12	16.33±2.59	16.39±2.58	0.103±0.159	0.061
	b	12	15.10±1.47	15.17±1.46	0.069±0.026	0.110

The  $\Delta E$  of all adhesive groups showed significant color alterations ranging from 2.46 to 3.15  $\Delta E$  units. The greatest color change was found in teeth bonded with the System1+ composite followed by the Unite, Transbond XT, and Grengloo composites (Table 2).

Pairwise comparisons by the Games-Howell test showed a significant difference between the control group and each of the experimental groups ( $P < 0.001$ ). However, the color assessments showed that the  $\Delta E$  was not significantly different between the adhesive groups (Table 3).

**Table 2.** Minimum and maximum total color difference ( $\Delta E$ ) and the results of one-way analysis of variance (ANOVA) for  $\Delta E$  (N=12)

Adhesive	$\Delta E$ (Mean $\pm$ SD)	Maximum $\Delta E$	Minimum $\Delta E$	P-value
Grengloo	2.4652 $\pm$ 0.95239	3.72	0.86	< 0.001
Transbond XT	2.6064 $\pm$ 0.86260	3.74	0.86	< 0.001
Unite	3.1592 $\pm$ 0.28183	3.78	2.61	< 0.001
System 1	2.9551 $\pm$ 0.81296	3.88	0.91	< 0.001
Control	0.1421 $\pm$ 0.07276	0.32	0.06	< 0.001

SD=Standard Deviation

**Table 3.** Results of pairwise comparisons of the mean total color difference ( $\Delta E$ ) by the Games-Howell test

I	J	Mean difference (I-J)	P-value	95% CI	
				Lower bound	Upper bound
Grengloo	Transbond XT	-0.141	0.995	-1.2426	0.9603
	Unite	-0.694	0.17	-1.5976	0.2098
	System 1+	-0.490	0.661	-1.56	0.5849
	Control	3.323	< 0.001	1.4332	3.2131
Transbond XT	Unite	-0.553	0.272	-1.3747	0.2692
	System 1+	-0.394	0.844	-1.3642	0.6669
	Control	2.464	< 0.001	1.898	3.031
Unite	System 1+	0.204	0.919	-0.5729	0.9811
	Control	3.017	< 0.001	2.451	3.584
System 1+	Control	2.813	< 0.001	2.0531	3.57

CI=Confidence Interval

**Table 4.** The number of samples in each color difference ( $\Delta E$ ) category of all groups after debonding and cleaning procedures

	$\Delta E < 1$	$1 \leq \Delta E < 3.7$	$\Delta E \geq 3.7$	Total
	Invisible	Visible, clinically acceptable	Visible, clinically unacceptable	
Grengloo	2	9	1	12
	16.7%	75%	8.3%	100%
Transbond XT	2	9	1	12
	16.7%	75%	8.3%	100%
Unite	0	11	1	12
	0%	91.7%	8.3%	100%
System 1+	1	8	3	12
	8.3%	66.7%	25%	100%
Control	12			12
	100%			100%

After the adhesive removal procedures, visible and unacceptable color changes (mean  $\Delta E \geq 3.7$ ) were observed in 8.3% of teeth bonded with light-cured composites

and 16.7% of teeth bonded with chemically cured composites. However, no significant difference was found in  $\Delta E \geq 3.7$  between the two groups (P=0.666; Tables 4).

## DISCUSSION

Various color measuring devices have been introduced to the field of dentistry to enhance the reliability, variability, and accuracy of shade selection [18]. Today, the emphasis is on objective color assessments rather than subjective visual comparisons using acrylic resin shade guides.

Spectrophotometers, colorimeters, and image analysis devices implement measurements according to the CIE (Commission Internationale de l'Éclairage) system, which interprets color differences numerically. Briefly, the CIE  $L^*$  parameter indicates the degree of brightness,  $a^*$  is the red/green coordinate, and  $b^*$  is the yellow/blue coordinate [18].

To obtain accurate results and to detect the slightest changes in the color of the specimens, the SpectroShade Micro device was utilized in the present study, and the enamel color was determined in accordance with the CIE  $L^* a^* b^*$  color system; thus, the total color difference was represented as  $\Delta E$ . It has been acknowledged that the threshold level of the  $\Delta E$  for visually perceptible tooth color change is 1  $\Delta E$  unit. Amounts between 1 and 3.7 and exceeding 3.7 are regarded as clinically acceptable and unacceptable color changes, respectively [19].

In the current study, the experimental groups showed significant color changes ranging from 2.46 to 3.15, which exceeded the threshold level for visible color changes, regardless of the type of composite used. In-vitro and in-vivo studies have found conflicting results regarding the effects of orthodontic bonding agents on enamel color. In this respect, a clinical study was conducted by Karamouzos et al [14] using chemically cured (System 1+) and light-cured (Transbond XT) composite adhesives. They found that the enamel color altered significantly after orthodontic treatment [14]. In agreement with this study, Gorucu-Coskuner et al [5] reported that fixed orthodontic treatment results in visible and clinically unacceptable enamel discoloration. Boncuk et al [3] found that among all types of adhesives, an etch-and-rinse adhesive system, such as Transbond XT, shows the highest discoloration. Additionally, they found that tooth discoloration occurs during bonding and debonding procedures [3].

In the current study, 12.5% of the bonded teeth showed visible and unacceptable color changes. This finding agrees with the changes reported by Karamouzos et al (12.98%) [14] and Corekci et al (12.50%) [20].

In the present study, no significant difference was found in the  $\Delta E$  between the chemically cured and light-cured adhesive groups. In contrast to the current study, Karamouzos et al [14] found that the chemically cured composite was associated with greater enamel color changes compared to the light-cured composite. This is probably because of the conditions of clinical studies (the role of saliva or patient's oral hygiene and diet). Also, they compared one adhesive of each type; therefore, this result might be due to differences between these two adhesives. Hence, we compared two chemically cured adhesives with two light-cured adhesives. In a short-term treatment, Corekci et al [20] found visible enamel color changes. They used conventional light-cured resin composites, including Grelgloo and Transbond XT, and found no difference in the mean  $\Delta E$  between these groups [20]. This finding is in agreement with our results.

Several etiologic factors might contribute to enamel color changes during and after fixed orthodontic treatment. The thin residual adhesive layer that remains on the enamel surface upon the debonding of the brackets and even after polishing with the average thickness of 31.2 to 200.2  $\mu\text{m}$  [21] is susceptible to discoloration due to exogenous changes related to food colorant absorption or endogenous changes related to the structural properties of adhesives [10]. Chemical components of resins such as different types of filler particles and matrix compositions, the quality of polymerization, and curing time affect the color stability of composites and can be an explanation for different obtained results [12,22-24]. Internal or bulk discolorations occur due to the presence of photo-initiators, such as Camphorquinone, as well as unconverted C=C bonds [12]. The decomposition of the initiators can be related to changes in the  $b^*$  parameter toward yellow [23]. In this study, artificial photoaging was used to simulate internal discolorations.

Few studies have been conducted regarding composite discolorations induced by colorants. Faltermeier et al [25] reported that tea causes the most external discoloration after 72 hours.

Thus, in the current study, immersion in a tea solution was selected. Moreover, samples were stored in water for 48 hours. It has been reported that storage of composites in water greatly influences the color stability [10]. The hydrophilic matrix of polymers causes water sorption due to the presence of hydroxyl, carboxyl, and phosphate groups. This subsequently results in white and opaque shades [26]. Additionally, water facilitates the penetration of colorants into the adhesive structure [10].

One of the considerable factors attributed to tooth discoloration is surface roughness, which can modify the light scattering properties of teeth, causing a white appearance [16,27,28]. Enamel surface roughness ensues acid-etching, bracket debonding, and adhesive removal procedures, and it might cause plaque accumulation, food colorant absorption, tooth caries, and finally, enamel discoloration [2]. Enamel loss after conventional acid-etching has been reported to be 4 to 170  $\mu\text{m}$  [2]. Nevertheless, Eliades et al [9] confirmed that debonding and cleaning procedures are more invasive than acid-etching. The remnant resin tags contribute to the changes of the enamel refractive index and influence the color parameters in several ways [27]. Also, the opacity of resin composite materials increases during polymerization due to the different refractive indices of monomers and polymers [29].

The use of rotary instruments for removing adhesive remnants causes enamel surface scratches in addition to enamel loss [2,4]. Nonetheless, iatrogenic damages depend on the operator's expertise and control. Regarding the effects of polishing, some studies have reported that a polished enamel surface shows better resistance to discoloration [15,17].

In the current study, the mean  $L^*$  increased (shifted toward white) in all groups after adhesive remnant removal with low-speed

tungsten carbide burs and polishing with Sof-Lex discs.

In a study conducted by Gorucu-Coskuner et al [5], the mean  $L^*$  decreased after adhesive removal with tungsten carbide burs and increased after polishing with Sof-Lex XT discs; there was no significant difference between the mean pre- and post-treatment  $L^*$ . This study showed the importance of polishing after bracket removing procedures. In a clinical study, Kaya et al [13] used a low-speed 12-blade tungsten carbide bur for adhesive cleaning and fluoride-free pumice for polishing. They reported a significant increase in the lightness ( $L^*$ ) of the color of the teeth during the first three months after treatment [13]. Furthermore, in a study conducted by Hosein et al [30], comparing low-speed and high-speed tungsten carbide burs, low-speed burs caused less enamel loss.

In this study, because of the small sample size, we could not separately investigate the effects of polishing. In addition to the adhesive material, bracket debonding and adhesive removal procedures can influence dental enamel color. Considering the conflicting results obtained from in-vitro and clinical studies, this complex phenomenon seems to be affected by several factors. Clinical studies with larger sample sizes are required to investigate several etiologic factors that influence enamel discoloration during fixed orthodontic treatment.

## CONCLUSION

Under the conditions of the present study:

- 1- All color parameters ( $L^*$ ,  $a^*$ , and  $b^*$ ) of the specimens increased significantly after debonding and cleaning procedures.
- 2- Bonding and debonding procedures had a significant effect on dental enamel color.
- 3- The greatest color alteration was observed in the System 1+ group.
- 4- There was no statistically significant difference in enamel discoloration between the chemically cured and light-cured adhesive groups.

## CONFLICT OF INTEREST STATEMENT

None declared.

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