Original Article

Effects of different orthodontic adhesives and resin removal techniques on enamel color alteration

Yasemen Boncuk[a]; Zafer C. Çehreli[b]; Ömür Polat-Özsoy[c]

ABSTRACT

Objective: To investigate the color alterations in enamel following the use of different orthodontic bonding resins and adhesive residue–removal burs.

Materials and Methods: Metal brackets were bonded to extracted human premolars (n = 175) by using an etch-and-rinse adhesive system, a self-etch adhesive system (SEP), or a resin-modified glass ionomer cement (RMGIC). After 24 hours of photoaging, the brackets were removed and the adhesive residue on the tooth surfaces was cleaned with either a tungsten carbide bur or a Stainbuster bur. Tooth colors were measured with a spectrophotometer at baseline, after adhesive removal, and after additional photoaging. Color evaluation was made, and color differences induced by photoaging were calculated. Statistical evaluation was made using the Kruskal-Wallis test and the Mann-Whitney *U*-test, with Bonferroni correction.

Results: All specimens showed discoloration at varying levels. The highest color change was observed in the etch-and-rinse adhesive/tungsten carbide bur group. When the etch-and-rinse and self-etch adhesives were used, adhesive-remnant removal with Stainbuster burs resulted in significantly lower discoloration. The type of bur did not affect the extent of enamel discoloration in the RMGIC group.

Conclusions: Orthodontic treatment alters the original color of enamel, and both the adhesive system and the resin-removal methods are responsible for this change. When brackets are bonded with the etch-and-rinse system or the SEP, cleaning the adhesive residuals with Stainbuster burs is recommended for minimal change. RMGIC can be safely cleaned with tungsten carbide burs. (*Angle Orthod.* 2014;84:634–641.)

KEY WORDS: Enamel color; Resin removal; Orthodontic treatment

INTRODUCTION

The adhesion between orthodontic resins and enamel is unique in dentistry in that it is intended to be temporary, yet durable enough to withstand orthodontic forces. Following completion of orthodontic therapy, the brackets and bonding resins must be removed with minimum trauma to the tooth and, ideally, without any resin remnants. Complete elimination of the residual adhesive resin attached to the enamel surface is mandatory to avoid prolonged accumulation of bacterial plaque that may further lead to decalcification and periodontal problems.[1,2]

Removal of the residual adhesive can cause physical changes on enamel, ranging from surface roughening to microscopic fractures.[1,3–5] Eliades et al.[4] reported that the color of the enamel is also affected by debonding and subsequent cleaning procedures. In addition to the effects of iatrogenic surface roughness, changes in the color of enamel may also result from discoloration of the residual resin that has irreversibly penetrated the surface despite the cleaning procedures.[4,6,7] Resin residuals may change tooth color because of both the internal changes via physicochemical reaction of the adhesive resin and the external changes caused by superficial absorption of food pigments.[6,7] However, even under laboratory conditions, it is virtually impossible to eliminate the entire adhesive residue on the enamel surface without the aid of strong magnification. Provided that this

[a] Private Practice, Ankara, Turkey.
[b] Professor, Department of Pediatric Dentistry, Hacettepe University, Ankara, Turkey.
[c] Associate Professor, Department of Orthodontics, Baskent University, Ankara, Turkey.
Corresponding author: Dr Ömür Polat-Özsoy, Baskent University Faculty of Dentistry, Department of Orthodontics, 11. sk No: 26 Bahcelievler, Ankara, Turkey
(e-mail: omurpolatozsoy@gmail.com)

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theoretical goal is accomplished, such complete reduction of resin-penetrated enamel may lead to considerable loss of sound tooth structure. Thus, availability of an orthodontic bonding agent with both the least discoloration potential and the ability to remove its residue by a simple protocol would be most desirable.

Despite a plethora of studies evaluating the bond strength of different orthodontic adhesives and surface alterations after bracket debonding,[8,9] only a few studies have focused on possible changes in the color of enamel after treatment. In a clinical study, the color values were measured in patients before and after orthodontic treatment, and it was reported that the color of natural teeth changed after orthodontic treatment.[10] Other laboratory studies have evaluated the discoloration of orthodontic adhesives[11–15] and the color alterations on enamel after finishing and polishing.[4] Results obtained in those studies are still inconclusive regarding the contributory effects of different protocols and resin removal techniques on the color changes of the enamel during treatment. Based on these considerations, the purpose of this study was to investigate the color alterations on enamel following the use of different orthodontic bonding adhesives and adhesive residue–removal burs.

MATERIAL AND METHODS

The material of the study consisted of freshly extracted premolars obtained from patients for whom extraction treatment had been indicated. The research protocol, the laboratory study protocol including the use of extracted human teeth, and the consent form were evaluated and approved by the Baskent University Institutional Review Board and Ethics Committee.

According to power analysis, 22 samples for each group were needed to obtain a statistical significance of at least a 0.2-unit difference in terms of ΔE (ΔE = total color difference) at 80% power and 5% error. Assuming possible specimen loss during the procedures, 25 teeth were assigned to each group. The teeth were obtained from patients aged 15 to 20 years, with the strict inclusion criteria of being sound, noncarious, and free of restorations, fractures, white spot lesions, and iatrogenic damage during extraction. All extracted teeth were immediately cleansed of tissues and debris and were stored in distilled water at room temperature until the experiments.

Specimen Preparation

The crowns were cleaned with pumice for 10 seconds using a low-speed rubber cup and rinsed for 30 seconds. Thereafter, the crowns were separated from the roots using high-speed, water-cooled diamond burs. Self-curing acrylic was prepared and poured into plastic cylindrical moulds, and the crowns were embedded in the resin with their vestibular surfaces facing upward. In order to standardize the area of adhesion and subsequent color measurements, custom adhesive tags (8 mm in diameter) with inner rectangular perforations (window size: 3 × 3.5 mm) were prepared and adhered to the vestibular surface of the crowns.

Adhesive Procedures

Of the 175 teeth, 25 served as control specimens. The remaining were randomly assigned to three experimental groups (n = 50 each) with respect to the adhesive tested (Figure 1). The following adhesive protocols were employed:

Group 1 (control). The enamel surfaces were left untreated and were only subjected to color assessment before and after photoaging.

Group 2. Enamel was etched with 37% orthophosphoric acid for 15 seconds, rinsed with air-water spray for 20 seconds, and air dried for 10 seconds. Transbond XT Adhesive Primer (3M Unitek, Monrovia, Calif) was used in conjunction with Transbond XT Adhesive Resin (3M Unitek) according to the manufacturer's instructions for bonding metal brackets with 0.018-inch slots (Ormco; Sybron Dental Specialties, Glendora, Calif). Following removal of excess adhesive from the margins, light curing was performed with an LED source (3M Elipar S10; 3M Unitek) for 10 seconds.

Group 3. A self-etch adhesive system (Transbond Self-Etching Primer [SEP]; 3M Unitek) was used in conjunction with Transbond XT Adhesive Resin as with group 2.

Group 4. Following pretreatment of enamel surfaces with 20% polyacrylic acid, the brackets were bonded with light-cured resin-modified glass ionomer cement (RMGIC; Fuji Ortho LC; GC Corp, Tokyo, Japan). The cement was light cured for 20 seconds from both the mesial and distal aspects.

Before photoaging, the bonded specimens were kept in distilled water at room temperature for 24 hours (Figure 2).

Color Assessment

Color assessment was performed three times in the experimental groups and two times in the control group. Measurements were made from the rectangular area in the middle of the adhesive tags using a handheld spectrophotometer (SpectroShade Micro; MHT, Verona, Italy; Figure 3). Before each measurement, the spectrophotometer was calibrated. For each

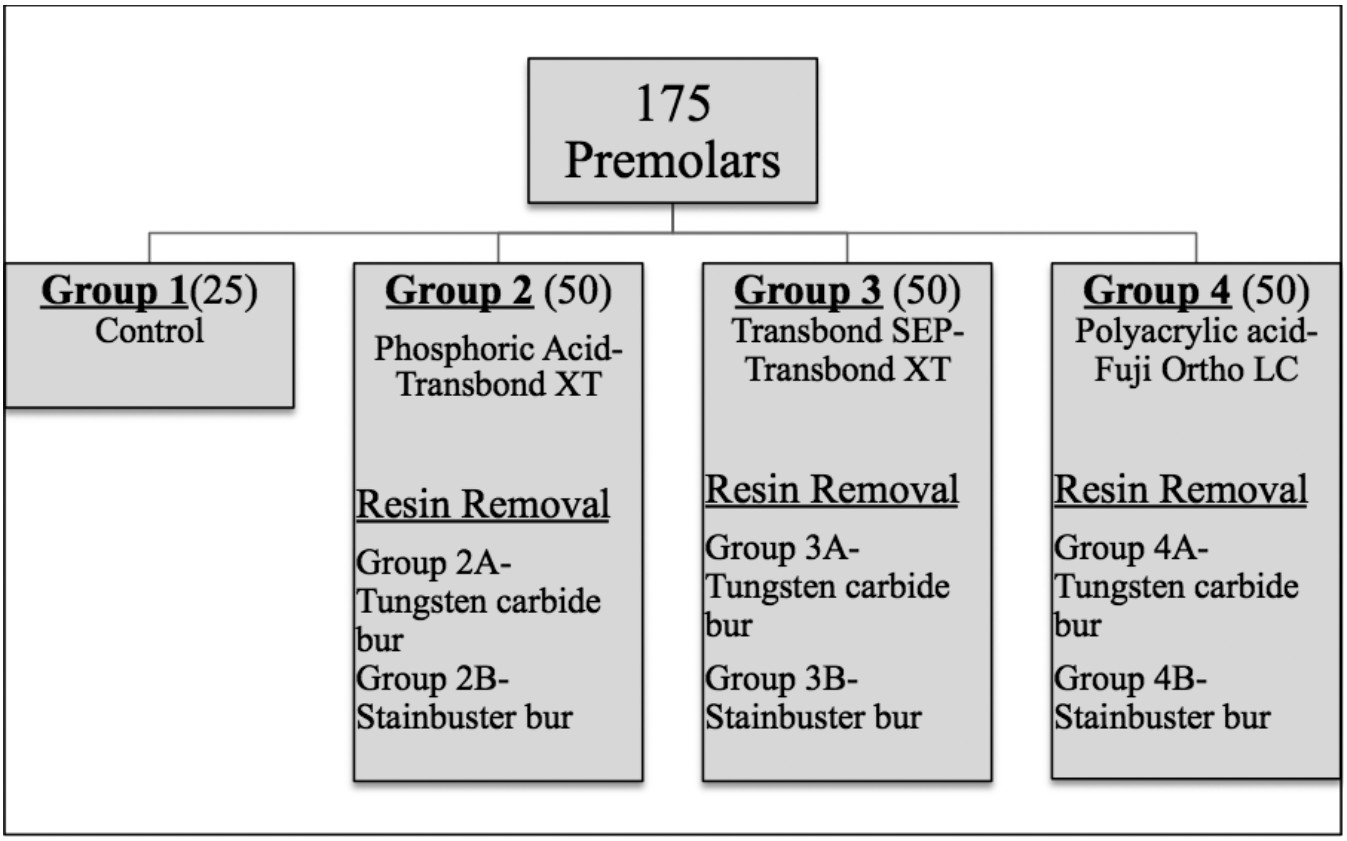

Figure 1. Schematic explanation of the four groups investigated.

specimen, three measurements were made in order to minimize the margin of error and calculate the average of three measurements. Color evaluation was made in accordance with the CIE (Commission Internationale de l'Eclairage) L*a*b* color system (lightness, red/green, and blue/yellow). The following formula was used for color comparisons:

$$\Delta E_{2-1} = \left[(\Delta L)^2 + (\Delta a)^2 + (\Delta b)^2\right]^{\frac{1}{2}}$$
$$= \left[(L_2 - L_1)^2 + (a_2 - a_1)^2 + (b_2 - b_1)^2\right]^{\frac{1}{2}}$$

The Δ values calculated in this study were as follows:

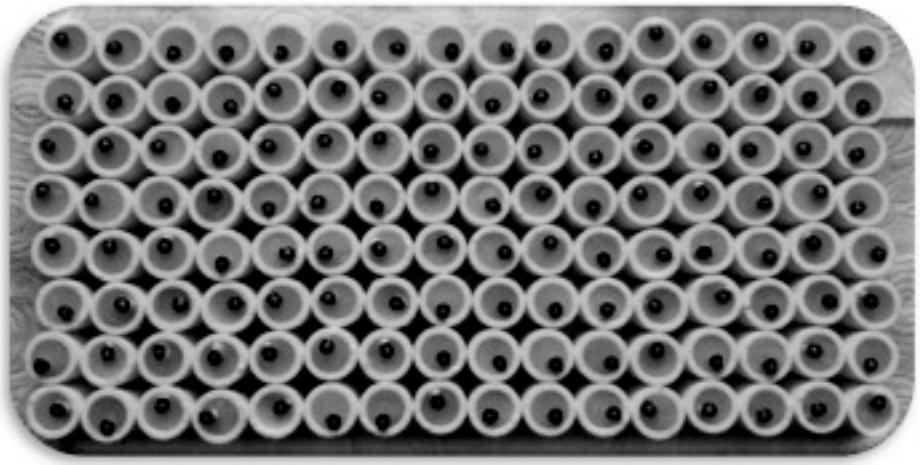

Figure 2. Crown specimens embedded in acrylic blocks, with custom adhesive tags to standardize the area of color assessment.

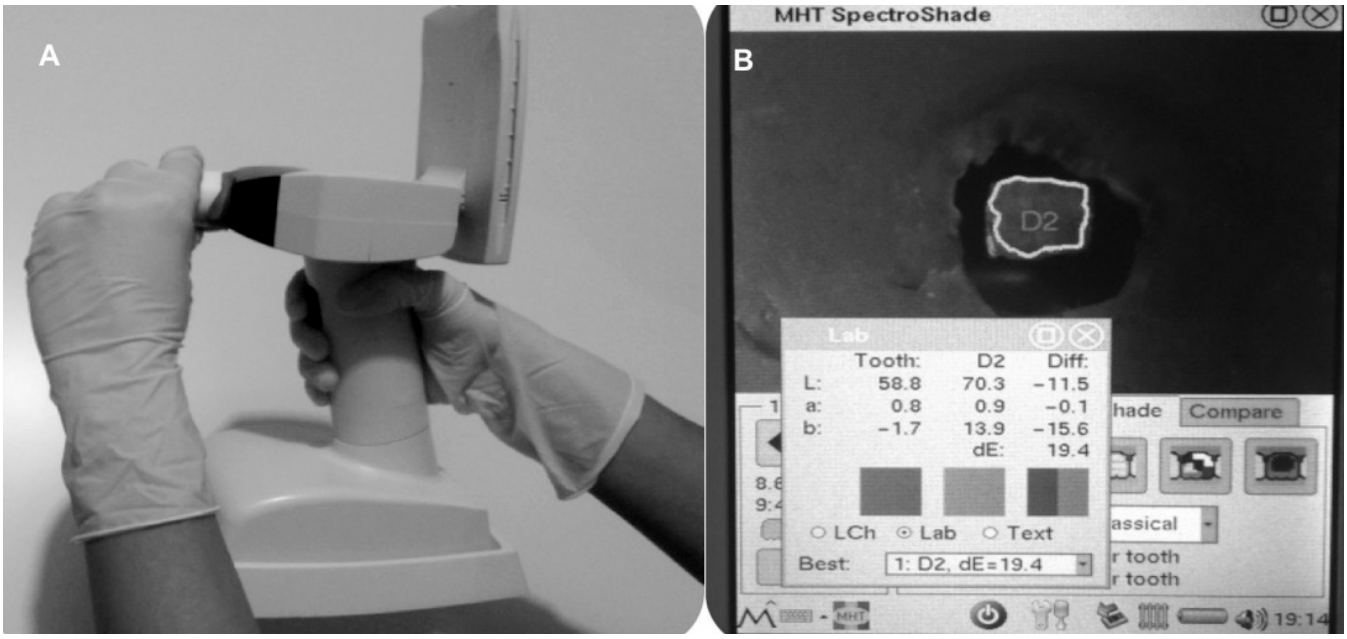

Figure 3. (A) Color assessement using a Spectroshade Micro device. (B) Measurement screen of the device.

ΔE 1: The difference between the values obtained at the beginning of treatment (before adhesive procedures) and after cleaning the surfaces (baseline-debonding). Clinically, this value indicates the color change throughout the orthodontic treatment.

ΔE 2: The difference between the values at the beginning of the treatment and the final values (baseline-ageing). Clinically, this value indicates the color change that occurred both during and after the orthodontic treatment.

ΔE 3: The difference between the values obtained after cleaning the surfaces and the final values (debonding-ageing), and clinically indicates the coloring that occurs after the treatment.

In the control group, color measurement was conducted at the beginning and after photoaging. Thus, only the ΔE 1 value was calculated. In the experiment groups, tooth colors were measured before adhesive procedures, after cleaning of the enamel surfaces, and after the second photoaging. Thus, three Δ values were calculated.

Photoaging Procedure

Photoaging was performed in order to stimulate internal discoloration. This procedure induces aging equivalent to exposure to sun irradiation in Central Europe for 30 days.[16] For this purpose, the specimens were placed in a photoaging device (Atlas Suntest CPS+; Atlas Inc, Geluhausen, Germany) with the power configured at 50,000 kJ/m^2. Photoaging was achieved by continuous exposure of specimens to 135,000 Lux light at 400 nm for 24 hours. Photoaging was applied once to the control group and twice to the experimental groups.

Debonding and Resin Removal

After photoaging, the brackets were removed with a debonding plier (Chifa; HPDR135.140 140; TMX Medical Instruments, Matick, Mass). In each experimental group, debonded specimens were divided into two subgroups (A and B; n = 25 each) for testing the efficacy of the type of bur for cleaning residue.

In subgroups 2A, 3A, and 4A, residuals were cleaned with 12-blade tungsten carbide burs (Busch, Düsseldorf, Germany). In subgroups 2B, 3B, and 4B, cleaning was performed with Stainbuster composite burs (Abrasive Technology, Lewis Center, Ohio) reinforced with glass fiber and zirconium. The burs in both groups were mounted on a low-speed, water-cooled contra-angle, and cleaning was performed under loupe magnification (3.3×) to simulate clinical conditions.

Statistical Analysis

The distribution of variables and the homogeneity of the variances were checked with Shapiro-Wilk and Levene tests. Descriptive statistics were indicated as the median and interquartile range. The reliability of the *L*, *a*, and *b* measurements at baseline (T0), after adhesive residue removal (T1), and after additional photoaging (T2) were determined with the intraclass correlation coefficient (ICC) at a 95% confidence interval.

Table 1. Intraclass Correlation Coefficients and 95% Confidence Intervals for Repeatability of the *L*, *a*, and *b* Measurements at T0, T1, and T2[a]

Variables	T0 (Mean [Min–Max])	T1 (Mean [Min–Max])	T2 (Mean [Min–Max])
L	0.9954 (0.9941–0.9965)	0.9988 (0.9984–0.9991)	0.9985 (0.9981–0.9989)
a	0.9930 (0.9909–0.9946)	0.9946 (0.9928–0.9960)	0.9962 (0.9951–0.9971)
b	0.9953 (0.9939–0.9964)	0.9986 (0.9982–0.9990)	0.9992 (0.9990–0.9994)

[a] *L* indicates lightness; *a*, red/green; *b*, blue/yellow; T0, baseline; T1, after adhesive residue removal; T2, after additional photoaging; Min, minimum; Max, maximum.

The Kruskal-Wallis test and the Mann-Whitney *U*-test were used with Bonferroni correction to compare the effects of the adhesive systems and cleaning methods on ΔE 1, ΔE 2, and ΔE 3 median values. The differences between the three ΔE median values among the cleaning methods and the adhesive system subgroups were evaluated using the Wilcoxon signed-ranks test with Bonferroni correction.

RESULTS

Eight teeth had enamel cracks after debonding and were excluded from the study. For each measurement, the ICC values indicating the reliability of the L, a, and b measurements repeated at T0, T1, and T2 were above 99% (Table 1). The median, interquartile range, and minimum-maximum ΔE values as well as the number and percentage of ΔE values that are over the clinical threshold ($\Delta E = 3.7$) are presented in Table 2.

The color change was similar for the ΔE 1 and ΔE 2 values in groups 2A, 3A, 3B, and 4A, and both were significantly higher than that of ΔE 3 (Table 3). There was no significant difference between the ΔE 1 and ΔE 3 values in group 2B, whereas the ΔE 2 value was significantly higher than that of ΔE 3. No significant difference was observed between the Δ values in group 4B (Table 3).

In both the etch-and-rinse and the SEP groups, the color change observed with the tungsten carbide bur was significantly higher than that obtained with the Stainbuster bur (Table 4), with the former being significantly higher than that of the control. Within the RMGIC subgroups, the amount of change for the ΔE 1 value was similar for both the cleaning methods and the control group (Table 4).

Cross-comparisons of the ΔE 1, ΔE 2, and ΔE 3 levels with respect to the adhesive systems and cleaning methods are presented in Table 5. Within the etch-and-rinse subgroups, the color change observed at the ΔE 1, ΔE 2, and ΔE 3 levels in subgroup 2A were significantly higher than those of 2B. Within the SEP subgroups, the color change ΔE 1 and ΔE 2 levels in subgroup 3A were significantly higher than those of subgroup 3B. However, there was no significant difference between the subgroups at level ΔE 3. Within the RMGIC subgroups, the color change at level ΔE 3 in group 4B was higher than that of subgroup 4A. However, there was no significant difference between the subgroups at levels ΔE 1 and ΔE 2 (Table 5).

DISCUSSION

The CIE L*a*b* system is considered to be the standard color space, and the mathematical magnitude of color changes is indicated as ΔE.[17,18] The human eye has restricted capability to see such differences and cannot perceive ΔE values below 1.[19] The ΔE values between 2 and 3.7 represent the clinically perceivable but acceptable range of differences. It has been reported that ΔE values of 3.7 and higher cannot be accepted under clinical conditions.[20] Therefore, as with previous studies, the ΔE threshold value was accepted as 3.7 units herein.[4,10–15]

Enamel discoloration after orthodontic treatment is often overlooked in daily practice. According to

Table 2. The Median, Interquartile Range, and the Minimum and Maximum ΔE Values of the Groups[a]

	ΔE 1 (Baseline-Debonding)					ΔE 2 (Baseline-Aging)					ΔE 3 (Debonding-Aging)				
Group	Med	IR	Min	Max	n (%)	Med	IR	Min	Max	n (%)	Med	IR	Min	Max	n (%)
1 (control)	4	2.73	0.7	10.6	14 (56.0)	–	–	–	–	–	–	–	–	–	–
2A	6.2	3.28	1.6	11.2	20 (83.3)	7.1	2.7	3.1	11.9	22 (91.7)	2.6	1.92	0.8	5.7	7 (29.2)
2B	2.7	2.02	1.1	7.9	5 (22.7)	3.5	2.28	0.5	7.2	10 (45.5)	1.6	0.84	0.8	4.4	1 (4.5)
3A	6	2.3	3.9	10	23 (100)	5.5	1.26	3.9	6.9	23 (100)	1.5	1.4	0.4	4.4	3 (13.0)
3B	4.5	1.72	2.8	10.3	18 (78.3)	4.2	1.28	1.7	7.2	17 (73.9)	1.4	1.12	0.4	4.7	3 (13.0)
4A	4.1	2.05	1.9	9.7	14 (56.0)	5.1	3.35	1.5	10.4	16 (64.0)	2.4	0.84	1	5.8	3 (12.0)
4B	3	2.24	0.9	10.3	8 (32.0)	5.4	5.09	1.6	11.2	18 (72.0)	4.2	4.13	1.7	10.5	16 (64.0)

[a] Med indicates median; IR, interquartile range; Min, minimum; Max, maximum. 2A, etch-and-rinse adhesive/tungsten carbide burs; 2B, etch-and-rinse adhesive/Stainbuster burs; 3A, self-etch adhesive/tungsten carbide burs; 3B, self-etch adhesive/Stainbuster burs; 4A, resin-modified glass ionomer cement (RMGIC)/tungsten carbide burs; 4B, RMGIC/Stainbuster burs. For each ΔE value, the columns marked "n (%)" indicate the number and percentage of ΔE values of groups that are over the clinic threshold ($\Delta E = 3.7$).

Table 3. Comparisons Between the ΔE 1, ΔE 2, and ΔE 3 Levels Within the Adhesive Systems and Cleaning Methods[a]

	ΔE 1 (Baseline-Debonding) (Med [IR])	ΔE 2 (Baseline-Aging) (Med [IR])	ΔE 3 (Debonding-Aging) (Med [IR])
Group 2: total-etch adhesive system			
2A-tungsten carbide	6.2 (3.28)*	7.1 (2.70)**	2.6 (1.92)*,**
2B-Stainbuster	2.7 (2.02)	3.5 (2.28)**	1.6 (0.84)**
Group 3: self-etch adhesive system			
3A-tungsten carbide	6.1 (2.30)*	5.1 (1.26)**	1.5 (1.40)*,**
3B-Stainbuster	4.5 (1.72)*	4.2 (1.28)**	1.4 (1.12)*,**
Group 4: RMGIC			
4A-tungsten carbide	4.1 (2.05)*	5.1 (3.35)**	2.4 (0.84)*,**
4B-Stainbuster	3.1 (2.24)	5.4 (5.09)	4.2 (4.13)

[a] Med, median; IR, interquartile range; RMGIC, resin-modified glass ionomer cement.

* The difference between ΔE 1 and ΔE 2 is statistically significant ($P < .001$).

** The difference between ΔE 1 and ΔE 3 is statistically significant ($P < .001$).

Karamouzos et al.,[10] the optical characteristics of enamel are changed during orthodontic treatment, with the color change being affected by several factors. External coloring occurs as a result of superficial absorption of food pigments, while internal coloring occurs during aging. In the present study, photoaging was performed to stimulate internal coloring. A color change above the threshold (ie, $\Delta E = 3.7$) observed in 56% of the control specimens confirms the efficacy of this method. As explained previously,[14,15,21] the lack of saliva, the food coloring, and the inability to simulate the mechanic abrasion caused by brushing are the limitations of this methodology. In the present study, the magnitude of color change was greater during orthodontic treatment than after treatment, with the latter being below the threshold. These findings corroborate those of Eliades et al.[4] and Jahanbin et al.,[15] who observed the highest color change after debonding.

Tungsten carbide burs are known to produce minimal damage to the enamel during removal of adhesive residue.[22–24] Fiber-reinforced composite burs require a longer time to remove adhesive remnants after debonding but may offer the advantage of providing a smoother surface compared to tungsten carbide.[14,25] In the present study, the total color changes observed in the etch-and-rinse and SEP groups were significantly lower in the Stainbuster subgroups than in the tungsten carbide group. This finding can be explained by the fact that Stainbuster burs provide a smoother enamel surface and increase light reflection.[14,25]

In the present study, the finding that the etch-and-rinse/tungsten carbide bur group exhibited the highest total color change can be explained by the occurrence of thicker and longer resin extensions formed after phosphoric acid etching.[26] Accordingly, this combination may not be suitable for clinical use. Compared to the etch-and-rinse adhesive, the lesser extent of total color change observed in the self-etch/tungsten carbide bur combination strongly suggests shorter resin extensions are produced by the SEP,[27–29] which in turn causes less discoloration.[30] As for the RMGIC, the changes observed after adhesive removal by both types of burs were low, confirming that the RMGIC did not produce resin extensions and that the bond between the enamel and the cement was predominantly chemical rather than micromechanical.[26] However, with regard to the total change (ie, discoloration after the orthodontic treatment), it was interesting to observe that the RMGIC/Stainbuster group exhibited the only value among the test groups that was above the clinic threshold ($\Delta E = 3.7$). This unexpected result suggests that RMGIC residuals that are invisible to the eye at clinical magnification may still exist on the enamel surface after cleaning. Coupled with the unfavorable color stability of RMGIC,[31] these residuals may lead to clinically unacceptable discoloration values as observed herein. Further studies using elemental analysis should be carried out to confirm this assumption. However, based on the present

Table 4. Comparisons Between the Adhesive System and the Cleaning Method With Respect to the ΔE 1 (Baseline-Debonding) Value[a]

	Control (Med [IR])	Total Etch (Med [IR])	Self Etch (Med [IR])	RMGIC (Med [IR])	*P**
	4.0 (2.73)^{ABEab}				
Tungsten carbide		6.2 (3.28)^{ACac}	6.1 (2.30)^{BDac}	4.1 (2.05)^{CD}	<.001
Stainbuster		2.7 (2.02)^{EFbc}	4.5 (1.72)^{DFc}	3.1 (2.24)^{D}	<.001
*P***		<.001	<.001	.064	

[a] Med, median; IR, interquartile range; RMGIC, resin-modified glass ionomer cement.

* Comparisons made between the control group and the adhesive system groups among the cleaning methods are considered statistically significant for $P < .025$ according to the Kruskal-Wallis test with Bonferroni correction; ** comparisons made between the control group and the cleaning methods among the adhesive systems are considered statistically significant for $P < .017$ according to the Kruskal-Wallis test with Bonferroni correction. In each row, the difference between groups that are indicated with the same uppercase letter is statistically significant ($P < .025$); in each column, the difference between groups that are indicated with the same lowercase letter is statistically significant ($P < .017$).

Table 5. Cross-Comparisons of the ΔE 1, ΔE 2, and ΔE 3 Levels With Respect to the Adhesive Systems and Cleaning Methods[a]

	Total-Etch (Group 2) (Med [IR])	Self-Etch (Group 3) (Med [IR])	RMGIC (Group 4) (Med [IR])	*P**
ΔE 1 (baseline-debonding)				
Tungsten carbide	6.2 (3.28)***	6.1 (2.30)****	4.1 (2.05)***,****	<.001
Stainbuster	2.7 (2.02)*****	4.5 (1.72)****,*****	3.1 (2.24)[d]	<.001
*P***	<.001	<.001	.023	
ΔE 2 (baseline-aging)				
Tungsten carbide	7.1 (2.70)***,*****	5.1 (1.26)*****	5.1 (3.35)***	.002
Stainbuster	3.5 (2.28)***	4.2 (1.28)	5.4 (5.09)***	.005
*P***	<.001	<.001	.347	
ΔE 3 (debonding-aging)				
Tungsten carbide	2.6 (1.92)	1.5 (1.40)	2.4 (0.84)	.009
Stainbuster	1.6 (0.84)***	1.4 (1.12)****	4.2 (4.13) ***,****	<.001
*P***	<.001	.668	<.001	

[a] Med, median; IR, interquartile range; RMGIC, resin-modified glass ionomer cement.

* Comparisons between the adhesive systems among the cleaning methods are considered statistically significant for $P < .0083$ according to Kruskal-Wallis test with Bonferroni correction; ** comparisons between the cleaning methods among the adhesive systems are considered statistically significant for $P < .0056$ according to Mann-Whitney *U*-test with Bonferroni correction; *** the difference between the total-etch group and the RMGIC group is statistically significant ($P < .0083$); **** the difference between the self-etch group and the RMGIC group is statistically significant ($P < .001$); ***** the difference between the total-etch group and the self-etch group is statistically significant ($P < .0083$).

results, the use of Stainbuster burs cannot be recommended for removal of RMGIC.

CONCLUSIONS

- Discoloration occurs on enamel during and after orthodontic treatment. Both the orthodontic adhesive systems and the burs used to remove their residuals on tooth surfaces are responsible for this effect.
- The highest color change was observed in the etch-and-rinse/tungsten carbide bur group. This combination is not recommended for clinical use in terms of enamel discoloration.
- When the brackets are bonded with the etch-and-rinse or SEP systems, cleaning the adhesive residuals with Stainbuster burs is recommended for minimal color change. For the RMGIC, tungsten carbide burs may provide less enamel discoloration in the long run.

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