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Influence of different bonding agents on the color stability of enamel after orthodontic bracket removal

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Abstract

Objective: This study aimed to assess the staining susceptibility of the hybrid layer remaining on the enamel surface after bracket removal, focusing on various bonding agents applied for the bonding process.

Methods: A total of 120 enamel discs were obtained from bovine incisors. The specimens were divided into 5 groups (n=24) according to the bonding agent applied, as follows: Group 1: Control, Group 2: Transbond XT, Group 3: Proseal, Group 4: Icon + Transbond XT, and Group 5: Icon + Heliobond. After composite removal, half of the specimens were exposed to a tea solution and the other half to a tea + citric acid solution (n=12). The "L", "a", and "b" color components were spectrophotometrically assessed at various stages including pre-bonding (T1), after debonding (T2), and after 24-hour immersion in the discoloration solution (T3). The color changes (ΔL, Δa, Δb) were analyzed by a two-way ANOVA at $P<0.05$.

Results: In all groups, a small shift in all color components was observed after debonding and polishing the surface. All groups showed similar, noticeable color changes after exposure to the discoloration solutions. Neither the type of bonding agent nor the type of staining solution had a significant influence on ΔL, Δa, and Δb values between different treatment stages ($P>0.05$ for all comparisons).

Conclusions: Despite enamel polishing, some discolorations remain on the enamel after debonding, possibly due to the primers applied during bracket bonding. The type of bonding agent and the staining solution does not significantly affect the color stability of teeth after debonding.

Keywords: Bis-GMA, Bonding agent, Debonding, Orthodontic treatment, Staining, Tooth discoloration

Introduction

Fixed orthodontic therapy plays an essential role in achieving optimal tooth alignment. This treatment procedure involves bracket bonding and subsequent debonding. The primary objective of orthodontic procedures is to induce tooth movement without compromising the enamel's initial integrity. The bonding process introduces a hybrid layer on the enamel surface, formed by the penetration and polymerization of monomers during bracket attachment. This layer, however, remains susceptible to the penetration of external factors and staining solutions even after bracket removal, potentially affecting the esthetic outcomes of orthodontic therapy (1, 2).

The orthodontic literature describes the hybrid layer as an enamel-adhesive complex formed by the infiltration and polymerization of monomers on the roughened enamel surface (1, 3). The roughening of the enamel surface is essential for enabling monomer penetration and providing micro-mechanical retention. Although etching with phosphoric acid creates deeper enamel grooves, the penetration depth is lower for self-etching primers. This may affect the staining susceptibility of bonded teeth.

Orthodontic bonding agents mainly contain bisphenol A-glycidyl methacrylate (Bis-GMA), and triethylene glycol dimethacrylate (TEGDMA) monomers at different concentrations. Previous studies highlighted how

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bonding or primer compositions affect the hybrid layer's vulnerability to stains after acid etching and bracket attachment (1, 4-6). However, the impact of bonding compositions on the hybrid layer's resistance to staining after bracket removal has not been thoroughly explored. Understanding this effect may help clinicians in maintaining the esthetic integrity of the enamel surface and developing methods to enhance the resistance of the hybrid layer to staining (1, 3, 7-10).

Icon (DMG America, New Jersey, USA) is well-known for the prevention and treatment of incipient caries. It primarily contains TEGDMA, which contributes to its smaller molecular size and deeper penetration capabilities. It is possible that the use of Icon, due to its sole TEGDMA monomer, provides more effective penetration of the bonding agent to the enamel surface, and thus enhances resistance to discoloration as compared to primers with lower TEGDMA content.

This study was conducted to evaluate the effect of different primers, applied during bracket bonding, on enamel color changes following debonding and composite removal. The color stability of enamel bonded with various primers was also assessed after exposure to two staining solutions.

Materials and methods

Sample preparation

One hundred and twenty enamel discs were prepared from bovine incisors. To prepare the discs, the crowns were carefully separated from the roots using a continuous water-cooling system to avoid thermal damage. The enamel discs with a diameter of 3 mm and 3 mm thickness were obtained from the labial parts of the crowns. This process was carried out using a diamond-coated trephine bur (Intensiv SA, Lugano-Grancia, Switzerland) under irrigation. The enamel discs were then polished with sandpaper (Struers, Birmensdorf, Switzerland) to a uniform thickness of 3 mm.

An auto-polymerizing acrylic resin was used to surround the labial surfaces of the teeth, forming blocks with dimensions of 6 mm in diameter and 3 mm in thickness. This provided stable specimen handling during the bonding, debonding, and exposure to staining solution stages and facilitated color assessments. The surfaces were then meticulously polished using a sequence of water-cooled carborundum discs (Struers, Erkrat, Germany) with varying grits (1200, 1400, and 4000) to achieve a uniformly smooth and polished finish necessary for precise color measurements.

Subsequently, the bracket bonding and debonding process was applied to enamel surfaces under standard conditions. Adhesives were then removed using a sharp scaler and a standardized polishing system (1-3).

Grouping and primer applications

The enamel specimens were randomly divided into five equal groups based on the utilized bonding protocol (n=24). The groups were as follows:

Group 1 (Control): No primer was applied to the enamel surface.

Group 2 (Transbond XT): The Transbond XT primer (3M, Minnesota, USA) was applied as per manufacturer instructions. It contains TEGDMA (55%) and Bis-GMA (45%).

Group 3 (Proseal): The Proseal sealant (Reliance Orthodontic Products Inc., Itasca, Illinois, USA) was applied as per the manufacturer's instructions. It is a self-etch system and contains a urethane acrylate oligomer (30%) and polyethylene glycol diacrylate (30%).

Group 4 (Icon + Transbond XT): In this group, Icon (DMG America, Ridgefield Park, New Jersey, USA), which primarily contains TEGDMA (99%), was applied followed by Transbond XT.

Group 5 (Icon + Heliobond): In this group, Icon was used to improve the penetration effectiveness of the bonding agent. Heliobond (Ivoclar Vivadent, Schaan, Liechtenstein), which contains both TEGDMA (40%) and Bis-GMA (60%), was applied after Icon application.

Staining process

The specimens in each group were then divided into two subgroups (n=12) based on the discoloration agent applied. One subgroup was exposed to a tea solution, and another subgroup was immersed in a mixture of tea and citric acid.

The preparation of the staining solution involved soaking five black tea bags in 1 liter of boiling water for 10 minutes. For the acidified tea solution, 0.1 M citric acid was added to achieve a pH of 4.0. The specimens were placed in the staining solutions for 24 hours, and then thoroughly rinsed with water.

Color measurement and analysis

Color components were measured before bonding (T1), after debonding (T2), and following a 24-hour staining period (T3), using a digital spectrophotometer (Easy Shade; Vita Zahnfabrik, Bad Sackingen, Germany).

The following color components were measured:

'L' value: It shows the degree of illumination within a sample and ranges from 0 (black) to 100 (white).

'a' value: It represents the red-green axis, where an increase in a value indicates a more reddish color.

'b' value: It represents the yellow-blue axis, where an increase in the b value indicates a more yellowish color.

The differences in these values (ΔL, Δa, Δb) were calculated to quantify the enamel color changes between different treatment stages, as explained in the following:

ΔL: This parameter represents the difference in lightness. A positive ΔL indicates a lighter color, whereas a negative ΔL indicates a darker color.

Δa: This represents the difference in color along the red-green axis. A positive Δa indicates a shift towards red, and a negative Δa indicates a shift towards green.

Δb: This parameter represents the difference in color along the yellow-blue axis. A positive Δb indicates a shift towards yellow, and a negative Δb indicates a shift towards blue.

The effect of different primers on color changes was measured between different time points as follows:

T1-T2: The change in color between baseline and after debonding

T2-T3: The change in color between the situations after debonding and after staining

T1-T3: The change in color between baseline and after staining

Statistical analysis

Normal distribution of the data was confirmed via the Kolmogorov-Smirnov test (P>0.05). A two-way ANOVA was run for statistical comparisons. The analysis was conducted with SPSS software (SPSS Inc., Chicago, IL, USA, version 21.0) and the significance level was set at P<0.05.

Results

Table 1 presents the mean and standard deviation (SD) of changes in color components between different treatment stages in the study groups. Comparisons of ΔL, Δa, and Δb values in the study groups are illustrated in Figures 1 to 3, respectively.

In all groups, a small change in all color components was observed after debonding and polishing the enamel surface, as compared to the baseline values. Remarkable color changes were observed in all specimens after exposure to staining with either tea or tea + citric acid solutions, as illustrated in Figures 1 to 3. The two-way ANOVA revealed that neither the type of bonding agent nor the type of staining solution had a significant influence on ΔL, Δa, and Δb values between different treatment stages (P>0.05 for all comparisons). This indicates that the color changes observed in the study groups were comparable to each other in both staining solutions.

Discussions

Material selection is important in orthodontic treatments, affecting treatment esthetic outcomes. The present study evaluated the color stability of the hybrid layer created by different bonding agents after bracket removal. Bovine teeth were used for color measurements due to their structural similarity to human enamel (11, 12).

In this study, ΔL, Δa, and Δb were used to quantify and analyze changes in enamel color before and after orthodontic bracket removal and staining, providing detailed information about the nature and extent of alterations in individual color components. The results indicated that the process of debonding itself provides negligible color changes on the enamel surface. However, exposure to tea or tea + citric acid caused remarkable alterations in color components. Although

Table 1. Mean and standard deviation (SD) of changes in L, a, and b parameters between different treatment stages in the study groups

	L1-L2	L2-L3	L1-L3	a1-a2	a2-a3	a1-a3	b1-b2	b2-b3	b1-b3
Control	1.67 ± 0.59	6.29 ± 3.90	8.53 ± 1.42	0.01 ± 0.09	-2.07 ± 1.09	-2.06 ±1.13	0.29 ± 0.34	-11.74 ± .80	-11.46 ± 1.03
XT	1.74 ± 0.97	6.86 ± 1.54	8.03 ± 4.53	-0.17 ± 0.14	-1.52 ± 0.85	-1.69 ± 0.81	-0.26 ± 1.05	-10.83 ± 0.26	-11.08 ± 1.05
Proseal	3.02 ± 1.45	5.83 ± 1.33	7.47 ± 1.13	-0.07 ± 0.15	-2.60 ± 1.06	-2.67 ± 1.10	0.02 ± 1.27	-12.12 ± 0.87	-12.10 ± 1.80
Icon + Helio	3.02 ± 1.45	4.68 ± 1.53	7.70 ± 1.59	-0.26 ± 0.22	-2.33 ± 1.46	-2.59 ± 1.50	-0.21 ± 0.61	-12.73 ± 0.40	-12.94 ± 2.09
Icon + XT	1.74 ± 1.13	6.61 ± 2.04	8.35 ± 1.41	-0.06 ± 0.11	-2.56 ± 1.13	-2.62 ± 1.14	-0.17 ± 0.91	-11.96 ± 2.01	-12.12 ± 2.11
CA- Control	0.67 ± 0.46	6.91 ± 2.38	7.57 ± 2.39	0.03 ± 0.08	-2.59 ± 0.61	-2.56 ± 0.60	0.45 ± 0.22	-14.7 ± 1.45	-13.72 ± 1.48
CA- XT	0.66 ± 0.71	7.79 ± 1.50	8.45 ± 1.80	-0.03 ± 0.18	-2.17 ± 0.60	-2.2 ± 0.66	0.13 ± 0.54	-13.14 ± 0.16	-12.83 ± 2.17
CA- Proseal	1.25 ± 0.58	6.17 ± 1.69	7.43 ± 1.78	0.12 ± 0.23	-2.97 ± 1.15	-3.09 ± 1.22	0.06 ± 0.54	-14.40 ± 2.05	-14.34 ± 2.01
CA- Icon + Helio	0.65 ± 0.67	5.67 ± 1.35	6.33 ± 1.35	-0.14 ± 0.09	-2.41 ± 0.91	-2.55 ± 0.91	-0.54 ± 0.48	-14.27 ± 1.53	-14.81 ± 1.39
CA- Icon + XT	0.80 ± 0.55	5.96 ± 1.63	6.77 ± 1.58	0.05 ± 0.24	-2.70 ±0.97	-2.65 ± 0.93	-0.04 ± 1.09	-14.35 ± 1.07	-14.38 ± 1.59

XT: Transbond XT, Helio: Heliobond, CA: Citric acid

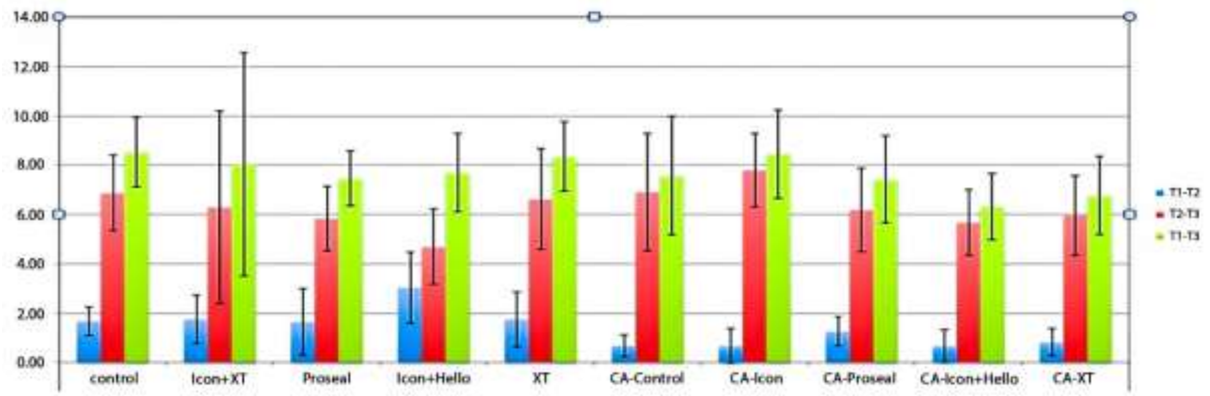

Figure 1. Comparison of ΔL values between different treatment stages among the groups after staining by tea or tea + citric acid solutions (XT: Transbond XT, Helio: Heliobond, CA: Citric acid)

the observed color changes after debonding were not clinically significant, they should be considered when planning orthodontic treatments with fixed attachments. Discussing these potential esthetic changes with patients and their families is crucial for informed consent, emphasizing that color alterations may occur between the stages of pre-bonding (before bracket placement) and after debonding (after bracket removal).

Our findings revealed no significant difference in enamel color stability between the self-etch (Proseal) and total-etch (Heliobond and Transbond XT) primers after debonding. This finding suggested that self-etching primers, which simplify the bonding process and potentially reduce procedural errors (13), do not compromise color stability of the tooth surface. Both self-etching and conventional primers effectively maintained enamel esthetics after debonding. This indicates similar performance of self-etch and total-etch primers in minimizing esthetic changes on the enamel surface. However, self-etch primers may cause inferior results concerning bond strength or microleakage (14-16), which should be considered in the material selection.

The different primers and sealants used in this study did not significantly affect color stability of enamel after exposure to staining solutions. The present outcomes are in line with those of Vilchis et al. (17), who found no significant difference in enamel color changes and bracket debonding rates among orthodontic patients whose brackets were bonded using self-etching primers and conventional bonding systems. Romano et al. (18), found that the self-etching primer was less successful than the conventional system in terms of bonding effectiveness. Differences in surface wettability and viscosity between bonding systems could influence their application effectiveness and bonding quality.

A primary goal of orthodontic treatment is to restore the enamel surface to its pre-treatment condition after debonding. However, due to the physical principles, the

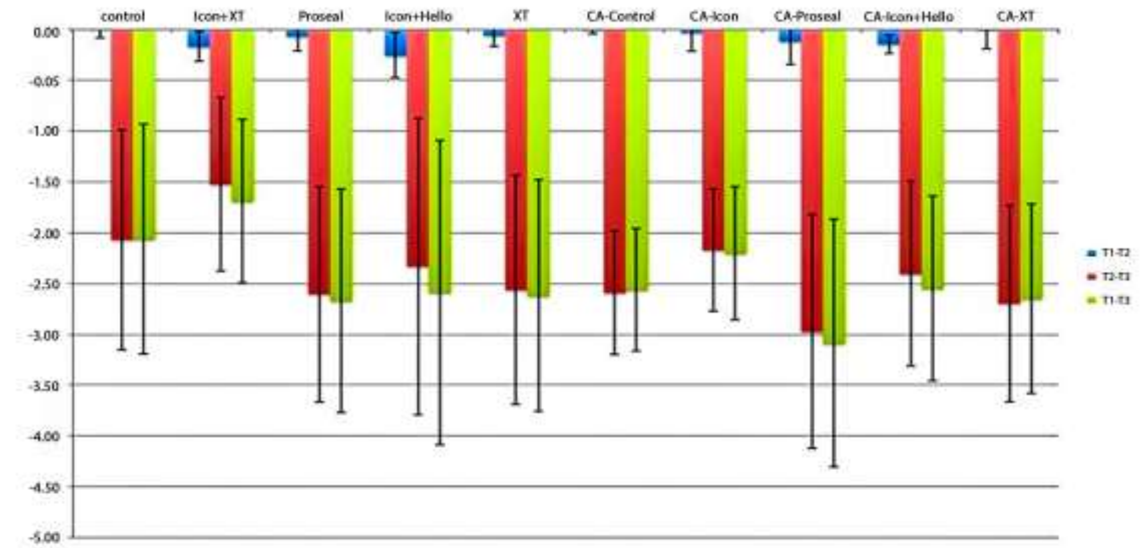

Figure 2. Comparison of Δa values between different treatment stages among the groups after staining by tea or tea + citric acid solutions (XT: Transbond XT, Helio: Heliobond, CA: Citric acid)

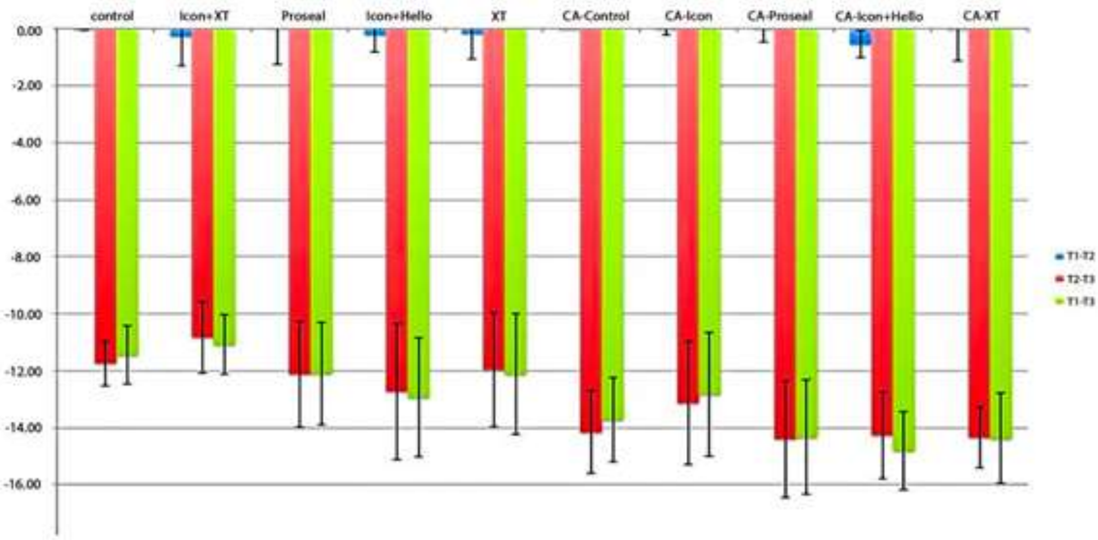

Figure 3. Comparison of Δb values between different treatment stages among the groups after staining by tea or tea + citric

bonding process inevitably leaves a hybrid layer, which is integrated into the enamel surface and is not removed (11, 15). Primers rich in TEGDMA, such as Icon, are known for deeper penetration, whereas those with higher Bis-GMA content have shallower penetration (13, 14).

In this study, there was no significant difference in the degree of discoloration observed after exposure to staining solutions with neutral or acidic pH. Another key finding of this study was that primers with different chemical content showed similar resistance to discoloration after the debonding process. This indicated that the surface properties of the hybrid layer formed by different adhesives did not significantly affect the enamel's susceptibility to discoloration. Therefore, a decision for choosing a primer should be based on parameters rather than the enamel discoloration effect such as bond strength and ease of use.

The results of this study are in line with the findings of Nakamichi et al. (12), Atash et al. (15), and Li et al. (16), who found that the primer's chemical composition does not distinctly influence the enamel's susceptibility to color changes when exposed to staining agents.

The protection against demineralization is an important feature of orthodontic bonding agents. In the present study, Icon was used in groups 4 and 5 to improve the penetration effectiveness of the bonding agent. It is also possible that the use of Icon before bracket bonding provides caries protection around brackets, although this property should be evaluated in future investigations.

Transbond XT adhesive and paste are one of the standard materials used for bonding orthodontic attachments and have been the focus of many past studies investigating color stability or bond effectiveness (19-22). Previous studies on adhesive systems with antibacterial properties and fluoride release (as in Transbond XT), emphasized the importance of such features in bonding agents to prevent enamel demineralization during orthodontic treatments (23, 24).

This study was focused on a specific set of bonding agents, which may limit the generalizability of findings to other bonding systems. Future research should continue to investigate the complex interplay between adhesive materials, and enamel color changes at longer intervals to optimize the esthetic results of orthodontic treatments.

Conclusions

Based on the findings of this study, the following conclusions can be drawn:

1- Despite enamel polishing after debonding and composite removal, small discolorations remain on the tooth surface, possibly due to the hybrid layer remaining after bracket debonding. This change indicated that the enamel surface could not be fully restored after bracket removal.
2- There was no significant difference in the amount of discoloration observed after bracket debonding between the different bonding agents.
3- The different primers applied for orthodontic bonding showed comparable resistance to discoloration after exposure to the neural or acidic tea solutions.

Conflict of interest

None declared.

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