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SCIENTIFIC SECTION

Enamel colour changes after debonding using various bonding systems

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Objective: To test the possible association between enamel colour alteration and resin tag depth.

Design: *In vitro* laboratory study.

Setting: Department of Orthodontics, Alexandria University, Egypt.

Materials and methods: Fifty freshly extracted human premolar teeth were equally divided randomly into a control and four experimental groups. Teeth in Group I received only enamel prophylaxis. Teeth in Groups II and III were etched with 35% phosphoric acid for 15 and 60 seconds, respectively. Teeth in Group IV were conditioned with Prompt L-pop self-etching primer and in Group V with Xeno III self-etching primer, according to the manufacturer's instructions. Orthodontic brackets were bonded to the teeth in all experimental groups using Transbond XT composite. Following bracket debonding, finishing and polishing were performed. Enamel colour was evaluated spectrophotometrically at baseline and then after debonding, with the corresponding colour differences ΔE calculated. Resin tags lengths were measured on sectioned teeth in each experimental group under scanning electron microscope.

Results: All experimental groups showed clinically perceivable colour change after debonding and finishing as all values were exceeded the clinical colour detection threshold of $\Delta E=3.7$ units. Significant differences ($P<0.05$) in resin tag length were found in all experimental groups. Significant moderate correlation was found between colour change and resin tags length when all teeth were combined and tested, irrespective of group.

Conclusions: Moderate evidence exists that shorter resin tag penetration produces less change in enamel colour following clean-up and polishing. Self-etch primers produce less resin penetration and these systems may produce less iatrogenic colour change in enamel following orthodontic treatment.

Key words: Enamel colour, resin tags, orthodontic bonding

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Introduction

A considerable amount of scientific work has concluded that orthodontic attachment bonding and debonding can be associated with adverse effects on tooth enamel. These effects include identified as enamel loss, decalcification, microcracks, scratches and abrasions.[1] Apart from the formation of structural and surface defects, the foregoing variables may affect enamel colour as well.[2]

Despite the evidence for enamel white spot formation associated with orthodontic treatment, the incidence of enamel colour changes induced by bonding and debonding procedures has attracted a limited number of investigators. Most of these studies have shown that bonding and debonding procedures can cause noticeable enamel colour alterations.[1,3–7]

Enamel colour alterations after orthodontic treatment may be related to the post-debonding resin removal protocols involving grinding with various instruments and the penetration of resin tags into the enamel structure.[3] Since resin impregnation in the enamel structure cannot be reversed by debonding and cleaning procedures,[1] enamel colour alteration may occur by direct absorption of food colorants and products arising from the corrosion of the orthodontic appliance[4] or may be the change in the refractive index of the region, modifying the diffusely reflected light component.[3]

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Relevant data indicate that the depth of the resin tag penetration increases when the enamel is etched with 35% phosphoric acid than when enamel is conditioned with self-etching primers.[8–12] The present study was undertaken to test the null hypothesis that there is no difference in the colour change of enamel after finishing following the removal of brackets bonded by different bonding protocols. The association between colour change and lengths of remnant resin tags was also investigated.

Material and methods

In order to calculate an appropriate sample size, the threshold of clinically detectable colour change of $\Delta E=3.7$[13] was used as a mean difference for comparison between two groups using a *t*-test. The standard deviation of colour change was set at 3.35.[7] At $\alpha=0.05$ and a power of 0.80, the sample size yielded 7 (http://statisticalsolutions.net/pss_calc.php). It was decided to collect 10 samples for each group for a total sample size of 50.

Fifty human premolar teeth extracted for orthodontic purposes were collected from subjects of age ranging from 12–16 years. All the subjects were born and residents in Alexandria, Egypt. The average level of fluoride in drinking water in Alexandria is 6 ppm, which is considered optimally fluoridated for the average temperature in the region. No additional fluoride is added to the drinking water.[14] The teeth did not have visible caries, cracks, decalcification or discoloration on their buccal surface. Immediately after extraction, the teeth were cleaned under running water and stored in a black container in distilled water at 37°C for the entire duration of the study so that any effects of temperature and lighting are eliminated.[6]

Following storage of all teeth, the root of each tooth was embedded in black cold cure acrylic resin in a rectangular metal mould to create acrylic blocks. Each tooth block was randomly assigned a number from 1 to 50. These numbers were used following initial colour determination to randomly assign the samples to the study groups using a random sample generator. A black 35 mm circular sample holder with a 6 mm diameter window in the centre was fabricated with self-cure acrylic resin to accommodate each of the acrylic blocks. The window corresponded to the middle of the buccal crown surface of each tooth to facilitate a mean to standardize the enamel surface intended for bonding and analysis. A notch was made in order to accurately place the holder in the positioning box in a standardized setting. A black square 30×30 cm wooden box with a 6 mm window in the centre was used to position the sample holder in a standardized setting. The window of the box and sample holder were aligned to correspond to the outer diameter of the probe of the spectrophotometer (VITA Zahnfabrik, Bad Sackingen, Germany) and to each other (Figure 1).

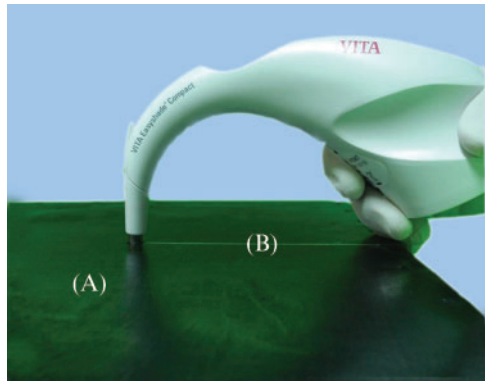

Figure 1 Tooth colour recording by spectrophotometer. The probe (A) of the spectrophotometer was inserted into the window of the box, while the spectrophotometer was centred with the marked reference line to standardize its position (B) during all colour recordings

Prior to colour measurement, all teeth were cleaned with a rubber prophylaxis cup at low speed with a mixture of oil free non-fluoridated pumice and water, and then thoroughly rinsed with running water. The sample holder having the tooth sample was placed in the positioning box. The steel probe of the spectrophotometer was inserted into the window of the box and placed perpendicular to and flush with the tooth surface to be analysed (Figure 2).

In order to minimize the measuring error, three readings per sample were taken. Reading recording verification was obtained when the total colour difference between the two readings taken in a row did not exceed the threshold of 1 ΔE unit. Readings with a difference of ΔE more than 1 unit were discarded and new readings were taken. Where a difference of ΔE more than 1 unit persisted, the average of the two nearest measurement was used. Following another calibration cycle, the entire process was repeated for the next tooth.

All enamel colour recordings were made on wet enamel surfaces. A VITA Easy shade Compact reflectance spectrophotometer was used for all colour recordings according to the CIE (Commission Internationale de l'Eclairage) $L^*a^*b^*$ order systems;[15,16] where L^* corresponds to the value or degree of lightness, a^* coordinates designate position on red/green axis and b^* coordinates designate position on yellow/blue axis. The instrument

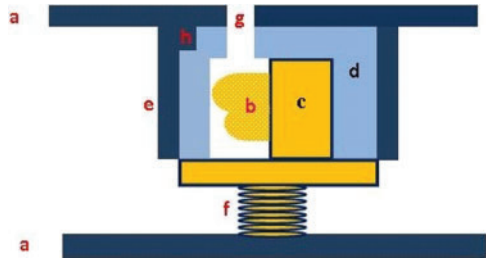

Figure 2 A schematic diagram showing a cross-section through the black box (a). The premolar (b) in the acrylic mould (c) are positioned in the mould holder (d) to a receptacle (e) onto the inside of the top of the box. A spring (f) fixed to the the inside of the base of the box is used to push the mould holder against the hole (g) at the top of the box where the colour is measured. A notch (h) in the model holder is used to orient the mould to the same position in the box

employs a 0/0 optical geometry (source and receiver fibre optics are parallel and are spatially separated).

After initial colour measurement, the teeth were randomly assigned into five groups of 10 each, according to the bonding protocol used:

- Group I: The control group received only enamel prophylaxis, and was used to check the effect of storage on tooth colour;
- Group II: The teeth were etched with 35% phosphoric acid etching gel Ultra Etch (Ultradent Products, Inc., South Jordan, UT, USA) for 15 seconds, then washed and dried. A single coat of primer Transbond XT (3M Unitek, Monrovia, CA, USA) was applied on the etched area of all the teeth;
- Group III: The teeth were etched with 35% phosphoric acid etching gel for 60 seconds then washed and dried. A single coat of primer (Transbond XT) was applied on the etched area of all the teeth;
- Group IV: The self-etching primer Prompt L-pop (3M ESPE Dental Products; 3M Center, St Paul, MN, USA), which contains both acid and primer, was applied on each tooth surface and left undisturbed for 15 seconds, followed by the application of gentle stream of oil free compressed air to get a thin film, as recommended by the manufacturers.
- Group V: The self-etching primer Xeno III (DENTSPLY International, World Headquarters, York, PA, USA) which contains both acid and primer was applied after mixing the liquids from bottle A and B, on each tooth surface and left undisturbed for 20 seconds, followed by the application of gentle stream of oil free compressed air to get a thin film, as recommended by the manufacturer.

Standard edgewise premolar brackets (Leone S.p.A. Sesto Fiorentino — Firenze, Italy) were then bonded to the teeth at the centre of the buccal surface in all experimental groups using light cure composite resin (Transbond XT). The bracket was positioned firmly on each tooth surface in the centre of the buccal surface. Excess composite was removed from around each bracket base with a sharp dental scaler and then light cured for 20 seconds (10 seconds from the mesial and 10 seconds from distal aspects of each bracket).

After 48 hours of storage, all brackets were debonded using bracket removing pliers with a peeling type force. The specimens were clamped to a bench top while the brackets were debonded. Removal of adhesive remnants was performed using 12-fluted tungsten carbide bur (Komet Gebr, Brasseler, Lemgo, Germany) operated at low speed[17] with appropriate water cooling followed by extra fine Sof-lex polishing discs (3M ESPE Dental Products; 3M Center). All finishing and polishing procedures proceeded till a normal luster was restored to the enamel surface observed by the naked eye. Burs and discs were only utilized once per surface. Bonding, debonding and finishing procedures were performed by the same operator under normal dental chair light (NA).

Following finishing and polishing, final colour measurements took place to each tooth by the same VITA easy shade compact spectrophotometer employing the same procedure. Three readings were taken per tooth as was done initially. Colour differences before and after bonding (ΔE) were calculated for each tooth using the following equation.[15]

$$\Delta E = \left[\left(L_1^* - L_2^*\right)^2 + \left(a_1^* - a_2^*\right)^2 + \left(b_1^* - b_2^*\right)^2 \right]^{1/2}$$

where L_1^* and L_2^* are the values of L^* at baseline and after finishing, a_1^* and a_2^* are the value of a^* at baseline and after finishing and b_1^* and b_1^* are the values of b^* at baseline and after finishing.

In order to measure the resin tag depth, the crowns of the teeth in Groups II, III, IV and V were sectioned buccolingually into two halves (mesial and distal) parallel to the long axis of the tooth using a diamond disc. The medial surface of the mesial segment of each tooth was ground with 1200 grit sandpaper under water till the surface appeared smooth and polished without any irregularity observed by the naked eye. A 1% nitric acid solution was applied for 30 seconds, rinsed with water and air dried overnight to remove the smear layer.[18] Examination was conducted using a scanning electron microscope (JSM-6360 LA; JEOL Ltd, Tokyo, Japan) operated at 30 kV.

The enamel surface was scanned and photographed at a magnification of $\times 1500$ for resin tags measurement. The

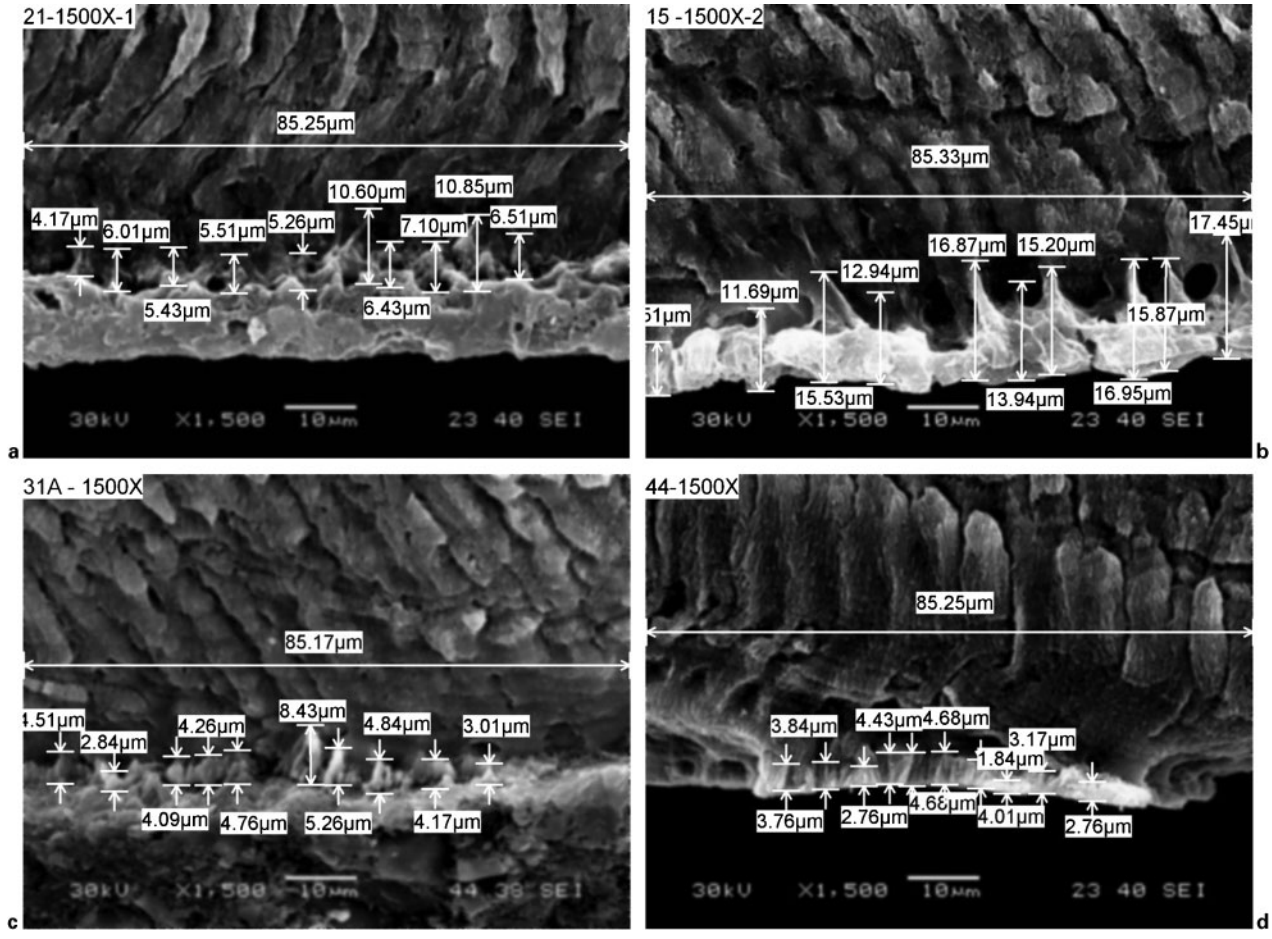

Figure 3 Scanning electron micrographs of cut enamel surface showing the measurement of resin tags (RT) in (a) Group II, (b) Group III, (c) Group IV and (d) GroupV (×1500)

10 most visible resin tags well spread on 85 µm of the micrograph were selected and measured using computer software (Figure 3).

The means and standard deviations were calculated for the values of ΔE and resin tag lengths. Comparisons of ΔE and resin tag lengths among the study groups were done using analysis of variance followed by Tukey's *post hoc* test for pairwise comparisons. Correlations between ΔE and resin tag lengths in each group and in all specimens were done using Pearson's correlation coefficient. The level of significance level was set at 5%.

Results

To determine the reliability of the collected data, the three values for measuring colour components (L^*, a^* and b^*) were compared using intra class correlation coefficient showed high reliability (ICC=0.99, 0.98 and 0.99 for L^*, a^* and b^*, respectively).

There was a statistically significant colour change after debonding and finishing among all groups. The greatest colour change was found in Group III, followed by Groups II, IV, V and I in descending order. Pairwise comparisons showed a significant colour change after debonding and finishing between the control group and each of the experimental groups. However, the colour change was not different between the experimental groups (Table 1).

In order to find out whether the colour change was clinically perceivable or not, colour change values were compared with the 'critical value for clinical detection' which was selected at ΔE=3.7 units.[13] All experimental groups showed higher values for ΔE than the critical value.

The scanning electron microscope images of the teeth showed a variation in the depth of penetration of the resin into the etched enamel in different groups. The resin tags lengths in Group II were between 4.17 and 10.85 µm, in Group III between 8.51–17.45 µm, in

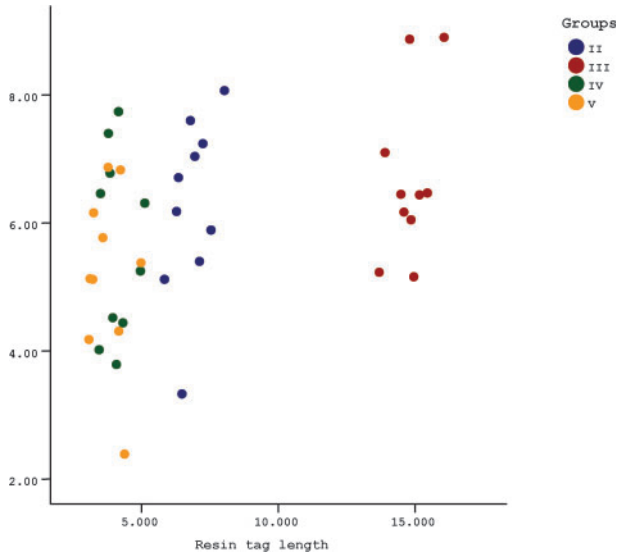

Figure 4 Scatter plot between ΔE and resin tag length in all groups

Group IV between 2.84–8.43 μm, whereas in group V, they were between 1.84 and 4.68 μm (Figure 3).

There was statistically significant difference in resin tags length among the four experimental groups. The longest resin tags existed in Group III followed by Groups II, IV and V in descending order (Table 2). Pairwise comparisons showed that the resin tags were significantly longer in Group III than every other group. The resin tags in Group II were significantly longer than in Groups IV and V, and significantly shorter than Group III. No significant difference in resin tag lengths was found between Groups IV and V (Table 2).

None of the experimental groups showed a significant correlation between the colour change and resin tag length. However, when the data from all the experimental groups were pooled, a significant positive correlation of moderate strength was found between colour change and resin tag length (Table 3 and Figure 4).

Discussion

All experimental groups showed significant colour change between baseline and finishing. The colour change in all groups exceeded the threshold for clinical colour detection of 3.7 units.[13] There was a significant difference in resin tag depth between the two total etch groups (II and III), and between the total etch groups (II and III) and self-etching primer groups (IV and V). There was no difference in resin tag penetration between the two self-etching primer groups. A moderate positive correlation was elicited between resin tag lengths and the amount of colour change when the experimental groups were pooled together.

The significant colour change in the experimental groups, both statistically and clinically, underscores the clinical significance of the effects induced by bonding, debonding and finishing procedures. Using the same methodology, Kim *et al.*[7] reported significant colour changes in human premolar teeth between baseline and after debonding and polishing. Infiltration of enamel by resin tags was suggested to change the refractive index of the enamel modifying the diffusely reflected light component and hence influencing colour parameters.[3] Moreover, the change in enamel surface caused by finishing procedures may alter the specular light

Table 2 Comparison of resin tag lengths among study groups.

	Resin tag length			
	Group II	Group III	Group IV	Group V
Mean (SD)†	6.86 (0.65)[a]	14.79 (0.70)[b]	4.12 (0.56)[c]	3.78 (0.64)[c]
P value	<0.0001*			

*Based on ANOVA.
†*Post hoc* based on Tukey.
[a]Significant difference from Groups III, IV and V, $P<0.0001$.
[b]Significant difference from Groups II, IV and V, $P<0.0001$.

Table 1 Comparison of ΔE (colour change) among study groups.

	ΔE				
	Group I	Group II	Group III	Group IV	Group V
Mean (SD)†	1.60 (0.29)[a]	6.26 (1.40)[b]	6.68 (1.30)[b]	5.67 (1.45)[b]	5.21(1.35)[b]
P value	<0.0001*				

*Based on ANOVA
[a]Significant difference with Groups II, III, IV and V, $P<0.001$.
[b]Significant difference with Group I, $P<0.001$.
†*Post hoc* based on Tukey.

Table 3 Correlation between ΔE (colour change) and resin tag lengths.

	Correlation between ΔE and resin tag length				
	Group II	Group III	Group IV	Group V	All groups
Pearson coefficient	0.50	0.46	0.02	−0.12	0.38
P value	0.14	0.18	0.96	0.75	0.02*

*Statistically significant at $P \leqslant 0.05$.

component (L^* value) of the colour parameters, which is highly sensitive to the cleaning and finishing procedures.[19] In addition, any enamel loss during finishing procedures would affect the degree of light reflected form the tested surface.[6]

Eliades *et al.*[3] found no significant difference in colour change between a group of teeth bonded using the acid etch technique and composite, and another bonded with glass ionomer cement with no prior etching. This was attributed to the effect of the surface roughness and the altered morphological picture induced by debonding and finishing, which might outweigh the effect caused by the presence of remaining resin tags. This study showed similar results despite the fact that a low speed rotary instrument was used in order to avoid any enamel marring during finishing.

Similar studies found an increase in resin tag length with an increased duration of application of phosphoric acid.[20,21] Shorter resin tags were reported with the use of self-etching primers in comparison to phosphoric acid.[8] This may be attributed to the difference in the concentrations of phosphoric acid etchant and phosphoric acid esters in self-etching primers.[12]

The absence of any significant correlation between colour change and resin tags lengths within any of the groups tested may be related to the small number of teeth included in each group. The moderate correlation found upon pooling the groups may be attributed to the hypothesis that adhesive removal and finishing procedures are more invasive relative to the resin tags penetration with regard to enamel colour alterations.[3]

This study attempted to correlate the change in enamel colour to the depth of resin tag penetration. Several bonding methods were used to induce variable resin tag lengths. Low-speed burs were used to remove remaining resin to avoid any alterations to the enamel surface and hence colour change related to these procedures. All procedures of spectrophotometry were carefully controlled and standardized. However, the sole effect of resin tag length on enamel colour change cannot be delineated since the colour of the enamel is affected by many factors inherent to all stages of appliance bonding and removal. An interesting finding was that the colour change in all the experimental groups never exceeded twice the critical value of 3.7 units. This reflects a consistency in procedure much sought after by many clinicians.

An iatrogenic colour change of enamel seems inevitable. Several materials are available commercially for bonding orthodontic brackets. Some of these materials may have less effect on the change of enamel colours than others. This may be attributed to less adhesive remnants, easier clean-up or less enamel penetration. From this study, we can conclude:

- there is some evidence, albeit moderate, that the shorter the resin tag penetration the less change in enamel colour following clean-up and polishing;
- self-etch primers produce less resin penetration. All other factors being equal, these systems may produce less iatrogenic colour change in enamel following orthodontic treatment.

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