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Comparison of enamel colour changes associated with orthodontic bonding using two different adhesives

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SUMMARY The purpose of this study was to evaluate the enamel colour changes associated with bonding of brackets with a no-mix (one-phase) adhesive resin (Unite) and a glass-ionomer adhesive (GC Fuji Ortho). Thirty recently extracted premolars were used in the investigation. Black rectangular pieces of adhesive tape with a 3-mm diameter window were used to standardize the enamel surface intended for analysis. The teeth were divided into two groups of 15 teeth each, brackets (Starfire TMB) were bonded with the two adhesives, and the enamel surfaces were colourimetrically evaluated at three time intervals: (a) before bonding (baseline), (b) following debonding and cleaning, and (c) after artificial photo-ageing for 24 hours. The CIE colour parameters (L*, a*, b*) were recorded and averaged for each material, interval group, and the corresponding colour differences (ΔE) were calculated. The results were statistically analysed using two-way ANOVA repeated measures, and Scheffé multiple range test at $\alpha = 0.05$ level of significance.

All differences noted exceeded the threshold for clinical detection ($\Delta E = 3.7$). The highest differences were recorded for the baseline–debonding interval for both adhesives used. No difference was found with respect to ΔE between etching-mediated and no etching-mediated bonding implying that the debonding cleaning process involving adhesive grinding may be more invasive relative to acid etching with regard to enamel colour alterations.

Introduction

One of the undesirable effects of bonding of orthodontic attachments to enamel with the acid etching technique, is the formation of white spots due to decalcification (Mizrahi, 1982). The prevalence (Øgaard *et al*., 1988a), methods of examination (Øgaard and Ten Bosch, 1994), and prevention and treatment (Øgaard *et al*., 1988b, 1997) of decalcification have been studied extensively. In general, orthodontic treatment-induced white spot lesion formation has been shown to take place even 5 years following orthodontic therapy (Øgaard, 1989).

Recently, resin-modified glass-ionomer adhesives have been used for orthodontic bonding based on their higher survival probability relative to conventional glass ionomers (Mitchell *et al*., 1995). These materials have shown promising results with respect to reducing the prevalence of demineralization *in vivo*, whilst presenting bond strength and failure rates comparable with those found for composite resin adhesives (Evans and Oliver, 1991; Fricker, 1998; Cacciafesta *et al*., 1998).

Despite the relatively extensive evidence available on decalcification, the incidence of enamel colour changes associated with orthodontic bonding has not been investigated. Enamel colour alterations may derive from the irreversible penetration of resin tags into the enamel structure at depths reaching 50 μm (Silverstone *et al*., 1975). Since resin impregnation in the enamel structure cannot be reversed by debonding and cleaning procedures (Sandisson, 1981), enamel

discolouration may occur by direct absorption of food colourants and products arising from the corrosion of the orthodontic appliance (Maijer and Smith, 1982).

The hypothesis tested in this investigation was that the procedures associated with bonding and debonding may alter the colour variables of the enamel surface. Therefore, the purpose of this study was to assess the enamel colour alterations associated with bonding of orthodontic brackets with an orthodontic resin and a glass-ionomer adhesive.

Materials and methods

Thirty premolars extracted for orthodontic reasons not more than 30 days from testing were used in the study. In black rectangular pieces of adhesive tape, a round opening of 3 mm in diameter was cut to match the size of the colourimeter window. The tape was applied to the middle third of the buccal surface of the tooth to facilitate a means to standardize the enamel surface intended for analysis. It was further secured on the premolar crown with cyanoacrylate glue, applied on the mesiodistal crown surfaces to avoid contamination of the prospective bonding buccal surface. The teeth were code-numbered for identification purposes, and the exposed enamel windows were colourimetrically evaluated by means of a colourimeter (Microcolour, Data Station, DrLange, Braiveinstruments, Leige, Belgium) according to the CIE Lab system (Commision Internationale de l' Eclairage, L*, a*, b*) employing a repeated measures design (n = 5). The CIE colour L* parameter corresponds to the value or degree of lightness in the Munsell system, whereas the a* and b* co-ordinates designate positions on red/green (+a* = red, –a* = green) and yellow/blue (+b* = yellow, –b* = blue) axes.

The teeth were then divided in two groups of 15. The first group was subjected to 37 per cent orthophosphoric acid etching gel (Etching agent, Reliance, Itasca, IL, USA) for 30 seconds, rinsed, and dried. Brackets (Starfire TMB, 'A' Company/Ormco, Glendora, CA, USA) were bonded to the first group with an orthodontic no-mix (one-phase) adhesive resin (Unite, 3M/Unitek, Monrovia, CA, USA), according to the manufacturer's instructions. Brackets were bonded to the second group of teeth with a chemically-cured, resin-modified glass-ionomer orthodontic cement of universal shade (GC Fuji Ortho, GC Corp., Tokyo, Japan) without prior enamel treatment as suggested by the manufacturer. All specimens were immersed in water for 48 hours and the brackets were then debonded using a debonding plier. Removal of adhesive remnants was performed with sequential use of 12- and 30-fluted tungsten carbide burrs (Fressima, FIT, Turin, Italy) operated at low speed, whereas the efficacy of the process was confirmed with light microscopic examination of randomly chosen specimens with the use of an incident light optical microscope (Microphot, Nikon, Kogaku, Tokyo, Japan). All bonding, debonding, and adhesive removal procedures were performed by an orthodontist, and all enamel colour recordings were made on wet enamel specimens. Following debonding and cleaning of resin, additional self-adhesive tape was applied over the original wherever it was deemed necessary to secure the integrity of the enamel window margins. However, in four cases the teeth were excluded from the study because alterations to the enamel window dimensions occurred during the experimental procedures. On the remaining 26 teeth (13 per adhesive group) enamel colourimetry was again performed as previously described.

All specimens were then subjected to artificial accelerated photo-ageing with the use of a light exposure apparatus (Suntest CPS plus, Atlas material testing technology, Geluhausen, Germany), involving exposure of the enamel surfaces to 24-hour continuous irradiation of 55,080 kJ/m^2 corresponding to an illuminance of approximately 135,000 Lux at 400 nm. This procedure induced ageing equivalent of exposure to sun irradiation in Central Europe for 30 days (Atlas Suntest Bulletin, 1998). For this purpose, the specimens were maintained in double distilled water at 38 ± 2°C and black temperature (BT) of 55°C, according to proposed guidelines for ageing of dental polymeric materials (DIN EN 27491, 1991). Following photo-ageing, a third colour determination was performed. Colour

parameters were averaged for each group and colour differences (ΔE) were calculated using the following equation (Bureau Central de la Commision Internationale de l'Eclairage, 1978):

$$\Delta E = [(\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2]^{1/2},$$

which becomes more accurate with increasing ΔE (Seghi *et al*., 1989).

The ΔE combinations corresponding to the two materials (resin and glass-ionomer adhesives) for the three protocols employed in the study (baseline, following debonding, and after photo-ageing), were statistically analysed using two-way ANOVA repeated measures with bonding material and condition serving as discriminating variables. Differences among groups were further investigated using the Scheffé multiple range test at $\alpha = 0.05$ level of significance.

Results

Table 1 presents the ANOVA for the two materials at the three intervals employed in the study. The results indicate that both material and condition have significant effects, while the interaction term was insignificant allowing the assignment of effects to individual parameters, i.e., interval and material (Sokal and Rohlf, 1995).

Table 2 shows the ΔE differences among groups with respect to material and condition used. The largest differences involved baseline debonding, whereas the smallest differences were observed for both resin and glass-ionomer adhesives for the debonding photo-ageing condition.

Table 1 ANOVA for the ΔE with respect to the materials (adhesive resin and glass-ionomer adhesive) and conditions (baseline, debonding, photo-ageing) employed in the study.

Source of variation	DF	Mean square	*F*	Probability > *F**
Model	3	464.9	29.6	0.00
Material (M)	1	108.9	6.9	0.01
Condition (C)	2	642.9	40.9	0.00
Interaction M × C	2	14.1	0.9	0.4
Error	72	15.6		

*The value in this column represents the probability that the observed results could have occurred by random chance.

Table 2 ΔE differences for the two orthodontic adhesives (resin, glass-ionomer) at the three conditions (baseline, debonding, photo-ageing) employed in the study ($n = 13$, $\alpha = 0.05$).

Material-condition group	ΔE (mean ± SD)	Scheffé grouping[1]
ΔE_{GI} baseline-debonding[2]	16.5 ± 3.9[3]	A
ΔE_{AR} baseline-debonding	13.7 ± 4.7	A
ΔE_{GI} debonding-ageing	6.4 ± 3.1	B
ΔE_{AR} debonding-ageing	5.6 ± 2.7	B

[1]Means with same letter are not significantly different at the $\alpha = 0.05$ level.
[2]AR and GI subscripts denote adhesive resin and glass-ionomer materials, respectively.
[3]The threshold for clinical detection of colour difference was 3.7.

Discussion

Generally, ΔE values less than 1 unit are considered as a colour match, since they cannot be identified by independent observers (Seghi *et al*., 1989). Although it has been proposed that differences exceeding 2 units may indicate colour change (Wozniak, 1987), most studies set the proposed acceptance limit for colour matching to 3.7 units, beyond which the differences are clinically visible (Johnston and Kao, 1989). In the present study the colour difference threshold was set at 3.7 units. It is interesting that all differences noted were found to exceed the threshold value for clinical detection implying the clinical significance of the effects induced

The larger differences observed for baseline debonding relative to the debonding photo-ageing for both materials may be explained by the invasive nature of the debonding and cleaning-related procedures. For the resin adhesive, the post-debonding and adhesive cleaning enamel surface was mainly composed of cut enamel infiltrated by resin tags, occupying the sites of enamel rods dissolved from acid-etching. As the

depth of resin-infiltrated enamel usually reaches 30–50 μm (Silverstone *et al*., 1975), the refractive index of the region may be altered, modifying the diffusely reflected light component, thus influencing the colour parameters.

For the glass-ionomer adhesive, where no enamel conditioning was performed, the main surface features following debonding and cleaning are those of polished enamel. This is because the mechanical retention facilitated by these materials is limited to the flow characteristics of the cement which allow for adequate enamel wetting and establishment of a reversible hydrolytic molecular bond mechanism between ionized glass-ionomer carboxyl groups and enamel calcium (Peters *et al*., 1974; Wilson *et al*., 1983).

The lack of statistically significant differences with respect to ΔE between the baseline and debonding mechanisms implies that the effect of the surface roughness induced by cleaning and polishing procedures may outweigh any differences in the composition of enamel surfaces subjected to debonding. This observation is of importance to orthodontists who may adversely affect the roughness of the bonding surface by grinding the enamel during adhesive removal. The enamel cleaning technique adopted in this study involved the use of low speed rotary instruments to limit the influence of the process on tissue integrity.

The specularly reflected light component, a surface roughness-dependent parameter, is highly sensitive to cleaning and polishing procedures influencing the L* values of the substrate (Chung, 1994). Even though the dependence of colour on surface texture and roughness has been clearly shown, it must be emphasized that the pattern of this relationship is currently unknown (Davis *et al*., 1995). Recently, a direct relationship has been found for opacity and L* in resin composite and resin modified glass-ionomers (Omomo *et al*., 1998). Opacity depends partly on surface roughness, since rough surfaces demonstrate a white appearance due to the increased contribution of surface-localized random specular reflections (Inokoshi *et al*., 1996). However, the correlation between opacity and roughness is as yet unknown.

Photo-ageing induced further changes in the ΔE values of the debonded surfaces above the colour difference threshold of 3.7 units adopted in the present study. Discolouration of the resin tags may account for the ΔE values recorded in the resin adhesive specimens. This colour instability has been attributed to the formation of oxidation by-products containing chromophore groups such as carbonyls arising from the addition reaction to the pendant carbon-carbon double bonds of the crosslinked network (Ruyter and Svedsen, 1978; Ruyter, 1980). Moreover, for chemically-activated systems, oxidation of auxochrom groups present in amine accelerators and inhibitors, such as tertiary amino or hydroxyl groups, may modify the colour at a rate determined by the type of substitution of the aromatic ring (Asmussen, 1983; Bowen and Argentar, 1967). Decomposition of the initiators has been found to be consistent with discolouration in b* values towards yellow (Leibrock *et al*., 1997).

The mechanism underlying the post-debonding photo-ageing of the enamel samples bonded with glass-ionomer adhesives is currently unknown. Possibly, the initial low pH of the glass-ionomer, which induces local dissolution of apatite and redeposition of calcium fluoride salts, may alter the colour characteristics of enamel.

In general, adverse effects on enamel induced by orthodontic bracket bonding and debonding have been identified as:

(1) enamel loss caused by etching (van Waes *et al*., 1997);
(2) enamel alterations during fixed orthodontic treatment due to the inhibition of remineralization leading to decalcification and, possibly, to caries development (Årtun and Thylstrup, 1986; Øgaard, 1989);
(3) enamel microcracks, scratches, and abrasions induced by the adhesive debonding and cleaning procedures (Zachrisson and Årtun, 1979).

The above parameters may affect the enamel colour to a varying extent. For example, acid etching and debonding-cleaning procedures have been shown to lead to loss of 10–50 μm of enamel (van Waes *et al*., 1997).

While the foregoing considerations indicate that the colour of the substrate may be affected by a multi-factorial set of parameters that can be identified in all stages of appliance bonding and removal, it seems that some alterations in enamel colour are inevitable. This may be due to the irreversible nature of microstructural modifications associated with enamel bonding and debonding procedures, as well as the low tolerance of colour variables to induced variations.

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