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In vitro colour stability of aesthetic brackets

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SUMMARY Contrary to their popularity in satisfying aesthetic demands, plastic brackets still present some problems because of their decreased hardness and wear resistance. A problem of plastic brackets is discolouration, due to ultraviolet (UV) light and food dyes.

The aim of this study was to investigate the colour stability of aesthetic brackets during UV irradiation and exposure to food dyes. Four different polymer brackets were exposed in a Suntest CPS+ ageing device to a xenon lamp to simulate natural day light. Because most tooth-coloured bracket systems are used in adult treatment, red wine, coffee, and tea were chosen as food colourants. After 24 and 72 hours of exposure, colour measurements were performed by means of a spectrophotometer according to the CIE $L^*a^*b^*$ system and colour changes (ΔE^*) were computed. Statistical differences were investigated using three-way analysis of variance (ANOVA).

With the exception of the Aesthetic-Line bracket, almost all investigated polymer brackets showed clinically unacceptable discolouration during *in vitro* exposure to colourants. Most of the brackets became yellower after UV light treatment. In spite of the short exposure period of 72 hours, almost all polymer brackets showed undesirable discolouration.

These current *in vitro* findings indicate that even newly developed plastic brackets, consisting of composite materials or modern polymers (polyoxymethylene) may have clinically unacceptable colour stability in the long-term.

Introduction

Although plastic and ceramic brackets improve the appearance of fixed appliances, they are still far from ideal in fulfilling the requirements of orthodontic brackets. The advantages of ceramic brackets are colour stability and strength. Nevertheless, the use of ceramic brackets may result in problems with excessive bond strength, damage to the enamel during removal, and bracket breakage because of brittleness (Arici and Regan, 1997).

Initially plastic brackets were manufactured from unfilled polycarbonate. Nowadays, alternative polymers such as polyoxymethylene and composite are used. Composite brackets are reinforced with special fillers, or consist of a fibreglass reinforcement. In addition, plastic brackets with a metal slot are available. Safe debonding is uncomplicated because of the low modulus of polymer appliances and a peel-off effect similar to that found for metal brackets (Zinelis *et al.*, 2005). Contrary to their popularity in satisfying aesthetic demands, plastic brackets still present some problems because of their decreased hardness, wear resistance, and an inability to withstand the torquing forces generated by rectangular wires (Arici and Regan, 1997). The main problem of plastic brackets is discolouration, because of ultraviolet (UV) light and food dyes.

There are internal and external causes for the discolouration of aesthetic brackets. External discolouration can be caused by food dyes and coloured mouth rinses (Khokar *et al.*, 1991; Seher and Viohl, 1992; Dietschi *et al.*, 1994; Leibrock *et al.*, 1997). The material, e.g. the polymeric structure or filler content, and surface roughness play a decisive role in the extent of discolouration caused by diverse substances (Dietschi *et al.*, 1994; Leibrock *et al.*, 1997). The amount of colour change can be influenced by a number of factors including oral hygiene, water sorption, and incomplete polymerization (Arthur *et al.*, 2004). The reason for internal discolouration can be found in UV irradiation and thermal energy. UV light is able to induce physico-chemical reactions in the polymer, which cause irreversible colour changes of the brackets.

The purpose of the present *in vitro* study was to investigate the influence of food dyes and UV irradiation on plastic brackets. Four different plastic brackets, two composite, one polymer (polyoxymethylene), and one experimental composite bracket were exposed to UV irradiation and food dyes for 72 hours.

Materials and methods

A total of 160 right upper central incisor brackets were investigated. The groups (40 per bracket group) consisted of the composite bracket, Aesthetic-Line (Forestadent, Pforzheim, Germany), the plastic bracket Brillant (Forestadent), the composite bracket Envision (Ortho Organizers, San Marcos, California, USA), and one experimental bracket, 'Exper'. The Exper bracket was a composite bracket, consisting of urethane dimethacrylate as a monomer matrix and a functional silane-treated SiO_2 filler. The filler content was 40 vol%.

The Exper brackets were first produced by hand mixing the monomer and filler in appropriate portions. To obtain a homogenous mixture, the composite matrix was additionally mixed in a mixing device (Speed Mixer DAC 150FVZ, Hauschild Engineering, Hamm, Germany) for 60 seconds (1800 rpm). After preparation, the composite was stored in opaque receptacles to prevent premature polymerization. To avoid the formation of bubbles, the composite was placed carefully in a mould made of a silicone impression of a Brillant bracket and polymerization was carried out using the polymerization device Targis-Power-Lichtofen (Ivoclar-Vivadent AG, Schaan, Liechtenstein) for 25 minutes. After polymerization, the Exper brackets were taken out of the silicone mould and the surplus was removed with a scalpel.

As food dyes, red wine (Chateau Romefort 2001, Bordeaux, France), coffee (Krönung, Jacobs, Bremen, Germany), and tea (Darjeeling, Lord Nelson, Lidl, Neckersulm, Germany) were chosen and placed in three small receptacles. In each receptacle, eight samples per bracket group were stored for 72 hours. After 24 and 72 hours, colour measurements were performed. Eight brackets per group, which served as the controls, were stored in distilled water under light exclusion for the same period.

To investigate the influence of UV irradiation on the brackets, eight samples of each group were subjected to artificial ageing following DIN EN 27491 (1991) (International Organization for Standardization, 1985) in a Suntest CPS+ ageing device (Figure 1, Heraeus Instruments, Hanau, Germany). The brackets were exposed to a filtered xenon lamp with an irradiation value of 765 W/m² for 24 and 72 hours. This technique is able to simulate a light strength of approximately 160 kLux and corresponds to intensive natural sunlight in equivalent exposure time. To simulate the moist environment of saliva, each 20-minute cycle consisted of a 3-minute rinse with deionised water at 37°C followed by a 17-minute dry phase. After 24 and 72 hours, the colour values of the brackets were measured and compared with the control group.

The colour measurements were carried out using the Minolta spectrophotometer CM-C3500 (Minolta Co. Ltd, Tokyo, Japan) with a pinhole diaphragm diameter of 3 mm according to the CIE $L^*a^*b^*$ system (Commission Internationale de l'Eclairage, 1976). A colour graph consisting of L^*, a^*, and b^* co-ordinates can be produced by means of mathematical transformations. The L^* parameter corresponds to the degree of lightness and darkness and the a^* and b^* values to the chroma, where $+a^*$ is red, $-a^*$ is green, $+b^*$ is yellow, and $-b^*$ is blue (Eldiwany *et al.*, 1995). Ruyter *et al.* (1987) reported that a colour change (ΔE^*) of 3.3 is visually perceptible. Therefore, in this investigation, colour changes of $\Delta E^* \geq 3.3$ were considered to be clinically unacceptable. The calculation ΔE^* between two colour positions in the three-dimensional $L^*a^*b^*$ colour space (Figure 2) is as follows:

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

Statistics

Statistical differences were investigated using three-way ANOVA. The level of significance was set at $\alpha = 0.05$. The median, 25th and 75th percentiles were calculated.

Results

All the examined brackets showed a significant discolouration after 24 hours of storage in red wine (Figure 3a, Table 1). Significant colour changes during exposure to red wine ($\Delta E^* > 5$) were observed for Envision and Brillant brackets. After 72 hours storage, all brackets showed a significant enhancement of discolouration compared with 24 hours ($P = 0.012$).

Comparing different colouring agents and UV light treatment, red wine caused the greatest colour changes followed by coffee. Tea and UV light resulted in less colour change (Table 1). The Envision bracket showed significantly greater discolouration in comparison with the other bracket groups ($P = 0.012$, Table 2).

Figure 1 Overall view of the Suntest CPS+ ageing device.

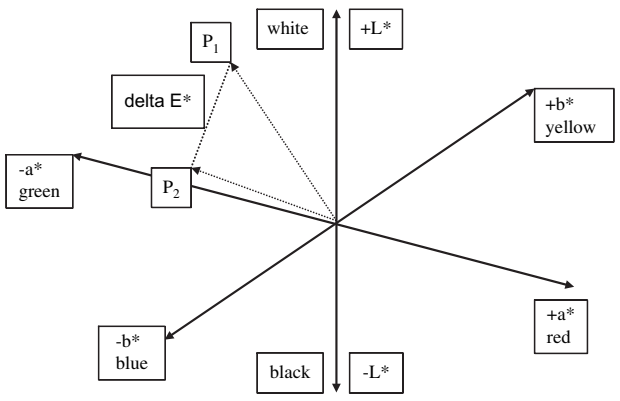

Figure 2 Colour difference ΔE^* in a three-dimensional colour space. The L^* parameter corresponds to the degree of lightness and darkness. The a^* and b^* values correspond to the chroma, where $+a^*$ is red, $-a^*$ is green, $+b^*$ is yellow, and $-b^*$ is blue. Three-dimensional colour point before (P1) and after ageing (P2)

With the exception of the Aesthetic-Line bracket, unacceptable colour changes of $\Delta E^* > 3.3$ were determined for all brackets after storage in coffee (Figure 3b). A significant increase ($P = 0.012$) in discolouration after 72 hours compared with 24 hours of exposure time was observed for the Brillant and Aesthetic-Line brackets (Table 1).

The Exper bracket showed small changes in colour ($\Delta E^* < 2.2$) after storage in tea for 24 and 72 hours (Figure 3c, Table 1). In contrast, median values of 6 ΔE^* units (24 hours) and 7 ΔE^* units (72 hours) were measured for the Envision bracket after exposure to tea (Table 3).

After 24 hours of exposure to UV light, only the Envision bracket demonstrated undesirable colour changes ($\Delta E^* > 3.3$) compared with the control group (Figure 3d). Clinically acceptable colour stability was observed for the Brillant, Aesthetic-Line, and Exper brackets after UV light exposure (Table 3). All brackets showed a significant increase of ΔE^* values by enhancing the UV light exposure time from 24 to 72 hours (Table 1).

After 72 hours of storage, red wine caused the greatest colour changes of all investigated brackets in comparison with the other food dyes (Figure 4, Table 3).

Discussion

Colour changes can be distinguished by a colourimeter or visually. However, the sensitivity of the human eye in

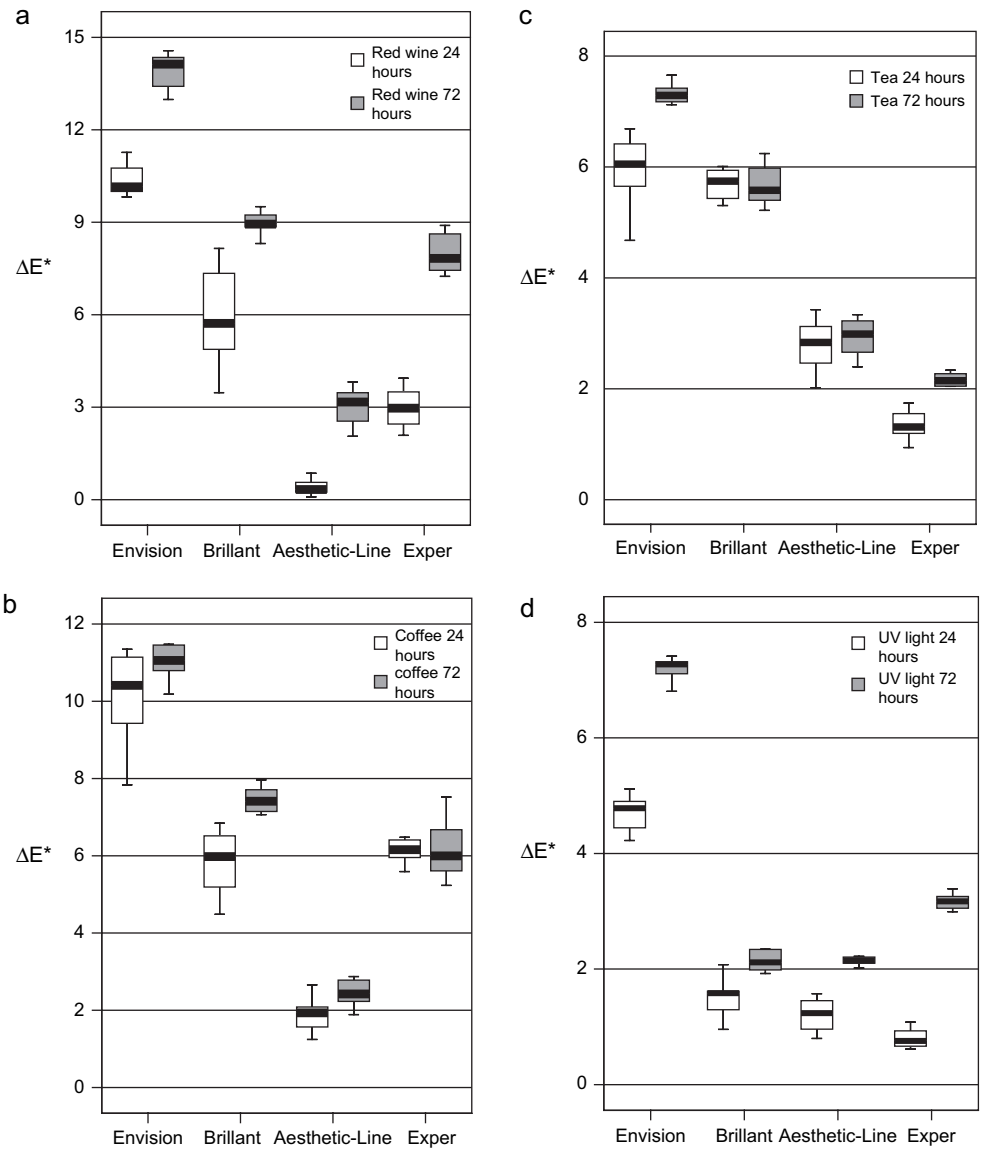

Figure 3 Discolouration ΔE^*after 24 and 72 hours of exposure to (a) red wine, (b) coffee, (c) tea, and (d) ultraviolet (UV) light. Boxplots show the median, 25th and 75th percentiles; error bar indicates minima and maxima.

Table 1 Statistical analysis of discolouration (ΔE^*) after 24 hours compared with 72 hours following exposure to food dyes or ultraviolet (UV) light. Three-way analysis of variance test, *P*-values.

	Envision	Brillant	Aesthetic-Line	Exper
Red wine (24–72 h)	0.012	0.012	0.012	0.012
Coffee (24–72 h)	n.s.	0.012	0.012	n.s.
Tea (24–72 h)	0.012	n.s.	n.s.	0.012
UV light (24–72 h)	0.012	0.017	0.012	0.012
Red wine–coffee	0.012	0.012	n.s.	0.017
Red wine–tea	0.012	0.012	n.s.	0.012
Red wine–UV light	0.012	0.012	0.025	0.012
Coffee–tea	0.012	0.012	0.012	0.012
Coffee–UV light	0.012	0.012	n.s.	0.012
Tea–UV light	n.s.	0.012	0.012	0.012

n.s., not significant.

Table 2 Statistical analysis of discolouration (ΔE^*) of the bracket groups after 72 hours of exposure to food dyes or ultraviolet light. Three-way analysis of variance test, *P*-values.

	Red wine	Coffee	Tea	Ultraviolet light
Envision–Brillant	0.012	0.012	0.012	0.012
Envision–Aesthetic-Line	0.012	0.012	0.012	0.012
Envision–Exper	0.012	0.012	0.012	0.012
Brillant–Aesthetic-Line	0.012	0.017	0.012	n.s.
Brillant–Exper	0.012	0.012	n.s.	0.017
Aesthetic-Line–Exper	0.012	0.012	n.s.	0.012

n.s., not significant.

Table 3 Median values and standard deviations of discolouration (ΔE^*) after 24 and 72 hours of exposure to food dyes or ultraviolet (UV) light.

	Envision	Brillant	Aesthetic-Line	Exper
Red wine 24 h	10.15 ± 0.55	5.72 ± 1.51	0.33 ± 0.12	2.97 ± 0.59
Red wine 72 h	14.13 ± 0.68	8.94 ± 0.40	3.17 ± 0.65	7.83 ± 0.59
Coffee 24 h	10.41 ± 1.28	5.98 ± 0.83	1.93 ± 0.43	6.16 ± 0.31
Coffee 72 h	11.06 ± 0.52	7.41 ± 0.34	2.42 ± 0.32	6.00 ± 0.70
Tea 24 h	6.05 ± 0.65	5.74 ± 1.30	2.84 ± 0.46	1.31 ± 0.27
Tea 72 h	7.29 ± 0.46	5.58 ± 0.61	2.99 ± 0.39	2.15 ± 0.35
UV light 24 h	4.78 ± 0.52	1.58 ± 0.33	1.24 ± 0.28	0.76 ± 0.18
UV light 72 h	7.27 ± 0.23	2.12 ± 0.44	2.15 ± 0.16	3.17 ± 0.30

observing small colour differences is limited and the interpretation of visual colour comparisons is subjective. Therefore, colourimetric measurements are necessary to allow reproducible results of colour determination (Buyukyilmaz and Ruyter, 1994; Rinke *et al.*, 1996).

Numerous tests have been used for artificial ageing of dental materials to investigate colour stability *in vivo* and *in vitro* (Rosentritt *et al.*, 1998; Stober *et al.*, 2001; Arthur *et al.*, 2004). As clinical testing is difficult to carry out and

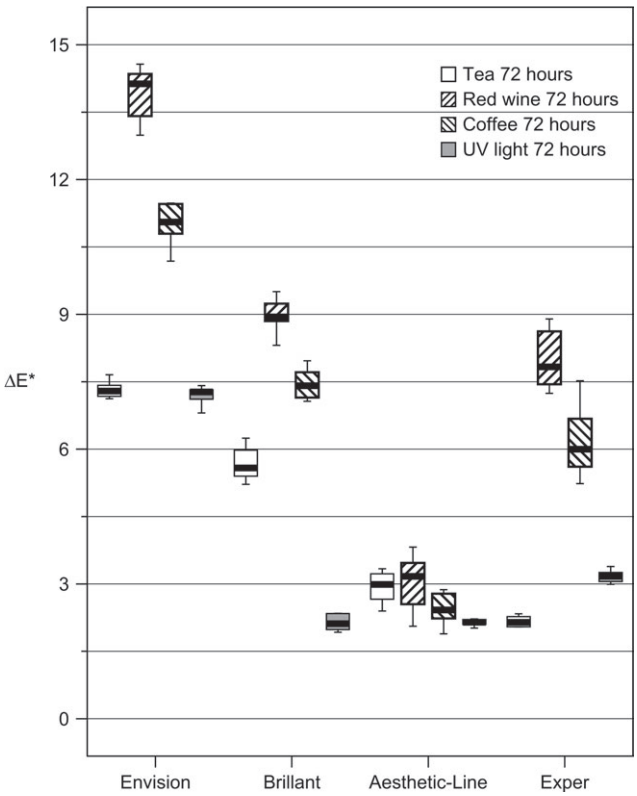

Figure 4 Discolouration ΔE^* after 72 hours of exposure to food dyes or ultraviolet (UV) light. Boxplots show the median, 25th and 75th percentiles; error bar indicates minima and maxima.

results may not be comparable due to a combination of miscellaneous factors, an *in vitro* investigation was undertaken. In this study, the exposure time to red wine, coffee, tea, and UV light was set to 72 hours, as Stober *et al.* (2001) reported that a period of 24-hour artificial treatment is too short to investigate discolouration of dental composites.

Rosentritt *et al.* (1999) examined the *in vitro* colour stability of veneer composites after exposure to UV light for 72 hours and storage in red wine or coffee for 10 days. They described discernible but acceptable colour changes ($\Delta E^* < 3.3$) after UV irradiation (72 hours). They reported no synergetic effects on colour behaviour after UV ageing and storage in food dyes.

Compared with the results of other similar *in vitro* studies of colour stability of dental composites (Um and Ruyter, 1991; Seher and Viohl, 1992; Fruits *et al.*, 1997), colour stability of the polymer brackets investigated in this research was unsatisfactory. With the exception of the Aesthetic-Line bracket, almost all polymer brackets showed clinically unacceptable discolouration during *in vitro* exposure to colourants, and seemed to become yellower after UV light treatment. The cause of this yellow discolouration was investigated by Ferracane *et al.* (1985) who found that yellowing of the polymer was accompanied by a reduction in the quantity of residual unreacted double bonds in the

resins. They stated that a possible explanation for the yellowing could be an oxidation of the unreacted C=C to produce coloured peroxide compounds. Thus, the polymeric structure and filler content, as well as the polymerization conversion, seem to be the most important factors, which influence the colour stability of dental polymers.

In the present study, red wine caused the greatest colour changes in comparison with other food dyes after 72 hours of exposure. Only the Aesthetic-Line bracket showed, after 72 hours of UV irradiation and food dye exposure, a clinically acceptable ΔE^*. Undesirable discolouration after 72 hours of storage in red wine, coffee, and tea was observed for the Envision and Brillant brackets, consisting of polyoxymethylene. Satisfactory colour stability was measured for those brackets only after UV irradiation. This polymer bracket seems to be more susceptible to external discolouration, caused by food dyes, than to UV light leading to internal discolouration. The Envision bracket is manufactured from a special thermoplastic polyurethane, which is post-cured by heat treatment. Despite this, the bracket showed colour changes after 72 hours of artificial ageing.

Arthur *et al.* (2004) suggested that changes in the optical properties within the polymer could be responsible for colour changes seen clinically. They stated that chemical discolouration was due to the oxidation of unreacted double bonds in the matrix of the polymer and the subsequent formation of degradation products from water diffusion or the oxidation of the polymer.

Many variables can affect composite colour stability (Eldiwany *et al.*, 1995). On the one hand, chemical differences among the resin components, such as polymeric structure, residual monomers, and the concentration of amines and diketones may influence colour stability. On the other hand, differences in both filler content and composition may explain the fact that composites with a higher content of inorganic filler showed better colour stability than polymers with a low filler content (Eldiwany *et al.*, 1995; Ruyter, 1995).

Conclusions

According to Ruyter *et al.* (1987), a ΔE^* of 3.3 is visually perceptible and therefore clinically unacceptable. In this *in vitro* investigation, an exposure time of 72 hours was chosen. In spite of this short exposure period, almost all investigated polymer brackets showed undesirable discolouration. Nevertheless, it should be remembered that this was an *in vitro* study, and care should be taken in interpreting the results to those that might occur in the oral cavity.

These present *in vitro* findings indicate that even newly developed plastic brackets, consisting of composite materials or modern polymers, may have clinically unacceptable colour stability in the long term.

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