European Journal of Orthodontics 31 (2009) 556–562
doi:10.1093/ejo/cjp030
Advance Access Publication 27 May 2009

Measurement of discolouration of orthodontic elastomeric modules with a digital camera

Sung-Hee Kim and Yong-Keun Lee
Department of Dental Biomaterials Science and Dental Research Institute, School of Dentistry, Seoul National University, Korea

SUMMARY The objective of this study was to measure discolouration using a digital camera on various types of clear orthodontic elastic modules, immersion solutions, and time periods to determine whether the cause of discolouration of these modules was due to simple staining, chemical degradation, or both. Three types of clear orthodontic elastomeric modules were investigated [Plastic ligatures (AO); Power 'O's 012 (OC); dispense-A-tie (TP)]. The elastomeric modules were immersed in the stretched condition in distilled water (control group) and in 75 per cent ethanol for chemical degradation and 2 per cent methylene blue for simple staining. After 0, 1, 2, 3, 6, 9, 12, 15, 18, and 21 hours and 1, 2, 3, 4, and 5 days of immersion, digital images of the modules were taken and processed using commercial software. The differences in colour changes depending on the type of elastomeric modules, immersion solution, and immersion period were analysed using a three-way analysis of variance and Tukey's multiple comparison test. The colour changes in the ethanol and methylene blue solutions by immersion period were analysed with regression analysis.

There were significant differences in discolouration depending on the type of elastomeric modules, immersion solution, and immersion period ($P<0.05$). The range of colour changes (ΔE^*_{ab}) was 1.0–20.0 units for AO, 0.6–30.0 units for OC, and 1.1–18.8 units for TP, independent of immersion solution and time. Methylene blue resulted in the greatest colour change. Discolouration due to chemical degradation by the ethanol solution mainly occurred in the first few hours, reached a plateau with no further increase over time, and was greater than staining by methylene blue in that period. Discolouration due to staining by methylene blue, however, continued to increase over the whole immersion period. Therefore, discolouration of elastomeric modules was a result of chemical degradation as well as staining in the early stages but in the later stages was due only to simple staining.

Introduction

The demand for aesthetic orthodontic appliances has increased because contemporary orthodontics provides a service to a larger number of adults. Ceramic brackets have become popular as aesthetic appliances and have been available for clinical use for approximately 20 years in spite of several negative clinical properties (Karamouzos *et al.*, 1997). The use of clear elastomeric modules to ligate ceramic brackets has enhanced the aesthetic value of these appliances. However, the modules can discolour if patients consume certain foods or beverages, such as coffee and tea, between appointments (Lew, 1990). This can result in an aesthetic problem; while ceramic brackets are stain resistant, the modules are subject to discolouration by certain foods with a high staining potential.

A spectrophotometer is an instrument widely used for measuring surface colour because of its reliability and accuracy (Paravina and Powers, 2004). However, it is difficult to measure the colour of orthodontic elastomeric modules using a spectrophotometer because of limitations such as the need for a relatively large measurement area and geometric problems caused by the curvature of the elastomeric modules (Jarad *et al.*, 2005).

Recent advances in photography and computer science have resulted in the widespread use of digital cameras for colour imaging. Images produced with a digital camera can be analysed using imaging software enabling the collection of quantitative colour parameters from the whole or parts of such images. This is a more cost-effective and simpler process than the use of traditional colour measurement devices such as a spectrophotometer or a colorimeter (Cal *et al.*, 2004; Dozic *et al.*, 2004; Jarad *et al.*, 2005; Wee *et al.*, 2006; Luo *et al.*, 2007). In addition, a very high and statistically significant correlation was found to exist between the spectrophotometer and digital camera for all of the Commission Internationale de l'Eclairage (CIE, 2004) L^*, a^*, and b^* colour co-ordinates (Jarad *et al.*, 2005). Therefore, when combined with appropriate calibration protocols, digital cameras, especially commercial single-lens reflex (SLR) digital cameras, show potential to be used in colour measurement for clinical dentistry (Wee *et al.*, 2006). The use of computer processing of photographic images to monitor changes in tooth brightness after bleaching has been investigated by Bentley *et al.* (1999), who concluded that computer analysis of digitized photographic images with internal colour controls provides

an index of tooth brightness that is reproducible from image to image. Images of teeth using an image analysis system adapted for tooth whiteness measurements have been investigated by Lath *et al.* (2007). Those authors concluded that the adapted digital image analysis system could provide an alternative method for whiteness measurement.

There are several studies on the threshold levels for colour differences (ΔE^*_{ab}) that are visually perceptible or clinically acceptable (Ruyter *et al.*, 1987; Douglas and Brewer, 1998; Lagouvardos *et al.*, 2004). Units of 3.3 ΔE^*_{ab} were considered as a perceptible threshold based on resin composite materials (Ruyter *et al.*, 1987). As a clinical perceptible threshold, the ΔE^*_{ab} value of those ratings judged a perfect match by the United States Public Health Service criteria was found to be 3.7 ΔE^*_{ab} units based on resin composite veneer restorations and their comparison teeth (Johnston and Kao, 1989). To determine valid acceptability and perceptibility tolerances for shade mismatch in an actual clinical condition, the CIELab co-ordinates and colour differences between the fixed right central incisor denture tooth and the interchangeable left central incisor denture teeth using a spectroradiometer were obtained by Douglas *et al.* (2007). The colour difference perceived by 50 per cent of dentists was 2.6 ΔE^*_{ab} units and the value at which 50 per cent would remake the restoration due to a colour mismatch was 5.5 ΔE^*_{ab} units. Therefore in the present study, a colour difference of 2.6 ΔE^*_{ab} units was regarded as a perceptibility threshold and 5.5 ΔE^*_{ab} units as an acceptable threshold.

Since the introduction of synthetic elastomeric modules in the 1960s, a large number of studies have been performed. However, most were related to the friction resistance of elastomeric ligatures (Baccetti and Franchi, 2006; Hain *et al.*, 2006), force decay (Genova *et al.*, 1985; Nattrass *et al.*, 1998), and the caries-preventive effect of fluoride-releasing elastomers (Benson *et al.*, 2004a,b; Kalha, 2004). The issue of ageing of elastomeric modules and the resultant force decay pattern has received increased interest since polyurethanes are not inert materials (Eliades *et al.*, 2005).

Discolouration of resin-based materials may be caused by intrinsic or extrinsic factors. Lee *et al.* (2007) reported that the amount of discolouration by 2 per cent methylene blue after immersion of resin composites was dependent on the type of composite resin. Long-term survival of polymeric materials in the oral environment is of great concern. Studies on the behaviour of these materials in a wet *in vitro* environment have been mainly conducted in water and in oral/food-simulating liquids. A 75 volume per cent ethanol–water solution is recommended by the Food and Drug Administration Guidelines of the USA (1988). It is used to simulate beverages (including alcohol), vegetables, fruits, and syrups (Sideridou *et al.*, 2007).

Even though it is generally recognized that the discolouration of orthodontic elastomeric modules by certain foods can influence the aesthetic performance of tooth-coloured orthodontic appliances such as ceramic brackets, there are no quantitative studies on this subject. In addition, the degradation of orthodontic polyurethane elastomeric modules in the intraoral environment may be associated with discolouration. Discolouration of elastomeric modules may be reduced by determining the cause of discolouration and minimizing its potential consequences as much as possible. The objectives of this study were therefore to measure the discolouration of clear orthodontic elastomeric modules depending on the type of module, the immersion solution, and immersion period, and to determine whether the cause of discolouration of these modules was simple staining or chemical decomposition. The null hypothesis of the present study was that there would be no significant difference in colour changes of clear orthodontic elastomeric modules depending on the type of modules, immersion solution, and immersion period.

Materials and methods

Three types of clear orthodontic elastomeric modules were investigated [Plastic ligatures (AO); Power 'O's 012 (OC); dispense-A-tie (TP); Table 1].

Stainless steel nails were inserted in the file holes of endodontic file boxes (Hanil Dental Ind., Seoul, Korea) and the elastomeric modules were stretched and fixed between the nails to simulate the clinical environment (Lam *et al.*, 2002; Eliades *et al.*, 2005). The distance between the nails was 8.5 mm, which induced approximately 50 per cent elongation of the elastic module compared with its original length. The specimens were divided into three groups and immersed as stretched in distilled water, an ethanol–water solution (75 per cent ethanol v/v), and a 2 per cent methylene blue solution. After 0, 1, 2, 3, 6, 9, 12, 15, 18, and 21 hours and 1, 2, 3, 4, and 5 days of immersion, the specimens were cleaned in an ultrasonic cleaner (Branson 8510R-DTH, Branson Ultrasonics, Danbury, Connecticut, USA) for 15 minutes, rinsed, and dried with paper towel. Colour measurements were made before and after immersion for the specified periods. For each experimental combination (material/solution/period), five specimens were tested.

A commercial SLR camera, Nikon D50 (Nikon Corp., Tokyo, Japan) with Tamron SP AF 90mm f/2.8 Di 1:1 Macro lens (Tamron Corp., Saitama, Japan), was used. The digital

Table 1 Clear orthodontic elastomeric modules investigated in this study.

Code	Brand name	Manufacturer
AO	Plastic ligatures (clear/854-279)	American Orthodontics, Sheboygan, Wisconsin, USA
OC	Power 'O's 012 (clear/.012/640-0075)	Ormco, Glendora, California, USA
TP	Dispense-A-tie (Ligatures, clear/383-001)	TP Orthodontics Inc., La Porte, Indiana, USA

camera was set to manual mode, which allowed total control of the shutter speed and aperture size. The shutter speed was set at 1/5 seconds with an aperture of F32, and the film sensitivity was set at International Organization for Standardization 200 sensitivity mode with 1:1 lens magnification (Wee *et al.*, 2006). In order to calibrate the red, green, and blue (RGB) values of the images, the white balance was set to customized 'preset mode' following the manufacturer's instructions using a standard grey card (Fotowand, Sudwalde, Germany) which has 17.68 per cent reflectance. The camera was fixed with an adaptor on a copy stand to provide an optical set-up of 0 degrees observation to the object. Digital images were taken in a darkroom. As a light source, fluorescent tubes (FPX 36EX-950, Master PL-L 36/950/4P; Philips Electronics Korea Ltd., Seoul, Korea), reportedly having a correlated colour temperature of 5300 K and a colour rendering index of 91, were used. The fluorescent tubes were bidirectionally fixed at an angle of 45 degrees and at a distance of 45 cm from the platform where the elastomeric modules were placed. A standard grey card (Fotowand) was used because neutral light grey is considered to be the ideal background for shade matching (Paravina, 2002).

Digital image files were opened in commercial software (Adobe Photoshop, version 7.0; Adobe Systems Inc., San Jose, California, USA). Four areas (average 5 × 5 pixels) were randomly selected using the 'eyedropper' tool. The CIE L^*, a^*, and b^* values of each area were obtained using the 'Lab sliders' in the software. L^* is in the range of 0–100 and a^* and b^* in the range of −120 to 120. The L^*, a^*, and b^* values were calculated by averaging the four areas of each specimen. The three-dimensional CIELab colour order system provides a useful standardization technique for colour difference assessments. The system includes three colour co-ordinates. CIE L^* corresponds to the value (degree of lightness) in the Munsell system, and a^* and b^* co-ordinates designate the positions on the red/green and yellow/blue axes, respectively ($+a$ = red, $-a$ = green; $+b$ = yellow, $-b$ = blue). Colour difference (ΔE^*_{ab}) was calculated as: $\Delta E^*_{ab} = [(\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2]^{1/2}$ (CIE, 2004).

Statistical analysis

The differences in colour change, depending on the type of elastomeric modules, immersion solution, and immersion period, were analysed using a three-way analysis of variance. Tukey's multiple comparison was performed as a *post hoc* test using the Statistical Package for Social Science, Version 12 (SPSS Inc., Chicago, Illinois, USA, $P = 0.05$). Colour changes in the ethanol and methylene blue solutions by immersion period were analysed with regression analysis. Distilled water served as the control.

Results

Colour changes (ΔE^*_{ab}) after immersion in the solutions are presented in Table 2 while the colour changes which

Table 2 Mean and standard deviation (in parentheses) of colour changes (ΔE^*_{ab}) of plastic ligatures (AO), Power 'O's (OC), and dispense-A-tie (TP) after immersion in distilled water (DW), an ethanol–water solution (EtOH; 75 per cent ethanol v/v), and 2 per cent methylene blue (MB).

Immersion period (hours)	Immersion solution	AO	OC	TP
1	DW	1.6 (0.7)	1.7 (0.2)	1.2 (0.4)
	EtOH	6.0 (0.7)	9.5 (1.0)	6.6 (0.9)
	MB	1.3 (0.4)	4.8 (0.9)	3.2 (0.8)
	Total	2.9 (2.3)	5.3 (3.4)	3.7 (2.4)
2	DW	1.3 (0.4)	1.5 (0.6)	1.6 (0.5)
	EtOH	6.3 (1.3)	10.8 (0.9)	7.1 (0.6)
	MB	2.3 (1.2)	5.7 (1.0)	3.8 (0.4)
	Total	3.3 (2.4)	6.0 (4.0)	4.2 (2.4)
3	DW	1.8 (0.5)	1.3 (0.3)	1.2 (0.4)
	EtOH	6.7 (0.7)	11.8 (1.4)	7.9 (1.1)
	MB	1.9 (1.1)	6.6 (0.7)	4.7 (0.9)
	Total	3.5 (2.5)	6.5 (4.5)	4.6 (2.9)
6	DW	2.6 (0.7)	1.3 (0.6)	1.4 (0.7)
	EtOH	7.1 (1.2)	11.3 (1.3)	7.7 (1.0)
	MB	4.8 (1.4)	9.3 (0.6)	7.1 (0.7)
	Total	4.8 (2.2)	7.3 (4.6)	5.4 (3.0)
9	DW	1.5 (0.7)	1.0 (0.3)	1.1 (0.6)
	EtOH	6.9 (0.8)	10.9 (1.0)	7.6 (0.7)
	MB	6.2 (1.0)	11.6 (1.1)	8.4 (0.7)
	Total	4.9 (2.6)	7.8 (5.1)	5.7 (3.5)
12	DW	1.4 (0.4)	0.8 (0.2)	1.5 (0.4)
	EtOH	6.3 (1.0)	10.6 (1.1)	7.3 (0.9)
	MB	7.7 (0.7)	14.1 (1.1)	8.8 (0.9)
	Total	5.1 (2.9)	8.5 (5.9)	5.9 (3.3)
15	DW	1.1 (0.5)	0.6 (0.4)	1.8 (0.8)
	EtOH	7.2 (0.7)	10.9 (0.5)	6.3 (0.7)
	MB	10.2 (2.4)	15.7 (1.4)	6.7 (2.3)
	Total	6.2 (4.1)	9.1 (6.6)	4.9 (2.7)
18	DW	1.0 (0.2)	0.7 (0.3)	2.1 (0.7)
	EtOH	6.8 (0.7)	11.0 (1.0)	7.8 (0.4)
	MB	10.6 (0.6)	14.7 (2.1)	7.8 (2.1)
	Total	6.1 (4.1)	8.8 (6.3)	5.9 (3.0)
21	DW	1.1 (0.5)	1.0 (0.5)	1.9 (0.6)
	EtOH	7.1 (0.5)	11.0 (0.8)	7.2 (0.4)
	MB	10.6 (1.5)	16.1 (0.9)	9.7 (1.2)
	Total	6.2 (4.1)	9.4 (6.5)	6.3 (3.5)
24	DW	1.4 (0.3)	0.9 (0.4)	1.5 (0.3)
	EtOH	6.8 (1.3)	10.7 (0.8)	7.8 (0.9)
	MB	11.9 (1.5)	19.8 (1.0)	10.1 (2.1)
	Total	6.7 (4.6)	10.5 (8.0)	6.5 (4.0)
48	DW	1.2 (0.3)	1.0 (0.3)	1.5 (0.7)
	EtOH	7.4 (1.2)	11.1 (0.7)	7.5 (1.0)
	MB	14.9 (1.5)	23.2 (0.9)	10.2 (1.6)
	Total	7.8 (5.9)	11.8 (9.4)	6.4 (3.9)
72	DW	1.4 (0.3)	1.4 (0.7)	1.8 (1.0)
	EtOH	7.2 (0.9)	10.8 (0.8)	6.0 (1.0)
	MB	15.4 (0.6)	26.1 (0.4)	15.4 (2.0)
	Total	8.0 (6.0)	12.8 (10.6)	7.7 (6.0)
96	DW	1.2 (0.4)	1.0 (0.4)	1.1 (0.4)
	EtOH	6.9 (0.7)	11.4 (0.8)	6.4 (1.0)
	MB	18.1 (0.6)	28.9 (1.3)	14.9 (2.3)
	Total	8.7 (7.3)	13.8 (11.9)	7.5 (6.0)
120	DW	1.2 (0.5)	1.0 (0.4)	1.7 (0.8)
	EtOH	7.8 (0.7)	11.5 (1.1)	6.2 (0.7)
	MB	20.0 (2.0)	30.0 (1.2)	18.8 (2.6)
	Total	9.7 (8.2)	14.1 (12.4)	8.9 (7.6)
Total	DW	1.4 (0.6)	1.1 (0.5)	1.5 (0.6)
	EtOH	6.9 (1.0)	11.0 (1.0)	7.1 (1.0)
	MB	9.7 (6.0)	16.2 (8.2)	9.3 (4.6)
	Total	6.0 (4.9)	9.4 (7.9)	6.0 (4.3)

occurred over time for each elastomeric module are shown in Figure 1 and for each solution in Figure 2. The colour changes by type of elastomeric module were in the range of 0.6–30.0 for OC, 1.1–18.8 for TP, and 1.0–20.0 for AO. The colour changes by immersion solution were 0.6–2.6 in distilled water, 6.0–11.8 in ethanol, and 1.3–30.0 in methylene blue. The colour changes in methylene blue were significantly greater than those in distilled water or ethanol ($P<0.05$). The colour changes by immersion period were for 1 hour 1.2–9.5, 2 hours 1.3–10.8, 3 hours 1.2–11.8, 6 hours 1.3–11.3, 9 hours 1.0–11.6, 12 hours 0.8–14.1, 15 hours 0.6–15.7, 18 hours 0.7–14.7, 21 hours 1.1–16.1, 1 day 1.0–19.8, 2 days 1.0–23.2, 3 days 1.4–26.1, 4 days 1.0–28.9, and 5 days 1.0–30.0. There was an increase in colour change the longer the immersion period.

For the type of elastomeric module, independent of the immersion solution and immersion period, the following order of colour change was observed: AO (mean: 6.0 ΔE^*_{ab} units) = TP (mean: 6.0 ΔE^*_{ab} units) < OC (mean: 9.4 ΔE^*_{ab} units; Tukey's test, $P<0.05$). For the immersion solution, independent of the type of elastomeric module and immersion period, the following order of colour change was observed: distilled water (mean: 1.3 ΔE^*_{ab} units) < ethanol (mean: 8.3 ΔE^*_{ab} units) < methylene blue (mean: 11.7 ΔE^*_{ab} units; Tukey's test, $P<0.05$). The results for the immersion period, independent of the type of elastomeric modules and immersion solution, are presented in Table 3. The mean colour changes of the materials increased as the immersion time increased.

Regression analysis for the colour changes in ethanol and methylene blue was performed. Figure 3 shows the colour changes following immersion. Colour changes in methylene blue according to immersion period were statistically significant ($P<0.05$), but not significant for ethanol.

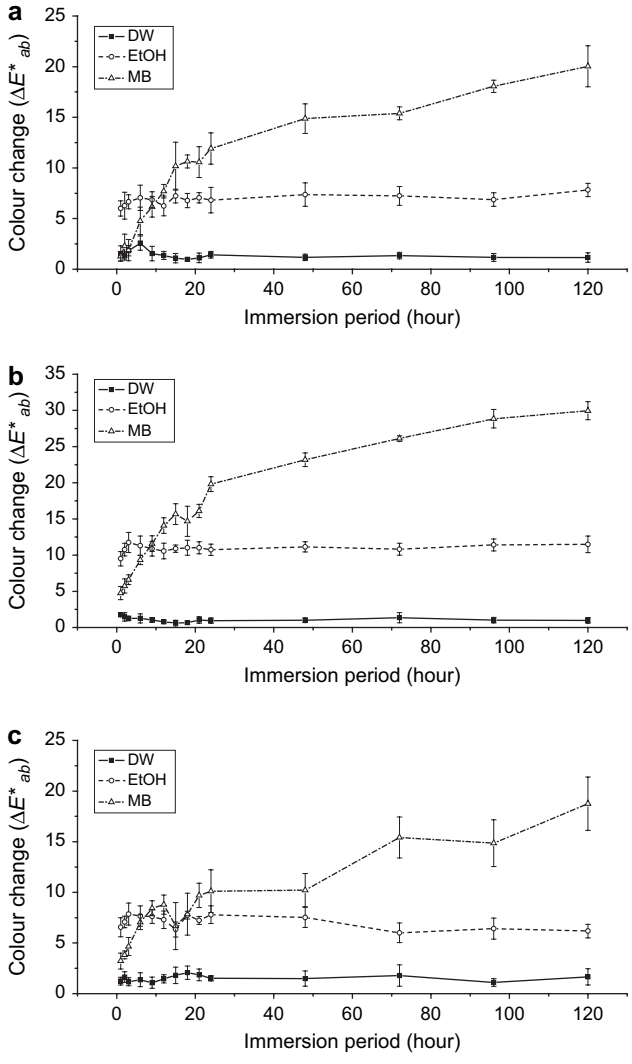

Figure 1 Colour changes of plastic ligatures (a) (AO), (b) Power 'O's (OC), and (c) dispense-A-tie (TP) after immersion in distilled water (DW), ethanol (EtOH), and methylene blue (MB).

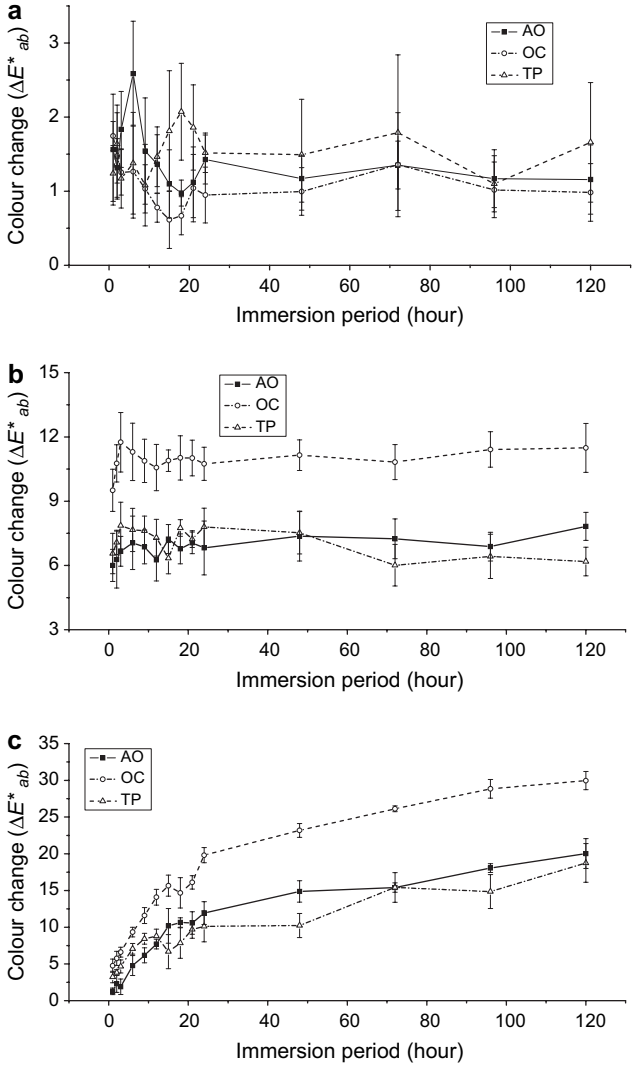

Figure 2 Colour changes of plastic ligatures (AO), Power 'O's (OC), and dispense-A-tie (TP) after immersion in distilled water (a), ethanol (b), and methylene blue (c).

Table 3 Tukey's honestly significant difference groups by immersion period.

Immersion period (hour)	Subset									
	1	2	3	4	5	6	7	8	9	10
1	4.0									
2	4.5	4.5								
3		4.9								
6			5.8							
9			6.1	6.1						
12			6.5	6.5	6.5					
15				6.7	6.7	6.7				
18					6.9	6.9				
21						7.3	7.3			
24							7.9			
48								8.7		
72									9.5	
96									10.0	
120										10.9
Significance	0.478	0.903	0.104	0.228	0.646	0.255	0.203	1.000	0.592	1.000

Means for groups in homogeneous subsets are displayed. Based on Type III sum of squares, the error term is mean square (error) = 0.995.

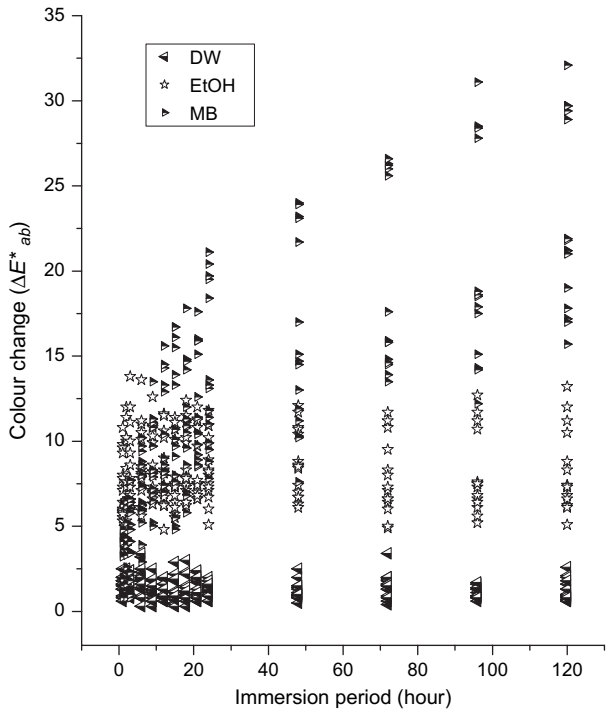

Figure 3 Scattergram of colour changes in the immersion solutions, distilled water (DW), ethanol (EtOH), and methylene blue (MB).

For all three modules, for 0–10 hours immersion, the colour changes in ethanol were greater than those in methylene blue; however, this trend was reversed after 10 hours. For AO and OC, although there were minor deviations, the colour changes in methylene blue increased rapidly within 20 hours of immersion and then increased slowly; however, in ethanol, the colour changes ceased after 5 hours immersion without any further increase. For TP, the colour changes in ethanol were similar to those of AO and OC; however, the colour changes steadily increased in methylene blue (Figure 1). The colour changes of OC in ethanol and methylene blue were greater than those for the other two modules (Figure 2).

Discussion

The null hypothesis of the present study was rejected because there were significant differences in the colour changes of elastomeric modules dependent on the type of module, immersion solution, and immersion period. The colour changes (ΔE^*_{ab}) of elastomeric modules were in the range of 0.6–30.0 ΔE^*_{ab} units for OC, 1.1–18.8 ΔE^*_{ab} units for TP, and 1.0–20.0 ΔE^*_{ab} units for AO, almost all of which were regarded as perceptible ($\Delta E^*_{ab} > 2.6$; Douglas *et al.*, 2007). In addition, except for distilled water, the colour changes in ethanol and methylene blue after 9 hours immersion were higher than the acceptable threshold value ($\Delta E^*_{ab} > 5.5$; Douglas *et al.*, 2007). Independent of immersion period and immersion solution, the greatest increase in mean colour change was for OC. The immersion solution also influenced colour change, with methylene blue resulting in the greatest colour change for all modules. The mean colour change was influenced by immersion period. Independent of the type of elastomeric module and immersion solution, the mean colour changes of the materials showed an increase over time. With regard to the reduction in discolouration after a longer immersion period such as 20 hours immersion in methylene blue, this may be due to the measurement error in the present study, which is shown by the high standard deviations (Figure 1).

The elastomeric ligatures and modules were made of polyurethane, which are thermosetting polymers, that have a '– (NH) – (C = O) –O–' structural unit and are formed by step reaction (condensation) polymerization. The manufacture of polyurethane elastomers involves several stages. These polymers have short rigid portions (the aromatic rings and the ureas) joined by short flexible 'hinges' (the diamine linker and the CH_2 group between the aromatic ring) and long very flexible portions (the polyether) whose length can be adjusted (Brantley and Eliades, 2001; Eliades *et al.*, 2005).

To investigate the structural characteristics of orthodontic polyurethane elastomeric modules and their changes produced by mechanical and chemical ageing (Eliades *et al.*, 2005), this study was performed under the following conditions: 50 per cent elongation for mechanical ageing and immersion in an ethanol–water solution (3:1 v/v) for chemical ageing. In another study, investigating the tensile strength and extension to tensile strength of elastomeric ligatures over a 12 week period, an *ex vivo* assembly made with an Ormco Mini-Diamond bracket was used in order to simulate a clinical situation (Lam *et al.*, 2002). It was concluded that the mean extension to tensile strength ranged from 8.3 to 10.0 mm for Unitek ligatures and from 6.9 to 10.4 mm for Ormco ligatures. When an elastomeric ligature is stretched, the surface property of the material will be changed, which can influence the reaction with the surrounding environment such as staining substances.

The present investigation was performed on stretched orthodontic elastomeric modules which simulated clinical conditions. Even though such stretching and water immersion also, to some degree, result in degradation of orthodontic elastomeric modules, ethanol–water solutions induced more accelerated ageing and degradation than stretching (Eliades *et al.*, 2005). Therefore, in the present study, distilled water was used as the control, ethanol to determine the colour change due to chemical degradation, and methylene blue to determine the colour change due to simple staining.

As mentioned previously, although spectrophotometric measurements are capable of reliably quantifying the colour of dental materials, it is difficult to measure the surface colours of elastomeric modules using a spectrophotometer (Jarad *et al.*, 2005). For this reason, only one study has been carried out on the discolouration of orthodontic elastomeric modules (Lew, 1990), in which discolouration was measured using a visual analogue scale. However, the protocol was limited and was subject to human evaluation, although the author reported that inter-examiner variance was less than 4 per cent (Lew, 1990).

Spectroradiometers have been used to investigate the colour of dental substances. ten Bosch and Coops (1995) used a spectroradiometer to measure the reflection spectrum of the teeth and CIELab colour co-ordinates were calculated from the spectra. However, colour co-ordinates measured with a small-window spectrophotometer deviate significantly from those measured using a spectroradiometer. This difference can be explained by the wavelength-dependent edge loss that arises in small-window colour measurement (Bolt *et al.*, 1994). In addition, correlation between the colours measured with a spectrophotometer and a spectroradiometer has not yet been established. Therefore, colour co-ordinates, perceptibility, and acceptability thresholds for colour differences measured with a spectroradiometer could not be compared directly with values based on spectrophotometers (Douglas *et al.*, 2007).

However, the digital camera has shown potential for use in the colour measurement process of clinical dentistry. A very high and statistically significant correlation was found to exist between a spectrophotometer and digital camera for all CIE L^*, a^*, and b^* colour co-ordinates (Jarad *et al.*, 2005). The highest significant agreement (spectrophotometirc values of 60 per cent) was found with a 5.0 megapixel camera (Jarad *et al.*, 2005). It has also been reported that the high resolution capacity of a digital camera appears to be able to increase the reliability of colour measurement (Elter *et al.*, 2005). Therefore, colour measurement in the present study could be considered relatively reliable because the resolution capacity of the Nikon D50 camera was 6.1 megapixels.

In several studies using digital cameras for colour measurement, the RGB values, rather than the CIE L^*, a^*, and b^* values, were obtained from digital images. The CIE L^*, a^*, and b^* values were then calculated on calibration models with the use of converting software (Dozic *et al.*, 2004; Jarad *et al.*, 2005; Wee *et al.*, 2006). To convert the RGB values obtained with the Adobe Photoshop (version 5.5) to the CIE L^*, a^*, and b^* values, a software (Colour Metric Converter) was used because in the older Adobe Photoshop (version 5.5), the CIE L^* values were given on a scale of 0–256 rather than 0–100 (Jarad *et al.*, 2005). However, in the present investigation, the CIE L^*, a^*, and b^* values from the Adobe Photoshop (version 7.0) were adopted directly because the software supports 0–100 CIE L^* scales. Therefore, colour difference (ΔE^*_{ab}) was calculated as: $\Delta E^*_{ab} = [(\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2]^{1/2}$ (CIE, 2004).

Conclusions

The present study showed that discolouration of clear orthodontic elastomeric modules resulted from both chemical degradation and simple mechanical staining. Discolouration due to chemical degradation by ethanol mainly occurred in the first few hours and then reached a plateau. But discolouration due to simple staining by methylene blue continued to increase over the whole immersion period. Therefore, it can be concluded that discolouration of clear orthodontic elastomeric modules is mainly due to chemical degradation in the early stage and to simple mechanical staining in the later stages. Further

studies are required to determine the mechanism of staining. Such investigations will require more complex and more informative methods to measure colour change.

Address for correspondence

Professor Yong-Keun Lee
Department of Dental Biomaterials Science
School of Dentistry
Seoul National University
28 Yeongeon-dong
Jongro-gu
Seoul 110-749
Korea
E-mail: ykleedm@snu.ac.kr

Funding

Korea Science and Engineering Foundation (KOSEF) Science Research Center grant funded by the Korean Ministry of Education, Science and Technology (MEST) through Bone Metabolism Research Center (No. 0617-20080007).

References

Baccetti T, Franchi L 2006 Friction produced by types of elastomeric ligatures in treatment mechanics with the preadjusted appliance. Angle Orthodontist 76: 211–216

Benson P E, Douglas C W, Martin M V 2004a Fluoridated elastomers: effect on the microbiology of plaque. American Journal of Orthodontics and Dentofacial Orthopedics 126: 325–330

Benson P E, Shah A A, Campbell I F 2004b Fluoridated elastomers: effect on disclosed plaque. Journal of Orthodontics 31: 41–46

Bentley C, Leonard R H, Nelson C F, Bentley S A 1999 Quantitation of vital bleaching by computer analysis of photographic images. Journal of the American Dental Association 130: 809–816

Bolt R A, Bosch J J, Coops J C 1994 Influence of window size in small-window colour measurement, particularly of teeth. Physics in Medicine and Biology 39: 1133–1142

Brantley W A, Eliades T 2001 Orthodontic materials—scientific and clinical aspects. Thieme, Stuttgart

Cal E, Sonugelen M, Guneri P, Kesercioglu A, Kose T 2004 Application of a digital technique in evaluating the reliability of shade guides. Journal of Oral Rehabilitation 31: 483–491

Commission Internationale de l'Eclairage (CIE) 2004 Colourimetry. Technical report, 3rd edn. Bureau Central de la CIE, Vienna. CIE publication no. 15

Douglas R D, Brewer J D 1998 Acceptability of shade differences in metal ceramic crowns. Journal of Prosthetic Dentistry 79: 254–260

Douglas R D, Steinhauer T J, Wee A G 2007 Intraoral determination of the tolerance of dentists for perceptibility and acceptability of shade mismatch. Journal of Prosthetic Dentistry 97: 200–208

Dozic A, Kleverlaan C J, Aartman I H, Feilzer A J 2004 Relation in colour of three regions of vital human incisors. Dental Materials 20: 832–838

Eliades T, Eliades G, Silikas N, Watts D C 2005 *In vitro* degradation of polyurethane orthodontic elastomeric modules. Journal of Oral Rehabilitation 32: 72–77

Elter A, Caniklioglu B, Deger S, Ozen J 2005 The reliability of digital cameras for colour selection. International Journal of Prosthodontics 18: 438–440

Genova D C, McInnes-Ledoux P, Weinberg R, Shaye R 1985 Force degradation of orthodontic elastomeric chains—a product comparison study. American Journal of Orthodontics 87: 377–384

Hain M, Dhopatkar A, Rock P 2006 A comparison of different ligation methods on friction. American Journal of Orthodontics and Dentofacial Orthopedics 130: 666–670

Jarad F D, Russell M D, Moss B W 2005 The use of digital imaging for colour matching and communication in restorative dentistry. British Dental Journal 199: 43–49

Johnston W M, Kao E C 1989 Assessment of appearance match by visual observation and clinical colourimetry. Journal of Dental Research 68: 819–822

Kalha A 2004 Fluoridated elastomers do not reduce plaque around orthodontic brackets. Evidence-Based Dentistry 5: 96

Karamouzos A, Athanasiou A E, Papadopoulos M A 1997 Clinical characteristics and properties of ceramic brackets: a comprehensive review. American Journal of Orthodontics and Dentofacial Orthopedics 112: 34–40

Lagouvardos P E, Diamanti H, Polyzois G 2004 Effect of individual shades on reliability and validity of observers in colour matching. European Journal of Prosthodontics and Restorative Dentistry 12: 51–56

Lam T V, Freer T J, Brockhurst P J, Podlich H M 2002 Strength decay of orthodontic elastomeric ligatures. Journal of Orthodontics 29: 37–43

Lath D L, Wildgoose D G, Guan Y H, Lilley T H, Smith R N, Brook A H 2007 A digital image analysis system for the assessment of tooth whiteness compared to visual shade matching. Journal of Clinical Dentistry 18: 17–20

Lee Y K, Lu H, Oguri M, Powers J M 2007 Changes in colour and staining of dental composite resins after wear simulation. Journal of Biomedical Materials Research Part B, Applied Biomaterials 82: 313–319

Lew K K 1990 Staining of clear elastomeric modules from certain foods. Journal of Clinical Orthodontics 24: 472–474

Luo W, Westland S, Brunton P, Ellwood R, Pretty I A, Mohan N 2007 Comparison of the ability of different colour indices to assess changes in tooth whiteness. Journal of Dentistry 35: 109–116

Nattrass C, Ireland A J, Sherriff M 1998 The effect of environmental factors on elastomeric chain and nickel titanium coil springs. European Journal of Orthodontics 20: 169–176

Paravina R D 2002 Evaluation of a newly developed visual shade-matching apparatus. International Journal of Prosthodontics 15: 528–534

Paravina R D, Powers J M 2004 Esthetic colour training in dentistry. Mosby, St Louis.

Ruyter I E, Nilner K, Moller B 1987 Colour stability of dental composite resin materials for crown and bridge veneers. Dental Materials 3: 246–251

Sideridou I D, Achilias D S, Karabela M M 2007 Sorption kinetics of ethanol/water solution by dimethacrylate-based dental resins and resin composites. Journal of Biomedical Materials Research Part B, Applied Biomaterials 81: 207–218

ten Bosch J J, Coops J C 1995 Tooth colour and reflectance as related to light scattering and enamel hardness. Journal of Dental Research 74: 374–380

Wee A G, Lindsey D T, Kuo S, Johnston W M 2006 Colour accuracy of commercial digital cameras for use in dentistry. Dental Materials 22: 553–559