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Colour and translucency of tooth-coloured orthodontic brackets

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SUMMARY The objective of this study was to determine the reflected and transmitted colours and the diffuse light transmittance of tooth-coloured brackets. Four ceramic and four plastic brands were evaluated and five brackets of each brand were tested. Reflected colour and spectral reflectance of the labial surface of the brackets were measured according to the Commission Internationale de l'Eclairage (CIE) colour scale and transmitted colour and diffuse spectral transmittance measured with a spectrophotometer. One-way analyses of variance were performed for the reflected and transmitted colour co-ordinates (CIE L^*, a^*, and b^*) and for light transmittance according to bracket brand.

The range for CIE L^* (lightness) was 36.2–50.3, for a^* (red–green parameter) –1.3–3.8 and for b^* (yellow–blue parameter) –2.9–11.2. All these colour co-ordinates were influenced by bracket brand ($P < 0.05$). Diffuse light transmittance was also influenced by bracket brand and ranged from 44.9 to 75.9 per cent ($P < 0.05$).

Colour and transmittance varied by bracket brand. Variations in optical properties influenced the aesthetic performance of the brackets and the degree of cure of the adhesive that is possible through the brackets. Further studies on the clinical implications of colour matching of tooth-coloured brackets with teeth should now be performed.

Introduction

Three types of orthodontic brackets are currently available: metal, ceramic, and plastic based. As the number of adults seeking orthodontic treatment increased (Khan and Horrocks, 1991), ceramic brackets were introduced to meet the increasing demand for more aesthetic appliances (Birnie, 1990). In the mid 1980s, the first ceramic brackets made of monocrystalline and polycrystalline ceramic materials became widely available (Winchester, 1991; Harris *et al.*, 1992); the most apparent difference between the two types of brackets being their optical clarity (Swartz, 1988; Liu *et al.*, 2005). Subsequently, the perceived need for more appealing appliances led manufacturers to develop various types of ceramic brackets (Theodorakopoulou *et al.*, 2004).

Plastic brackets have been used for more than 30 years (Kusy and Whitley, 2005). The early brackets were made of polycarbonate, which absorbed water and changed colour during orthodontic treatment (Reynolds, 1975). Newer types of reinforced plastic brackets were subsequently introduced (Bishara and Fehr, 1997) but, whether they are filled or unfilled, polymers are too weak to act as a satisfactory bracket material (Brantley and Eliades, 2001). The manufacture of composite brackets is different in that it is based on the controlled addition of fillers to a synthetic resin matrix, which is then subjected to injection moulding (Powers *et al.*, 1997).

The optical properties of tooth-coloured brackets have a number of clinical implications: firstly, colour matching with the underlying tooth, and, secondly, light transmittance through the bracket which influences the degree of cure of adhesive through the bracket. Although it is generally claimed that tooth-coloured brackets provide high aesthetics (Faltermeier *et al.*, 2006), there have been few studies on the colour matching of these brackets with the dentition. This lack of previous research may be related to the technical difficulties involved in the colour measurement of brackets, the geometry of which hinders accurate colour measurement with a spectrophotometer or a colourimeter.

When a light-cured orthodontic adhesive is used with a metal bracket, it is usually cured at the incisal and cervical edges (indirect irradiation). When the adhesive is irradiated directly through a translucent bracket, the degree of cure of the adhesive is influenced by the translucency of the bracket. The correlation between the diffuse light transmittance of ceramic brackets and the degree of cure of adhesives and direct light transmittance through ceramic brackets have been evaluated (Eliades *et al.*, 1995a,b).

Although various properties of tooth-coloured brackets have been investigated (Reynolds, 1975; Powers *et al.*, 1997; Faltermeier *et al.*, 2006), there are few studies determining optical properties such as colour and translucency. The current study aimed to evaluate the reflected and transmitted colours of tooth-coloured brackets and to determine their diffuse light transmittance. The null hypotheses were as follows: (1) there are no significant differences in the reflected and transmitted colour co-ordinates of tooth-coloured brackets according to bracket brand and (2) there is no significant difference in the light transmittance of these brackets.

Materials and methods

Materials

Four ceramic and four plastic commercial brands were investigated (Table 1). All brackets were 0.018 inch, Roth prescription for the maxillary central incisor. Five brackets of each brand were tested.

Methods

Reflected colour and spectral reflectance measurement

Reflected colour was calculated according to the Commission Internationale de l'Eclairage (CIE) LAB colour scale (2004) by measuring the ratio of the reflected light to the incident light (spectral reflectance) under specified geometric conditions. Reflected colour and spectral reflectance of the labial surface of the brackets were measured according to the CIELAB colour scale relative to the standard illuminant D65 using a reflection spectrophotometer (CM-3500d, Minolta, Osaka, Japan) equipped with an integrating sphere, with external light excluded using a zero calibration cylinder (CIE L^* = 0.09, a^* = 0.01, and b^* = 0.01, average reflectance = 0.01%, zero calibration box, CM-A124, Minolta; CIE, 2004). These conditions eliminated the influence of background variations (Lee *et al.*, 2005). The ultraviolet (UV) component of the illumination and the specular component of reflection were included [specular component included (SCI) mode]. The measuring aperture diameter size was 3 mm, and the illuminating and viewing configuration was CIE diffuse/10 degrees geometry. The measurements were repeated three times for each bracket.

According to the manufacturers of the spectrophotometer (Minolta), the photometric range is 0–175 per cent and the resolution 0.01 per cent. The repeatability in spectral reflectance is within 0.20 per cent standard deviation (SD) and that in chromaticity within ΔE^*_{ab} 0.05 SD when a white calibration plate is measured 30 times at 10 second intervals.

In the CIELAB colour space, L^* is a measure of the lightness of an object and is quantified on a scale such that perfect black has an L^* value of zero and a perfect reflecting diffuser an L^* value of 100. The CIE a^* value is a measure of redness or greenness, and b^* is a measure of yellowness or blueness. a^* and b^* co-ordinates approach zero for neutral colours. Chroma was calculated as $C^*_{ab} = (a^{*2} + b^{*2})^{1/2}$ (CIE, 2004).

Transmitted colour and spectral transmittance measurement

Generally, transmitted colour is calculated according to the CIELAB colour scale, by measuring the ratio of the transmitted light to incident light (spectral transmittance) under specified geometric conditions. Transmitted colour and diffuse spectral transmittance of the brackets were measured according to the CIELAB colour scale relative to the standard illuminant D65 using a spectrophotometer (Color-Eye 7000A, GretagMacbeth Instruments Corp., New Windsor, New York, USA), equipped with an integrating sphere. Illuminating and viewing configurations complied with CIE diffuse/8 degrees geometry (CIE, 2004). The UV component of illumination and the specular component of reflection were included (SCI mode).

Opaque cardboard specimen fixing plates, with central windows the same size as those of the brackets, were fabricated. Light transmittance of the specimen fixing plate was zero when there was no window, and for the window-opened plate, 3.62 ± 0.20 per cent compared with the full diameter (20 mm) opening. The measurements were repeated three times for each specimen.

According to the manufacturer of the spectrophotometer (GretagMacbeth), the photometric range of this spectrophotometer is 0–200 per cent and the resolution 0.001 per cent. The repeatability of a white tile is 0.01 ΔE^*_{ab}, the wavelength accuracy 0.1 nm, and wavelength precision 0.05nm, within a 400- to 700-nm range.

Table 1 Brackets investigated in this study.

	Code	Brand name	Composition	Manufacturer
Ceramic	CLY	Clarity	Polycrystalline alumina, stainless steel slot	3M Unitek, Monrovia, California, USA
	CRV	Crystalline V	Polycrystalline alumina, silica coated	Tomy, Tokyo, Japan
	INP	Inspire Ice	Monocrystalline alumina	Ormco, Orange, California, USA
	LUX	Luxi II	Polycrystalline alumina, gold reinforced	Rocky Mountain Orthodontics, Denver, Colorado, USA
Plastic	EST	Esther II	Composite	Tomy
	IMG	Image	Composite	Gestenco International, Gothenburg, Sweden
	SIL	Silkon Plus	Filler reinforced plastic	American Orthodontics, Sheboygan, Wisconsin, USA
	SPR	Spirit MB	Ceramic reinforced polycarbonate	Ormco

The size of all of the brackets was 0.018 inch, Roth for tooth 11.

Table 2 Reflected colour co-ordinates of the tested brackets.

	Code (Table 1)	CIE L^*	CIE a^*	CIE b^*	Chroma†
Ceramic	CLY (1)‡	48.7 (1.4)§	−0.1 (0.3)	1.3 (0.5)	1.4 (0.4)
	CRV (2)	42.0 (1.5)	−0.3 (0.2)	−2.9 (0.7)	3.0 (0.7)
	INP (3)	50.3 (1.7)	0.0 (0.1)	−0.1 (0.2)	0.1 (0.1)
	LUX (4)	48.9 (3.3)	3.8 (1.3)	11.2 (2.6)	11.9 (2.7)
Plastic	EST (5)	36.2 (1.5)	−0.5 (0.4)	−2.8 (1.4)	3.0 (1.1)
	IMG (6)	38.8 (0.6)	0.2 (0.4)	1.2 (0.3)	1.2 (0.3)
	SIL (7)	39.2 (1.1)	−0.5 (0.1)	0.2 (0.3)	0.6 (0.2)
	SPR (8)	47.6 (2.5)	−1.3 (0.3)	0.9 (0.4)	1.7 (0.2)
HG‖		5; 6,7; 2; 8,1,4; 1,4,3	8; 7,5,2,1,3; 2,1,3,6; 4	2,5; 3,7,8,6,1; 4	3,7,6,1; 7,6,1,8; 8,2,5; 4

†Chroma was calculated as $C^*_{ab} = (a^{*2} + b^{*2})^{1/2}$.
‡Numerical codes used in the *post hoc* test to indicate homogeneous subsets.
§Standard deviations in parentheses.
‖HG indicates homogeneous subsets based on Scheffe's multiple comparison test ($P < 0.05$).

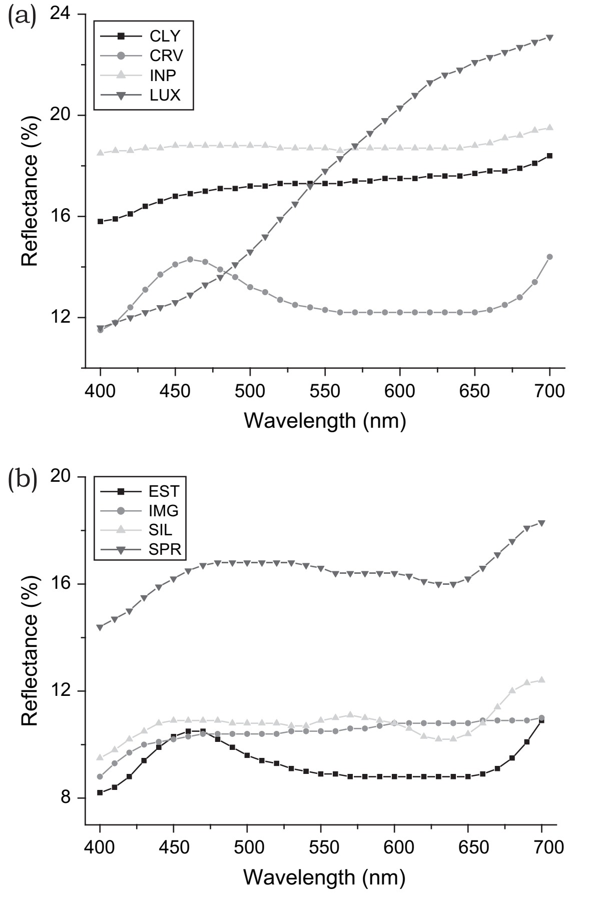

Figure 1 Spectral reflectance curves for the ceramic (a) and plastic (b) brackets.

Statistical analysis

To determine the difference in colour co-ordinates and light transmittance, one-way analysis of variance was performed according to bracket brand. The difference by bracket type (i.e. ceramic or plastic) was not considered because, based on the results of the present study, significant variations were found between bracket types. The means were compared with Scheffe's multiple comparison test ($\alpha = 0.05$).

Results

The reflected colour co-ordinates of the brackets are shown in Table 2. The range for CIE L^* was 36.2–50.3, for a^* −1.3 to 3.8, and for b^* −2.9 to 11.2. The distribution of chroma was similar to that of the CIE b^* value. All colour co-ordinates were influenced by bracket brand ($P < 0.05$). Among the eight brands of brackets, Inspire Ice was the lightest in reflected colour and Luxi II was the most chromatic and yellow tinted.

Spectral reflectance curves for the ceramic and plastic brackets are presented in Figure 1a,b, respectively. The Luxi II bracket showed an obvious increase in reflectance as the wavelength increased, which resulted in a high CIE b^* value. The Spirit MB bracket showed higher reflectance, which resulted in a high CIE L^* value, compared with the other plastic brackets.

The transmitted colour co-ordinates of the brackets are shown in Table 3. The range for CIE L^* was 12.6–18.8, for a^* −1.0 to 0.7, and for b^* 0.0–2.8. The distribution of chroma was similar to that of the CIE b^* value. All colour co-ordinates were influenced by bracket brand ($P < 0.05$). Among the eight brands, Esther II was the lightest in transmitted colour and Silkon Plus the most chromatic and yellow tinted.

Spectral transmittance curves for the ceramic and plastic brackets are shown in Figure 2a,b, respectively. The Inspire Ice bracket showed the highest transmittance and the Crystalline V an obvious change with wavelength. Among the plastic brackets, Esther II demonstrated the highest transmittance and Silkon Plus and Spirit MB showed lower transmittance. Transmittance varied by wavelength.

Table 3 Transmitted colour co-ordinates of the tested brackets.

	Code	CIE L^*	CIE a^*	CIE b^*	Chroma†
Ceramic	CLY (1)‡	15.8 (0.7)§	0.1 (0.2)	0.2 (0.3)	0.4 (0.2)
	CRV (2)	15.9 (0.9)	0.1 (0.2)	0.2 (0.3)	0.3 (0.2)
	INP (3)	17.9 (0.9)	0.1 (0.2)	0.0 (0.4)	0.4 (0.1)
	LUX (4)	12.6 (0.8)	0.7 (0.3)	1.4 (0.4)	1.6 (0.5)
Plastic	EST (5)	18.8 (0.4)	0.1 (0.1)	0.4 (0.3)	0.4 (0.3)
	IMG (6)	18.0 (1.2)	0.2 (0.2)	1.7 (0.4)	1.7 (0.4)
	SIL (7)	15.1 (1.3)	0.4 (0.3)	2.8 (0.5)	2.9 (0.5)
	SPR (8)	14.6 (0.7)	−1.0 (0.3)	1.2 (0.3)	1.6 (0.1)
HG‖		4,8; 8,1,7,2; 2,3,6; 3,6,5	8; 1,3,2,5,6,7; 6,7,4	3,1,2,5; 5,8; 8,4,6; 7	2,1,3,5; 4,8,6; 7

†Chroma was calculated as $C^*_{ab} = (a^{*2} + b^{*2})^{1/2}$.
‡Numerical codes used in the *post hoc* test to indicate homogeneous subsets.
§Standard deviations in parentheses.
‖HG indicates homogeneous subsets based on Scheffe's multiple comparison test ($P < 0.05$).

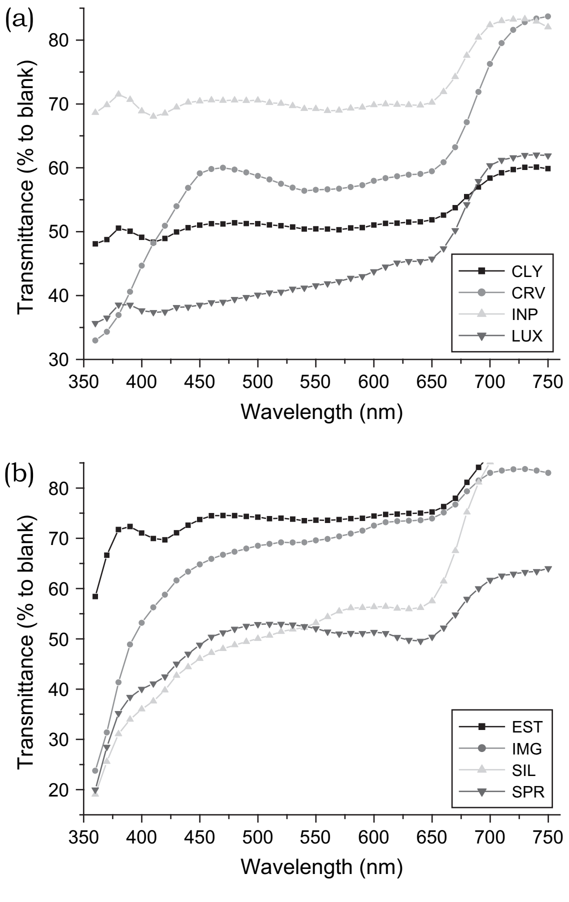

Figure 2 Spectral transmittance curves for the ceramic (a) and plastic (b) brackets.

The mean diffuse light transmittance (percentage ratio to the window-opened plate) of the brackets in the wavelength range 360–750 nm is presented in Figure 3. Regardless of bracket type, varied light transmittance was observed in the range of 44.9–75.9 per cent. These light transmittance values were influenced by bracket brand ($P < 0.05$).

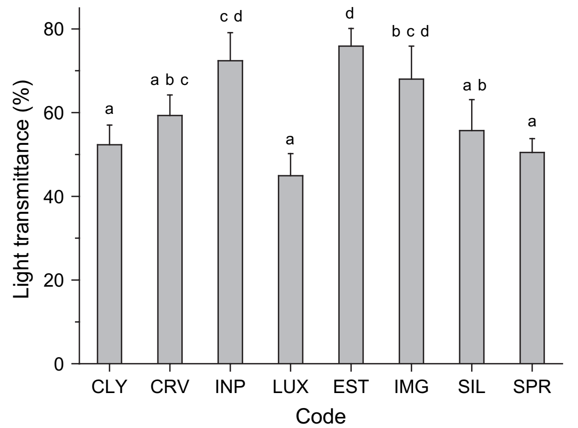

Figure 3 Diffuse light transmittance (%: ratio to the window-opened plate). Where bracket types are marked with the same letters, this indicates no statistically significant difference between the groups (Scheffe's multiple comparison test).

Discussion

The null hypotheses of the present study were rejected as there were significant differences, both in reflected and transmitted colour, by bracket brand and a significant difference in the light transmittance of these brackets. The thickness and geometry of the tested brackets, which varied according to the brand, had a significant influence on the translucency and colour of the brackets. In addition to the colour difference by bracket brand, colour stability of tooth-coloured brackets during orthodontic treatment is also clinically important. Based on the current study, colour stability of these brackets could be reliably evaluated.

The colour of aesthetic brackets should ideally match those of natural teeth. However, the colour co-ordinates of natural teeth vary according to the colour measurement protocols used and also by race, gender, and age (Bolt *et al.*, 1994; Li, 2003). Since the colour co-ordinates of natural teeth vary, shade guides may be used as substitutes

(Lee *et al.*, 2001, 2002). Based on the same measurement protocols used in the present study (Lee *et al.*, 2001, 2002), the reflected colour co-ordinates (CIE L^*, a^*, and b^*) for the Vita Lumin vacuum shade guide (Vita Zahnfabrik, Bad Sackingen, Germany) were 40.8–52.8, −1.2 to 1.4, and 3.9–13.5, respectively, and those for the Chromascop shade guide (Ivoclar Vivadent, Schaan, Liechtenstein) 49.4–62.5, −1.1 to 4.5, and 6.8–20.9, respectively. The range for the CIE L^* values of the eight tooth-coloured brackets assessed in the present study was 36.2–50.3. However, before considering a comparison of the colour co-ordinates of the shade guides with those of the brackets, one factor that should be borne in mind is that the colour of the brackets was measured over a zero calibration cylinder, which will decrease the CIE L^* value because the light reflectance of this box was nearly zero (0.01%). In contrast, the enamel portion of a shade guide tab is backed by a dentine-shaded opaque backing; hence, the measured CIE L^* values of shade guide tabs are likely to be higher than those of the brackets. In view of this limitation, direct comparison of colour co-ordinates of brackets with those of shade guide tabs has limited practical applications. Production of a ceramic dental restoration that matches a target shade is dependent on porcelain thickness, and up to 70 per cent colour differences have been reported between restorations and the shade tab due to a high CIE L^* in the restoration (Douglas and Przybylska, 1999). Therefore, in addition to background conditions, the influence of other factors on colour matching, such as the thickness and geometry of brackets, should be studied further.

The range for the CIE a^* values of the two shade guides has been reported to be −1.2 to 4.5 and for b^* values 3.9–20.9 (Lee *et al.*, 2001, 2002). As the range for the CIE a^* values of the tooth-coloured brackets measured in the present study was −1.3 to 3.8, the ranges for the CIE a^* values of the brackets and shade guides appeared similar. While for CIE b^*, the values were −2.9 to 11.2, indicating a discrepancy between the brackets and the shade guides. While the CIE a^* and b^* values of tooth-coloured brackets were in a similar hue range in the CIE colour space (CIE, 2004), the background conditions and aperture sizes for the colour measurements of the shade guide tabs and brackets were different, which may have influenced the measured colour and these factors should be considered. The individual composition and morphological features of the tested brackets may have influenced the measured colour and translucency. However at this stage, it is difficult to establish the influence of these factors and further studies are required.

Although dental shade guides have been used for many years, the range of shades is not consistent with natural teeth (O'Brien *et al.*, 1991). This inconsistency makes the colour matching of tooth-coloured brackets with natural teeth even more complicated. In addition, colour measured with a shade guide tab is variable for several reasons: the tabs are not a uniform colour, the shade guides vary between batches, the standard illuminant varies, and there are inherent difficulties with colour measurements for tooth-shaped objects (Schwabacher and Goodkind, 1990; O'Brien *et al.*, 1991). There are also disadvantages in using a colourimeter for measuring tooth colour, including the fact that the instruments are designed to measure flat surfaces and small aperture colourimeters are prone to significant edge-loss effects (van der Burgt *et al.*, 1990; Bolt *et al.*, 1994; ten Bosch and Coops, 1995). These problems could also have influenced bracket colour measurement, as the shape and dimensions are more complex and smaller than those of natural teeth. Therefore, this study utilized reliable colour measurement of brackets using a spectrophotometer. The results indicate that the coefficient of variation (CV: SD/mean) for the reflected colour co-ordinates was in the range 1.4–6.8 (mean: 3.8) per cent for CIE L^*, −323.5 to 166.2 (mean: −63.3) per cent for a^*, and −208.8 to 123.7 (mean: −3.3) per cent for b^*. This indicates that the CV values for CIE a^* and b^* were high but for L^* they were low, which confirmed the reliability of the measurement protocol used in the present study. Similar results were obtained for the transmitted colour.

Transmitted colour is important when a bracket is viewed over transmitted light and, as brackets are sometimes viewed clinically from the side, this might influence the colour match of brackets with teeth. However, studies are recommended to investigate this further.

Optical properties of ceramic brackets have previously been evaluated using diffuse light transmittance spectroscopy. The results showed that monocrystalline alumina brackets had the highest diffuse transmittance values at 468 nm, followed by polycrystalline alumina and polycarbonate-base alumina types (Eliades *et al.*, 1995a). In the present study, the monocrystalline bracket, Inspire Ice, showed higher transmittance than the other ceramic brackets, but similar light transmittance values to those of plastic brackets (Esther II and Image). Light transmittance alone should not be a criterion for the selection of a bracket; it should be considered together with clinical performance.

Eliades *et al.* (1995a) evaluated the extent of direct light transmittance of aesthetic brackets and the correlations between the transmittance, the structure, morphological factors, and composition were determined. The results showed that all three factors significantly affected light transmission. Absolute values obtained by Eliades *et al.* (1995a) were based on direct transmittance; therefore, direct comparison with the present study is not possible.

Camphoroquinone, which is generally used as a photoinitiator in light-cured resin-based materials, absorbs light between 350 and 550 nm, peaking at 468 nm (Wendl *et al.*, 2004). The results of the present study showed varied light transmittance depending on wavelength (Figure 2a,b). Light transmittance generally increased as the wavelength increased; therefore, the average value in the wavelength range was calculated (Figure 3).

Conclusions

Within the limitations of the present study, the ranges for the reflected colour co-ordinates were wide: 36.2–50.3 for CIE L^*, −1.3 to 3.8 for a^*, and −2.9 to 11.2 for b^*, and diffuse light transmittance was 44.9–75.9 per cent. These variations would influence the aesthetic performance of tooth-coloured brackets and the degree of adhesive cure through the brackets. Further studies on colour matching with teeth should be performed and more clinically orientated, simulated models for the evaluation of the degree of adhesive cure through the brackets should also be developed.

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