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A comparative *in vitro* study of the strength of directly bonded brackets using different curing techniques

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SUMMARY The aim of this study was to compare, by shear testing, the bond strengths after 1 and 24 hours of a light-cured resin (Enlight) and a light-cured glass ionomer cement GIC (Fuji Ortho LC) using various polymerization lamps (halogen, high performance halogen, xenon, and diode) for the direct bonding of brackets. The self-curing resin (Concise) was used as the control.

The analysis was carried out using the SPSS program. For group comparison purposes, the single factor variance analysis (ANOVA) and the *post-hoc* test (Tukey's HSD) were used. The level of significance was established at $P < 0.05$. When comparing two mean values the *t*-test for independent random samples was employed.

All polymerization lamps achieved the minimum bond strength of 5–8 MPa. With Enlight LV, bond strength was dependent on curing time (the halogen lamp achieved the highest bond strength of 10.0 MPa, $P < 0.001$, with a curing time of 40 seconds. The other lamps showed similar results) and on the mode of cure (the highest bond strength values were achieved by four-sided curing, $P = 0.04$). Fuji Ortho LC, on the other hand, was independent of the duration of light curing and the type of lamp used. The bond strengths of the resin-modified glass ionomer cement (RMGIC) were similar to or somewhat higher than those achieved with light-cured composite resin ($P = 0.039$) when lamps with short polymerization times were used, but were significantly lower ($P < 0.001$) when compared with the self-curing composite adhesive. After 24 hours, the bond strengths of all adhesives showed a significant increase: Enlight 19 per cent, Fuji Ortho LC 6.6 per cent, Concise 16 per cent.

Bond failure occurred for Enlight at the bracket–composite resin adhesive interface in 90 per cent and with Concise in 57 per cent. However, Fuji Ortho LC showed far more cohesive and mixed failures, indicating an improved bond between bracket and cement.

Introduction

The direct bonding of brackets with composite adhesives and the acid etch technique resulted in many advantages (simple handling, good adhesion, reduced gingival irritation, improved aesthetics, and a reduction in caries) (Bishara *et al.*, 1998; Graf and Jacobi, 2000).

The resins currently available allow different types of activation (light, chemical, chemical/physical) and preparation (paste systems, paste–liquid or powder–liquid systems) (Eller and Plenk, 1994).

Light polymerizing composites have the advantages of an increased processing time, exact bracket positioning, earlier residue removal, and in comparison with chemically cured cements, a very good, and initially even higher (Jonke *et al.*, 1996), bond strength (Greenlaw *et al.*, 1989; Armas Galindo *et al.*, 1998). The potential risks of decalcification around the bracket as a result of inadequate hygiene, possible loss of enamel due to phosphoric acid etching and debonding due to moisture sensitivity, make alternative materials important, especially as fluoride release has no long-term effects (Brown and Way, 1978; Diedrich, 1981; Strother *et al.*, 1998).

The use of glass ionomer cement (GIC) was first described by Wilson and Kent (1972) and Kent *et al.* (1973). Its advantages are simple processing, sustained release of fluoride and reabsorption from fluoride toothpastes (Hatibovic-Kofman and Koch, 1991), chemical adhesion to enamel and dentine via ion and hydrogen bridges (therefore etching can be dispensed with) and to pre-treated gold and platinum alloys (Kent *et al.*, 1973; Hotz *et al.*, 1977), higher mechanical properties compared with conventional cements, similar thermal expansion to hard tooth structure (Morand and Jonas, 1995), bonding in the presence of moisture (Wilson and Kent, 1972), although there is an initial high degree of water solubility if recently cured (Städler, 1994), and primary radio opacity (Mathis and Ferracane, 1989). Disadvantages include significantly lower bond strength (Trimpeneers *et al.*, 1996), limited processing times and the mixing process.

The subsequently developed resin-reinforced GIC [= light-cured GIC or resin-reinforced, resin-modified GIC (RMGIC)] has the advantages of conventional GICs while displaying improved physical and mechanical properties. Fuji Ortho LC achieved a clinically acceptable bond strength in a moist working atmosphere and with an unetched enamel surface (Graf and Jacobi, 2000), for the direct bonding of brackets without damaging the enamel. When high bond strengths are required, the enamel surface may be acid etched (Cohen *et al.*, 1998; Lippitz *et al.*, 1998; Graf and Jacobi, 2000). When using Fuji Ortho LC the manufacturer recommends not completely drying the teeth and claims good bond strength if the enamel surface is moist or contaminated by saliva. However, various studies have reported different results. Liebmann and Jost-Brinkmann (1999) and Süssenberger *et al.* (1997) measured higher shear bond strengths on dry enamel, whereas Cacciafesta *et al.* (1998b) and Jobalia *et al.* (1997) determined a higher bond strength when moisturizing the enamel surface with water or saliva. On the other hand, a study by Béress *et al.* (1998) on Fuji Ortho LC cement found no significant difference between moist and dry enamel surfaces. The caries-preventing property (fluoride release and absorption) (Evrenol *et al.*, 1999), and its gentle and simple debonding are further advantages.

The polymerization equipment previously used consisted primarily of halogen lamps that function on the principle of a light bulb (Bockhorst, 2001). These lamps emit ultraviolet and visible light, filtered to leave a spectrum that peaks in the blue wavelengths (mainly 400–510 nm) (Städtler, 1994). In this way, the absorption area of practically all composites is covered. Most energy is lost in the infrared spectrum because it is emitted as heat radiation, leading to the low degree of efficiency of normal light bulbs of 2 per cent, at a light intensity (dependent on the lamp used) of 300–800 mW/cm^2. The lifespan (50–75 hours; Städler, 1994) is increased by a factor of 1.5–2 due to the halogen supplement, compared with normal light bulbs, and efficiency is 10–20 per cent higher. Curing times are given as 40–60 seconds.

High performance halogen lamps with shorter curing times and an increased performance of over 1000 mW/cm^2 are also available. These lamps have a conventional construction—the higher light intensity is mainly achieved by special light guides, i.e. focusing the light on to a smaller beam hole.

As an alternative there is also other polymerization equipment with different modes of function, such as the xenon arc lamp, the diode lamp and the argon laser.

Xenon arc lamps (also known as plasma lamps) are gas discharge lamps (Bockhorst, 2001). The light spectrum depends on the type of gas or metal vapour used. When subjected to a current, the gas used, dependent on the desired wavelength, becomes conductive (= plasma condition of the gas) through increased ionization. Electrons stimulated in this way emit electromagnetic radiation (= light) when reverting to the lower energy base condition. The available equipment emits a relatively constant light intensity of 1400–2400 mW/cm^2 (Lindner *et al.*, 1995). Gas discharge lamps exceed the efficiency of a light bulb by a factor of 5–10. The lifespan is several hundred hours; curing times are a few seconds.

Light emitting diode (LED) lamps (Tietze and Schenk, 1993 ; Schaerer *et al.*, 2001) are light sources based on semi-conductor technology (III/V connections) that are distinguished by extremely high mechanical durability, a very long lifespan (10^5–10^6 hours) and high and constant light efficiency. The colour and wavelength depend on the material used. For polymerization, the Ga/N, Zn/Se or Si/C diodes, which emit blue light, are relevant. To achieve the required light intensity for polymerization, many diodes must be linked to optical systems.

The purpose of this study was to investigate the bond strength of a light-cured resin adhesive and of a RMGIC using various light polymerization lamps. The shear bond strength of brackets bonded with a chemical-curing resin (Concise) was also measured and used as the control.

Materials and methods

Within a period of 1 year, 400 human teeth were collected (intact buccal surface, no caries or plier marks from extraction, no chemical preparation) and stored in a 10 per cent formaldehyde solution for 3 weeks prior to use. Four hours before use the teeth were placed in distilled water, cleaned with a fluoride-free paste (pumice stone) at a low speed for 15 seconds, rinsed with water (15 seconds) and dried with oil-free compressed air.

The enamel surfaces were etched for 30 seconds with 37 per cent phosphoric acid gel and rinsed for 30 seconds with water when the composite adhesives Enlight and Concise were used. The bonding agents, Ortho Solo and Scotchbond, were applied on a dry enamel surface. Using Fuji Ortho LC cement, acid etching with a 10 per cent polyacrylic acid lasted for 20 seconds. It was then rinsed for 30 seconds and the cement was applied to a wet enamel surface. Concise, Fuji Ortho LC, and Enlight LV were applied according to the manufacturers' instructions, and the surplus on the edges of the bracket was thoroughly cleaned.

The luminous power output of each lamp was checked with a luminous power dose rate meter before and after use. With the exception of the LED lamp, the manufacturers' specified luminous power output was confirmed using the available measuring devices. For the LED lamp, the measuring instructions supplied by the manufacturer were referred to. If supplied by the manufacturer, the prescribed or recommended curing times were strictly adhered to, and the light source placed as close as possible to the tooth, but without touching the bracket (generally, light intensity decreases with the square of its distance). The curing of the mesial and distal sides was carried out for practical reasons (short curing times for some lamps), but a significant increase in bond strength (P = 0.04) was achieved by four-sided curing. After bonding, the teeth were embedded in acrylic and the bond strength was measured by shearing off the brackets.

To guarantee reproducible debonding, a casting mould with a bridge in the middle (made of square steel wire for bracket positioning) which was fastened parallel to the casting mould surface (Figure 1) for the acrylic embedding (cold polymer) was built. The shear test with the universal mechanical testing machine (Shimadzu Autograph AGS-D-Serie, 10 kND; Instron Corp., Canton, Massachusetts, USA) (Figure 2) was performed at a feed rate of 0.5 mm/minute. Deformation of the bracket wings when shearing off was avoided by placing a square steel wire in the bracket slot. By aligning the vertical surfaces of the acrylic block and the machine's mounting device, it was possible to transfer the achieved parallelism and position the shear knife parallel to the seat of the bracket base. The shear knife was led up to the bracket base so that there was no lever action whatsoever. Shear power was registered in Newtons (N) and recorded as force/surface in Megapascales (MPa). Shear bond strength testing took place at 1 and 24 hours after bonding with all three adhesives (storage prior to testing was in a moist chamber with distilled water).

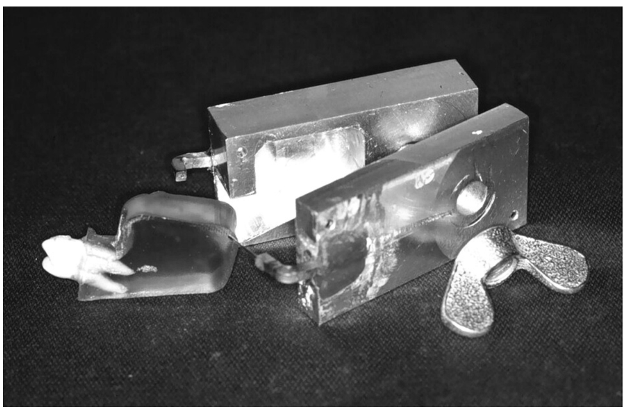

Figure 1 The casting mould with a test specimen.

Figure 2 The universal testing machine.

The brackets, adhesives, and lamps used are described in Tables 1–3.

The following dose rate meters were used for light power: Coltolux light meter (Coltène/Whaledent Inc., Cuyahoga Falls, Ohio, USA), Cure Rite visible curing light meter (Dentsply International, York, USA) and Spectra Physics laser power meter (University of Technology, Graz, Austria).

To determine the adhesive remnant index (ARI) the brackets were examined under a stereomicroscope with a 10–66-fold magnification (Zeiss SV11; Carl Zeiss Corp., Göttingen, Gemany).

Statistics

Descriptive and explorative data analysis was used. The analysis was carried out using the SPSS program (SPSS, Chicago, Illinois, USA). For group comparison the single factor variance analysis (ANOVA) and Tukey's HSD *post-hoc* test were used. The level of significance was established at $P < 0.05$. When comparing two means, the *t*-test for independent random samples was employed.

Results

Curing the Enlight adhesive with the halogen lamp (40 seconds) resulted in a significantly higher bond strength 1 hour after curing ($P < 0.001$) (Table 4). The other lamps showed no significant difference in bond strength between the selected curing times. A polymerization time of 2×1 seconds was too short for a clinically acceptable bond strength (2×2, 2×3 seconds, however, were adequate) when using the xenon lamp. Similar bond strengths 1 hour after curing were achieved with Fuji Ortho LC using various lamps (Table 5). The slightly lower bond strength when using the high performance halogen lamp can be explained by the adhesive's own variance. The descriptive statistics of the bond strengths (MPa) after 1 hour using the Concise adhesive are shown in Table 6. The comparison of the adhesives, using the single factor variance analysis, differed with a significance of $P < 0.001$. According to Tukey's HSD post-hoc test, the bond strength of Concise was significantly higher ($P < 0.001$) than those of Enlight and Fuji Ortho LC. The bond strengths of the Enlight and Fuji Ortho LC cements also differed significantly ($P = 0.039$) (Table 7). The bond strengths of the adhesives Enlight LV, Fuji Ortho LC, and Concise 24 hours after curing are summarized in Table 8.

To determine the difference 1 and 24 hours after curing, a *t*-test for independent random samples was used. This resulted in significant differences between the three adhesives (Enlight: $P < 0.001$; Fuji Ortho LC: $P = 0.020$; Concise: $P = 0.01$). Based on the mean values,

Table 1 The brackets used in the study (Ormco Corp., West Collins, Orange, USA).

Name	Torque	Angulation	Tooth	Bracket base	Base area (mm^2)
Optimesh XRT 340-6807	0	0	Second molar	Mesh base	13.0
Ormesh twin 340-0500	0	0	Lower central universal	Mesh base	9.7
Ormesh twin 340-0604	0	0	Premolar/canine universal	Mesh base	14.0
Ormesh twin 340-0401	0	0	Upper central universal	Mesh base	16.9

Table 2 The adhesives used in the study.

Name	Ingredients	Type of curing	Bonding agent
Fuji Ortho LC (GC Europe, Leuven, Belgium)	Powder—Fl.Al. silicate glass 100 per cent Liquid—polyacrylic acid 20–22 per cent, 2-hydroxyethyl methacrylate 35–40 per cent, 2,2,4, trimethyl hexamethylene dicarbonate 5–7 per cent, triethylene glycol dimethacrylate 4–6 per cent; camphorquinone: activator	Light- and self-curing	None
Enlight LV (Ormco Corp.)	Dimethacrylate—monomer 20–30 per cent, silicate filler: 70–80 per cent, other supplements: 4 per cent, among them camphorquinone as the activator	Light-curing	Ortho Solo
Concise (3M Unitek, Perchtoldsdorf, Austria)	Part A—quartz (70–80 per cent), bisphenol A (14–20 per cent), diglycidylether-dimethacrylate, triethylglycoldimethacrylate (3–8 per cent) Part B—quartz (70–80 per cent), bisphenol A (15–20 per cent), diglycidylether-dimethacrylate, triethylglycoldimethacrylate (3–8 per cent)	Self-curing	Scotchbond

Table 3 The lamps used in the study.

Type	Name	Light intensity (mW/cm^2)	Wavelength (nm)	Curing time (seconds)
Halogen	Optilux 401 (Kerr Corp., West Collins, Orange, USA)	550	400–510	2 × 20
High performance halogen	Optilux 501 (Kerr Corp.)	Booster mode: 1100	400–510	2 × 5
Plasma (xenon)	Apollo 95 E /Elite (DMD, Woodland Hills, USA)	Curing mode: 1600	460–490	2 × 1, 2 × 2, 2 × 3
Diode (LED)	GCeLight (GC Europe, Leuven, Belgium)	750	440–490	2 × 9, 2 × 12 (fast cure mode)

LED, light emitting diode.

the increases from 1 to 24 hours in bond strengths were: Enlight 19 per cent, Fuji 6.6 per cent, Concise 16 per cent.

To determine the mode of fracture, a modification of the ARI (Oliver, 1988) was used (Artun and Bergland, 1984) (Table 9): V = no adhesive on the enamel surface; IV = less than 10 per cent adhesive on the enamel surface; III = between 10 and 90 per cent adhesive on the enamel surface; II = between 90 and 100 per cent adhesive on the enamel surface; I = 100 per cent adhesive on the enamel surface.

Discussion

All polymerization lamps (curing times of 4 and 6 seconds when using the xenon lamp, 10 seconds using the high performance halogen lamp, 18 seconds using the LED lamp, and 40 seconds using the halogen lamp) achieved the minimum acceptable bond strength of 5–8 MPa (Reynolds, 1975) with the adhesives used. The bond strength of Enlight LV was dependent on the curing time (the halogen lamp achieved the highest bond strength with a curing time of 40 seconds) as well as on the type of curing (the highest bond strength rates were reached using four-sided curing). The RMGIC on the other hand remained relatively independent of the length of light curing and the type of lamp. This can be attributed to its three curing reactions (light- and self-curing resin component, conventional acid/base reaction of the GIC). The highest bond strength (including, however, an increased risk of enamel damage) was

Table 4 Descriptive statistics (MPa) of bond strengths 1 hour after curing using Enlight with various lamps.

	Number	Halogen* 20 seconds (m)/ 20 seconds (d)	High performance halogen 5 seconds (m)/ 5 seconds (d)	Xenon 1 second (m)/ 1 second (d)	Xenon 2 seconds (m)/ 2 seconds (d)	Xenon 3 seconds (m)/ 3 seconds (d)	Diode 9 seconds (m)/ 9 seconds (d)	Diode 12 seconds (m)/ 12 seconds (d)	
Molars	10	10.0	7.4	3.0	7.0	8.5	7.0	7.9	Mean
		1.4	1.4	0.8	1.3	1.6	1.7	1.4	SD
		10.3	7.0	3.0	7.0	8.2	6.8	8.2	Median
		12.4	9.8	4.8	9.0	11.3	9.7	9.8	Maximum
		7.7	5.4	1.9	5.3	6.0	4.9	5.6	Minimum
Premolars	5	9.5	5.8	3.5		5.2		5.8	Mean
		1.6	1.3	1.1		0.7		1.6	SD
		9.7	5.2	4.1		5.1		4.9	Median
		11.4	8.0	4.5		6.4		8.4	Maximum
		7.1	4.9	2.2		4.6		4.6	Minimum
Upper incisors	5	7.7	4.9	3.1		5.7		5.6	Mean
		1.3	1.5	0.8		1.4		1.6	SD
		7.4	4.7	2.9		5.5		5.4	Median
		9.2	7.3	4.1		7.4		7.7	Maximum
		5.8	3.5	2.4		3.8		3.9	Minimum
Lower incisors	5	10.9	10.1	4.7		7.7		7.8	Mean
		1.5	1.8	1.0		1.4		1.6	SD
		10.6	9.3	4.9		7.8		7.6	Median
		12.8	12.1	5.9		9.8		9.8	Maximum
		9.2	8.3	3.3		6.3		5.8	Minimum

m, mesial; d, distal; SD, standard deviation.
*$P < 0.001$.

Table 5 Descriptive statistics of bond strengths (MPa) 1 hour after curing using Fuji Ortho LC with various lamps.

	Number	Halogen 20 seconds (m)/ 20 seconds (d)	High performance halogen 5 seconds (m)/ 5 seconds (d)	Xenon 1 second (m)/ 1 second (d)	Xenon 2 seconds (m)/ 2 seconds (d)	Xenon 3 seconds (m)/ 3 seconds (d)	Diode 9 seconds (m)/ 9 seconds (d)	Diode 12 seconds (m)/ 12 seconds (d)	
Molars	10	10.2	7.9	9.4	10.2	9.9	8.7	9.2	Mean
		1.9	0.9	2.2	1.9	2.7	2.0	1.9	SD
		10.3	7.8	9.3	10.0	9.0	8.7	9.0	Median
		13.6	9.4	13.6	14.4	15.0	11.6	11.9	Maximum
		7.5	6.8	5.6	7.8	7.3	6.0	6.6	Minimum
Premolars	5	8.2	7.5			9.4		8.0	Mean
		1.8	1.4			1.9		1.5	SD
		7.1	7.8			9.3		7.7	Median
		10.3	8.9			12.1		9.9	Maximum
		6.8	5.1			7.1		6.1	Minimum
Upper incisors	5	6.3	6.4			7.6		7.5	Mean
		1.5	1.0			2.3		2.4	SD
		5.3	6.3			6.8		7.5	Median
		8.3	7.7			11.0		11.2	Maximum
		5.1	5.0			5.0		4.7	Minimum
Lower incisors	5	11.5	10.1			11.3		9.8	Mean
		2.7	1.9			1.6		2.8	SD
		13.1	9.6			10.7		10.9	Median
		14.0	12.3			13.5		12.3	Maximum
		8.1	8.0			9.8		6.2	Minimum

m, mesial; d, distal; SD, standard deviation.

Table 6 Descriptive statistics of the bond strengths (MPa) 1 hour after curing using Concise.

	Number	Bond strength after 1 hour (MPa)	
Molars	10	13.21	Mean
		1.45	SD
		13.70	Median
		14.81	Maximum
		10.26	Minimum
Premolars	5	11.24	Mean
		3.02	SD
		9.91	Median
		15.43	Maximum
		7.82	Minimum
Upper incisors	5	13.08	Mean
		1.41	SD
		12.93	Median
		15.38	Maximum
		11.65	Minimum
Lower incisors	5	9.67	Mean
		1.56	SD
		9.30	Median
		12.34	Maximum
		8.35	Minimum

SD, standard deviation.

Table 7 Strengths (MPa) of all applied adhesives.

	Mean	SD	Minimum	Maximum
Enlight LV	8.44	2.70	3.50	16.13
Fuji Ortho LC	9.19	2.38	4.73	14.96
Concise	13.02	2.76	7.82	20.03

SD, standard deviation.

achieved with Concise. Retief (1974) specified 9.7 MPa as the lowest bond strength which led to enamel fracture at debonding. Diedrich (1981) reported enamel fracturing at tensile loads of 9–11 MPa.

In the present study, no differences were found between chemically- and light-activated resin adhesives on smaller bracket bases, e.g. lower incisors, as good initial polymerization was possible with light activation. It should be taken into consideration that in contrast to chemical-curing, light-curing resin has a substantially lower bond strength on large bracket bases, e.g. upper incisor brackets, especially with lamps with short curing times.

When comparing the adhesives, the bond strengths of the RMGIC and the light-cured resin cement were similar (with lamps using short polymerization times the bond strengths of Fuji Ortho LC were somewhat higher). Compared with the self-curing resin cement, however, they were significantly lower. Therefore, the light-cured GICs, with their advantages mentioned in the introduction (especially the constant fluoride release), certainly present a viable alternative, in particular in bonding molars. This result essentially confirms the studies of Bishara *et al.* (1998) and Komori and Ishikawa (1999) where the bond strength of RMGIC was found to correspond to light-cured resin bonding with acid conditioning of the enamel. Jobalia *et al.* (1997) found the bond strength of RMGIC on a moist enamel surface conditioned with a 10 per cent polyacrylic acid to be slightly higher than with resin bonding. When using Concise, Cohen *et al.* (1998), Süssenberger *et al.* (1997) and Lopez-Barajas and Brusola (1997) also established that the self-curing resin adhesive had a higher bond strength than Fuji Ortho LC.

Table 8 Descriptive statistics of bond strengths (MPa) 24 hours after curing of all applied adhesives with various lamps.

	Halogen 20 seconds (m)/ 20 seconds (d)	High performance halogen 5 seconds (m)/ 5 seconds (d)	Xenon 3 seconds (m)/ 3 seconds (d)	Diode 12 seconds (m)/ 12 seconds (d)	Concise	
Enlight (10 molars)	13.23	7.79	9.60	10.17		Mean
	2.51	1.43	2.44	2.74		SD
	13.67	7.85	9.24	10.36		Median
	16.13	9.78	14.08	14.04		Max
	8.10	5.64	6.56	6.27		Min
Fuji Ortho (10 molars)	10.56	8.67	10.96	9.49		Mean
	2.75	1.95	1.77	2.40		SD
	11.24	8.21	11.16	8.76		Median
	14.23	12.81	13.44	14.94		Max
	6.25	6.71	8.49	6.61		Min
Concise (10 molars)					15.35	Mean
					2.58	SD
					15.09	Median
					20.03	Max
					10.95	Min

m, mesial; d, distal; SD, standard deviation.

Table 9 Absolute (percentage) value for the adhesive remnant index (ARI).

		Halogen + Enlight	High performance halogen + Enlight	Xenon + Enlight	LED + Enlight	Halogen + Fuji	High performance halogen + Fuji	Xenon + Fuji	LED+ Fuji	Concise
ARI										
V	0%	0 (0)	0 (0)	0 (0)	0 (0)	1 (3)	2 (6)	1 (3)	0 (0)	0 (0)
IV	<10%	0 (0)	0 (0)	0 (0)	0 (0)	8 (23)	7 (20)	8 (23)	9 (26)	3 (9)
III	<90%	2 (6)	5 (14)	4 (11)	4 (11)	17 (49)	21 (60)	16 (46)	19 (54)	12 (34)
II	>90%	33 (94)	30 (86)	31 (89)	31 (89)	9 (26)	5 (14)	10 (29)	7 (20)	20 (57)
I	100%	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
Number of teeth		35	35	35	35	35	35	35	35	35

LED, light emitting diode.

On the other hand, Graf and Jacobi (2000) and Flores *et al.* (1999) achieved significantly higher shear bond strengths using Fuji Ortho LC. However, etching was carried out with phosphoric acid and not, as recommended by the manufacturer, a 10 per cent polyacrylic acid. During *in vivo* testing, Cacciafesta *et al.* (1998a), without acid conditioning, was able to establish a lower, and Fricker (1998), with acid conditioning, a similar bracket loss rate compared with resin adhesives when bonding with Fuji Ortho on a moist enamel surface. In contradiction to this are studies that report lower bond strengths than those achieved with resin adhesives (Komori and Ishikawa, 1997; Bishara *et al.*, 1999, 2000; Owens and Miller, 2000).

Based on the mean results, an increase in bond strength was found with all adhesives (Enlight 19 per cent, Fuji 6.6 per cent, Concise 16 per cent) after 24 hours. The light-activated resin adhesive showed the largest increase, indicating that the polymerization process (the chain reaction where methacrylate monomers are networked by splitting the double bonds) continues after the exposure to light has ceased. Regarding Enlight, the highest bond strength 1 and 24 hours after curing was achieved with the halogen lamp. This demonstrates that the primary formation of radicals, by light activation of the photo-initiator, seems to be decisive for the subsequent delayed curing reaction.

The ARI is influenced by many factors including bracket design and tooth curvature (O'Brien *et al.*, 1988). Diedrich (1981) reported that the failure site is dependent on the micromechanical retention achieved by acid etching, which can differ from tooth to tooth and even on a single tooth. Ødegaard and Segner (1990) described the weakest link on metal brackets as that between the adhesive and the retentive bracket base (the retentive surface remains filled with adhesive). In the present investigation, this was found to be 90 per cent true when using Enlight and 57 per cent true with Concise (as the grid base is always filled with adhesive, the 100 per cent rate was not used in this study). However, when Fuji Ortho LC was used, cohesive and mixed failures dominated, indicating good bonding of the bracket and the cement. Anchorage to the enamel surface achieved with conventional acid bonding is stronger than with RMGIC.

Conclusion

Regarding bond strength, all the tested lamps can be used with the recommended curing times. When a high bond strength is required or in cases of occlusal interference and the use of large bracket bases, longer polymerization times should be considered, especially when using lamps with short curing times. If possible four-sided curing or placing the wire in the bracket slot should be carried out after 24 hours. The use of the chemically-cured composite adhesive, Concise, should be reserved for rebonding or the cementing of active elements with high strength requirements.

Both Fuji Ortho LC and Enlight LV can be classified as good bonding materials, in particular in the posterior tooth segments, where adequate moisture control and accurate light guide positioning may be difficult.

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