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The crystal growth technique—a laboratory evaluation of bond strengths

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SUMMARY An *ex vivo* study was carried out to determine differences in the bond strengths achieved with brackets placed using a crystal growth technique compared with a conventional acid-etch technique. A solution of 37 per cent phosphoric acid was used for acid-etching and a commercially available polyacrylic acid gel, Crystal-lok^{TM} for crystal growth. A heavily-filled composite resin was used for all samples to bond brackets to healthy premolar teeth extracted for orthodontic purposes. Polycrystalline ceramic and stainless steel brackets were used and tested to both tensile and shear failure using an Instron Universal Testing machine. The tensile and shear bond strengths were recorded in kgF. In view of difficulties experienced with previous authors using different units to describe their findings, the data were subsequently converted to a range of units in order to facilitate direct comparison.

The crystal growth technique produced significantly lower bond strengths than the acid-etch technique for ceramic and stainless steel brackets, both in tensile and shear mode. The tensile bond strength for stainless steel brackets with crystal growth was 2.2 kg compared with 6.01 kg for acid-etch, whilst with ceramic brackets the tensile bond strengths were 3.9 kg for crystal growth and 5.55 kg for acid-etch. The mean shear bond strength for stainless steel brackets with crystal growth was 12.61 kg compared with 21.55 kg for acid-etch, whilst with ceramic brackets the shear bond strengths were 7.93 kg with crystal growth compared with 16.55 kg for acid-etch. These bond strengths were below those previously suggested as clinically acceptable.

Introduction

The direct bonding of orthodontic attachments has traditionally relied upon mechanical retention achieved by etching of the enamel surface. The most commonly used etchant material is 37 per cent orthophosphoric acid, either in solution or gel form. Etching produces pits for micro-retention and increases the wettability of the enamel by creating a high energy hydrophobic surface facilitating resin penetration (Newman and Facq, 1971; Beech and Jalaly, 1980). Etching also removes a finite amount of surface enamel with additional enamel inevitably removed during debonding and clean-up procedures leading to an overall loss of the superficial fluoride-rich layer.

A crystal-growth technique was introduced by Smith and Cartz (1973) which claimed to avoid permanent alteration to the enamel surface. The technique uses polyacrylic acid with residual sulphate ion to condition the teeth, forming crystals of calcium sulphate dihydrate or gypsum which are chemically bonded to the enamel (Årtun and Bergland, 1984; Maskeroni *et al.*, 1990). The polyacrylic acid interacts with the enamel surface to produce ionized carboxyl groups. Strong ionic bonding between calcium ions at the enamel surface and the carboxyl groups provides crystal enucleation sites for the gypsum crystals, which in turn provide mechanical retention for the bonding resin. Polyacrylic acid produces only slight enamel etching, but in the presence of residual sulphate ion, needle-like crystal projections appear on the enamel surface when viewed at higher magnification (Beech, 1972). Acid concentration and contact time affect the crystal morphology, while the nature of the sulphate ion affects the crystal structure and ultimate bond strength (Maijer and Smith, 1979; Farquhar, 1986; Jones and Pizarro, 1994; Pizarro *et al*., 1994).

The bond strength achieved using the crystal-growth technique is dependent on the strength of the chemical bond formed between the enamel and the gypsum crystals since studies have suggested that bond failure occurs exclusively at the resin/enamel interface (Årtun and Bergland, 1984; Read *et al*., 1986). Previous research suggests that the bond strength achieved with the crystal-growth technique is between one- and two-thirds that achieved with conventional acid-etching (MacPhee *et al*., 1985; Farquhar, 1986; Maskeroni *et al*., 1990). In clinical use, bond failure rates of 64.4 per cent have been reported with the crystal-growth technique, compared with 3.4 per cent using conventional techniques (MacPhee *et al*., 1985).

One of the problems associated with the interpretation of bond strength data is the lack of consistency in units used by authors. This was highlighted by Fox *et al*. (1994) in a critique of past studies. Their findings showed that the units used included measures of force alone such as kilograms (kg or kgF), Newtons (N) or Mega-Newtons (MN), or alternatively measures which related the debonding force to bracket base area such as lb/in^2, kg/cm^2, N/mm^2, MN/m^2, and, more recently, the SI unit Megapascals (MPa). Their conclusions were that results should be expressed in Newtons or MegaPascals, but this does not enable the reader to compare critically the results of previous work expressed in other units.

The aim of this study was to compare the tensile and shear bond strengths achieved with a commercially available crystal growth gel and conventional acid-etching. In addition, the resulting data were converted to a range of units used by previous investigators to permit comparison.

Materials and methods

A total of 120 healthy premolar teeth extracted for orthodontic purposes were stored in water at 4°C until required. Sixty polycrystalline ceramic brackets (Fascination™; Dentaurum, Ispringen, Germany) and 60 stainless steel brackets (Ultratrimm™; Dentaurum) were bonded to the enamel using a hybrid composite resin (Orthodontic Concise™; 3M, Monrovia, California, USA). Half the samples in each bracket group were bonded using a 60-second application of 37 per cent phosphoric acid solution and the other half using a 30-second application of Crystal-lok™ gel (Orthon Dental Inc., Victoria, British Columbia, Canada) as recommended by the manufacturer for the crystal-growth technique. A rigid bonding protocol was adhered to, following which the samples were left to air cure for 10 minutes before storing in water at 37°C for 24 hours. The samples were then tested to failure in an Instron Universal Testing machine, with half tested in tensile mode and half in shear mode. The tensile or shear bond strength was recorded for each sample. A Student's *t*-test was used to determine the statistical significance of intergroup comparisons for enamel preparation technique and bracket type in both tensile and shear mode.

Results

The results are presented in Tables 1 and 2. Mean tensile and shear bond strengths are expressed in kgF to enable direct comparison with the majority of previously published work. The data have then been converted to a range of units used in previous and contemporary studies to enable a wider comparison. The results from this investigation expressed in kgF, N, kg/cm^2, and MPa are presented in Table 3.

The results of the tensile bond testing indicated that the bond strengths achieved with the crystal growth technique were lower for both ceramic and steel brackets than the comparable bond strengths achieved with acid-etching. With steel brackets, the crystal-growth bond strength was only 37 per cent of that with etching, whilst with ceramic brackets it was 70 per cent (Table 1).

Table 1 Tensile bond strengths (kgF).

	Metal brackets		Ceramic brackets			
	Mean	95% CI	Mean	95% CI	*t*	*P*
Acid etch	6.01	4.85–7.17	5.55	4.47–6.63	0.625	NS
Crystal growth	2.20	1.41–2.99	3.90	2.90–4.90	2.864	**
t	5.826		2.430			
P	***		*			

NS = non-significant; *$P < 0.05$; **$P < 0.01$; ***$P < 0.001$.

Table 2 Shear bond strengths (kgF).

	Metal brackets		Ceramic brackets			
	Mean	95% CI	Mean	95% CI	*t*	*P*
Acid etch	21.55	17.61–25.49	16.55	12.12–20.98	1.814	NS
Crystal growth	12.61	10.65–14.57	7.93	4.43–11.43	2.507	*
t	4.367		3.285			
P	***		**			

NS = non-significant; *$P < 0.05$; **$P < 0.01$; ***$P < 0.001$.

Table 3 Tensile and shear bond strengths from this investigation expressed in a range of units.

	Metal/AE		Metal/CG		Ceramic/AE		Ceramic/CG	
	Shear	Tensile	Shear	Tensile	Shear	Tensile	Shear	Tensile
kgF	21.55	6.01	12.61	2.2	16.55	5.55	7.93	3.9
N	211.2	58.9	123.6	21.6	162.2	54.4	77.7	38.2
kg/cm^2	269.4	75.1	157.6	27.5	206.9	69.4	99.1	48.75
MPa	18.8	5.25	11.0	1.9	14.5	4.85	6.9	3.4

Shear bond testing demonstrated that the bond strengths with the crystal-growth technique were again inferior to acid-setching. With steel brackets the crystal growth bond strength was 58 per cent of that with etching, whilst with ceramic brackets it was 48 per cent (Table 2).

With the crystal growth technique, tensile bond strengths were higher with ceramic brackets than steel ($P < 0.01$), whilst in contrast, shear mode demonstrated higher bond strengths with steel brackets than ceramics ($P < 0.05$). With the acid-etch technique, there were no significant differences in mean bond strength between steel and ceramic brackets for either tensile or shear modes (Tables 1 and 2).

When comparing the two techniques, with stainless steel brackets the acid-etch technique produced consistently greater mean bond strengths than the crystal-growth technique in both tensile and shear modes, these differences being highly statistically significant ($P < 0.001$). This was true, but to a lesser extent with ceramic brackets. The acid-etch group showed a significantly higher mean shear bond strength ($P < 0.01$), but only a weak significantly higher mean tensile bond strength ($P < 0.05$) than the crystal-growth samples (Tables 1 and 2).

Discussion

Both Farquhar (1986) and Read *et al.* (1986) reported that crystal-growth produced a shear bond strength with steel brackets only 33 per cent as strong as acid-etching. However, Farquhar (1986) achieved a mean shear crystal bond strength of 6.3 kg and Read *et al.* (1986) of 3.3 kg, both of which were significantly lower than the mean bond strength of 12.61 kg achieved in this study. MacPhee *et al.* (1985) reported a crystal bond strength 66 per cent as strong as acid-etch, whilst Jones and Pizarro (1994) with a 'basic crystal growth solution' demonstrated a bond strength 55 per cent as strong. These results are in closer agreement with the 58 per cent reported in this study. Although MacPhee *et al.* (1985) did not report their raw data, Jones and Pizarro (1994) reported a crystal bond strength of 132.4 N, and with acid-etch 238.6 N which compares favourably with the results of this study (123.6 N and 211.2 N, respectively—where 1 kg = 9.8 N). In a more recent study investigating Crystal-lok™, Knox and Jones (1995) reported shear bond strengths of 73 N for crystal growth and 225.8 N for acid etch, demonstrating a crystal bond strength 32 per cent of that of acid etch. As a result, they commented on the unsuitability of the technique as an alternative to acid-etching.

Using ceramic brackets in shear mode Maskeroni *et al.* (1990) reported a crystal bond strength 48 per cent of that achieved with acid-etching which is in agreement with the findings in this study. Their reported mean shear bond strengths for ceramics with acid-etch (13.88 MPa) and crystal growth (6.71 MPa) compare well with those found in this investigation (14.5 MPa and 6.90 MPa, respectively, where 1 MPa = 14.3 kg/cm^2). In this study, the mean tensile bond strengths achieved for both the ceramic (48.75 kg/cm^2) and stainless steel (27.5 kg/cm^2) groups using the crystal-growth technique fell below the 60–80 kg/cm^2 (4.2–5.6 MPa) recommended by Reynolds (1975) as the minimum required for clinical reliability. These findings seem to support previous work by Bishara *et al.* (1993) using a simulated tensile debonding procedure, when it was noted that with some bracket/adhesive combinations crystal bond strengths were disappointingly low and came very close to the critical level. This suggests that at present the reliability of the bond strength achieved with the crystal growth technique may be inadequate for clinical use, although modifications in the chemistry of the sulphate ion have been suggested by Jones and Pizarro (1994) as a possible solution.

Conclusions

Resin bonding systems have been developed which achieve higher bond strengths than may be clinically necessary and the debonding of orthodontic brackets with subsequent removal of adhesive remnants may result in loss of surface enamel. The higher bond strength associated with ceramic brackets further increases the risk of enamel damage at removal (Bishara *et al.*, 1993). The crystal growth technique produces reduced bond strengths when compared with acid-etching and leaves fewer adhesive remnants for clean-up which may, at first sight, seem advantageous. However, the commercially available crystal growth gel tested in this study produced excessively reduced bond strengths lower than those recommended for reliable clinical use.

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