

Indirect bonding—a new transfer method

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SUMMARY The aim of this *in vitro* study was to investigate both shear bond strength (SBS) by shear testing of indirectly bonded brackets, and the accuracy of a new transfer method, the Aptus bonding device (ABD). For comparison, the SBS of directly bonded brackets in two experimental arrangements was also measured. The precision of the positioning of the indirect bracket transfer was assessed by photographic superimposition and three-dimensional (3D) measurement of the bracket positions on the working and plaster models using a 3D laser scan. Statistical analysis was carried out by means of descriptive and explorative data using the SPSS program. To compare groups, a one-factor analysis of variance and *post hoc* tests (Tukey-HSD) were used. The level of significance was set at $P < 0.05$.

SBS using indirect and direct bonding, with the same experimental arrangement and the same adhesives (Concise and Transbond), showed no significant differences. For direct bonding, using only one adhesive (Transbond), lower values were observed, but they were only statistically significant for the premolar teeth. The clinically required minimum bond strength of 6 MPa was achieved in all groups.

Superimposition of the photographs of the indirectly bonded upper labial segment brackets showed no deviations. The results of the 3D measurement of the positions of the brackets on the working and plaster models only yielded small deviations (0.15 mm along the X-axis in the centre, 0.17 mm along the Y-axis, and 0.19 mm along the Z-axis). The ABD is a useful adjunct to bond placement and does not compromise bond strength.

Introduction

Bonding brackets using light-curing composites is the current technique used for bracket attachment. The advantages include prolonged working time, early removal of excess adhesive, and a higher bond strength, especially when compared with chemically cured composites (Greenlaw *et al.*, 1989; Jonke *et al.*, 1996; Galindo *et al.*, 1998) and accurate positioning of brackets. This light-cured bonding technique, however, involves considerable time and expenditure. In order to minimize working time with light-curing adhesives, lamps with high light intensities inducing short polymerization times (Silverman and Cohen, 2000; Cacciafesta *et al.*, 2002; Manzo *et al.*, 2004), adhesives which do not require ‘drying out’ (Jobalia *et al.*, 1997; Lippitz *et al.*, 1998; Graf and Jacobi, 2000), and so-called ‘all-in-one adhesives’ (etching, priming, and bonding in one working step; Cinader, 2001; Velo *et al.*, 2002; Larmour, 2003; Miller, 2005) have been developed.

Indirect bonding offers a further possibility to shorten the chairside bonding process and to relocate the time factor to the laboratory.

Silverman *et al.* (1972) used an unfilled methyl-methacrylate-based adhesive (BisGMA) in order to bond plastic brackets onto a model. Silverman and Cohen (1975) improved this technique by using a perforated mesh base and ultraviolet (UV) cured BisGMA resin. Most indirect bonding can be traced back to a previously developed process (Thomas, 1978). A liquid catalyst resin is applied during chairside bonding onto a composite layer that has

been pre-cured in the laboratory (filled BisGMA adhesive). A thin layer of sealer is additionally bonded onto the enamel. The chemical curing process begins when both components are brought into contact with each other on placement of the tray. The transfer tray is removed after polymerization. Using this technique, bond strength similar to direct bonding was achieved (Hocevar and Vincent, 1988; Shiao *et al.*, 1993a,b). One of the criticisms of this method was that complete polymerization did not occur. For this reason, a modified technique was developed, with both components mixed before application (Hickham, 1993; Moskowitz *et al.*, 1996; Miles, 2000). Other techniques make use of water-soluble adhesives for placing the brackets in the laboratory setting. This adhesive is removed after creation of the transfer tray (White, 1999).

Apart from the use of chemically and thermally cured composites (Sinha *et al.*, 1995a,b), translucent transfer trays also allow light-cured composite adhesive to be used for coating the bracket base. Here, the previously mentioned advantages of light-cured adhesives come to the fore (Kasrovi *et al.*, 1997; Read and Pearson, 1998; Sondhi, 1999).

Numerous investigators have used modifications to achieve improvements in the indirect bonding technique (Simmons, 1978; Moshiri and Hayward, 1979; Read, 1987; Cooper and Sorenson, 1993; Hickham, 1993). The exact positioning of brackets using technical aids (‘ray set’, where adhesive layers allow corrections to be made in all three planes; Melsen and Biaggini, 2002) and the possibility of checking demarcation lines and bracket positions using a

fluorescent marker and UV light (Collins, 2000) introduced to this procedure an exact accuracy. This cannot be achieved through direct bonding, particularly in posterior areas, which is crucial to the efficiency of certain biomechanics. The shortened working time is convenient for both patient and orthodontist. This can be compared with the disadvantages in the form of technical reliability, laboratory time, obtaining additional casts, increased costs, and possible hygiene considerations arising from excess adhesive.

Gorelick (1979) reported that only 17 per cent of orthodontists used indirect bonding, and this technique is still today only slowly finding acceptance.

The aim of this investigation was to determine shear bond strength (SBS) and the transfer accuracy of a new indirect bonding method.

Materials and methods

For indirect bonding, a working model, with embedded teeth (set-up 35–45 simulating the situation in the mouth), was prepared. From this model, a transfer plaster model was replicated, and brackets (Ormco Corporation, West Collins Orange, USA; 340-1500 LJ front, 347-1208 LJ3 right, 347-1308 LJ3 left, 340-1504 LJ 4, and 340-1505 LJ 5) were positioned using self-curing composite adhesive (Concise, 3M Unitek, Monrovia, California, USA). The transfer of the brackets from the plaster to the working model was carried out using the Aptus bonding device (ABD; Aptus, Papendrecht, The Netherlands), and the brackets were bonded with the light-cured adhesive Transbond XT (3M Unitek) after the enamel surfaces of the embedded teeth were prepared for acid etching.

Intact human teeth, extracted for orthodontic reasons, were collected (no buccal caries, forceps damage from extraction, or chemical pre-treatment) and stored in a 10 per cent formaldehyde solution until use and then transferred to distilled water 4 hours before use.

The ABD was used as the new transfer device for the indirect bonding (Figure 1). This is a horseshoe-shaped instrument with seven compressed air-driven pistons. Steel wires are bent from the pistons to the brackets, which are bonded onto the model, and are attached to the brackets using a silicone-based polymer. The ABD system is positioned between the upper and lower models by means of a bite registration device.

The bite registration, which is obtained at the first appointment, is on a removable, also horseshoe-shaped, thin splint and can be fixed on the ABD system both for the working process in the laboratory and the indirect bonding of the brackets in the mouth. After releasing the brackets from the model, which are then attached to the ABD, transfer to the mouth is carried out after appropriate oral preparation (drying, cleaning, and conditioning the enamel surface) and applying an adhesive onto the bracket base.

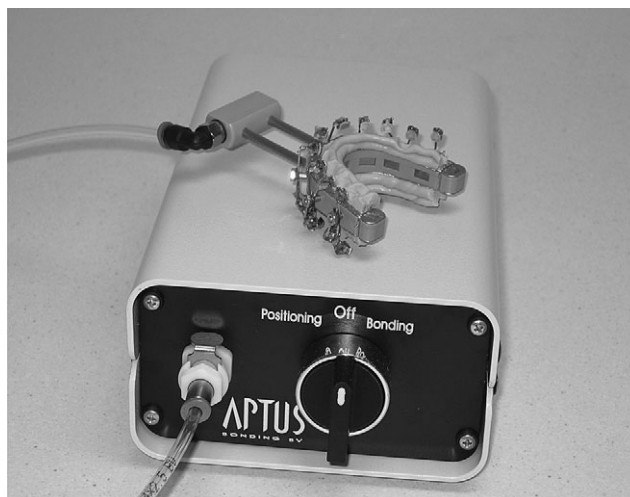


Figure 1 The Aptus bonding device.

Next, the patient bites into the bite registration device attached to the ABD. The ABD is now activated with compressed air and the brackets are pressed onto the teeth with a continuous force by means of inward moving pistons. This pressure of 6 atmospheres is equivalent to the pressure of direct bonding and does not alter the bite position in the existing occlusal impressions. After polymerization of the adhesive, the wires are moved out of the way and the ABD is removed.

The teeth were arranged in the embedding device in the shape of a dental arch and fastened with peripheral wax. The buccal surfaces of the teeth were positioned vertical to the embedding plane with the use of a protractor and embedded in self-curing acrylic (Figure 2). The brackets were attached to the plaster model by means of the parallelometer and the self-curing adhesive Concise so that the bracket wing plane lay parallel to the surface of the embedding device (Figures 3 and 4). Excess adhesive around the bracket was carefully removed. The ABD was positioned on the model using the bite registration device. The buccal surfaces of the embedded teeth were cleaned with a non-fluoride paste (pumice stone, Ernst Hinrichs GmbH, Goslar, Germany), defatted with alcohol, and prepared for the acid etching technique.

Subsequently, transfer to the working model was carried out using the bite registration device on the ABD (Figure 5). Indirect bonding was undertaken using Transbond XT after the enamel surfaces were etched with 37 per cent phosphoric acid for 20 seconds. Light curing was carried out for 12 seconds mesial and 12 seconds distal to the brackets using a light-emitting diode lamp (GCE Light, GC Europe, Leuven, Belgium; light intensity 750 mW/cm², wavelength 440–490 nm, curing time 2 × 12 seconds).

The tooth arch was then divided into individual blocks with the cut surfaces vertical to the surface of the embedding device and thus also to the bracket wing plane.

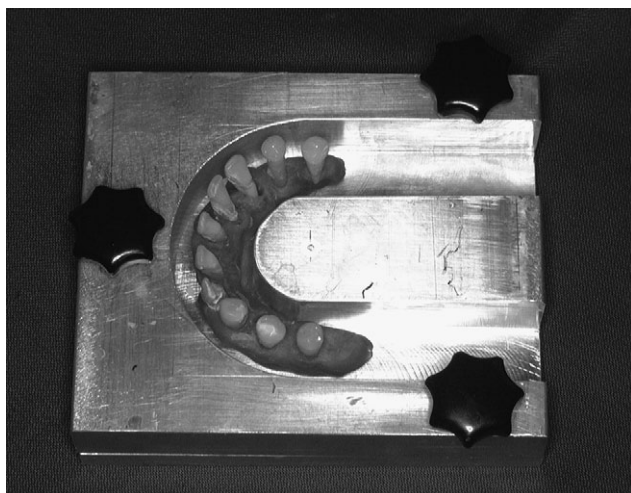


Figure 2 Teeth embedded in acrylic.

Direct bonding was carried out in two experimental arrangements, each with a different adhesive coating: (1) in an experimental series, as in the indirect method, the brackets were fastened on the plaster teeth using Concise and bonded onto the working model with the embedded teeth using Transbond light-cured adhesive (etching with 37 per cent phosphoric acid and light curing for 12 seconds mesial and 12 seconds distal to the brackets); (2) the brackets were bonded directly onto the enamel surfaces of the embedded teeth (after acid etching preparation) using Transbond XT.

The acrylic blocks were produced in the same way as previously described. SBS testing was carried out using an Instron measuring device (Shimadzu Autograph, AGS-D-Series 10 kND; Instron Corp., Canton, Massachusetts, USA) at a feed rate of 0.5 mm/minute.

By aligning the vertical surfaces of the acrylic block and the mounting device of the testing machine, 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. Bond strength was registered in Newtons and indicated as force per area in megapascals.

The accuracy of the positioning of the indirect bracket transfer was assessed by photographic superimpositioning of the bonded upper labial segment brackets on the model after indirect bonding in the mouth and by a three-dimensional (3D) measurement of the bracket positions on the working and plaster models.

Photographs of the model with the bonded brackets of the upper labial segment were superimposed on *in vivo* photographs of the same detail immediately after indirect bonding and assessed at reference points on the bite registration device. Reproducibility of the film was undertaken using a special rod on which the camera and bite registration devices were attached to one end. The plaster

model with the bonded brackets was positioned on the bite registration device and the upper labial segment brackets photographed as image detail. After indirect bonding and applying the bite registration device, the same image detail could be established again, superimposed, and visually checked by the marked reference points.

Measurement of the model was carried out using a 3D laser scan (Willy Tec, Munich, Germany), which scanned the object from above in 0.6 µm steps by means of a laser beam. The reflection of the laser beam from the object was captured by an optical measuring device and electronically evaluated in order to digitally depict the model. The 3D scanned models (working and plaster models) are shown in Figure 6. Two points were determined for each tooth on each model (mesial and distal edge of the bracket base), measured three-dimensionally and finally superimposed. As a control for the superimposition, more points (e.g. mesial and distal cutting edge) were chosen, measured three-dimensionally and superimposed in the same way.

To determine the adhesive remnant index (ARI; Årtun and Bergland, 1984), the brackets were examined under a stereomicroscope with a 10- to 66-fold magnification (Zeiss SV11; Carl Zeiss Corp., Göttingen, Germany).

Statistical analysis

Evaluation of the data was carried out using the Statistical Package for Social Sciences (version 14, SPSS Inc., Chicago, Illinois, USA). To compare groups, a one-factor analysis of variance (ANOVA) and *post hoc* tests (Tukey-HSD) were used. The level of significance was set at $P < 0.05$.

Results

The results of the SBS tests are shown in Table 1 and graphically depicted in Figure 7.

SBS using indirect and direct bonding with the same experimental arrangement (and adhesives) showed no significant differences.

Although lower values were achieved with direct bonding using Transbond, they were only statistically significantly lower for the premolar teeth (there was a difference between this group and the indirect bonding group with a significance of 0.008 after the one-factor ANOVA using the *post hoc* test and with a significance of 0.003 from the direct bonding group using Concise and Transbond). The clinically required minimum bond strength of 6 MPa was achieved in all groups. (Reynolds, 1975; Littlewood *et al.*, 2001).

Superimposition of the photographs of the labial segment brackets on the plaster model and after indirect bonding in the mouth at marked reference points showed no visual differences.

The results of the 3D measurements when the bracket positions on the working and plaster models were compared



Figure 3 Positioning the bracket using parallelometer.

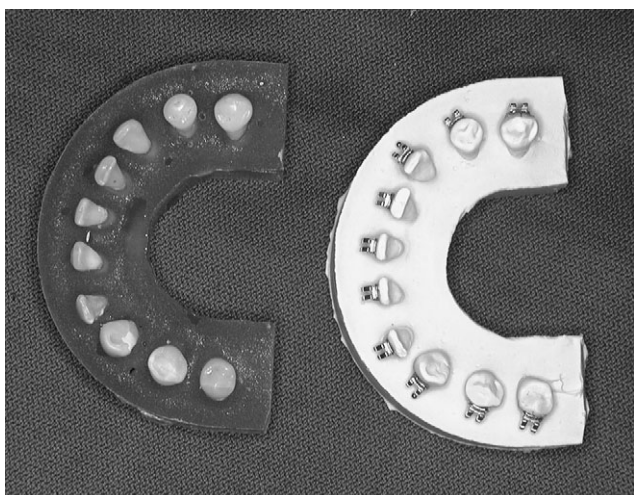


Figure 4 Working and plaster cast models.

and showed good correlation. In the *X*-axis, there was a mean deviation of 0.15 mm (minimum 0.01, maximum 0.26), in the *Y*-axis 0.17 mm (minimum 0.1, maximum 0.45), and 0.19 mm (minimum 0.02, maximum 0.3) along the *Z*-axis.

In the case of superimposition of 3D points on chosen arbitrary measuring points (e.g. mesial and distal cutting edges), there was a good correlation in all three spatial dimensions (Table 2).

To determine the mode of fracture, a modification (Oliver, 1988) of the ARI was used. The results are shown in Table 3.

Discussion

Indirect bonding offers many advantages combined with safety, especially the exact positioning of brackets. One of the main problems, however, is their transfer to the mouth with precision and sufficient adhesion.

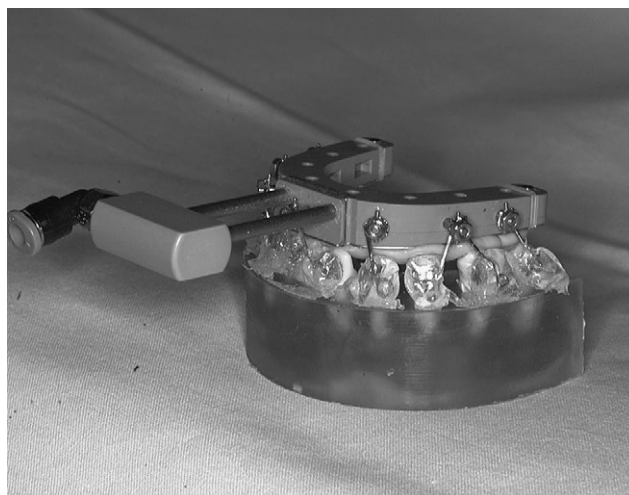


Figure 5 Bracket transfer using the Aptus bonding system and bite registration device.

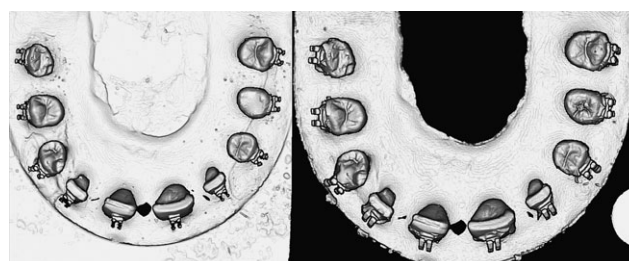


Figure 6 Scanned three-dimensional image of the models.

Currently, there are various transfer trays for indirect bonding available—opaque, translucent silicone-based polymer, and thermoplastic transfer devices (Collins, 2000; White, 2001), and it is even possible to bond a dental arch in one step using special transfer trays (Echarri and Kim, 2004). Compared with single-tooth transfer caps, these trays shorten the chairside time and result in improved moisture control of the prepared enamel surfaces and protection against respiration air. Using the ABD, it is even possible to bond both arches at the same time.

Bond strength associated with a 5 per cent bracket rate loss seems sufficient for daily clinical work. Littlewood *et al.* (2001) suggested a minimum adhesion value of 5.4 MPa, where brackets can be lost in 5 per cent of cases. Zachrisson and Brobakken (1978) determined a higher bracket rate loss with indirect bonding. On the other hand, Aguirre *et al.* (1982) reported a lower rate loss. Sinha *et al.* (1995a,b) reported a loss of 5 per cent, which corresponds to a percentage rate of 1–5, generally described in the literature, and Gia *et al.* (2003) also found no significant differences in SBS between indirect and direct bonding.

Other groups have reported no significant difference when comparing SBS between direct and indirect bonding (Hocevar and Vincent, 1988; Milne *et al.*, 1989; Shiau *et al.*, 1993a,b). Additionally, Klocke *et al.* (2004b) found

Table 1 Descriptive statistics with direct and indirect bonding using different adhesives. Indirect bonding: Concise and Transbond; direct I: Concise and Transbond; and direct II: Transbond.

	Group	N	Minimum	Maximum	Mean	SD
Anterior teeth	Indirect (MPa)	20	6.5	16.14	9.4	2.4
	Direct I (MPa)	20	6.1	14.2	9.7	2.2
	Direct II (MPa)	20	6.0	13.9	9.2	2.2
Canine	Indirect (MPa)	10	5.9	10.9	8.0	1.7
	Direct I (MPa)	10	6.8	11.7	9.3	1.7
	Direct II (MPa)	10	5.7	10.1	8.0	1.3
Premolar	Indirect (MPa)	20	6.4	11.9	8.5	1.5
	Direct I (MPa)	20	6.2	11.5	8.7	1.4
	Direct II (MPa)	20	4.4	9.7	7.1	1.3

SD, standard deviation.

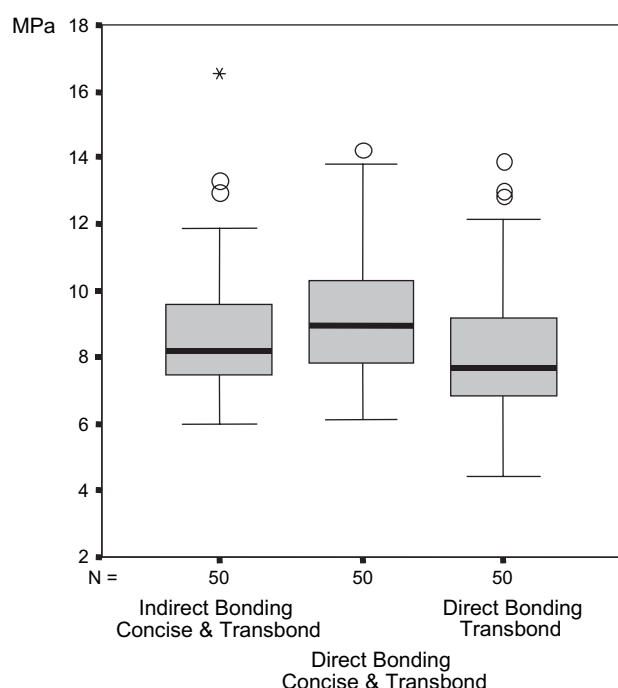


Figure 7 Bonding strengths of all teeth with indirect and direct bonding using different adhesives.

no significant difference in SBS in the bonding interval between 30 minutes and 24 hours. *In vivo* investigations have also shown no higher rate loss associated with indirect bonding (Sinha *et al.*, 1995a,b; Polat *et al.*, 2004).

The different bonding methods in these previously mentioned studies all showed sufficient SBS. With respect to the minimum SBS of 6 MPa according to Reynolds (1975) for orthodontic bonding, this was achieved. There were no significant differences between the indirect or direct bonded group. The group directly bonded with only Transbond showed slightly lower values, but these were only significant for the premolar teeth. Particularly with indirect bonding, removal of the transfer trays and direct

Table 2 Measured data of three-dimensional superimposition on plaster and working models in millimetres.

	Axis		
	X	Y	Z
MP(1)	46.88	110.20	25.36
MP(2)	46.70	110.17	25.47
Deviation	-0.18	-0.03	0.10
MP(1)	15.04	77.74	23.58
MP(2)	14.91	77.71	23.33
Deviation	-0.13	-0.03	-0.25
MP(1)	43.66	58.30	27.02
MP(2)	43.58	58.06	27.10
Deviation	-0.07	-0.23	0.09

MP, measuring point.

Table 3 Adhesive remnant index (ARI) scores with direct and indirect bonding using different adhesive coatings. V, no adhesive on enamel; IV, less than 10 per cent of adhesive on enamel; III, less than 90 per cent, but more than 10 per cent; II, more than 90 per cent, but less than 100 per cent, and V, 100 per cent adhesive on enamel.

ARI	%	Indirect bonding Concise and Transbond	Direct bonding Concise and Transbond	Direct bonding Transbond
V	0	0	0	0
IV	<0	15	21	8
III	<90	23	16	22
II	>90	12	13	20
I	100	0	0	0
Number of teeth	50	50	50	50

ligation of the first wire required a certain resistance force. Clinically observed loss of brackets may be traced back to the stress factor at removal of the transfer unit. However, with these patients, the silicone, which links the brackets with the steel wires of the ABD system, was increased to strengthen the attachment. This represents one of the disadvantages: namely, on the one hand, creating sufficient rigidity for the positional stability of the bracket and on the other, maintaining flexibility so that the removal of the transfer tray is not too traumatic or difficult. To maintain position stability, Hickham (1993) used two translucent silicone-based polymer trays with differing hardness: a 2 mm thick tray placed on a 1-mm thick tray.

The thickness of the adhesive layer is an influential factor on SBS (Jost-Brinkmann *et al.*, 1992). Whereas thicker layers are necessary in lingual bonding to balance out tooth shapes, in indirect buccal bonding the adhesive layer is kept as thin as possible. For direct bonding of brackets, the adhesive layer is kept at a minimal level by the force acting against it, while with indirect bonding this pressure is shifted to the transfer trays. Whereas a constant pressure can be

built up with single-transfer caps, this is not possible when transferring whole tooth arches. In these circumstances, the ABD system appears to be advantageous since during the bonding procedure a compressed air system of 6 atmospheres is brought to bear on the brackets.

The composite sealer layer could represent a weak spot due to the pre-cured composite layer, as has been described in repair work on composites (Boyer *et al.*, 1984; Saunders, 1990; Shiao *et al.*, 1993a). A variety of repair mechanisms between composite layers have been detailed. On the one hand, a chemical reaction between the composite resin and unsaturated molecule groups takes place on the substrate surface (Vankerckhoven *et al.*, 1982; Puckett *et al.*, 1991). The polymerization between the old substrate and new composite resin is based on free carbon double bonds of the functional group of the existing polymer matrix (Gregory *et al.*, 1990; Lastumäki *et al.*, 2002). Most covalent bonding is possible within the first 24 hours after polymerization (Saunders, 1990).

Additional mechanical bonding occurs when the monomers of the new adhesive create a penetrative network on the cured adhesive by means of a dissolving action (Lastumäki *et al.*, 2002). The probability of bonding with reactive monomers is reduced with increasing degrees of polymerization. Improved penetration on the surface, a dissolving effect and an enlargement of the polymer system has been described for unfilled or low-filled viscose composite resin (Mitsaki-Matsou *et al.*, 1991; Puckett *et al.*, 1991; Guzman and Moore, 1995; Shahdad and Kennedy, 1998; Klocke *et al.*, 2004b). In agreement with Klocke *et al.* (2002), it was shown that pre-cured composites may not always lead to lower bond strength. However, the bonding time interval of the two composite layers should not exceed 30 days (Klocke *et al.*, 2004a,b).

On the other hand, the increase in SBS is ascribed exactly to the pre-curing of a composite layer on the brackets (Tavas and Watts, 1984). This can be corroborated by results from infrared spectroscopic measurements, which showed incomplete polymerization in the case of light-cured adhesives under the bracket in the centre of the base (Wendl *et al.*, 2004).

Rebonding can be a difficulty with the ABD technique. For individual transfer caps, rebonding of brackets is relatively easy, and even in the case of silicone trays, the production of individual caps over the entire dental arches is straightforward. Rebonding is more difficult with the ABD system as there is no permanent tray to be used; thus direct bonding is required.

One significant advantage of the ABD system is that all types of bracket systems can be used. However, thermally cured adhesives, ceramic brackets, for instance, have to be separately bonded.

The accuracy of the indirect bracket transfer was assessed by superimposing the image details of the bonded labial segment brackets on the model and after indirect bonding in the mouth, and by 3D measurement of the bracket positions

on the working and plaster models. The measurement showed a mean deviation of 0.15 mm in the *X*-axis, 0.17 mm in the *Y*-axis, and 0.19 mm along the *Z*-axis. This corresponded to an extremely accurate transfer. The minimally raised maximum values in the *Y*-axis can be explained by the extra adhesive layer. However, these were values for an *in vitro* transfer. *In vivo*, soft tissue interferences could occur when bonding in the mouth is carried out. A dry-field system is required and, in addition, fluoride-releasing adhesives are recommended since surplus adhesive on the edges of the bracket cannot be avoided (Sinha *et al.*, 1995a,b).

The ARI is influenced by many factors including bracket design and tooth curvature. Diedrich (1981) reported that the fracture site is dependent on the micromechanical retention provided by acid etching, which can be different from tooth to tooth, and even for the same tooth, Ødegaard and Segner (1990) described the weakest link on metal brackets as being between the adhesive and the retentive bracket base (the retentive surface remained filled with adhesive). This applies in 40 per cent of cases of direct bonding with Transbond (owing to the mesh pad which is constantly filled with adhesive, the 100 per cent value was not used in this study). In contrast, indirect bonding with prepared composite adhesive on the bracket base principally resulted in cohesive fractures within the adhesive as a result of a breakdown in the continuity of the integration of C=C double bonds of methacrylate through different times of the curing reaction. Direct bonding in two phases (Concise and Transbond) also resulted in cohesive fractures. Whereas Sinha *et al.* (1995b) found similar fracture behaviour, Shiao *et al.* (1993b) reported fractures between the bracket and composite with both direct and indirect bonding.

Conclusion

In this laboratory investigation, the ABD was found to provide an accurate transfer method for indirect bonding of brackets. This method enables the majority of commercially available bracket systems to be bonded and allows both dental arches to be bonded in one stage. The bond strength tested *in vitro* is sufficient for orthodontic purposes and comparable with direct bonding.

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