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Influence of different tooth types on the bond strength of two orthodontic adhesive systems

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SUMMARY The aim of this investigation was to evaluate the effects of different tooth types on the shear bond strength (SBS) of two orthodontic resin adhesive systems *in vitro*.

Two hundred extracted sound human teeth were used in the study. Ten teeth of each tooth type were the mounted in acrylic resin leaving the buccal surface of the crowns parallel to the base of the moulds. In each experimental group, the adhesives (Transbond XT™ and Light Bond™) were applied to the etched enamel surfaces. The orthodontic composite resins were then applied to the surface in cylindrical-shaped plastic matrices. For SBS testing, a force transducer (Ultradent™) was applied at a crosshead speed of 1 mm/minute at the interface between the tooth and composite until failure occurred. Data were analysed using two-way analysis of variance (ANOVA), Kruskal–Wallis one-way ANOVA, a Bonferroni adjusted Mann–Whitney *U*-test, and an independent *t*-test.

Generally, it was found that tooth type had a significant effect on SBS ($P < 0.05$) with Light Bond™ showing a higher SBS than Transbond XT™ ($P < 0.05$). The highest bond strengths were observed for the upper central incisor and lower molars with Light Bond™ ($P < 0.05$) and the lowest mean bond strengths for the upper molars and lower canine with Transbond XT™ ($P < 0.05$). The results demonstrated that enamel SBS was significantly altered by both tooth type and adhesive system. Thus, the findings of this study confirm that enamel bond strength is not uniform for all teeth. These results may also explain the variability in the enamel-bonding efficacy of adhesives.

Introduction

The development of the acid etching technique by Buonocore (1955) and bonding of orthodontic brackets by Newman (1964) revolutionized the practice of clinical orthodontics. Orthodontic bonding to enamel surfaces resulted in significant improvements in treatment such as greater patient comfort, elimination of the need for pre-treatment tooth separation, decreased gingival irritation, improved oral hygiene and aesthetics, and reduced chair time (Reynolds and von Fraunhofer, 1976; Rajagapol *et al.*, 2004).

Bonding of brackets directly to the surface of teeth has become common practice; however, between 0.5 and 55.8 per cent of bonds fail (Zachrisson, 1977; O'Brien *et al.*, 1989; Hobson *et al.*, 2001; Adolfsson *et al.*, 2002 Linklater and Gordon, 2003). This may be both inconvenient and expensive for the patient and orthodontist and can compromise orthodontic treatment. A better understanding of the reasons for orthodontic bond failure may lead to improved techniques, which could reduce this constant (Hobson *et al.*, 2001). Various factors can affect bond failure, including operator technique and manual dexterity, patient behaviour, variation in the enamel surface, the type of etchant used and its duration of application, the adhesive used, bracket properties, and ligation forces (Hobson *et al.*, 2002; Murray and Hobson, 2003). Most of these factors are effective in clinical conditions. However, most studies are carried out *in vitro*. Under these conditions, variation in the enamel surface may also affect bond strength. Linklater and Gordon (2001) showed that significant differences in *ex vivo* bond strength between various bracket adhesive combinations did not correlate with clinical failure rates, which demonstrated no significant differences.

Information on the efficacy of bonding is often sought from measurements of bond strength on extracted teeth. The majority *ex vivo* bond strength testing takes place using premolars, although incisors, canines, and molars have been used (Hobson *et al.*, 2001). The results obtained from premolar testing have been interpreted as being applicable to all teeth in both dental arches. The validity of this interpretation has, however, not been proven. To date, several studies have examined whether premolar bond strengths are representative of all tooth types (Hobson *et al.*, 2001; Linklater and Gordon, 2001; Mattick and Hobson, 2000).

On the other hand, variations in enamel surface structure and their effects on bond strength of orthodontic brackets to enamel have received little attention (Hobson *et al.*, 2002). Whittaker (1982) reported that aprismatic enamel is greater in posterior than anterior teeth. The presence of aprismatic enamel might reduce the effectiveness of acid etching, resulting in reduced resin penetration and a weaker bond (Hobson *et al.*, 2002). Mattick and Hobson (2000) showed that the etched enamel surface varied between different tooth types and suggested that such differences may influence bond strength. Similarly, both Linklater and Gordon (2001) and Hobson *et al.* (2001) showed significant differences in the bond strength of different tooth types, but no significant differences between upper and lower teeth of the same type (Linklater and Gordon, 2001). Hobson *et al.* (2001), however, found statistically significant difference between upper and lower teeth of the same type.

In a number of studies (Büyükyilmaz *et al.*, 1995; Katona, 1997; Bishara *et al.*, 1998), upper and/or lower teeth of the same type are used together in the same group. In previous bracket studies (Zachrisson, 1977; Büyükyilmaz *et al.*, 1995; Katona, 1997; Bishara *et al.*, 1998), as the failures were often at the composite–bracket interfaces, the real value of the shear bond strength (SBS) to enamel of composite was not revealed. In addition, differences between tooth types *in vitro* might have an influence on the pattern and the rates of bond failure *in vivo*. The aims of this study were to determine whether these factors result in significant differences in SBS among different teeth, whether significant differences in SBS exist among the same teeth in the upper and lower arch when using two orthodontic adhesives, and whether significant differences in bond strength exist between the two different orthodontic adhesives on different tooth types.

Table 1 Mean ± standard deviation (SD) in megapascals (MPa) of shear bond strength values and statistical comparison of groups (n = 10).

Tooth type	Light bond (Mean ± SD)*	Transbond XT (Mean ± SD)*
Upper central	44.7 ± 7.8^{a}	33.8 ± 5.3^{ac}
Upper lateral	35.4 ± 6.1^{bcef}	30.8 ± 5.1^{ac}
Upper canine	36.2 ± 5.8^{acef}	28.7 ± 3.4^{bc}
Upper premolar	29.3 ± 5.3^{bdf}	25.6 ± 3.9^{bc}
Upper molar	30.9 ± 4.2^{bdf}	25.4 ± 3.7^{bc}
Lower central	32.7 ± 6.2^{bdf}	30.7 ± 5.7^{ac}
Lower lateral	31.8 ± 6.5^{bdf}	27.9 ± 5.2^{bc}
Lower canine	34.3 ± 4.6^{bdef}	25.6 ± 4^{bc}
Lower premolar	41.4 ± 6.1^{ace}	38.4 ± 4.1^{a}
Lower molar	43.4 ± 6.4^{ac}	39.2 ± 5.2^{a}

*Mann–Whitney U-test adjusted using Bonferoni's correction, means having the same letter in the same column are not statistically different from each other ($P > 0.05$).

Materials and methods

Ten sound teeth of each tooth type (upper and lower central incisor, lateral incisor, canine, premolar, and molar) extracted from patients between 13 and 40 years of age, for mainly orthodontic and periodontal reasons, were tested within 6 months of extraction. The tooth types are shown in Table 1. The teeth were stored at +4°C in a physiological saline solution until use. Teeth with hypoplastic areas, cracks, or gross irregularities of the enamel structure were excluded from the study. The criterion for tooth selection was no pre-treatment with a chemical agent such as alcohol, formalin, hydrogen peroxide, etc. Soft tissue remnants and calculus were removed from the teeth, following which they were cleaned with fluoride-free pumice and a rubber cup.

The roots of the teeth were cut off with a water-cooled diamond disk. The crowns were mounted in a 3cm diameter circular mould using chemically cured acrylic resin (Vertex, Zeist, The Netherlands). The labial of the tooth surfaces were perpendicular to the long axes of the moulds (Figure 1a). Prior to bonding, the labial surface of each tooth was polished for 1 minute with a combination of a polishing agent and a brush at a low speed (3000 rpm) using a micro motor.

The teeth were distributed into 20 experimental groups, each containing 10 teeth. The teeth were etched with 37 per cent orthophosphoric acid gel (3M Dental Products, St Paul, Minnesotta, USA) for 30 seconds, rinsed with water for 15 seconds, and dried with oil-free air for 10 seconds until a frosty white appearance of the etched enamel was observed.

For each experimental group, an orthodontic adhesive primer (Transbond XT™, 3M Unitek, Monrovia, California, USA or Light Bond™, Reliance Orthodontic Products, Itasca, Illinois, USA) was used and light cured in all groups. An orthodontic composite resin (Transbond XT™ adhesive paste or Light Bond™ paste) was added to the surface by packing the material into cylindrical-shaped plastic matrices with an internal diameter of 2.34 mm and a height of 3 mm (Ultradent™, South Jordan, Utah, USA) (Figure 1b). Excess composite was carefully removed from the periphery of the matrices with an explorer. The composite was cured with a curing light (Hilux™, Benlioğlu Dental, Ankara, Turkey) for 20 seconds. The intensity of light was at least 400 mW/cm^2. The specimens (Figure 1c) were then stored in distilled water at 37°C for 24 hours before bond strength testing. For SBS testing, the specimens were mounted in a universal testing machine (Model 500, Testometric, Rochdale, Lancashire, UK) (Figure 2). A force transducer (Ultradent™) attached to a compression load cell and travelling at a crosshead speed of 1 mm/minute was applied to each specimen at the interface between the tooth and composite until failure occurred. The notched blade was placed directly over the resin stub flush against the tooth. The maximum load (N) was divided by the cross-sectional area of the bonded composite posts to determine SBS in megapascals.

Figure 1 (a) The labial surface of one sample, (b) application apparatus of orthodontic composite on the enamel surface, and (c) the orthodontic composite block over enamel.

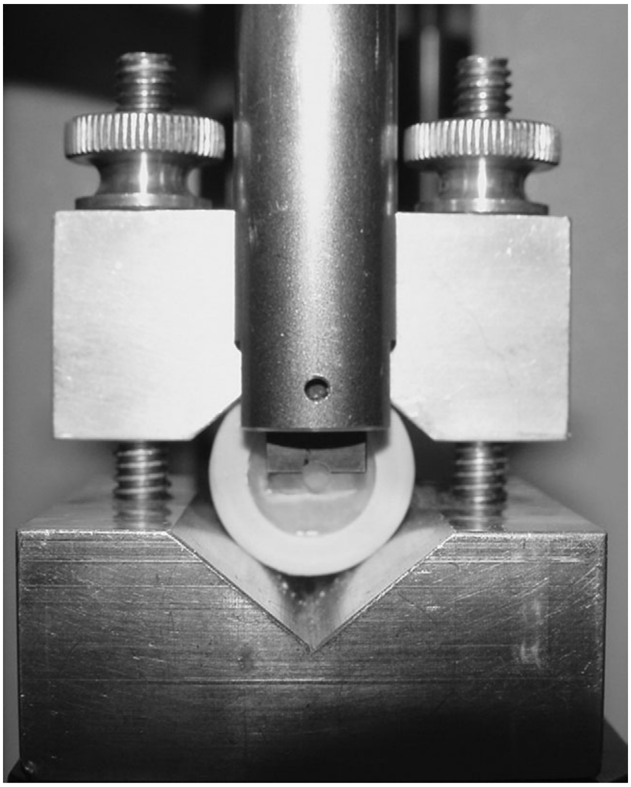

Figure 2 Application of force on the composite block.

Fracture analysis

Fracture analyses were performed using an optical stereomicroscope (Olympus™ SZ4045 TRPT, Osaka, Japan). Failures were classified as cohesive if more than 80 per cent of the resin remained on the tooth surface, adhesive if less than 20 per cent of the resin remained on the tooth surface, or mixed if certain areas exhibited a cohesive and other areas an adhesive fracture (Sengun *et al.*, 2002).

Statistical analysis

Descriptive statistics including means and standard deviations (SDs) were calculated for each group of teeth. The two factors (tooth type and adhesive) were analysed using two-way analysis of variance (ANOVA). A Kruskal–Wallis one-way ANOVA was used to determine differences in SBS between the groups at a significance level of $P \leq 0.05$. Pairwise comparisons between tooth types were performed using Bonferoni's adjusted Mann–Whitney *U*-test for each adhesive because of the inhomogeneities in variance ($P \leq 0.05$). As 36 pairwise comparisons were conducted on the same samples, the Type I error was adjusted using Bonferoni's correction, where $a = 0.05$ was divided by the number of tests (36) and the level of significance was set to 0.001. An independent *t*-test was used for general comparisons between teeth in the upper and lower arch and the adhesives.

Results

The descriptive statistics for each group are presented in Table 1 and Figure 3. Generally, it was found that both tooth type and adhesive had a significant effect on SBS ($P < 0.05$) with Light Bond™ showing a higher SBS than Transbond XT™ ($P < 0.05$). Generally, there were no significant differences between the bond strength values for the upper and lower arch teeth ($P > 0.05$). However, in the upper arch, while the anterior teeth (incisors and canines) exhibited greater bond strengths than the posterior teeth (premolars and molars), in the lower arch, the anterior teeth showed weaker bond strengths than the posterior teeth for both adhesive systems ($P > 0.05$). The highest mean bond strengths were found for the upper central incisor with Light Bond™ (44.7 ± 7.8 MPa) and the lowest for the upper molar teeth bonded with Transbond XT™ (25.4 ± 3.7 MPa).

The results of the Kruskal–Wallis ANOVA revealed significant differences in SBS among the various groups tested for both Light Bond™ and Transbond XT™ ($P < 0.05$). When the same tooth type in the upper and lower arch was compared, upper central from lower central, upper premolar from lower premolar, and upper molar from lower molar, there were significant differences for Light Bond™ ($P < 0.001$). Similarly, for Transbond Bond XT™, there were significant differences between both upper and lower premolars and also between upper and lower molars

($P < 0.001$). Other teeth of the same type did not show significant differences between each other ($P > 0.05$).

The fracture patterns of the specimens are shown in Table 2. In general, the greatest percentage of fractures was at the enamel–composite interface for both adhesive systems (85%). While Light Bond™ system showed adhesive (84%), mixed (10%), and cohesive (6%) failure patterns, Transbond XT™ exhibited adhesive (86%), mixed (0%), and cohesive (4%) fracture types.

Discussion

In the present study, the SBS of two orthodontic adhesives used to bond different tooth types in the upper and lower arch were measured after 24 hours. The results showed that enamel SBS was significantly affected by both tooth type and adhesive system. This finding is in agreement with Hobson *et al.* (2001) and Linklater and Gordon (2001), although the methodology was different. Those authors used brackets and found that the most frequent type of failure was adhesive type at the composite–bracket interface. Their results hinder determination of the real value of SBS at the enamel–composite interface. Bracket base design may contribute to the misalignment of load application during testing, making the bonding system prone to failure at the resin and enamel interface under brackets (Arici and Minors, 2002). It has also been found that variability exists among manufacturers with respect to the design or dimensions of the brackets in nominally identical prescriptions (Büyükyilmaz *et al.*, 1995). This variability poses a significant problem in studies evaluating bond strength (Katona, 1997). Since the thickness of the adhesive layer is small, the tips of the SBS test blades cannot be accurately placed once the force is applied. The tips of the test blades may deviate towards the joint between the adhesive and bracket base or between the adhesive and enamel, which may significantly affect the results. Blunting of the blades during use, particularly pointed blades, would have an increasing effect on the force level applied on later specimens (Arici and Minors, 2002). For these reasons, in the present study, orthodontic adhesives were applied directly to the enamel surfaces using a special apparatus and shear force was directed at the composite–enamel interfaces until fracture occurred. Since the main type of failures were adhesive (Light Bond™, 84% and Transbond XT™, 86%), the actual SBS between enamel and adhesives could be measured. In orthodontics, it is desirable that bond failure occurs at the enamel–adhesive interface facilitating simpler and quicker subsequent bracket replacement (Toledano *et al.*, 2003). Moreover, the cleaning procedures to remove adhesive remnants are always accompanied by a degree of enamel loss (Bishara *et al.*, 2000; Vicente *et al.*, 2004).

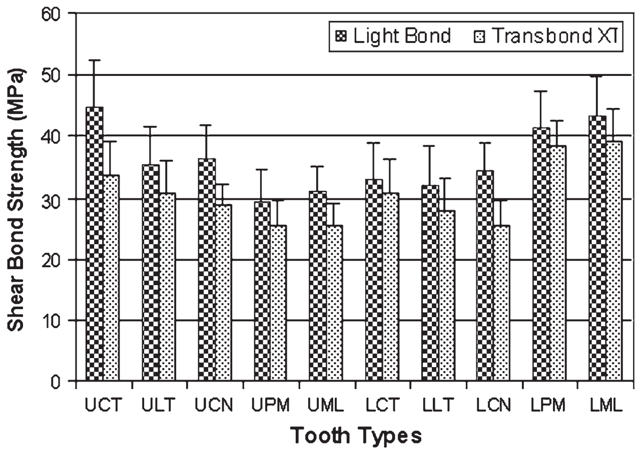

Figure 3 Mean shear bond strength values of Light Bond™ and Transbond XT™ to buccal enamel of different tooth types. UCT, upper central; ULT, upper lateral; UCN, upper canine; UPM, upper premolar; UML, upper molar; LCT, lower central; LLT, lower lateral; LCN, lower canine; LPM, lower premolar; LML, lower molar.

Table 2 Modes of failure after shear bond testing.

Tooth type	Light bond A/CC/CE	Transbond XT A/CC/CE
Upper central	7/2/1	7/2/1
Upper lateral	9/1/0	8/1/1
Upper canine	9/1/0	9/1/0
Upper premolar	8/1/1	9/1/0
Upper molar	9/1/0	10/0/0
Lower central	8/0/2	8/1/1
Lower lateral	8/1/1	9/1/0
Lower canine	9/1/0	10/0/0
Lower premolar	9/1/0	8/1/1
Lower molar	8/1/1	8/2/0

A, adhesive; CC, cohesive composite, CE, cohesive enamel.

In the upper arch, the finding that anterior teeth exhibited a significantly higher SBS than posterior teeth is in agreement with the results of Hobson *et al.* (2001) but not with the study of Linklater and Gordon (2001), who found that upper incisors demonstrated a significantly lower mean SBS than all other teeth. Whittaker (1982) observed that prismless enamel was more common on posterior than anterior teeth and Kodaka *et al.* (1991) suggested that prismless enamel showed a poor quality etch pattern. Similarly, Mattick and Hobson (2000), in an *in vitro* examination of the etch pattern achieved on the orthodontic bonding area of different tooth types to compare the extent and definition of etch achieved, reported that anterior teeth showed a better etch pattern than posterior teeth. This may be partly responsible for the high bond strength of the upper anterior teeth, although the relationship between etch pattern and bond strength is not entirely clear (Hobson *et al.*, 2001).

Surprising results were found in the present study for the lower arch, with anterior teeth showing a lower SBS than posterior teeth for both Light Bond™ and Transbond XT™.

Hobson *et al.* (2001) also found the same results with Transbond XT™ in the lower arch. The lower first molar, with more prismless enamel, showed the highest SBS for Transbond XT™ in both studies. These findings demonstrate that acid etching is not the only reason for insufficient enamel SBS. Normally, etching increases the wettability of the surface and facilitates the penetration of the resin into the enamel. A mechanical bond is formed between the resin adhesive and the enamel (Retief *et al.*, 1986). In enamel bonding, forming of qualified bonding areas, the 'hybrid layer' as in dentinal bonding, is important. The hybrid layer is responsible for micromechanical bonding. While micromechanical interlocking is believed to be a prerequisite to achieving good bonding clinically, the potential benefit of an additional chemical interaction between functional monomers and tooth substrate components has recently gained attention (Van Meerbeek *et al.*, 2003). Chemical bonding is connected to both enamel content and the chemical characteristics of the material. After acid etching, the mineral content of demineralized enamel is the primary factor in chemical bonding. Some adhesives are reported to provide a strong chemical bond strength to both enamel and dentine. It is, however, currently not known how much chemical interaction contributes to actual bonding effectiveness, i.e. the ratio of chemical bonding to eventual 'total' bonding effectiveness must be regarded as arbitrary since differences in substrate properties such as roughness, stiffness, etc., between the hydroxyapatite and enamel specimens are ignored (Van Meerbeek *et al.*, 2003). Consequently, this may explain why the bond strength produced by Light Bond™ was significantly greater than that of Transbond XT.

Linklater and Gordon (2001) claimed that the differences in SBS with tooth types may be related to gross anatomical variability. They reported that certain tooth types might have greater morphological variation than others, thereby generating a more variable adhesive film thickness, and alter bond strength characteristics.

In the present study, it was generally found that the bond strength produced by Light Bond™ was significantly greater than that of Transbond XT™. However, this difference was only statistically significant for the upper incisors. Vicente *et al.* (2004) observed, for premolar teeth, that Light Bond™ showed higher bond strengths than Transbond XT™. This is contrary to the findings of the present study. Oesterle *et al.* (2002) also found statistically significant differences when using SBS with different lights and exposure times to bovine mandibular incisor teeth after application of Light Bond™ or Transbond XT™. These variations among the studies may be due to different methodology and operator technique.

Significant differences were also found in SBS between the upper and lower centrals, the upper and lower premolar teeth, and the upper and lower molar teeth for Light Bond™ in the present study, when the same tooth type in the upper and lower arch was compared. For Transbond Bond XT™, there were significant differences between both the upper and lower premolars and the upper and lower molars. These findings are similar to those of Hobson *et al.* (2001), who noted significant differences in bond strength between upper and lower premolars and between molars for Transbond XT™. Similarly, in this study, upper molars showed the lowest SBS while the lower molars exhibited the highest SBS. The results suggest that bond strength studies should be performed using the same tooth type from either the upper or lower arch (Hobson *et al.*, 2001).

Reynolds and von Fraunhofer (1976) investigated the minimum bond strength values required in direct orthodontic bonding systems with bracket placement and confirmed that bond strengths of 5.9–7.8 MPa are clinically acceptable, although in the present study the test materials were not used with brackets. The SBS values achieved showed favourable results, in agreement with those recommendations. Clinical conditions may differ significantly since in an *in vitro* study the test conditions have not been subjected to the rigours of the oral environment (Bishara *et al.*, 1998). Heat and humidity in the oral cavity are highly variable. Posterior teeth are also exposed to higher masticatory forces *in vivo*. According to the results of several *in vivo* studies (Adolfsson *et al.*, 2002; Hobson *et al.*, 2002; Linklater and Gordon, 2003; Summers *et al.*, 2004), posterior teeth show a higher rate of bond failure than anterior teeth due to higher masticatory forces and difficulties with moisture control during bonding. Because of the probable differences *in vivo* and *in vitro* as well as the method of testing, a direct comparison cannot be made with the findings of the studies of Malkoc *et al.* (2005) and Demir *et al.* (2005).

Conclusions

1. The results show that enamel SBS is significantly changed with both tooth type and adhesive system. The findings confirm that enamel bond strength is not uniform for all teeth. These results may also explain the variability in enamel bonding efficacy of adhesives despite the same procedures being used.
2. For some tooth types, there were significant differences between the bond strength values of teeth in the upper and lower arch. To obtain reliable results in enamel bond strength studies, the same tooth type from the upper or lower arch should be used.
3. Generally, both adhesive systems provided adequate bond strength to enamel. However, Light Bond™ showed a higher SBS than Transbond XT™ for some tooth types.
4. As the bond failures were mainly adhesive, the SBS values of the two orthodontic adhesives, Light Bond™ and Transbond XT™ to enamel, were confirmed.

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