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Bond Strengths of Metal, Ceramic and Polymer Brackets in Combination with Different Enamel Preconditioning Methods

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Abstract

Introduction: Adhesive technology is widely spread throughout the different specialities of dentistry. In orthodontics the bonding of brackets accounts for a significant percentage of time in practice routine. Bond strength is dependent on several factors such as enamel conditioning, adhesive technology and the material and construction of the bracket base. It was the intention of the present study to investigate the bond strength in relation to the above mentioned parameters.

Method: Four different brackets (metal, ceramic, polymer, fiber reinforced polymer) were evaluated for their bond strength during tensile testing witha universal testing machineusing a conventional composite (Transbond MIP, XT) and in the case of the fiber reinforced bracket additionally a specially designed adhesive (Quick-Bond). Enamel conditioning was achieved with conventional etching, air-abrasion or a combination of both techniques. ARI (adhesive remnant index) scores were evaluated.

Results: There were significant differences between the types of enamel conditioning. All brackets showed significantly lower bonding forces when the enamel was prepared with air-abrasion alone. Metal brackets had the highest bonding strength and the fiber reinforced composite brackets with the conventional adhesive the lowest. The ARI scores showed good correlation to the bonding forces, with low bonding forces presenting as a detachment at the enamel-adhesive interface.

Conclusion: Air-abrasion alone showed significantly lower bonding forces than enamel conditioning with etching for all bracket types. This finding was independent of the bracket material, base design or adhesive system.

Keywords: Air-abrasion; Etching; Bonding; Tensile testing

Introduction

The introduction of adhesive systems for orthodontic bonding has dramatically decreased a time consuming step in fixed appliance therapy. Since the introduction of the adhesive technology by Buonocore [1] in 1955 and the first report of its use in bracket placement by Newman [2] in 1964, there have been considerable developments in all areas. Enamel etching was first performed with 80% phosphoric acid but soon changed to a 37% solution, which was routinely accepted by the end of the last millennium. Subsequently the introduction of self-etching primers has again brought a dramatic change in etching technology. Not only were new etching agents such as polyacrylic acid and maleic acid introduced [3-5], but the etchant was combined with the low viscosity composite matrix which potentially enhanced the penetration of the etching relief. Alongside the etchants, adhesives have also evolved. Whereas initially Newman [2] advocated the use of an epoxy resin, polyacrylic resins filled with different anorganic fillers are more commonly used today [6]. Finally the use of new materials in bracket manufacturing, such as different ceramics and polycarbonates also emphasizes the ongoing development and research in adhesive technology.

Air-abrasion has been proposed as a possible means of enhancing bond strength. It has been successfully applied to bands [7,8], brackets [9-11], lingual retainers [12] and for the re-use of failed brackets [13]. However results for enamel conditioning seem to be controversial for either air abrasion alone [14,15] or a combination of air abrasion and etching [14-17]. A clinical concern is the amount of irreversible enamel loss during the conditioning procedure. Both treatments, etching and air-abrasion were shown to induce similar substance loss [17]. However whereas air-abrasion leads to an unselective reduction of enamel, etching leaves organic structures intact, which might later remineralize [16].

The intention ofthe present study was to investigate the adhesion of metal, ceramic and plastic brackets in a tensile test when using different enamel conditioning methods such as air-abrasion, etching and a combination of both.

Material and Methods

225 bovine mandibular incisors were extracted and stored in a Ringer solution at 37°C. After separating the crown from its root, it was embedded in a cold hardening polymer (SR3/60 Quick, IvoclarVivadent, Ellwangen, Germany) with the buccal surface freely exposed from the polymer. The teeth were then grouped according to the four bracket types and three conditioning methods. Metal brackets (Mini Mono™, Forestadent, Pforzheim, Germany), ceramic brackets (Clarity™, 3MUnitek, Monrovia, USA) conventional polymer brackets

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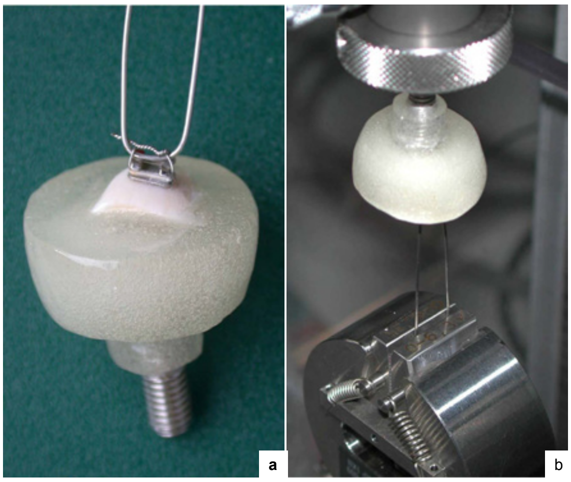

Figure 1: Tooth embedded for tensile testing with a bracket bonded on the labial surface and a round steel wire ligated with a stainless steel ligature (a). The samples were mounted on an Instron 4444 (b).

(Elegance™, Dentaurum, Ispringen, Germany) and fiber reinforced polymer brackets(Brilliant™, Forestadent, Pforzheim, Germany) were used in combination with a conventional adhesive (Transbond MIP™ and Transbond XT™, 3MUnitek, Monrovia, USA). In addition the bases of the polymer brackets were activated with a plastic primer (Grundierer 163-500-00, Dentaurum, Ispringen, Germany). A fifth bracket group consisted of the fiber reinforced Brilliant bracket bonded with Quick-Bond(Quick-Bond™, Forestadent, Pforzheim, Germany), a chemically cured adhesive designed for polymer brackets. The last group will be referred to as Brilliant+.

All teeth were pumiced, rinsed with water and dried with a blast of air.In the conventional etching group, a 37% phosphoric acid (Unitek etching gel 712-039, 3M Unitek, Monrovia, USA) was applied to the enamel for 15 seconds before it was rinsed and dried again. The air-abrasion group was prepared, using a KAVO handpiece(Rondoflex 2013, KAVO, Biberach, Switzerland) with 50µ Al_2O_3 particles for 2 seconds at a distance of 5 mm, followed by thorough rinsing and drying with air. For the combined group of etching and air-abrasion, the techniques were used as described above with etching following air-abrasion. SEM images (ESEM, Philips 30, Royal Philips Electronics, Netherlands) of the enamel surface of one single tooth were taken after preparation with the three enamel conditioning methods.

Transbond MIP was applied to the enamel with a micro brush and left for 15 seconds before being dispersed with a gentle stream of air. The primer was pre-cured for 5 seconds with a diode lamp (ORTHOLUX™ LED Curing Light 3M Unitek, Monrovia, USA.). Transbond XT adhesive was then applied to the bracket bases and the brackets were pressed firmly the teeth with the bracket positioning pliers. Excess composite was carefully removed and the samples were cured for 30 seconds. For the Brilliant+ group, Quick-Bond primer was applied to the bracket base and the enamel. Quick-Bond adhesive was then applied to the bracket base and the bracket was positioned on the tooth. Excess adhesive was again carefullyremoved and the brackets were left undisturbed for 10 minutes.

For tensile testing, the polymer blocks with the embedded teeth were mounted on the Instron 4444 (Instron Corp., Wilmington, Delaware, USA). A round steel wire (0.02“ diameter) was ligated with steel ligatures to the brackets. Mesial and distal to the slot, the steel wire was bent in a 90° angle, to allow the mounting mechanism ofthe Instron to hold both ends of the wire (Figure 1). Before testing, the specimens were again stored for 48 hours in 37°C ringer solution. The Instron was programmed with a crosshead speed of 0.1mm/sec.

All data was evaluated for normal distribution (Shapiro-Wilk test). Descriptive statistics were calculated including mean and standard deviations. A parametric paired t-test was applied to all groups with Origin Pro 6.1 software. The level of significance wasset to p= 0.05.

In addition the bonding interface was examined under 10x magnification using an ARI (adhesive remnant index) score [18], which identified 3 classes: ARI 1) < 10% adhesive remaining on the bracket, ARI 2) cohesive fracture, or equal distribution of adhesive, ARI 3) < 10% adhesive remaining on enamel.

Results

Tensile bond strength, ARI scores and statistical significance amongst the three pre-conditioning methods are given in Table 1. Table 2 shows the significances between the bracket types evaluated according to the three pre-conditioning methods.

Conventional etching

Bond strength of the MiniMono bracket was 4.9 MPa and significantly higher than the values for Clarity (3.2 MPa), Elegance (3.7 MPa) or Brilliant (3.45 MPa), which showed no significant inter-group difference. Although the values for Brilliant+ (4.3 MPa) were significantly lower than for MiniMonothey were also significantly higher than for the other remaining groups (Figure 2).

Air-abrasion

Within the Air-abrasion group, all brackets reacted only low levels of bond strength. The lowest bond strengths were found for Brilliant (1 MPa), which were significantly lower than for MiniMono (1.7 MPa), Clarity (2.1) or Elegance (1.9 MPa). The difference between Clarity and Elegance was significant as well. The Brilliant+ group (2.3 MPa) showed bond strengths comparable to MiniMono and Clarity and significantly higher than Elegance (Figure 3).

		MiniMono	Clarity	Elegance	Brilliant	Brilliant+
Etching	**MPa** **ARI**	4.89 +/- 0.63 1 (15)	3.24 + /-0.47 1 (14), 3(1)	3.66 + /-0.97 1 (14), 2(1)	3.45 + /-0.34 1 (13), 2(2)	4.3 + /-0.54 1 (15)
Air-abrasion	**MPa** **ARI**	1.69* + /-0.58 3(15)	2.05* + /-0.49 3(15)	1.89* + /-0.3 3(15)	0.99* + /-0.51 3(15)	2.32* + /-0.83 3(15)
Air-abrasion + etching	**MPa** **ARI**	5.21 + /-0.63 1 (15)	3.48 + /-0.43 1 (15)	4.21 + /-1.28 1 (12), 2(3)	3.78 + /-0.56 1 (15)	4.31 + /-0.54 1 (14), 3(1)

Table 1: Mean bond strengths in MPa, standard deviations and ARI scores. Significant differences (p<0.05) between the bond strength of the three pre-conditioning methods within one bracket type are marked with an asterisk "*".ARI score for tensile testing: 1 = composite remaining on the enamel, 2 = composite remaining on both sides, 3 = composite remaining on the bracket. The number of samples displaying a certain ARI score is given in parenthesis.

Air-abrasion and etching

MiniMono brackets (5.2 MPa) showed significantly higher values than all other groups. Brilliant+ (4.3 MPa) had significantly higher bond strengths than Clarity (3.5 MPa) or Brilliant (3.8 MPa). Elegance (4.2 MPa) was not significantly different from Brilliant+ (Figure 4).

Bond strength according to bracket type

Looking at the different conditioning methods for one bracket type, the following results were found. Shear forces for MiniMono were

	Clarity	Elegance	Brilliant	Brilliant+
MiniMono	e, +	e, +	e, a, +	e, +
Clarity		a,	a	e, +
Elegance			a	e, a
Brilliant				e, a, +

Table 2: Statistical significance ($p<0.05$) between the bracket types in relation to the three pre-conditioning methods. A significant difference between brackets is marked with ***e*** for conventional etching, ***a*** for air-abrasion and **+** for air-abrasion+etching.

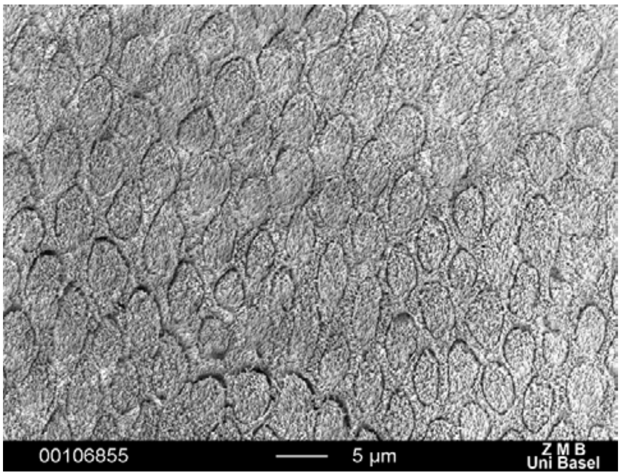

Figure 2: SEM image of an enamel surface etched for 15 s with 37% H_3PO_4.

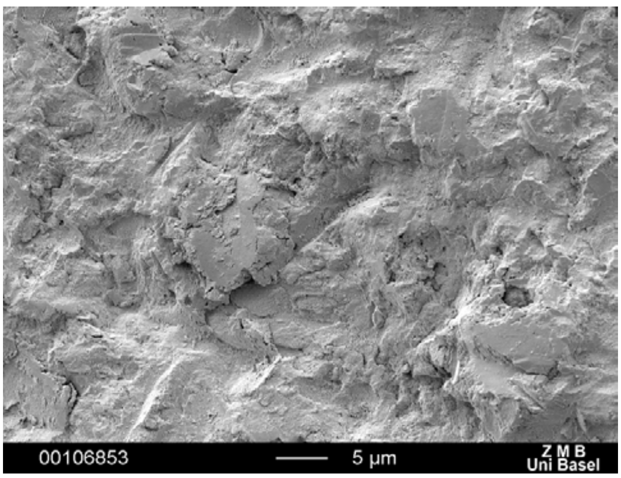

Figure 3: SEM image of an enamel surface after air abrasion with 50µ Al_2O_3 particles.

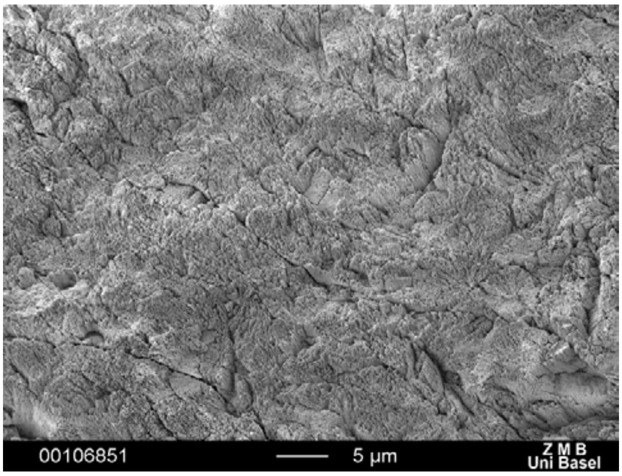

Figure 4: SEM image of an enamel surface after air abrasion with 50µ Al_2O_3 particles and additional etching with 37% H_3PO_4 for 15 s.

significantly higher with etching (4.9 MPa) and air-abrasion+etching (5.2 MPa) than for air-abrasion alone (1.7 MPa). The same was true for the Clarity bracket with 3.2 MPa, 3.5 MPa and 2.1 MPa, the Elegance bracket with 3.7 MPa, 4.2 MPa and 1.9 MPa, the Brilliant bracket with 3.5 MPa, 3.8 MPa, 1 MPa, as well as the Brilliant+ bracket with 4.3 MPa, 4.3 MPa, 2.3 MPa respectively.

ARI scores

In correlation to the bond strength, a clear distinction was found between the conditioning methods involving etching and the air-abrasion alone. With few exceptions the fracture occurred between the bracket base and the adhesive for the first group and between the enamel and the adhesive for the latter. For the MiniMonobracket this was true in all cases. Clarity showed one fractureline in the etching group which left adhesive on the bracket base. For the Elegance bracket, four of the 45 samples did not adhere to the described fracture characteristics. One probe of the etching group and three of the air-abrasion+etching showed adhesive partially remaining on the bracket base. The same stands true for two of the etched Brilliant specimens. One of the Brilliant+ samples conditioned with air-abrasion+etching failed in the adhesive-enamel interface.

Discussion

Adhesive technology has been one of the major developments in dentistry in the last century and has become a cornerstone for modern dentistry in all specialities. Since its introduction by Buonocore in 1955, constant research and development has led to the current adhesives and their recommended handling. The reliability of the bonding of adhesive and bracket to enamel is thereby influenced by many parameters such as enamel conditioning, the adhesive itself as well as the material and surface treatment of the bracket base.

Today a 37% solution of phosphoric acid is the standard [19,20]. This leads to a decalcification of the tooth surface, leaving a highly retentive relief with pores and ridges of intact enamel [21-23]. Air-abrasion is another method, which was first used to roughen and increase the bonding surface of extra oral materials as bracket bases, wires or bands [7,12,13,15] but it has also been proposed for the conditioning of enamel [16,17,24,25]. Abrasive particles (mostly Al_2O_3 50 my) are shot at high velocity (20m/s) towards the tooth surface and consequently abrade the enamel, leaving a roughened relief with indentions, which correspond to the impact craters of the Al_2O_3 particles.

Both techniques result in loss of enamel [26,27]. Acid etching has been described as leaving fissures of an average depth of 80µ [16]. It is probable that composite resin remains in the fissures after debonding and this might lead to enamel discoloration. As acid etching selectively dissolves the non organic parts of the enamel, the organic areas are left in place and might play a role in the remineralisation of etched enamel [17]. In contrast air-abrasion leads to a more uniform and permanent loss of enamel [16]. The amount of enamel loss with air-abrasion however can be controlled by the operator by usinglow pressure and a short application time [28].

In the present investigation the bond strength following air-abrasion was clearly below the minimum recommended values for bonding orthodontic attachments [29,30]. Only the metal brackets in combination with etching and air-abrasion+etching, attained values close to those recommended by the above mentioned authors. The other combinations,using different bracket materials (except Brilliant) and enamel conditioning involving etching and conventional composite showed detachments under tensile forces at approximately half the recommended values. The low detachment forces registered in this study are probably due to the test setting. In contrast to most studies [14,16,17] a tensile not shear test was chosen. Shear testing implies that the line of force is parallel to the tooth surface. In most cases during mastication this is probably the case. However when engaging a wire into the bracket slot, very often a tensile force with a force vector at 90° angle to the enamel surface is applied. This situation can also occur when food particles are pressed between tooth and archwire as a result of masticatory forces. Some authors have studied the relationship of the bonding force to the force vector [31,32]. It has been found that bonding forces can vary more than threefold when changing the force-vector by 60° from shearing to tension [32] and twofold when applying torsional moments rather than a unidirectional shear force to the bracket [31]. It is probable that such forces can occur in the clinical setting and this might explain isolated detachments of single brackets within the arch. From this point of view it is questionable whether shear force testing is relevant in orthodontic bonding, as the force vector of least resistance is a tensile one. In addition, other aspects related to bond failure are often not considered in shear testing. One is the distance between the force vector and the adhesive interface. A large distance results in a greater peel rather than a shear force. A second is the positioning of the bracket in the apparatus for the shear testing. It is almost impossible to exclude the possibility that the shear force does not load the tie wings of the brackets asymmetrically. This can lead to rotational moments, thus again interfering with the true mode of shear testing. The wide range of standard deviations often observed in shear testing [33-39] might be due to the above mentioned criteria.

The highest bonding forces were found in combination with the metal brackets. However the bracket material was less important when considering bonding strength than the chosen pre-conditioning of the enamel. Only the fiber reinforced Brilliant bracket bonded with the conventional Transbond MIP/XP adhesives showed bonding forces clearly less the other brackets. However when used in combination with the specially designed chemical adhesive these differences could be eliminated. The bonding forces showed good correlation to the ARI scores with fracturelines occurring in the bracket-adhesive interface for high bonding forces and in the enamel-adhesive interface for low bonding forces. This implies, that with air-abrasion alone,as a weak pre-conditioning method, or a contamination of the etched area during bonding, the plane of least resistance lies at the interface between enamel and adhesive. Thus the bracket adhesive interface is not important for the overall success in bonding. On the other hand, with conventional acid etching, the bonding forces between enamel and adhesive exceed the strength of the adhesive - bracket interface. Therefore future research should concentrate on the improvement of the adhesion of composite materials to the bracket bases.

Clinically a conventional preconditioning of enamel with 37% phosphoric acid can still be recommended. Metal brackets yielded the highest bond strengths in tensile testing and care must be taken when combiningpolymer brackets with conventional adhesives.

Conclusion

The study clearly shows disadvantages for air-abrasion when compared to conventional etching and a combination of air-abrasion and etching. The inadequacy of air-abrasion can not only be observed in respect to bonding forces, but also in the occurrence of the fracture-line, which was evaluated by an ARI score.

The combination of diverse bracket types with a conventional composite showed that not all systems are compatible. In particular the fiber-reinforced polymer bracket Brilliant showed very low bond strengths with the Transbond XT composite. The use of a special adhesive (Quick-Bond) eliminated this disadvantage.

Tensile testing for bracket bond strength is less common than shear testing and leads to lower mean forces than comparable shear force investigations. However tensile stresses are relevant as they might occur at the adhesive interface and explain unexpected failures.

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