Original Article

Shear bond strength of orthodontic brackets to enamel after application of a caries infiltrant

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ABSTRACT

Objective: To examine differences in the shear bond strength of orthodontic brackets on differently mineralized enamel surfaces after applying a caries infiltrant or conventional adhesive.

Materials and Methods: A total of 320 bovine incisors were assigned to eight pretreated groups, and the shear force required for debonding was recorded. Residual adhesive was evaluated by light microscopy using the adhesive remnant index. Statistical analysis included Kolmogorov-Smirnov, analysis of variance (ANOVA), and Scheffé tests.

Results: The highest bond strength (18.8 ± 4.4 MPa) was obtained after use of the caries infiltrant. More residual adhesive and fewer enamel defects were observed on infiltrated enamel surfaces. Brackets on demineralized enamel produced multiple enamel defects.

Conclusions: Acceptable bond strengths were obtained with all material combinations. A caries-infiltrant applied before bracket fixation has a protective effect, especially on demineralized enamel. (*Angle Orthod.* 2015;85:645–650.)

KEY WORDS: Shear bond strength; Caries infiltrant; Demineralization; Brackets

INTRODUCTION

Fixed orthodontic appliances are used routinely in the treatment of malocclusion, while enamel decalcification is common during bracket treatment.[1–3] After bracket removal, unsightly chalky-white spots may have developed, with the risk of progressing carious lesions.[4,5] The damaged enamel surfaces can be stabilized by minimally invasive means through caries infiltration. This treatment involves the application of a low-viscosity material that infiltrates porous enamel and closes the pores of the lesion.[6,7] Clinical studies have demonstrated the effectiveness of proximal caries infiltration in preventing caries progression.[6,8–10] Other noninvasive methods, such as the application of casein phosphopeptide amorphous calcium phosphate, are not effective and are therefore not recommendable in this regard.[11]

The masking of carious lesions is a beneficial side effect of caries infiltration.[12] While the lesions may not always disappear completely, cosmetic improvements are generally achieved. Kim et al.[13] published the first clinical study on the effect of caries infiltration in masking developmental and postorthodontic white-spot lesions. They reported partial masking in 33% and complete masking in 61% of postorthodontic lesions.

There is consistent evidence that demineralization of the enamel surface reduces the bond strength of orthodontic adhesive systems and that prior application of a caries infiltrant can prevent this. The purpose of the present study was to analyze the effects of a caries infiltrant (Icon) on the shear bond strength of primer-adhesive systems and demineralized enamel surface in different combinations. The study hypothesis was that use of a caries infiltrant combined with different adhesive techniques will not negatively influence shear bond strength to bovine enamel.

MATERIALS AND METHODS

A total of 320 bovine incisors, stored in 0.1% thymol solution for up to 6 weeks, were used. Standardized

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Table 1. Experimental Design[a]

Group	Demineralization	Infiltration	Phosphoric Acid	Adhesive
1	–	–	×	×
2	–	–	×	–
3	×	–	×	×
4	×	×	–	–
5	×	×	–	×
6	×	×	×	×
7	Distal	Distal	Mesial	Mesial
8	Distal	Distal	Mesial	Mesial + distal

[a] × indicates the steps completed per group.

enamel surfaces were created by grinding the labial surfaces under irrigation with a polishing machine (Metaserv Grinder-Polisher, Bühler, Düsseldorf, Germany) and 800-grit abrasive paper (waterproof silicon carbide paper, Struers, Willich, Germany) until a flat 7 × 7 mm surface area was obtained. These enamel specimens were randomly assigned to eight equal groups. The prepared specimens in groups 3 through 6 were evenly covered with an acid-resistant varnish (Express Finish, Maybelline, Paris, France) except for their standardized buccal areas. In groups 7 and 8, adhesive tape (Crystal Clear, tesa, Hamburg, Germany) was applied, covering the left segment of the standardized enamel surface and ending at the incisocervical center. A uniformly thin layer of varnish was then applied to the right segment. In groups 3 through 8, artificial white-spot lesions were created as per Buskes et al.[14] Subsequently, the specimens in the various groups were pretreated in accordance with predefined protocols (Table 1).

All materials were used as recommended by their manufacturers, including 37% phosphoric acid (Gel Etch, Ormco, Glendora, Calif), a primer-adhesive system widely used in dental studies (Transbond XT Primer [Bis-GMA, TEGDMA] and Transbond XT Light Cure Adhesive [Bis-GMA, ethoxylated bisphenol-A-dimethacrylate], 3M Unitek, Monrovia, Calif), and a caries infiltrant for microinvasive infiltration treatment (Icon system: Icon-Etch [15% hydrochloric acid], Icon Dry [99% ethanol], Icon-infiltrant [methacrylate-based resin matrix], DMG, Hamburg, Germany). The phosphoric acid was applied for 20 seconds using a conventional enamel-etching technique, followed by 10 seconds of water/air spraying and drying of the enamel surface. In the control group (group 1), the bonding agent was subsequently applied with a brush, followed by massaging, blow-drying, and 10 seconds of light-curing (Smartlite PS, Dentsply DeTrey, Constance, Germany).

Infiltration treatment of the artificially created white-spot lesions was initiated by etching the demineralized area once with Icon-Etch, according to the manufacturer's recommendations for 2 minutes, followed by 30 seconds of water spraying, drying, and applying Icon Dry for 30 seconds as an intermediate step to dry the lesion body completely. Subsequently, the Icon-infiltrant was applied for 3 minutes, followed by the removal of larger amounts of excess material with cotton rolls and 40 seconds of light curing. The resin infiltrant was then reapplied, allowed to soak for 1 minute and light-cured for 40 seconds.

Conditioning in groups 7 and 8 also involved the use of adhesive tape to separate the demineralized and nondemineralized areas (each 50%) on the enamel surface. The various infiltration treatment steps were applied to the demineralized distal half, with the healthy mesial half covered by a piece of tape that was replaced after each intermediate step. Once infiltration of the demineralized side had been completed, this side was taped for subsequent conditioning of the healthy side.

When the group-specific treatment protocol had been executed, steel brackets with a retentive mesh base for upper lateral incisors were applied (Ormco). The area of the bracket base was 12.9 mm^2, as specified by the manufacturer. Adhesive was applied to the base and to the bracket at the enamel surface, and 300 g of contact pressure was applied to the center of the bracket (Kontaktor, Cech, Neckartenzlingen, Germany) for 3 seconds, as per the manufacturer's recommendations.

Following removal of excessive material with a scaler, the composite was polymerized with an LED light (Smartlite PS, Dentsply DeTrey) from mesial to distal for 10 seconds. After light curing, specimens were stored in distilled water at room temperature for 24 hours. All ensuing shear bond experiments were performed with a universal testing machine (Z010, Zwick, Ulm, Germany) connected to a computer with testing software (testXpert II, Zwick). Each specimen was positioned such that the shear plunger engaged centrally, in a mesiodistal direction and parallel to the bracket base. The shear force was applied in an occlusogingival direction, the aim being to apply the force near the base (Figure 1).

Force transmission from the shear plunger occurred without impact, using a preload of 2 N and a uniform

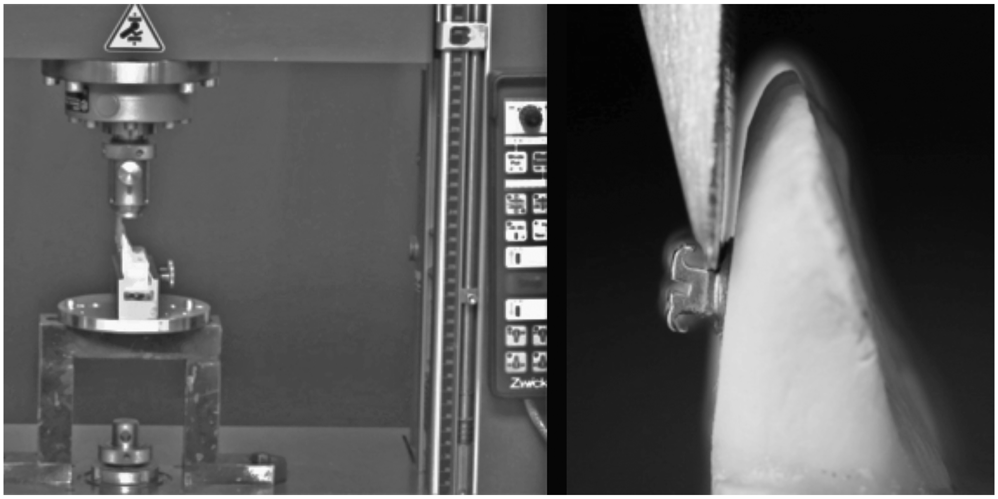

Figure 1. Left: shear apparatus with a specimen clamped in place. Right: shear plunger loading the bracket near its base at right angles.

speed of 1 mm/min. The shear force (N) measured at debonding was divided by the bracket base surface area and expressed as shear bond strength (MPa). Both the enamel surfaces and the bracket bases were then inspected for adhesive remnants at 20× magnification with a microscope (M420, Wild, Heerbrugg, Switzerland). Two indices were used for these ratings: the adhesive remnant index (ARI 0 = 0% of the surface covered by adhesive; ARI 1 = < 50%; ARI 2 = > 50%; and ARI 3 = 100%) and its modified version (ARImod), which includes an additional value for enamel lesions. Data were analyzed with statistics software (SPSS 20.0, IBM, New York, NY). A Kolmogorov-Smirnov test was applied to check whether distribution was normal, which was followed by a one-way variance analysis (ANOVA) and a Scheffé test for group comparison (with a significance level of .05).

RESULTS

Based on the following results, the hypothesis that the use of a caries infiltrant in combination with different adhesive techniques will not influence the shear bond strength to bovine enamel was partially accepted. Shear bond strength (SBS) values of groups ranged from 4.3 to 32.5 MPa (Figure 2). SBS values were highest (mean value: 18.6 MPa) within group 6 (infiltrated + primer-adhesive). Very similar values of 17.9 and 18.1 MPa, respectively, were observed in the control group and group 2 (no primer). Comparable bond strengths were also observed for the demineralized and conventionally conditioned enamel surfaces in group 3, with no significant differences between the above groups (Figure 2).

Mean SBS values were significantly lower in demineralized and infiltrated enamel surfaces without application of primer (group 4), at 11.3 MPa, and where infiltrated surface areas were reduced by 50% (groups 7 and 8), at 10.5 and 13.3 MPa, respectively. Infiltration treatment of demineralized enamel surfaces produced partial effects on SBS, including significantly lower SBS than in the control group among specimens conditioned with infiltrant only. Additional adhesive (group 5) and etching (group 6) were found to increase SBS to levels similar to those in the control group. Likewise, the additional use of primer also led to higher SBS among specimens whose infiltrated surface area had been reduced in size.

In all experimental protocols, the average bond strengths lay above the clinically required range (5 to 8 MPa).

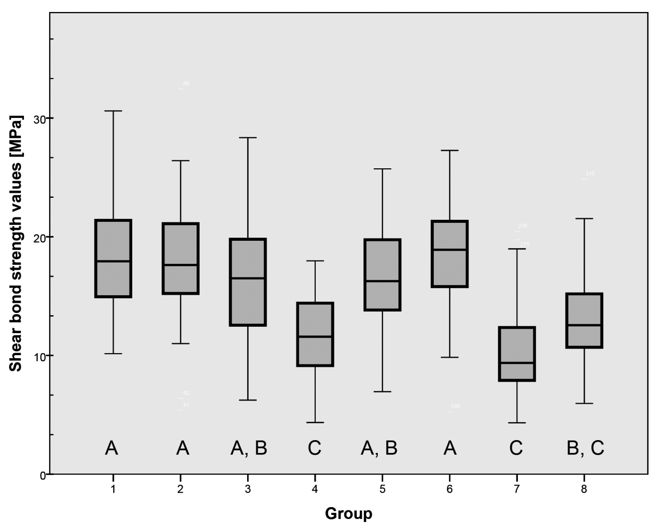

Figure 2. Boxplot diagram of the shear experiments in groups 1 to 8. A detailed intergroup comparison below the boxplots (post-hoc Scheffé test, alpha level .05) shows the significant differences between the groups by different capital letters. Groups with the same capital letter have no significant differences.

Table 2. Percent Distribution of Adhesive Remnant Index (ARI) and Adhesive Remnant Index (ARImod) Scores[a]

	ARI, %				ARImod, %				
Group	0	1	2	3	0	1	2	3	4
1	7.5	7.5	72.5	12.5	0	1.0	2.0	3.0	4.0
2	10.0	5.0	72.5	12.5	0	0	40.0	12.5	47.5
3	7.7	20.5	33.3	38.5	0	0	52.5	12.5	35.0
4	0	2.6	36.9	60.5	0	0	7.7	38.5	53.8
5	0	0	42.5	57.5	0	0	34.2	60.5	5.3
6	0	2.5	55.0	42.5	0	0	35.0	57.5	7.5
7	2.5	38.5	48.7	10.3	0	0	22.5	42.5	35.0
8	0	23.0	38.5	38.5	0	0	33.3	10.3	56.4

[a] ARI 0 = 0% of the tooth surface covered by adhesive; ARI 1 = < 50%; ARI 2 = > 50%; and ARI 3 = 100%; ARImod includes an additional value for enamel lesions.

Significant differences were also observed between the experimental groups in terms of adhesive remnants and enamel fractures. Most ARI scores of 3 were found in specimens where infiltrant had been applied (Table 2). At the same time, these groups revealed the fewest enamel defects. While most cases of enamel fracture were noted in the group with reduced infiltration area, numerous enamel defects were also found in the control group and on the demineralized surfaces that had been conditioned the traditional way.

DISCUSSION

The aim of this study was to analyze differences between orthodontic brackets in SBS associated with pretreatment application of a caries infiltrant. Permanent incisors from freshly slaughtered cattle were selected as enamel substrate. Bovine teeth are suitable experimental specimens because they are abundantly available, used in a wide variety of dental research fields, and have previously been confirmed as an appropriate substitute for human teeth.[15–17] For scientific purposes, it is necessary to create consistent artificial lesions with low variability and histologic characteristics similar to those of natural lesions. Demineralization as reported by Buskes et al.[14] is a reliable and widely used method.[18–21] Lesions created thus exhibit uniform dimensions and consistent histologic properties. Drawing from previous reports, we covered areas to be protected from demineralization with an acid-resistant varnish.[20,22] The artificially created lesions were treated with the caries infiltrant in line with the manufacturer's recommendations for vestibular lesions. The most frequently cited bond strengths for orthodontic brackets fall within the minimum range of 6 to 8 MPa.[23–27] Ortendahl and Thilander[28] regarded 4 MPa as adequate for the clinical application of brackets, while Diedrich[29] proposed that SBS of 5 to 10 MPa were appropriate for bracket fixation.

Numerous studies have used the Transbond XT primer-adhesive system as control material, and the SBS values reported are comparable to those obtained in our own study.[24,26,30,31] We observed no significantly adverse effects on SBS after omitting the adhesive on nondemineralized enamel and where brackets were not applied to demineralized enamel conditioned the traditional way. Similar outcomes have been reported in previous studies.[27,32–36] The use of phosphoric acid vs a hydrochloric acid for pretreatment with an infiltrant has been the subject of much debate because of the higher level of artificial enamel erosion through the use of HCl on the depth of the artificial enamel erosion.[7,37–39] We decided to use HCl in the present investigation on the basis of Belli et al.,[40] who reported incomplete dissolution of the surface layer on artificial white-spot lesions by H_3PO_4, and the manufacturer's recommendations.

Application of the caries infiltrant resulted in significantly lower shear-bond strengths when the conventional primer-adhesive system was omitted, possibly due to the high TEGDMA content of the former. Our study revealed a significant increase in SBS (approximately 47%) when the primer-adhesive system was applied to enamel in addition to the caries infiltrant. Stabilization of the previously infiltrated areas by the adhesive may account for this increase. Furthermore, the high TEGDMA content of the infiltrant not only facilitates penetration but also induces the formation of a thicker oxygen inhibition layer on the surface.[41] This layer may cause chemical bonding to the primer monomers. Our finding of increased SBS where a conventional adhesive is also used is consistent with observations from previous studies.[42]

Significantly lower bond strengths than those in the control group were obtained for the specimens were infiltrated surface areas were reduced by 50%, with the primer additionally used on the infiltrated zones of specimens in group 8 enhancing the bond strengths as compared with group 7. No comparable studies could be found in the literature. Previous investigations did not reveal any disadvantages regarding bond strength or residual adhesive when healthy enamel surfaces were infiltrated.[32,36,42] We therefore suggest that the entire vestibular tooth surface is covered for infiltration treatment.

Another relevant consideration besides bond strength is the residual adhesive upon debonding. The predominant finding after previous infiltration was the smallest number of enamel lesions and an ARI score of 3. This finding confirms that pretreatment caries infiltration strengthens the structure of enamel and offers better stress distribution during shear bond testing. Other authors have also reported a strengthening effect of caries through reducing susceptibility to enamel defects on demineralized surfaces.[18,32,42]

To summarize, pretreatment caries infiltration can affect bond strength as measured in vitro, producing the highest strength of all tested combinations when combined with the primer-adhesive system. Our in vitro results indicate that this minimally invasive caries infiltration technique warrants further clinical investigation if combined with subsequent adhesive bonding of brackets.

CONCLUSIONS

- There is no evidence that the application of a caries infiltrant in addition to a primer-adhesive system negatively affects bond strengths to enamel.
- Conversely, brackets may be attached to enamel previously subjected to long-term infiltration using a primer-adhesive system without compromising the bond strength.
- Infiltrated white-spot lesions are associated both with larger amounts of residual adhesive and with fewer enamel defects upon debonding.
- The use of a primer-adhesive system on previously infiltrated enamel may produce the highest bond strength. Conventional bonding of brackets to demineralized enamel significantly increases the risk of enamel fractures.

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