Original Article

Bond Strength of Disinfected Metal and Ceramic Brackets:
An In Vitro Study

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Abstract: The aim of this in vitro investigation was to test whether disinfecting with Chlorhexamed® fluid had an influence on the shear bond strength of metal and ceramic orthodontic brackets. Metal and ceramic brackets were fixed by the composite adhesives Transbond XT (light curing) and Concise (chemical curing) to 224 bovine permanent mandibular incisors. Bovine teeth were divided into eight groups of 28 each as group 1: metal bracket/Transbond XT, group 2: disinfected metal bracket/Transbond XT, group 3: metal bracket/Concise, group 4: disinfected metal bracket/Concise, group 5: ceramic bracket/Transbond XT, group 6: disinfected ceramic bracket/Transbond XT, group 7: ceramic bracket/Concise, and group 8: disinfected ceramic bracket/Concise. Adhesive bonding was done according to the manufacturers' instructions. As shown by group comparison (Kruskal-Wallis test, univariate analysis of variance, $P < .001$), the disinfection of metal brackets had no statistically relevant influence on shear bond strength ($P = .454$). However, disinfecting ceramic brackets with either adhesive led to a significant reduction in shear bond strength compared with the untreated ceramic bracket group ($P < .001$). The Fisher's exact test of the Adhesive Remnant Index (ARI) scores showed a significant difference within the metal group bonded with different adhesives ($P = .0003$). The ARI scores 1 and 2 were not reached by the ceramic bracket groups. The disinfection of the ceramic brackets is a suitable procedure for clinical use because the measured shear bond strength values were higher than 6–8 MPa required in orthodontics. (*Angle Orthod* 2005;75:836–842.)

Key Words: Disinfection; Adhesive; Bond Strength

INTRODUCTION

One of the most important developments in orthodontics in the past 40 years is the acid-etching technique. In this technique, introduced in 1955 by Buonocore,[1] micropores developed from acid etching with 85% phosphoric acid increase the enamel surface area and also allow the adhesive to penetrate the surface. This results in a reliable mechanical bond between bracket and tooth surface.

Since then composites and brackets have become indispensable tools in orthodontics. The aim in the ensuing period was not only to increase the bond strength and thus minimize the bracket loss rate but also to improve the esthetic result. In this context, little attention was paid to possibilities for disinfecting the brackets. This problem arises when brackets are removed from their original packaging and fall accidentally to the ground during treatment. In these cases, disinfection can prevent the need for discarding brackets. However, disinfecting brackets should not lead to a loss of bond strength. One usual disinfectant in dentistry is chlorhexidine.[2] It has been used since 1959 as an oral rinsing solution for dental plaque control[3–6] and for disinfecting removable dentures and cavities.

There have not been any studies on disinfecting

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TABLE 1. Untreated and Disinfected Groups

Group	Metal Brackets[a]	Group	Ceramic Brackets[b]
1	Untreated, bonding with Transbond™	5	Untreated, bonding with Transbond™
2	Disinfected (chlorhexidine), bonding with Transbond™	6	Disinfected (chlorhexidine), bonding with Transbond™
3	Untreated, bonding with Concise™	7	Untreated, bonding with Concise™
4	Disinfected (chlorhexidine), bonding with Concise™	8	Disinfected, bonding with Concise™

[a] Metal brackets: Mini-Mono bracket® (Roth-System, slot .022 inch, Forestadent®, Pforzheim, Germany).
[b] Ceramic brackets: Clarity™ (metal-reinforced ceramic bracket, slot .0022-inch, 3M Unitek, Monrovia, Calif).

brackets and bond strength thus far. For this reason, the present study will investigate whether disinfection with 0.1% Chlorhexamed® fluid (GlaxoSmithKline, Bühl, Germany) affects the bond strength of metal and ceramic brackets.

MATERIALS AND METHODS

In this study, 224 extracted bovine permanent mandibular incisors were used. After macroscopic control for enamel cracks and fractures, the teeth were stored in a solution of 0.2% thymol immediately after extraction. The crowns of the teeth were severed from the root with a grinding disk and again fixed in thymol until bonding.

We used 112 metal (Mini-Mono bracket®; Roth-System, slot 0.022 inch, Forestadent®, Pforzheim, Germany) and 112 ceramic brackets (Clarity™, metal-reinforced ceramic bracket, slot 0.022-inch, 3M Unitek, Monrovia, Calif) and the adhesives Transbond™ XT (light curing, 3M Unitek) and Concise™ (chemical curing, 3M Unitek). Maxillary central incisor 0.022-inch stainless steel mesh base brackets and ceramic bracket of translucent polycrystalline alumina with a mechanical base and a 0.022-inch metal slot were used. The average base area was 13.5 mm^2 for the metal brackets and 14.54 mm^2 for the ceramic brackets.

The teeth were divided into eight groups of 28 teeth each (Table 1). After cleaning the teeth with a pumice-water mixture, the brackets were bonded to the crowns of the teeth according to the manufacturer's instructions. In groups 2, 4, 6, and 8, the brackets were disinfected for five minutes in Chlorhexamed® (GlaxoSmithKline) fluid, removed with sterile pincers from the fluid, and dried with oil-free compressed air for 60 seconds before being bonded to the crowns of the teeth. The bovine teeth were etched with 37% phosphoric acid liquid (Etching Liquid, 3M Unitek) for 30 seconds, rinsed with air-water spray, and dried with oil-free compressed air for 20 seconds. The Transbond™ XT primer and adhesive was applied according to the manufacturers' recommendations. The light curing technique of the metal brackets was done with the Ortholux™ XT curing light (3M Unitek) directed on each interproximal side for 10 seconds. The ceramic brackets were light cured for 10 seconds, and the light was directed through the bracket. After the bonding procedures were completed, the specimens were stored in distilled water, and the debonding procedures were started one hour after the bonding.

The following shearing tests were carried out using an Instron universal testing machine (model 6025, Instron Ltd, UK). For this purpose, all bonded crowns were fixed in a special embedding mold in such a way that each bracket was positioned parallel to the direction of the force applied during the shear strength test. Attention was paid to ensure that the end of the tapered shear pin could grasp exactly between the bracket base and the occlusal bracket wing. This assured uniform shearing. The force was transferred to the shearing pin via a plane pressure plate. Thus the occlusogingival load applied to the bracket produced a pure shear force at the bracket-enamel interface. The shear-peel forces of each sample were measured at a traverse speed of one mm using a pressure cell with a 100-kN stamp. The results were recorded on a computer connected to the Instron machine.

The applied force stopped immediately after the fracture. The shearing forces required were read in newtons (N) on the Instron machine. The bond strengths were converted into units of N/mm^2 (MPa) according to the formula below and taking into account the retentive bracket base area. This was done to enable comparisons with other studies.

$$\text{Bond strength:} \qquad \text{Mpa} = \frac{\text{force } (N)}{\text{bracket base area } (\text{mm}^2)}$$

Determination of fracture sites

Quantitative analysis of residual adhesive on the tooth surface (ARI = Adhesive Remnant Index) was done visually after shearing the bracket and assessed according to Årtun and Bergland.[7] The ARI scores were recorded for each specimen to represent the mode of failure. A score of 0 indicates no adhesive left on the tooth, a score of 1 indicates less than half the adhesive left on the tooth, a score of 2 indicates more than half the adhesive left on the tooth, and 3 indicates all the adhesive left on the tooth, with a distinct im-

TABLE 2. Shear Bond Strength of All Test Groups (in MPa)[a]

	No Pretreatment				Disinfection With Chlorhexidine			
	Metal Bracket		Ceramic Bracket		Metal Bracket		Ceramic Bracket	
	T.XT Group 1	C.cise Group 3	T.XT Group 5	C.cise Group 7	T.XT Group 2	C.cise Group 4	T.XT Group 6	C.cise Group 8
Median	28.2	32.2	33.3	32.2	25.5	33.0	12.1	14.5
25th percentile	24.3	30.1	15.1	14.6	22.9	28.8	9.8	10.5
75th percentile	32.3	34.9	38.0	37.1	28.3	34.7	25.5	22.7
Minimum	16.6	26.4	9.8	7.0	18.7	12.5	6.8	8.5
Maximum	35.5	39.4	48.1	46.0	31.9	43.6	59.0	47.9
Mean value	27.9	32.4	28.5	28.0	25.6	31.2	19.2	18.9
Standard deviation	5.3	3.8	12.0	13.0	3.5	6.5	13.9	11.4
Number of samples	28	28	28	28	28	28	28	28

[a] T.XT indicates Transbond™ XT; C.cise, Concise™.

TABLE 3. Results of the Univariate Analysis of Variance: Multiple Group Comparison in Pairs (α Adjusted)

	Group 1	Group 3	Group 5	Group 7	Group 2	Group 4	Group 6	Group 8
Group 1	—							
Group 3	.136	—						
Group 5	.189	.858	—					
Group 7	.246	.738	.877	—				
Group 2	.454	.026	.040	.057	—			
Group 4	.265	.703	.840	.963	.063	—		
Group 6	.032	<.001*	<.001*	<.001*	.161	<.001*	—	
Group 8	.025	<.001*	<.001*	<.001*	.133	<.001*	.921	—

[a] Group 1: metal bracket/Transbond™ XT; group 3: metal bracket/Concise™; group 5: ceramic bracket/Transbond™ XT; group 7: ceramic bracket/Concise™; group 2: metal bracket/Transbond™ XT/Chlorhexamed® fluid; group 4: metal bracket/Concise™/Chlorhexamed® fluid; group 6: ceramic bracket/Transbond™ XT/ Chlorhexamed® fluid; group 8: ceramic bracket/Concise™/Chlorhexamed® fluid.

* Statistically Significant Difference

pression of the bracket mesh. The ARI score was assessed by the same operator.

Statistical evaluation

Statistical evaluation was done using the statistics program SPSS version 8.0 for personal computers.

The median values, 25th and 75th percentile, minimum and maximum values as well as the arithmetic mean values with the standard deviations were calculated to visualize the bonding strengths in relation to the following parameters: chemical disinfection, bracket type, and adhesive; their influence on the bond strength was checked by the analysis of variance. The significance for all statistical tests was predetermined at $P < .05$.

The Kruskal-Wallis test was used to check differences between the groups, with a significance value of $P < .05$. For post hoc tests, the Mann-Whitney test was used, with a level of significance of $P < .001$, which included the Bonferroni adjustment.[8]

For the frequency distribution of the ARI scores, the Pearson chi-squared test was used, with a significance value of $P < .05$. The level of significance after Bonferroni adjustment was $P < .0018$.

For the frequency distribution of the ARI score 1, Fisher's exact test was done, with a significance value of $P < .05$. The level of significance after Bonferroni adjustment was $P < .0018$.

RESULTS

Shearing of untreated and disinfected metal brackets (groups 1 and 2) bonded with Transbond™ XT

The median shear bond strength of untreated metal brackets was 28.2 MPa in group 1 and slightly higher than that of disinfected metal brackets (25.5 MPa) in group 2 (Table 2). The difference between the groups was not significant ($P = .454$) (Table 3).

Shearing of untreated and disinfected metal brackets (groups 3 and 4) bonded with Concise™

The shear bond strength of untreated and disinfected brackets was slightly higher when using Concise™. The median shear bond strength values of 33.0 MPa for disinfected brackets was slightly higher than that of untreated brackets (32.2 MPa) (Table 2). The difference between the two groups was not significant ($P = .703$) (Table 3).

A comparison of the bond strength of Transbond™ XT and Concise™ yielded similar results in that there were no significant differences ($P = .136$), ie, the type of adhesive used had no influence on the bond strength of metal brackets. Disinfected brackets had slightly higher shear bond strength if bonded with Concise™ rather than Transbond™ XT. However, the differences were not significant ($P = .063$) (Table 3).

Shearing of untreated and disinfected ceramic brackets bonded with Transbond™ XT (groups 5 and 6)

The shear bond strength of untreated ceramic brackets bonded with Transbond™ XT (group 5) was 33.3 MPa and clearly higher than that of disinfected ceramic brackets (12.1 MPa) (Table 2). The difference was statistically significant ($P = .001$) (Table 3). The same significant differences were achieved with Concise™ ($P = .001$) (Table 3).

Shearing tests of untreated and disinfected ceramic brackets using Concise™ (groups 7 and 8)

The median shear strength of untreated ceramic brackets bonded with Concise™ was 32.2 MPa and also higher than that of disinfected ceramic brackets (14.5 MPa) (Table 2). Here, too, the difference between the two groups was significant ($P = .001$) (Table 3).

There was no difference in the bond strength of untreated ceramic brackets when using Transbond™ XT and Concise™ ($P = .877$) (Table 3). Disinfected ceramic brackets likewise showed no differences with regard to the applied adhesive ($P = .921$) (Table 3), ie, the lower shear bond strength of ceramic brackets after disinfection thus was not due to the applied adhesive but solely to disinfection with chlorhexidine.

The analysis of variance showed that the reduced bond strength must be attributed to disinfection with chlorhexidine ($P = .001$). All other variables like adhesive ($P = .121$) and bracket type ($P = .059$) had no influence. Thus, it can be assumed that disinfection with chlorhexidine significantly reduces the bond strength of ceramic brackets but has no effect on metal brackets.

TABLE 4. Comparision of the Adhesive Remnant Index (ARI) Scores of the Disinfected and Untreated groups

	ARI Scores		
	1	2	3
Group 1	3	10	15
Group 2	3	14	11
Group 3	4	22	2
Group 4	2	9	17
Group 5	1	0	27
Group 6	0	1	27
Group 7	0	0	28
Group 8	0	0	28

TABLE 5. Frequency Distribution of Adhesive Remnant Index (ARI) Scores of the Significant Groups

	ARI Scores			
Group	1	2	3	*P*
1	3	10	15	.0003*
3	4	22	2	
3	4	22	2	.00009*
4	2	9	17	

* Statistically Significant Difference

Fracture site analysis

Fisher's exact test was used to evaluate the ARI scores between the groups. The results of this test indicate no difference between the groups. However, in Table 4 it is obvious that the ceramic bracket (groups 5, 6, 7, and 8) never reached the scores 1 and 2. In contrast the nondisinfected metal bracket group 3 was significant in comparison with the disinfected metal bracket group 4 ($P = .00009$) (Table 5).

Our test also revealed that there was a significant difference within the metal bracket groups 1 and 3 bonded with different adhesives ($P = .0003$) (Table 5). The differences indicate that not only the adhesives influence bond strength but also the disinfection.

DISCUSSION

This in vitro study aimed at finding out whether metal and ceramic brackets can be disinfected without reducing bond strength. It was found that the bond strength of brackets is slightly lower on bovine enamel than on human enamel. However, the difference was not statistically significant.[9,10] Gange[11] reports up to 25% reduction in bond strength on bovine teeth compared with human teeth. Nevertheless, Nakamichi et al[9] stated that bovine teeth are extremely suitable for this type of investigation on account of their planar and rather large surface.[12] We used two frequently applied orthodontic adhesives, Concise™[13–19] and Trans-

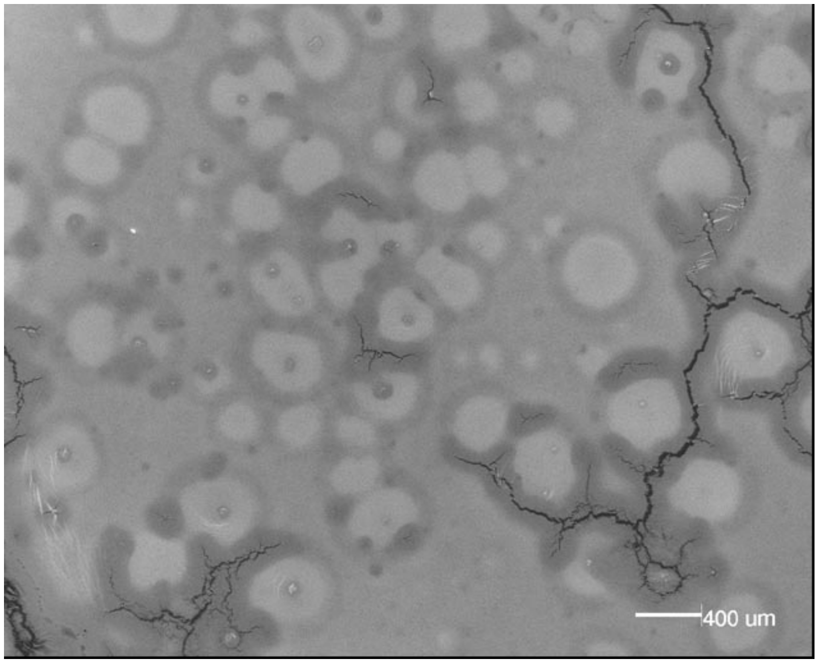

FIGURE 1. Scanning electron microscopic view (10×) of a Chlorhexamed® fluid-film on a glass object carrier surface after evaporation.

bond™ XT,[12,17,20–25] to detect possible interactions with the bracket type and disinfectant.

The bond strength is dependent on the type of bracket base. Metal brackets with a foil mesh base were used because they enable the best adhesive penetration and a strong bonding with respect to shear and tensile strength.[14,26] Ceramic brackets (Clarity™, 3M Unitek) have a nonpretreated base that adheres mechanically without requiring additional silanization.[27]

For good bonding, the tooth surface must be thoroughly cleaned and dried before the adhesion procedure. We used only a pumice-water mixture without glycerin or a flavoring additive to prevent the development of a film on the tooth surface. All brackets were firmly pressed on the tooth surface for five seconds to achieve a thin and even adhesive layer between the tooth and bracket. This was necessary because it has been demonstrated that the shear bond strength is reduced with increasing adhesive thickness.[28,29] The bond strength may also be influenced by the type of adhesive used. Light-cured adhesives such as Transbond™ XT may exhibit unfavorable bond forces starting at a thickness of 0.2 mm, whereas chemically cured adhesives such as Concise™ are not significantly influenced at a thickness of 0.6 mm.[30] Still, because of the varying surface structure of bovine teeth, a nonreproducible adhesive thickness could not be prevented in this study despite the high contact pressure. The resultant variability was offset by the number of tests performed.

There are no studies on the disinfection of brackets before bonding thus far. We used 0.1% chlorhexidine, which is also applied in dentistry for disinfecting cavities.[6] After disinfection, our brackets were dried for five seconds in oil-free compressed air and subsequently bonded to the prepared tooth surface.

The type of shearing is of great importance. In the mouth, brackets are continuously exposed to torsion, tensile, shear, or a combination of these forces, which cannot be reproduced in vitro. Shearing loads are generally considered suitable for testing the adhesive bond between the tooth surface and the bracket base.[11,31–33] This type of shearing is reproducible with the Instron machine, thus enabling comparisons. On the other hand, there is still controversy regarding the maximum bond strength of brackets. Bond strength of 6–8 MPa is considered adequate by Reynolds.[34] Higher stresses should be avoided to prevent enamel fractures during bracket removal.[35]

We observed a significant reduction in bond strength especially with chlorhexidine-disinfected ceramic brackets. The literature reports only a few studies examining the influence of chlorhexidine on the bond strength of composites. Perdigao et al[5] explained the reduced bonding strength of chlorhexidine-disinfected cavities with a residual film on the dentin surface that partially clogs the tubules and can therefore not be completely removed. In our case too, scanning electron microscopy (Cam Scan MaXim, Dortmund, Germany) disclosed a film on a glass object carrier surface after evaporation of the chlorhexidine solution (Figure 1). Thus, it must be concluded that this film influences especially the bond strength of ceramic brackets with their fairly smooth base but has hardly any effect on the retentive foil mesh base of metal brackets. This finding was confirmed by an analysis of variance.

Even though these in vitro tests are not comparable to in vivo trials, they nevertheless allow conclusions about the effect of chlorhexidine disinfection on bond strength. Bond strengths of 6–8 MPa, as demanded by various authors,[34,36] can easily be achieved.

The reduced bond strength is also reflected in the results on fracture site courses after bracket shearing. Though it is known with ceramic brackets that virtually the entire adhesive almost always remains on the tooth surface after shearing, it is impossible to achieve these values after disinfection with chlorhexidine. This observation was less marked when using metal brackets.

CONCLUSIONS

- The disinfection of metal brackets with chlorhexidine had no significant influence on the bond strength.
- Chlorhexamed® fluid as a disinfecting solution for ceramic brackets affects the bond strength significantly, but the clinically relevant bond strength did not fall below 6–8 MPa.
- Thus, in cases where it is necessary to disinfect metal or ceramic brackets, chlorhexidine could be a suitable solution for clinical application.

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