Bond strengths of two ceramic brackets using argon laser, light, and chemically cured resin systems

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Ceramic brackets were introduced to orthodontics in an attempt to meet the ever-increasing demand for more esthetic appliances. Although these brackets offer better esthetics, enamel fractures and cracks have been reported to occur during debonding procedures,[1] often resulting in the need for restorations. Consequently, the continuing challenge is to develop a bond that is strong enough to accomplish treatment but that can be broken for debonding without damage to the enamel surfaces.

Researchers have manipulated variables, such as acid etching time and material,[2-4] and type of adhesive[5,6] in attempts to reduce bond strength. But these manipulations have failed to result in bond strengths similar to those recorded with metal brackets.

Based on the work of Bowen, Reynolds[7] suggested a minimum bond strength of 60 to 80 kg/cm^2 (5.886 to 7.848 MPA) for clinical orthodontic treatment. Retief[8] reported enamel fractures on debonding with bond strengths of 140 kg/cm^2 (13.734 MPa).

Kelsey[9] et al. found that compressive, diametral tensile, transverse flexural strengths, and flexural modulus of composite resins were improved following argon laser polymerization as compared with visible light polymerization. Other studies[10,11] using argon lasers have supported these findings, and have also shown improved adhesion and increased bond strengths for dentin adhesive systems. The speed of curing that laser technology offers may have valuable application to ceramic bracket bonding.

Abstract

The present study compared tooth-bracket bond strengths using two types of ceramic brackets and three methods of polymerization: argon laser, conventional light, and chemical. Ninety extracted human premolars were prepared for bonding with pumice and gel etchant. Using single crystal alumina brackets with silanated bases, three groups of 15 teeth were bonded with one of the three polymerization methods. Similarly, three groups of 15 teeth were bonded with polycrystal alumina brackets with nonsilanated bases. Each bonded bracket was tested on an Instron tensile testing machine in shear mode to determine shear debonding strength. Fracture sites were recorded. Results demonstrated that (1) all combinations produced shear bond strengths greater than those considered clinically acceptable, (2) the mean shear bond strengths of the single crystal alumina brackets with silanated bases were significantly higher than those of the polycrystal alumina brackets with nonsilanated bases, and (3) no enamel fractures were found on debonding the chemically cured brackets while the light and laser groups exhibited a 10% rate of enamel fracture on debonding.

Key Words

Bond strength • Ceramic brackets • Resin • Argon laser

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Figure 1
Experimental setup for laser bonding of ceramic orthodontic brackets.

Figure 2
Apparatus ready for testing shear bond strength of bracket.

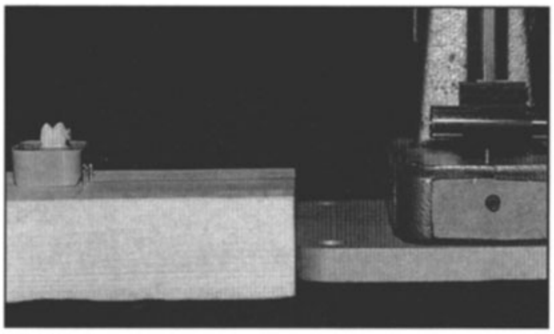

Figure 1

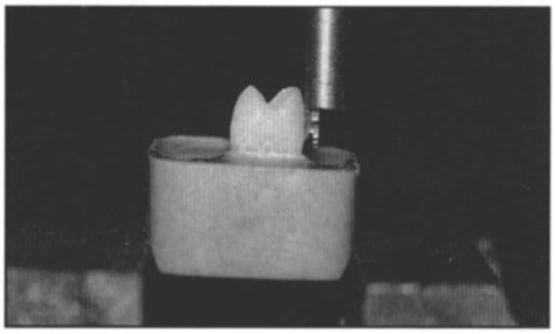

Figure 2

Few studies compare the bonding of ceramic brackets using conventional light, chemicals, and the argon laser for polymerization. The purpose of this investigation was to evaluate and compare the shear bond strengths of brackets bonded using three bonding techniques, and to examine the location of fracture sites following debonding procedures.

Materials and methods

A pilot study involving 12 human premolars was conducted to evaluate a platform with a specified distance for laser application and assess the time required for laser curing. A total laser cure time of 10 seconds at a wavelength of 488 nm was adopted for the present study, with a focal point of 5 mm.

In the present investigation, 90 extracted human premolars were stored in tap water for 3 weeks. The teeth had been extracted for orthodontic reasons and were free of both caries and restorations. They were examined under a light stereomicroscope (x8 mag) for enamel fractures or defects. Only teeth with no defects were selected for this study. The teeth were mounted in standardized 2.5 x 4.0 x 2.5 cm molds using Polyroqq resin (Polyroqq Dental Ventures of America, Inc, Calif).

The teeth were cleaned with pumice and water and treated with 37% phosphoric acid gel for 20 seconds. Copious water lavage was used, followed by drying using an air dryer until the enamel had a frosty white appearance. Ninety teeth were divided randomly into six groups of 15 each. Teeth in three groups were bonded with single crystal alumina brackets (Starfire, "A"-Company, Inc, Sorrento, Calif). This bracket has a smooth, silanated base and retention is chemical. It will be referred to as *A*. Teeth in the other three groups were bonded with polycrystal alumina brackets (Transcend Series 6000, Unitek Corp, Monrovia, Calif). This bracket has an irregular nonsilanated base with a thick layer of silica, and retention is mechanical. It will be referred to as *U*.

Bonding procedures

Three methods were used to bond the brackets to the teeth. Method one consisted of a light-cured microfilled resin (80 filled/wt, Transbond, Unitek) and laser energy for curing. The unfilled bonding agent was placed on the tooth and backet base, and a resin paste was applied to the base. The laser machine used was a Zeiss 30 SL-M (Zeiss, Germany) operating at 231 m watts for 10 seconds at a wavelength of 488 nm and a focal point of 5 mm. To obtain this focal point, a special jig was fabricated to place the specimen at a predetermined distance from the actual laser optic (Figure 1)

In the second method, the same light-cured microfilled resin adhesive system was applied in a similar manner, but polymerization of the resin adhesive was achieved using a visible-light curing unit (Ortholux, Unitek Corp, Monrovia, Calif). A total exposure time of 40 seconds was used on the buccal surface (10-second exposure each on the mesial, distal, occlusal, and gingival sides of the bracket).

The third method involved a one-step no-mix chemically-cured adhesive (Rely-a-Bond, Reliance Orthodontic Products, Inc, Itasca, Ill). The bonding agent was placed on the tooth and bracket base, then the resin paste was applied. The adhesive is a 69% by weight silica-filled paste.

Each of the 90 samples was subjected to a shear load on an Instron Universal testing machine at a crosshead speed of .02 inches/min (Figure 2). A sample holder was custom made to ensure a constant force parallel to the tooth surface, similar to the method of Sam and Chao.[12] Force at debond was recorded.

Debonded samples were examined under a stereomicroscope (x 8 mag, StereoZoom, Bausch & Lomb). The type of debond was recorded, either as cohesive or cohesive/adhesive. Cohesive debonds occurred when resin or bonding agent remained on the tooth and bracket, that is, when the resin failure occurred through the resin or the resin-bonding agent interface, but not at the enamel surface. Cohesive/adhesive debonds resulted when part of the tooth had no resin or bonding agent present; therefore, failure occurred in whole or in part at the tooth surface.

Statistical analysis

All measurements were accomplished by one operator (SJW). Analysis of variance was applied to compare bracket types and bonding methods. Differences between pairs of bonding methods were examined using Tukey's test for multiple comparisons. Fisher's exact test (for 2 x 3 tables) was used to examine the type of debond. Differences between pairs of bonding methods were examined using Fisher's exact test with a Bonferonni correction for multiple testing. Two-tailed tests of statistical significance were applied throughout, with P≤.05 as the test criterion.

Results

Bond strength was determined to be the force obtained at bond failure divided by the base area of the bracket. Values for the three groups are shown in Table 1. Six teeth that exhibited enamel fracture were not included in the statistical analysis. All fractures occurred on enamel with the brackets still bonded to the fractured buccal surface of the teeth.

Bonding strengths of the *U* brackets did not differ significantly among the laser-, light-, and chemically cured groups (P=.826). Among the *A* brackets, the three methods were statistically different (P=.027). Tukey's test for multiple comparisons indicated that the bond strength of the laser-cured brackets was significantly greater than that of the chemically cured brackets (P<.05). Assessing the means, however, it appears that the strengths of the light-cured and chemically cured bonds were similar and that both differed from the laser-cured bonds. There was insufficient statistical power to show that laser differed from light (P>.10).

Table 2 presents the means and standard deviations and indicates that the standard deviations were not equal between *A* and *U* groups. A logarithmic transformation improved the equality of the standard deviations. Logarithmic transformed data were used in the analyses. An analysis of variance comparing the two bracket types and three bonding methods indicated that there was a significant interaction between bonding method and type of bracket (P=.021). Therefore, it was necessary to look at the three bonding methods separately and the two bracket types separately.

Within the laser-bonded group, *A* brackets had a significantly higher mean bond strength than *U* brackets (P<.001). Within the light-bonded group, *A* brackets had a significantly higher mean bond strength than *U* brackets (P=.006). Within the chemically bonded group *A* brackets did not have a significantly higher mean bond strength than *U* brackets (P=.117).

The type of debond is shown in Table 3. Considering brackets bonded by laser, the *A* brackets debonded cohesively in 2 of 12 teeth (17%) while cohesive/adhesive debonds occurred in 10 teeth (83%). In the *U* brackets, 8 of 15 teeth experienced cohesive debonds (53%) and the remaining 7 teeth presented cohesive/adhesive debonds (47%).

In the light-cured group, the *A* brackets debonded cohesively in 6 of 14 teeth (43%), while cohesive/adhesive debonds occurred in the remaining 8 teeth (57%). There was only one case of cohesive debond with the *U* bracket. Out of 13 teeth, 12 teeth presented cohesive/adhesive debonds (92%).

Both *A* and *U* brackets presented 100% cohesive debonds in the chemically cured group.

Fisher's exact test for 2 x 3 tables indicates that the proportion of bond failure types differed among bonding methods (P<.001). The light-cured group had significantly more cohesive/adhesive failures than did the chemically cured group. The laser-cured group also had more cohesive/adhesive failures than the chemical-cured group. There were no significant differences in type of bond failure between the

Table 1
Bonding strength values (MPa)

Tooth	Laser cured		Light cured		Chemical cured	
	A[1]	*U*[2]	*A*[1]	*U*[2]	*A*[1]	*U*[2]
1	20.5*	15.3	11.8	14	5.8	15.8
2	26.0	19.5	20.1	14.6	19.0	10.0
3	35.6	13.0	36.8	18.9	18.5	13.8
4	37.9	15.2	30.2	16.1	37.5	13.9
5	31.4	17.3	13.9	16.6	30.9	18.4
6	37.1	16.2	22.7	9.2	27.5	11.2
7	30.8	14.2	29.4	14.8	13.0	20.4
8	22.7	16.2	27.7	11.4	13.3	16.6
9	29.2	11.7	15.7	27.4*	31.6	19.2
10	19.3*	12.0	23.4	32.4*	21.6	16.0
11	31.8	9.0	18.0	14.8	10.8	12.8
12	20.9	13.2	22.3	13.8	11.1	11.7
13	22.1	12.8	24.0*	15.9	14.7	14.2
14	24.2*	12.3	35.2	15.5	43.9	12.8
15	29.4	18.4	11.5	20.9	18.7	16.4

*Enamel fractures
[1]Single crystal alumina brackets with silanated bases (Starfire, "A"-Company Inc, Sorrento, Calif).
[2]Polycrystal alumina with irregular nonsilanated bases (Transcend, Unitek Corp, Monrovia, Calif

Table 2A
Bonding strengths

Curing method	Bracket (*A*[1] or *U*[2])	n	Mean MPa*	S.D.
Laser	*A*	12	29.58	5.75
	U	15	14.20	2.82
Light	*A*	14	22.76	8.23
	U	13	15.12	2.94
Chemical	*A*	15	21.19	10.89
	U	15	14.88	3.08

[1]Single crystal alumina brackets with silanated bases (Starfire, "A"-Company Inc, Sorrento, Calif).
[2]Polycrystal alumina with irregular nonsilanated bases (Transcend, Unitek Corp, Monrovia, Calif).
*Milipascals

Table 2B
Comparisons of mean bonding strengths

	Difference	P - Value
A[1]	.	027
Laser-Light	+6.8	>.10 (n.s.)
Laser-Chem	+8.4	<.05
Light-Chem	+1.6	>.10 (n.s.)
U[2]		
	-1.3	
	-0.7	.826
	+0.2	
Laser *A* - *U*	+15.1	<0.001
Light *A* - *U*	+7.7	.006
Chem *A* - *U*	+6.3	.117

laser- and light-cured groups.

The proportion of types of bond failures within the *U* group differed among bonding methods (P<.001). Both the laser- and light-cured groups had significantly more cohesive/adhesive failures than did the chemically cured group. The laser group also had a significantly higher rate of cohesive/adhesive failure than did the light-cured group.

In the laser group, enamel fractures in all cases involved dentin. Defects measured approximately 2.5 x 2.5 x 2.5 mm. Among the light-cured brackets, 1 sample in the *A* group (6.6%) and 2 samples in the *U* group (13.5%) exhibited enamel fractures. Among the laser-cured brackets, 3 samples in the *A* group (20%) and none in the *U* group exhibited enamel fractures. In total, 6 of the 60 brackets bonded with a photo-initiated system (laser or light) resulted in enamel fractures during debonding. The bonding strength values of these 6 teeth were not included in the statistical analysis because these values represent a measurement of the cohesive strength of the tooth enamel, not the bond strength of the brackets to the teeth.

Discussion

The results of this study confirmed previous research that demonstrated the high bond strengths of ceramic brackets.[1] All mean bond strengths, regardless of bonding agent, bracket type, or curing system were greater than those recommended by Retief[12] to avoid enamel damage. All bond fractures occurred at the resin/bracket interface.

In the laser- and light-cured resin-bonded groups, cohesive/adhesive failures ranged from 47 to 92%—that is, failure occurred at the resin/enamel interface frequently. In fact, 6 of these 60 teeth demonstrated enamel fracture. A 10% incidence of enamel fracture is high and should be considered unacceptable.

Transbond unfilled bonding agent was applied on the tooth and bracket base as recommended by the manufacturer for the photo-initiated (laser and light) resin-bonded groups. Bradburn and Pender[13] found that precuring with Transbond resulted in significantly higher bond strengths (13.5 to 1.78 MPa), fairly consistent with the bond strengths noted for *U* brackets in this study. Future research might investigate bond strengths if the Transbond unfilled resin is eliminated.

In contrast to the photo-initiated resin groups, all chemically cured brackets exhibited cohesive failures at debonding, with no enamel fractures. The finding is interesting since bond strengths exceeded the values recommended. The chemically cured resin appears to have the strongest bond at the enamel/resin interface as opposed to the resin/bracket interface. Viazis, Cavenaugh and Bevis[14] noted that 80% of chemically cured Transcend and Allure brackets failed between the bonding surface of the bracket and the adhesive. They propose that this may be due to the shattering of the monolayers of the bracket base silane. This study (Viazis et al.) is in contrast with that of Joseph and Rossouw,[1] who reported a 40% rate of enamel fracture using Transcend ceramic brackets with the chemically activated bonding system Concise. Concise is, however, a large-particle macrofilled resin, whereas Transbond is a microfilled resin.

Chemically cured bonding systems may be superior to laser- or light-cured bonding systems because of their decreased risk of enamel damage. However, cleanup procedures must also be

Table 3A
Type of bond failure

	A[1] chem retention silanated base			U[2] mech retention nonsilanated base		
	n	CO	CO/AD	n	CO	CO/AD
Laser	12	17%	83%	15	53%	47%
Light	14	43%	57%	13	8%	92%
Chemical	15	100%	0%	15	100%	0%

[1]Single crystal alumina brackets with silanated bases (Starfire, "A"-Company Inc, Sorrento, Calif).
[2]Polycrystal alumina with irregular nonsilanated bases (Transcend, Unitek Corp, Monrovia, Calif).

Table 3B
Comparison of types of bond failures (cohesive/adhesive)

	% Difference	P - Value
A		<.001
Laser-light	+26%	>.10
Laser-chem	+83%	<.05
Light-chem	+57%	<.05
U		<.001
Laser-light	-45%	<.05
Laser-chem	+47%	<.05
Light-chem	+92%	<.05
Laser *A* - *U*	+36%	.107
Light *A* - *U*	-35%	<.001
Chem *A* - *U*	0%	——

considered. Removal of excess resin bonding material can result in gouging, scratching, and pitting of enamel surfaces, and it is a time-consuming procedure. The Tungsten carbide bur at low speed creates a scratch pattern and loss of enamel.[15] Although unfilled resins are easier to clean up than filled resins, their removal still results in enamel loss.[16]

Regardless of the bonding system used, there were consistent differences in bond strengths. The bond strengths of the Starfire brackets were significantly higher than the Transcend Series 6000 brackets. This is in agreement with the research of Viazis, Cavenaugh, and Bevis,[20] who found the mean shear bond strength of the silane chemical bond is higher than the mean shear bond strength of the mechanical bond.

In a recent study by Eliades, Viazis, and Lekka,[17] Starfire brackets demonstrated a fairly even split between cohesive resin fracture (10 samples) and resin adhesive fracture at the bracket resin (11 samples) or resin enamel (1 sample) interface. The authors concluded that the high rate of cohesive bracket failure was due to the monocrystalline structure of the bracket. It must be noted, however, that the brackets were debonded using pliers, and no measurements of bond strengths were recorded. Few significant differences between light- and laser-cured brackets were noted in this study.

Conclusions

1. There were no differences noted in bond strengths between light- and laser-cured brackets. Among polycrystal alumina brackets with nonsilanated bases, the laser-cured specimens exhibited a significantly higher incidence of cohesive failures than did the light-cured brackets.

2. Regardless of the ceramic bracket used, single crystal alumina brackets with silanated base ("A"-Company Starfire) or polycrystal alumina brackets with nonsilanted base (Transcend *U* Series) or the curing system employed (Argon laser, conventional light, or chemical), all shear bond strengths were found to be greater than those considered clinically desirable.

3. The mean shear bond strengths of single crystal alumina brackets with silanated bases were significantly higher than those of the polycrystal alumina brackets with nonsilanated bases.

4. Upon debonding, no enamal fractures occurred among the chemically cured brackets. Light- and laser-cured brackets exhibited a 10% rate of enamel fracture on debonding.

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