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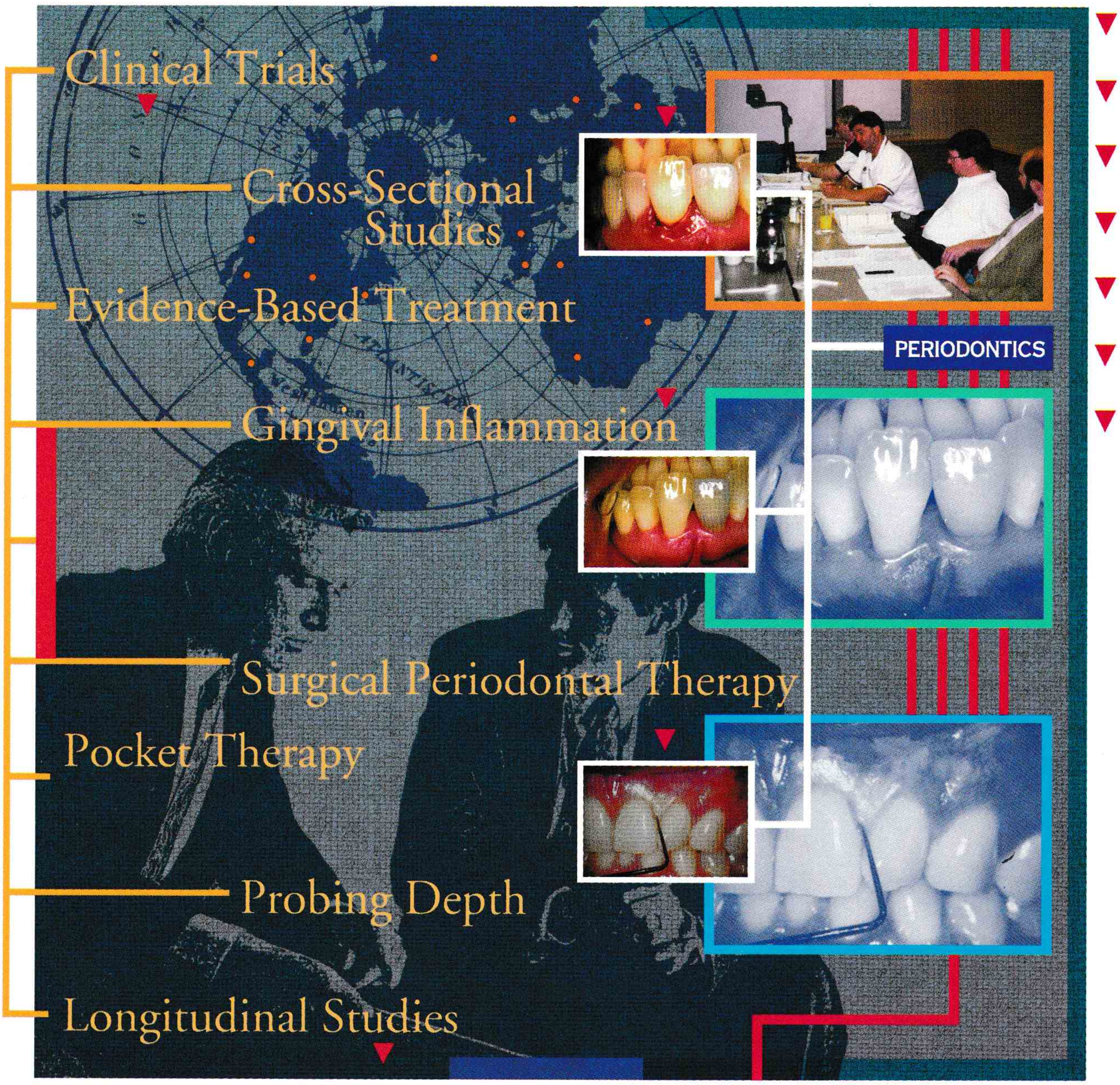

COMPARING THE TENSILE STRENGTH OF BRACKETS ADHERED TO LASER-ETCHED ENAMEL VS. ACID-ETCHED ENAMEL

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ABSTRACT

This study compared the tensile bond strength of brackets adhered to laser-etched enamel with that of brackets adhered to acid-etched enamel. Forty extracted, intact bovine teeth were treated with either 37 percent phosphoric acid for 15 seconds or neodymium:yttrium-aluminum-garnet laser on black-ink–coated enamel. After thermocycling, tensile stress was applied to the bonded specimens at a 0.1 millimeter/minute crosshead speed. A *t*-test comparison of means showed a significant difference between the laser-etched and acid-etched teeth, with the acid-etched teeth demonstrating significantly more tensile bond strength at a 95 percent level of significance.

Adhesion has been defined as the molecular attraction between surfaces of bodies in contact or the attraction between molecules at an interface[1]; it usually involves the bonding of substrate and adhesive in intimate contact across an interface.[2-3]

The classical micromechanical method of bonding resins to enamel[4] consists of cleaning the enamel, etching it with phosphoric acid, and rinsing and drying it. This acid-etching method has been used to promote adhesion since Buonocore[5] first described the technique to increase the bond strength of resins to enamel.

Etched enamel has an increased surface area over nonetched enamel and a high surface energy, which allows the resin to wet the surface and penetrate into the microporosity of the tooth,[3,6] where it hardens. Interlocking is achieved by the penetration of these resin "tags" into the substrate by the process of capillarity.[6] The resin tags[3] may penetrate 10 to 20 micrometers into the enamel porosity; the actual depth depends on the etching time.[7] Ideal acid-etching results are achieved with 37 percent phosphoric acid applied for a period of 15 seconds.[7-9]

Bovine enamel appears to be a suitable alternative to human enamel for bonding tests.[6,10] Bovine teeth have been used because of the limited availability of human teeth and the increased awareness of infection hazard to human teeth.[11]

Researchers have studied tensile bond strength for self-curing and light-curing orthodontic resin systems.[9,12] Shear strength has also been studied when resin is bonded to brackets on anterior and posterior teeth.[13]

Each type of laser produces a different effect on the same tissue, according to its wavelength. The neodymium:yttrium-aluminum-garnet, or Nd:YAG, laser has a wavelength of 1.06 μm and is usually operated in a pulsed mode. The Nd:YAG laser beam can be delivered through a fiber optic system. A red helium-neon marker laser[14] is used to aim the invisible Nd:YAG beam, which offers a great advantage for clinical use.

The Nd:YAG laser wavelength is absorbed better in pigmented than nonpigmented tissues.[15] The beam is readily reflected or absorbed by some metals, depending on their surface properties,[16] requiring careful operation in the presence of dental materials.[17] Operators can induce absorption of the Nd:YAG wavelength into superficial enamel by placing an initiator (that is, a dark organic substance such as ink) on the area in which etching is desired.[18,19]

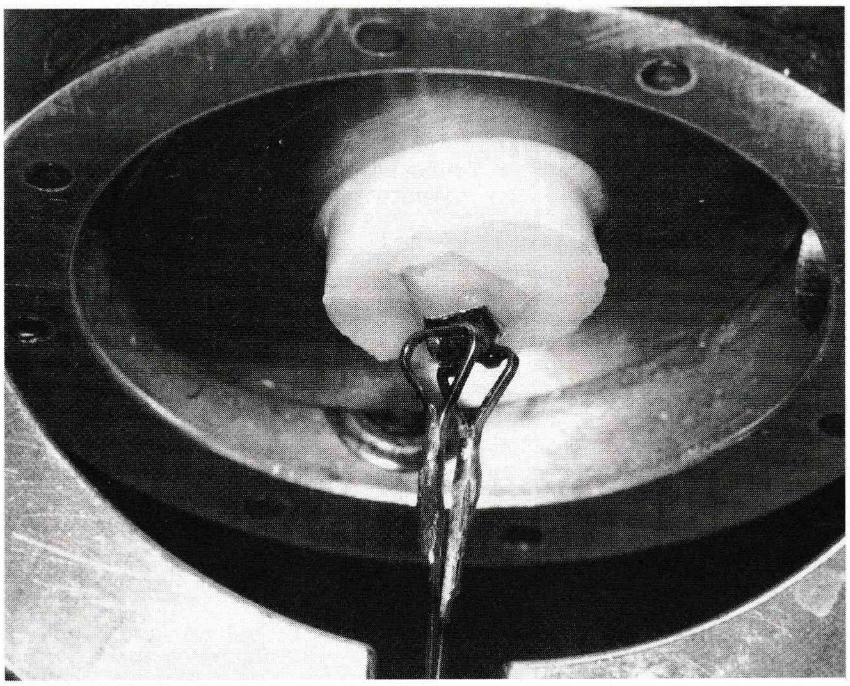

Figure 1. Specimen mounted in support device (Instron Testing Machine, Instron Corp.) for tensile bond test.

Recently, Hess[20] used an Nd:YAG laser to alter superficial enamel with 30 to 75 millijoules of energy output. The roughness produced on the enamel is similar to that on the acid-etched enamel. Abed and colleagues[21] concluded that there was no significant difference in bond strengths between gel-acid–etched and laser-etched enamel. However, the bond-strength values obtained for liquid-acid–etched enamel were significantly greater than those for laser-etched enamel ($P < .006$).

There are few reports of in vivo laser adhesive method tests, and those that have been done are inconclusive. Roberts-Harry recently conducted a preliminary clinical study in Bristol, England, on laser etching for orthodontic bracket placement.[22] Subjects consisted of eight patients needing fixed orthodontic appliances. A pulsed Nd:YAG laser was used to etch the enamel surfaces of the teeth before the orthodontic brackets were bonded with composite resin. Overall, laser bonding took considerably longer, was less reliable in terms of clinical bond strength and produced more discomfort than conventional acid etching.[22]

Unfortunately, there has been little clinical experience with lasers used on hard dental tissues, and the laser has not been tested extensively for use in adhesion as a possible alternative to acid etching. Melting, fusion and recrystallization of enamel, as well as surface roughening, occur in enamel that has been etched with a carbon dioxide laser.[23] The structurally altered enamel is able to resist the superficial demineralization that occurs after acid attack.[24-26] This could be useful in orthodontic treatment.

This study compared the tensile bond strength of metal brackets adhered to enamel etched with the Nd:YAG laser with that of enamel etched with 37 percent phosphoric acid to determine whether the Nd:YAG laser is effective for use in bonding brackets to enamel.

MATERIALS AND METHODS

A total of 40 bovine maxillary incisor teeth were chosen that were free of hypoplastic areas, cracks or gross irregularities in enamel structure. They were randomly assigned to one of two groups.

One of us (L.C.-P.) sectioned the roots from the coronal portion of the teeth. Extraneous mesial, distal and incisal areas were also removed. The middle third of the buccal surface of the crowns was flattened with sandpaper (100 and 600 grit) before the etching procedure. Teeth were cleaned ultrasonically in deionized distilled water, or DDW, for 5 minutes[27] and then stored in DDW at 37 C.

One of the authors prepared 40 standard, maxillary, central incisor 12-mm^2 mesh brackets (Ultratrimm, Dentaurum) for bonding by flattening their bases, and visually inspected them for flatness by placing them on a glass slab.[28] All brackets were rinsed with chloroform for 3 minutes in an ultrasonic cleaner and allowed to air-dry completely before bonding. We prevented contaminating the brackets by handling them only with forceps after cleaning.

Etching enamel. Specimens in Group A were etched for 15 seconds with 37 percent liquid phosphoric acid (Concise orthodontic bonding system kit, 3M/Unitek). Afterward, they were washed with an air/water spray for 20 seconds and rinsed.

Specimens in Group B were etched for 8 seconds (12.5 joules/square centimeter) with

TABLE

PEAK TENSILE LOAD FOR BONDED SPECIMENS IN ACID-ETCHED GROUP (A) AND LASER-ETCHED GROUP (B).

SPECIMEN NO.*	ACID-ETCHED GROUP (A)		LASER-ETCHED GROUP (B)	
	Peak Load (Kilograms)	Peak Load (Megapascals)	Peak Load (Kilograms)	Peak Load (Megapascals)
1	3.97	2.60	2.17	1.42
2	5.39	3.31	2.30	1.50
3	3.71	2.43	1.77	1.15
4	7.86	5.14	1.95	1.28
5	5.55	3.63	1.54	1.01
6	6.22	4.06	1.25	0.82
7	4.26	2.78	2.94	1.92
8	4.91	3.21	1.07	0.70
9	7.73	5.06	0.35	0.23
10	4.84	3.17	3.47	2.27
11	4.12	2.69	2.41	1.58
12	4.62	3.02	3.71	2.40
13	5.19	3.39	3.36	2.19
14	5.84	3.81	4.84	3.17
15	5.78	3.78	1.14	0.74
16	3.85	2.52	4.22	2.76
17	7.03	4.60	3.88	2.54
18	3.26	2.13	6.07	3.97
19	4.08	2.66	2.14	1.40

* The total number of specimens does not equal 40 because one specimen in each group became unbonded before testing.

the Nd:YAG laser (American Dental Laser) at 15 pulses per second/0.75 watts over a 3- × 4-mm window on the enamel coated with black ink (Pelikan).[18]

The bonding resin (Concise orthodontic bonding system kit) was then applied with a small sponge to the treated enamel in both groups.

The bracket was bonded by being firmly pressed against the tooth with forceps. Any excess resin expressed from under the base of the bracket was removed with a scaler before the resin polymerized. Each specimen was allowed to cure for 10 minutes before it was stored again in the DDW.

After bonding the brackets to the teeth, we used a centering device to embed the teeth in acrylic tubes. A primary centering jig, or PCJ (Arturo Contreras Technical Laboratory Shop), was prepared to fit exactly into a 0.750-inch inner-diameter/0.875-inch outer-diameter acrylic tubing.[28] The PCJ had been constructed so that the bracket would be centered inside the acrylic tubing with the base perpendicular to the walls of the tube. We placed a bracket into the PCJ by inserting its base into the recess cut in the jig.

We inserted the PCJ (which held the bracket) into a piece of acrylic tubing. Putty silicone (Exaflex, Heavy body, GC America) was then forced down into the tube and over the bracket tie wings to form the secondary centering jig, or SCJ. The SCJ held the tooth in such a position that the bracket, which was bonded to the labial surface, was positioned in the exact center of the tube with the bracket base perpendicular to the tube walls. A silicone separator was applied to the inner surface of the acrylic tubing to

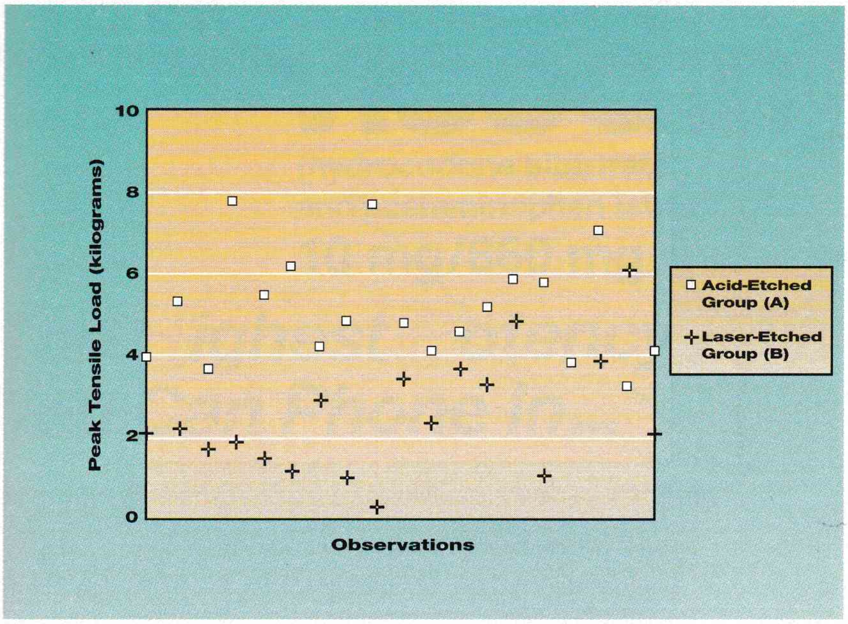

Figure 2. Peak load of bonded specimens in acid-etched group (A) and laser-etched group (B).

arator was applied to the inner surface of the acrylic tubing to better extract the specimens.

We mixed a clear orthodontic acrylic (Ortho Clear acrylic, Masel Industries) until it reached a runny consistency and poured it into the acrylic tube over the tooth specimen, thus forming a base to secure the specimen in the testing machine. We then removed the prepared tooth specimen from the acrylic tubing and returned it to the DDW for storage.

Thermocycling process. Two weeks after bonding and complete specimen preparation, one of us (K.M.) placed all of the tooth specimens in an automatic thermocycling apparatus. All of the specimens were thermocycled between water baths held at 7 C and 47 C, for a total of 2,500 thermal cycles. After thermocycling, we stored the teeth in DDW at 37 C until performing tensile testing 1 week later.

Tensile bond strength. We used an Instron Testing Machine (Instron Corp.) to test the tensile bond strength of each specimen (Figure 1). Orthodontic ligature wire was formed into two identically sized loops that were soldered together and to a straight piece of wire. This harness was fixed to the lower portion of the testing machine while the tooth specimen was fixed through a universal alignment device[29] to the upper, moving crosshead portion of the machine.

The tensile load was applied to the specimens at a 0.1 millimeter/minute crosshead speed.[27] The point at which the bracket broke off from the tooth was recorded in kilograms and megapascals. We used Student's *t*-test to analyze the test results.

RESULTS

The table presents peak tensile loads for bonded specimens in both groups. As Figure 2 shows, lower values are generally associated with the laser-etching method. However, some values in this group are relatively high.

Mean (± standard deviation) tensile values at the point of bond failure were 5.17 (± 1.3) kg in Group A (acid-etched) and 2.66 (± 1.4) kg in Group B (laser-etched). The *t*-test comparison of mean values demonstrated a significant difference between the laser-etched and acid-etched groups, with specimens in the acid-etched group exhibiting significantly more tensile bond strength at a 95 percent level of significance ($P < .05$).

Evaluation of the typical tension-deformation of the specimens due to debonding stress shows a different behavior in each group. Figure 3 represents a complex load curve in which the curve starts as a straight line but gradually curves when a certain stress value is exceeded. This is typical behavior of nonhomogeneous material (such as composite resin) under tensile forces. On the other hand, Figure 4 shows only the behavior seen in the first portion of the curve in Figure 3. This curve seems to illustrate adhesion failure, whereas the curve in Figure 3 illustrates the cohesive properties of the resin cement.

DISCUSSION

Many researchers have studied adhesion to enamel[1,2,5,9] and, at present, acid etching is probably the best method of bonding resins to enamel. Unfortunately, demineralization and initiation of caries around wire brackets are typical complications of orthodontic treatment. Laser-induced caries resistance[24-26] would be of interest in orthodontics.

Irradiation of enamel with a CO_2 laser reduces the risk of caries,[30] and researchers have found that increased mineralization of enamel has occurred.[31-33]

chemical components. The presence of pyrophosphate[34,35] and the reduction of carbonated apatite[23,36,37] reduce the acid solubility of enamel. Although this study used an Nd:YAG laser rather than a CO_2 laser, we believe—based on the senior author's unpublished research with electron microscopy—that the superficial melting and fusion of enamel achieved with an Nd:YAG laser may be comparable to that achieved with a CO_2 laser.

On the other hand, the tensile bond strength was lower for the laser-etched group than for the acid-etched group. This difference was probably due to better morphological change and increased surface area on the acid-etched enamel.[3,6] Acid etching results in a dissolution of hydroxyapatite, while laser etching produces microscopic cracks, fissures and craters in the enamel surface. Although some authors have observed that the roughness in laser-etched enamel is similar to that in acid-etched enamel,[20] the morphological alteration of enamel etched with the Nd:YAG laser needs to be studied further.

Some specimens in the laser-etched group did exhibit high tensile strength values (Table). White and colleagues[38] found that the Nd:YAG laser improved the strength of composite bonded to metal orthodontic brackets. However, Roberts-Harry[22] compared acid etching with laser etching of enamel before clinical placement of brackets, and found that laser irradiation for bonding was less reliable than acid etching. In our experiment, the standard error of the two groups was similar, although the range of strength values was 25 percent greater in the laser-etched group. Unfortunately, the mean bond

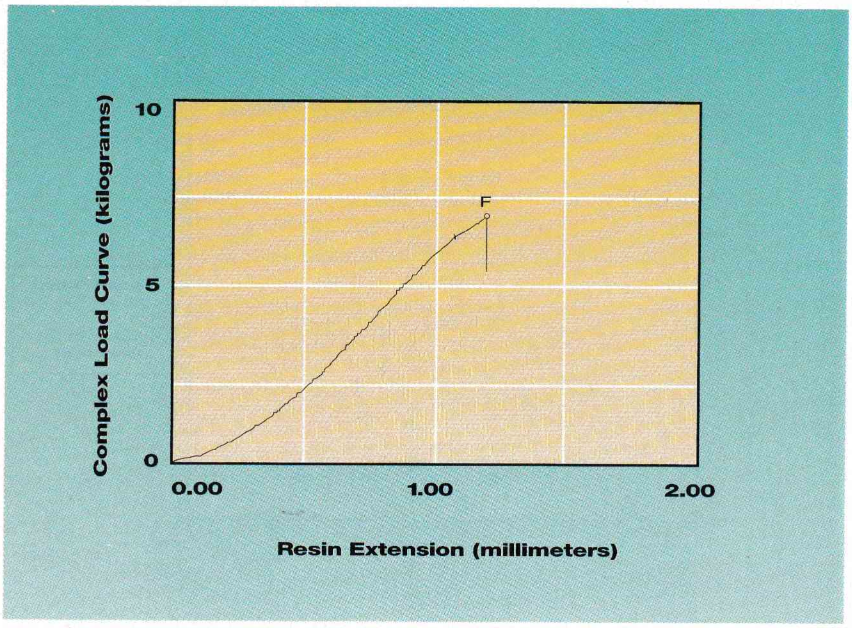

Figure 3. Typical tension-deformation curve for specimens in acid-etched group (A). F indicates the point of bond failure.

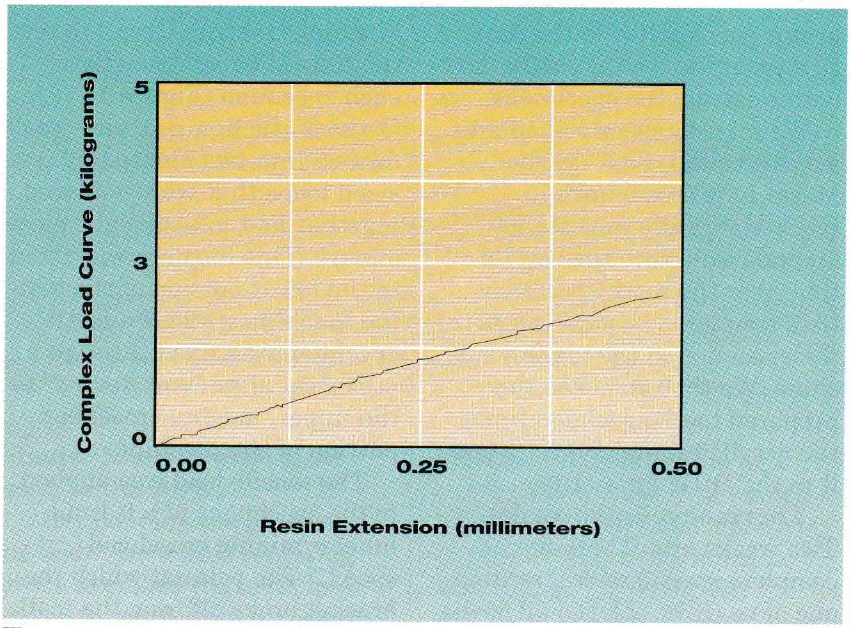

Figure 4. Typical tension-deformation curve for specimens in laser-etched group (B).

strength of the laser-etched group was only 50 percent that of the acid-etched group. Four specimens in the laser group failed at a bond strength of less than 1 MPa. Bond strengths this low would almost certainly result in clinical failure when force is exerted on the brackets.

When high forces are required, we do not recommend that laser etching be used to treat the enamel before bonding. Further research is needed to analyze the type of bonding resin failure, although the typical tension-deformation curve in the laser-etched group seems to

resemble adhesion failure (Figure 4). Thus, Nd:YAG lasers might be used to bond brackets if low forces are required for orthodontic treatment. In this study, the *t*-test comparison of means demonstrated a significant difference between the laser-etched and acid-etched groups, with the latter exhibiting significantly more tensile bond strength at a 95 percent level of significance.

SUMMARY

This study compared the true tensile bond strength of brackets adhered to Nd:YAG laser-etched bovine enamel with that of brackets adhered to acid-etched enamel. Mean tensile strength values at the point of bond failure were higher for the acid-etched group than for the laser-etched group. The load curve for each group exhibited different behavior. In the acid-etched group, the curve began as a straight line but gradually curved after a certain stress value was exceeded, demonstrating plastic deformation, most likely in the composite resin cement. In contrast, the curve for the laser-etched group exhibited failure before the stress level required for plastic deformation was reached. This is indicative of adhesive failure of the bond for this group. We conclude that etching enamel with the Nd:YAG laser is an ineffective pretreatment for bonding brackets to enamel. ■

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