Thermal Pulp Insult from Laser Debonding Ceramic Brackets

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by Frederick J.D. Schwendeman, D.M.D.

Abstract

In an attempt to identify a method of successfully debonding porcelain brackets without damaging the enamel or thermally insulting the pulp, a laser debonding method was investigated. Twenty human premolar teeth were bonded with ceramic brackets and then debonded with the aid of a laser. The bracket types investigated were polycrystalline alumina and monocrystalline alumina. A torsional force of 100 Nmm was applied to the base of each bracket prior to application of the laser energy. A continuous mode CO_2 laser set at 11 watts for 2 seconds (22 joules) was used for the debonding. A group of eleven electrothermally debonded monocrystalline brackets, a group of ten mechanically debonded monocrystalline brackets, and a group of ten mechanically debonded polycrystalline brackets were used as controls. The teeth were evaluated for site of bond failure, enamel alterations, and thermal conductance to the pulp chamber. The laser debonding times were very short (less than two seconds) resulting in displacement of the brackets before the laser beam was discontinued. This resulted in enamel damage in all but two samples, which just happened to be in the polycrystalline bracket group. All brackets debonded at the bracket/adhesive interface. Even with the direct application of the laser energy to the adhesive and enamel, the heat conducted to the pulp chamber was less than that seen in the electrothermally debonded controls, although not significantly so. This data confirms that the amount of thermal insult to the pulpal tissues during debonding with a continuous wave CO_2 laser is well within physiologic limits and no long term detrimental effects are to be expected.

Due to the artificially created enamel damage in the laser debonded groups, a second study was performed in which the brackets were held in place while the laser beam was applied for two seconds. In this second study of ten teeth, one tooth exhibited enamel damage. However, because the adhesive had to be removed before the enamel was evaluated, this data is inconclusive in regard to the possibility of enamel damage from the laser during debonding. The damage appeared as an enamel tear-out and not a melting, but the enamel may have been damaged by the laser and then torn out during removal of the adhesive. Further investigation needs to be carried out in regard to use of lasers in debonding ceramic brackets.

Introduction

Ceramic brackets have been a wonderful addition to orthodontic appliances. They allow patients that are very critical about esthetics a chance to receive orthodontic treatment and feel comfortable about their appearance. However, there have been several problems associated with treatment with ceramic brackets. One of these is difficulty in debonding, with enamel fractures occasionally being seen as a result of bond removal. Several investigations have evaluated methods of eliminating this problem, including a look at etching time, type of adhesive in relation to bond strength, special debonding devices, and specially coated brackets. In several studies, thermal debonding has been suggested as the best method of removing ceramic brackets. All investigations that measured heat transfer to the tooth from thermodebonding suggest thermal insult to the tooth is minor and insignificant. A histologic examination of thermally debonded teeth by **Jost-Brinkmann, et al. (1992)** showed some damage associated with thermal debonding of ceramic brackets. Several teeth showed localized pulpal damage with slight infiltration of inflammatory cells and some patients experienced pain. Even though there was some pulpal damage, the authors suggest that this is minor and more than likely completely reversible.

It is evident from previous literature that thermal debonding is useful and adequately safe. However, it would be advantageous to find a debonding system that could eliminate the thermal insult altogether. Laser debonding has been proposed as the solution.

Strobl, et al. (1992) and **Tocchio, et al. (1993)** have researched debonding of polycrystalline and monocrystalline ceramic brackets aided with a laser. The results are promising. Heat is generated through this process but the debonding times are less than those with thermal debonding, which should result in less heat transfer to the pulpal tissues. However, there has not been any previous examinations of the amount of heat conducted to the pulp chamber from laser debonding.

The purpose of this study is to investigate the amount of thermal insult that can be anticipated from debonding poly and monocrystalline porcelain brackets with a continuous wave CO_2 laser.

Review of the literature

The advent of ceramic brackets made orthodontic treatment a viable option for a large segment of the population that had previously found orthodontics to be esthetically unacceptable. Although the brackets have been very beneficial and will continue to be an important part of orthodontics, there are disadvantages as well as advantages associated with them.

Esthetics is the porcelain brackets' greatest advantage over traditional metal brackets, but they also have a higher compressive strength and greater hardness.[37] However, in some respects this greater hardness contributes to some of the disadvantages.

The disadvantages of porcelain brackets are that they are more expensive than metal brackets, they are brittle and susceptible to fracture, they can wear opposing teeth, and they are difficult to debond. A study by **Angolkar, et al. (1990)** also showed increased frictional resistance of archwires through porcelain brackets.

An important characteristic of porcelain brackets, as stated above, is their extreme hardness. However, the harder a material is the more it will wear an opposing material softer than itself. The Knoop hardness number (KHN) for ceramic brackets is in the range of 2400 - 2450, which is almost seven times as hard as enamel (KHN 343).[49] **Viazis, et al. (1989)** demonstrated cases of significant enamel abrasion in patients that occluded against ceramic brackets. **Viazis, et al. (1990)** also showed significantly greater enamel abrasion in teeth occluding against porcelain brackets than those occluding against metal brackets in an artificial oral environment.

The atomic structure that imparts hardness to ceramics also accounts for one of its biggest faults - its brittleness. Ceramics used in orthodontic brackets have highly localized, directional atomic bonds. This oxidized atomic lattice doesn't permit shifting of bonds and redistribution of stress. When stresses reach critical levels, interatomic bonds break and material failure occurs. This is called "brittle failure".[45]

Resistance to fracture is an important property for ceramics. Fracture toughness is the ability of a material to resist fracture along a crack or groove. Therefore, the finishing techniques are of utmost importance in bracket fabrication. If microcracks are present in brackets, it can make the brackets more susceptible to fracture. **Holt, et al. (1991)** found that fracture resistance of ceramic brackets appears to be adequate for clinical use. This study compared the fracture resistance of different ceramic brackets during arch wire torsion. The mean torques at fracture ranged from 3,706 - 6,177 gm-mm, with the mean torsional rotation at fracture ranging from 9.5° to 17.8°. Eight to ten degrees of torsional rotation of the arch wire produced sufficient orthodontic force to achieve the torque. However, fracture of ceramic brackets has been indicated to be a major clinical problem and the American Association of Orthodontist issued a statement recommending disclosure to patients regarding the difficulties experienced with the ceramic brackets. Even though it appears as though ceramic brackets should hold up to torsional forces, perhaps scratching of the brackets during clinical use predisposes them to fracture. Other forces other than torsional forces of the arch wire may also be a factor in the fracture of ceramic brackets.[20]

Initially, porcelain brackets didn't reach any appreciable degree of popularity due to their high bond failure rates. The first ceramic brackets were bonded to teeth by a purely mechanical bond between the adhesive and bracket through undercuts of various designs in the bracket base.[31] Laboratory testing of ceramic brackets with mechanical retention indicates that adhesive-to-bracket bond strengths are less than those of equivalent size foil/mesh metal brackets.[45] These ceramic bracket bases have considerably fewer mechanical undercuts than are found in mesh base designs, and therefore the ceramic brackets might be expected to have greater bond failure rates.[45]

Chemical bonding of porcelain brackets finally improved their bonding performance, and hence their popularity. **Viazis, et al. (1990)** demonstrated that the bond strengths of chemically retained porcelain brackets were significantly higher than ceramic brackets that were purely mechanically retained. This was accomplished by adding glass to the aluminum oxide base, which was subsequently treated with a silane coupling agent. The silane bonds with the glass and has a free end of its molecule that will react with the bonding materials. This produced exceptional bond strength which has led to difficulties in debonding. These high bond strengths can possibly exceed the fracture resistance of the bracket or shift the stresses of debonding from the bracket/adhesive interface to the enamel/adhesive interface. If this bracket/adhesive bond is too strong, a sudden impact loading that can be seen during debonding is more likely to cause failure in the more brittle ceramic and enamel than in the bonding material.[45]

The bond strengths of porcelain brackets compared with those of metal brackets have been investigated extensively, with variable results. **Joseph and Rossouw (1990)**, **Odegaard and Segner (1988)**, **Harris, et al. (1990)**, and **Viazis, et al. (1990)** have all shown that ceramic brackets with silanated bases have higher bond strengths than metal brackets. The shear bond strengths reported by **Viazis, et al. (1990)** for chemically retained ceramic brackets are the highest values ever reported in the literature. The maximum value exceeded 100 pounds of force. In comparing polycrystalline silane treated ceramic brackets to two types of metal brackets, **Odegaard and Segner (1988)** reported that the shear bond strengths were higher for the ceramic brackets, but the difference was only significant when compared to the grooved base metal brackets and not mesh based metal brackets. Also, **Britton, et al. (1990)** showed no difference between ceramic brackets and one metal type.

It appears that the excessively high shear bond strengths are associated with the silane treated ceramic brackets and most of the literature supports this. However, in direct comparison between mechanically retained and chemically retained ceramic brackets the results aren't as clear cut. **Viazis, et al. (1990)** and **Iwamoto, et al. (1987)** have demonstrated higher bond strengths for silanated brackets than those of untreated ceramic brackets. In addition, **Storm (1990)**, **Lush and Hood (1990)**, and **Hill, et al. (1991)** demonstrated more enamel damage associated with debonding smooth based silane treated ceramic brackets. **Redd and Shivapuja (1991)** showed enamel damage for chemically retained brackets as high as 86% for monocrystalline and 40% for polycrystalline brackets. In contrast to that data, **Guess, et al. (1988)** found no difference between silanated and untreated ceramic brackets and **Ostertag, et al. (1991)** found mechanically retained ceramic brackets to have a higher bond strength than chemically retained ceramic brackets. **Bamford (1991)** also investigated two types of chemically retained ceramic brackets and found no "gross" enamel damage.

Even with some conflicting data, the literature substantiates that debonding porcelain brackets can possibly lead to enamel damage. In response, there has been some move away from chemically retained porcelain brackets, back toward a purely mechanically retained bracket. In evaluating some purely mechanically retained brackets, **Winchester (1992)** found that only one out of 40 teeth exhibited enamel fracture and the damaged tooth was debonded with a shear force. None of the teeth debonded with a tensile force had enamel damage. **Amditis (1994)** also investigated the same mechanically retained bracket and found evidence of enamel damage in only 3 of 100 teeth after SEM evaluation. Of these three teeth, only one was debonded with a recommended debonding instrument. The two others were debonded with a ligature cutter.

Regardless of a few conflicting reports concerning bond strengths of silanated ceramic brackets, most investigators feel that the bond strengths are excessively high and pose significant problems. Some of these investigators have offered explanations for some of the conflicting data. **Amditis (1994)** and **Winchester (1992)** feel that the variation in bond strengths is due to variations in the adhesives used. In comparison of two different types of light cured adhesives, **Winchester (1992)** found a significant difference in bond strengths. An adhesive with 15% by weight filler content had higher bond strengths than an adhesive with 79% by weight filler content. This relationship between bond strength and filler content is in contrast to previous studies using metal brackets. Possibly the physical properties of the cements are emphasized since ceramic brackets are completely rigid and, unlike metal brackets, don't flex during debonding. **Joseph and Rossouw (1990)** demonstrated that ceramic brackets bonded with an auto cured resin have an increased, but not significantly so, bond strength over those bonded with light cured resins. However, **Viazis, et al. (1990)** found no difference in shear bond strengths with a chemical cure and a light cure adhesive.

Several authors feel that the type of debonding force applied can increase or decrease the amount of enamel damage associated with debonding. **Winchester (1992)** and **Ostertag, et al. (1991)** found that a tensile force favors debonding at the adhesive/bracket interface, while a shear or rotational force tends to move the site of bond failure toward the adhesive/tooth interface. **Ostertag, et al. (1991)** found that 100% of brackets debonded at the adhesive/bracket interface if debonded with a tensile force, while only 17% to 30% debonded at the adhesive/bracket interface when a shear or torsional force was applied. Furthermore, **Amditis (1994)** found that less than 40% of the brackets in his sample fractured at the adhesive/bracket interface when debonded with a ligature cutter that applied a pealing force, while greater than 60% of bond failures occurred at the adhesive/bracket interface when a debonding plier that applied a tensile force was used.

Whether or not the bond strengths of silanated porcelain brackets are always excessive, there have been numerous problems associated with their debonding. Many studies have shown that mechanical debonding of porcelain brackets results in a high percentage of fractured brackets.[5,11,31,43,44] Bracket fracture is potentially harmful to the patient as pieces of shattered brackets are sharp and could cause injury to intraoral tissues or the eyes, and they could even be ingested or aspirated.

As the bond failure of porcelain brackets tends to shift toward the enamel/adhesive interface, as has been shown to occur by **Siomka and Powers (1985)**, **Bishara and Trulove (1990)**, **Odegaard and Segner (1988)**, and **Gwinnett (1988)**, the potential for damage to the enamel increases.[5,22,31,43,49] Many studies have shown that enamel damage does occur with mechanical debonding of porcelain brackets.[5,22,31,43]

In order to decrease the potential for bracket and/or enamel fractures during debonding, some investigators have looked at methods of decreasing the bond strengths of porcelain brackets. Some of the suggested methods of decreasing the bond strengths have been a reduction of the etch time, restriction of the type of adhesive, and only using mechanically retained brackets.[17,23,43] **Maskeroni, et al. (1990)** suggested using a polyacrylic acid crystal growth technique instead of phosphoric acid to etch the enamel for bonding to porcelain. **Fox and McCabe (1992)** reported on a porcelain bracket with a thin polycarbonate laminate base in which the bond strength was similar to that of metal brackets, but the bond was less reliable, having more potential for lost brackets during treatment. Various methods of debonding porcelain brackets have also been studied. Many different mechanical debonding instruments have now been developed, most of which are designed to apply a tensile debonding force. **Swartz (1988)** suggested the use of high speed rotary abrasion to remove ceramic brackets. **Bishara and Trulove (1990)** evaluated ultrasonic debonding and found that a significantly greater percentage of brackets debonded at the enamel/adhesive interface when compared to mechanical debonding, but the likelihood of enamel damage was less. Both the high speed rotary abrasion and ultrasonic debonding have the distinct disadvantage of taking a greater amount of time.

Thus far, the most accepted, alternate method of debonding to come along has been electrothermal. Electrothermal debonding was first investigated by **Sheridan (1986)**. In this study, electrothermic debracketing (ETD) was investigated with metal brackets. Part I of this study measured the in vitro rise in temperature at the pulpal wall while Part II examined the histologic features of the pulp after ETD. Both parts of this study suggested that ETD is a physiologically acceptable alternative to conventional mechanical debracketing. Several authors suggest this as the answer to the ceramic debonding dilemma. **Bishara and Trulove (1990)** demonstrated that a significantly greater number of electrothermally debonded brackets debond at the bracket/adhesive interface when compared to mechanical debonding. **Ruggeberg and Lockwood (1992)** also showed that increasing the resin temperature decreased the debonding force needed, decreasing the chance of enamel damage. **Sernetz and Kraut (1991)** also demonstrated successful electrothermal debonding with failure occurring at the bracket/adhesive interface and no enamel damage. The only contrasting data to the above encouraging results is in a study by **Jost-Brinkmann, et al. (1992)**. This study indicated several problems associated with thermal debonding. Whenever more than one heating cycle was necessary, several teeth showed localized damage of the pulp with slight infiltration of inflammatory cells, bracket fractures occurred frequently, enamel damage could be shown, and with one of the adhesives more than one heating cycle was often necessary which caused pain lasting up to fifteen minutes.

The most significant problem associated with electrothermal debonding is the transfer of heat to the tooth. In evaluating two different electrothermal debonding instruments, **Brouns, et al. (1993)** exhibited average increases in pulpal temperature of 1.1°C for one type of electrothermal debonder and 3.6 - 5.2°C for a second type. **Sernetz and Kraut (1991)** also found temperature increases to be below 5°C.

As demonstrated by **Zach and Cohen (1965)**, thermal insult at temperature increases below 5.5°C should be completely reversible. They investigated pulpal temperature increases in the Macaca rhesus monkey. Intrapulpal temperature increases of 4°F (2.2°C) produced only minimal intrapulpal changes confined to the odontoblasts in continuity with the area of application of the heat. Sections taken at subsequent intervals of 7 days to 3 months after external heat application disclosed normal pulps with no trace of increased secondary dentine formation. These specimens were histologically unidentifiable from control unheated specimens.

At intrapulpal temperature increases of 10°F (5.5°C), a considerably more marked intrapulpal response was apparent, both immediately and after prolonged intervals. A lesion characterized as a burn was observed in all of these teeth upon which the heat source was allowed to rest longer than 10 seconds. These changes were confined to that area of dentin in direct continuity with the tubules of the surface heat source. Fifteen per cent of the teeth heated to 10°F failed to recover. Heat rises below this critical level were found to produce reactions relative in severity to the degree of heat, which almost invariably led to pulp recovery. Histologic investigations of thermally debonded teeth seem to validate this. **Kraut, et al. (1991)** saw no evidence of pulpal injury based in histologic exam of thermally debonded teeth while others did show localized damage of the pulp with slight infiltration of inflammatory cells.[11,23] Irreversible pulp damage is not to be expected with electrothermal debonding, but some patients may still complain of discomfort and even pain.[8,23] It does take quite a high temperature to debond ceramic brackets with electrothermal debonding and caution should be used with this procedure.

Sheridan (1986) demonstrated that temperatures of around 130°C were needed to successfully debond metal brackets, while

Jost-Brinkmann, et al. (1992) found adequate heating of the adhesive to range from 100°C to 170°C for different adhesives, with ceramic brackets. With these types of temperatures being generated to debond brackets, **Jost-Brinkmann, et al. (1992)** stated the importance of debonding brackets in the first attempt, even if it required using a higher temperature to get the brackets off faster. It is evident from the data obtained from previous studies that thermal debonding is useful and adequately safe from harmful side effects. However, it would be beneficial to find a debonding system that could decrease or even eliminate the thermal insult altogether.

Laser debonding has been proposed as the solution. The laser was first developed by Maiman in 1960.[46] The term laser is derived from the first letters of "light amplification by stimulated emission of radiation." Lasers produce a radiation of high intensity that can be focused to a small area because of the small angle of divergence and coherency of the beam. The radiation may be continuous or modulated, or the emission may occur in short pulses.[46] It has been reported that injury to the pulp may occur with lasers via thermal insult or transmission and scattering of the laser beam through enamel and dentin.[29] There has been differing reports on the biological status of the pulp following laser exposure to different types of lasers and on different animals.[1,13,27,40,42,46,52] It has been shown that there is a direct relationship between exposure energy and internal temperature in the pulp chamber.[28]

Some of the first research investigating the effects of laser radiation on intraoral tissues used a solid state, ruby laser, with a .694mm wavelength. With this laser, several studies exhibited harmful effects on the enamel and pulpal tissues of teeth. In hamsters, **Taylor, et al. (1965)** found enamel damage to occur at energy levels of 35 joules and more severe damage at 55 joules. At both energy levels, there was severe pulpal damage covering a large area which was slow to heal, if it healed at all. **Yamamato, et al. (1972)** also demonstrated cratering of enamel in rat incisors and severe but limited changes in dental pulps after exposure at an energy level of 28 joules. The reversibility of this damage was not investigated.

Adrian, et al. (1971), studying the effects of the ruby laser on dog incisors, did establish some threshold energy levels in order to prevent significant loss of calcified tooth structure and pulpal necrosis. However, **Stern, et al. (1972)** suggested that the ruby laser was not compatible with use intraorally due to its wavelength. At the ruby laser wavelength of .694μm, the enamel behaves like a diathermanous solid, dividing the laser energy into two components. One component, consisting of 80% of the energy, is largely reflected. The second component, consisting of only 20%, is absorbed into the tooth causing heating. As an alternative, the CO_2 laser was suggested as the ideal laser for intraoral use.[42]

The CO_2 laser is an infrared laser emitting energy of 10.6μm wavelength. **Stern, et al. (1972)** postulated that the CO_2 laser is well suited for dental application since the principal wavelength for the optical absorption of enamel (10.6μm) closely corresponds to CO_2 laser emission, and therefore deleterious heat transfer to the pulp should be minimal. Enamel behaves as an opaque solid from the standpoint of energy absorption at the CO_2 wavelength and heat conduction or penetration effects are almost eliminated. Heat is dissipated within a few mm of the surface. The thermal diffusion of the CO_2 laser in enamel is such that one would expect a temperature rise just below the surface (at about 10 μm depth) of only 5% of that incident on the enamel surface itself.[42]

In contrast, measurable thermal changes within the pulp chamber have been shown to occur at exposure with the CO_2 laser. In lasing the second premolar tooth of beagles for .1 seconds at 10 watts (1 joule), **Fisher and Frame (1984)** demonstrated that short blasts of laser energy may cause pulpal damage and degeneration and that visible cratering, extending into the enamel and dentine occurred. **Miserendino, et al. (1989)** found measurable thermal changes occurred at power levels above 2 watts for exposures greater than .5 seconds (1 joule) with the continuous wave CO_2 laser. Cratering of the enamel also occurred at low power, with more extensive damage at higher energy levels. According to **Miserendino, et al. (1989)** CO_2 laser exposure should remain below 10 Joules to be in the safety range for thermal insult to the pulp as established by **Zach and Cohen (1965)**.

Powell, et al. (1990) believe the most limiting factor for use of the CO_2 laser on dental hard tissues is the possibility of enamel damage. Pulpal damage was shown to be completely reversible up to energy levels of 4 joules. Even with energy levels of up to 8 joules the intrapulpal temperature changes were less than 6°F (3.3°C). Enamel damage was shown to occur in dog and human teeth with energy levels above 1.0 joule. This is consistent with other previous studies. However, at levels of up to 1.3 joules these changes were limited to microscopic superficial surface fusion, which in turn increases the enamel's resistance to demineralization.[42]

It is apparent that there are problems associated with the use of the CO_2 laser on oral hard tissues. However, these are basically irrelevant in the use of the CO_2 laser for debonding of ceramic brackets due to the energy absorption of the bracket and adhesive. The specular transmission of polycrystalline alumina drops to very low values at wavelengths shorter than 1500 nm (1.5mm)and therefore will rapidly scatter and disperse light.[47] Monocrystalline brackets on the other hand have produced different results. **Tocchio, et al. (1993)** states that they transmit greater than 80% of light with wavelengths between 250 and 4000 nm (.25 - 4 mm). But, **Strobl, et al. (1992)** found the monocrystalline brackets to be highly absorptive at the CO_2 laser wavelength of 10.6 mm.

Even if light did pass through the brackets, the adhesive resin itself would absorb the light energy. One would expect a transparent material such as the adhesive resin to transmit light, however it has been shown that a high energy can cause structural changes at the atomic level which greatly increases their light absorption.[9]

Strobl, et al. (1992) investigated the debonding of mono and polycrystalline alumina ceramic brackets using the CO_2 and Nd:YAG lasers. The CO_2 laser was very effective at debonding both types of brackets. However, the monocrystalline brackets tended to show cracking and plume formation at the energy level of 28 joules recommended by Strobl. The Nd:YAG laser required higher energy and longer exposure times unless the brackets were coated with a highly absorptive paste. Both bracket types debonded by thermal softening of the adhesive.

Tocchio, et al. (1993) studied the effects of debonding both bracket types with the KrF and XeCl excimer lasers and the Nd:YAG infrared laser. The average debonding times for the polycrystalline brackets were 3.1 seconds for the KrF laser, 4.8 seconds for the XeCl, and 23.7 seconds for the Nd:YAG. All of the monocrystalline brackets were blown off in less than .5 seconds, except with the Nd:YAG at lower power densities. Monocrystalline brackets debonded by photo or thermal ablation with direct interaction of the laser energy with the adhesive when the KrF, XeCl, and Nd:YAG lasers were used.

These two previous studies show promise for the use of lasers for debonding of ceramic brackets, but further investigation needs to be carried out. With laser energy absorption within the bracket or the adhesive, there does exist a possibility for thermal insult to the tooth, especially with longer debonding times. **Strobl, et al. (1992)** recommend a 2 second exposure time at 14.1 watts. At this total of 28 joules of energy, the residual debonding torque force for both mono and polycrystalline brackets approaches zero and the debonding times are less than those seen with thermal debonding. At this energy level, both types of brackets are debonded by thermal softening of the resin but it is localized and controlled, minimizing the possibility for thermal insult to the tooth. However, there has not been any previous examination of the amount of heat transferred to the pulp chamber. It is the purpose of this paper to measure the amount of thermal insult to the tooth and pulp.

Materials and Methods

In order to evaluate the efficacy of laser debonding, two groups of ten teeth were bonded with two different types of ceramic brackets, a monocrystalline porcelain bracket (Starfire, "A"-Company, San Diego, CA) and a polycrystalline porcelain bracket (Allure, G.A.C. International, Central Islip, NY). These teeth were debonded with a continuous wave CO_2 laser. To serve as controls, ten teeth bonded with Starfire brackets and ten teeth bonded with Allure brackets were debonded mechanically. In addition, a fifth group of eleven teeth bonded with Starfire brackets were electrothermally debonded for comparison with the laser debonded Starfire brackets. The mechanically debonded teeth were debonded according to the bracket manufacturers recommended method. Both the electrothermal and laser debonded teeth were evaluated as to thermal insult to the pulp and all teeth were evaluated in regard to enamel damage.

Fifty-one previously extracted premolars were used for the study. These teeth were stored in a .1 % Thymol/$H_2 0$ solution until needed. To prepare the teeth for experimentation, the apical third of the root was cut off and the root canals were debrided of pulpal tissues. Once the radicular tissues were removed, the teeth were mounted in acrylic in order to facilitate handling and control of force applied to the brackets. An access prep, through the proximal surface, was cut on all teeth used for electrothermal or laser debonding. This was for recording of intrapulpal temperatures. These preps were 5mm below the occlusal table and 1mm in height and 2mm in width. The coronal pulpal tissues were removed through these preps.

The brackets were bonded onto the teeth via the manufacturers specific instructions with Concise adhesive. Concise was selected for both bracket types for its consistency and its high bond strength, and also it has been shown to have high thermal conducting properties that are favorable for thermal debonding.[8] The general bonding regimen consisted of cleaning with pumice, followed by a thorough rinse and drying with compressed air. A 35% phosphoric acid etchant was applied to the enamel surface for the time recommended by both manufacturers (20 to 30 seconds). The etchant was rinsed off and the teeth were dried with the compressed air. The brackets were then bonded onto the teeth.

Forty-eight to seventy-two hours after bonding, the teeth were debonded. The controls were mechanically debonded via the manufacturers recommended method. The Allure brackets were removed by the ETM 346 direct-bond bracket removing pliers (ETM Corporation, Monrovia, CA) while the Starfire brackets were debonded with the Starfire TMB debonding pliers ("A"-Company, San Diego, CA) (see photographs #1, 2, and 3). For electrothermal debonding of the Starfire brackets, the Electro-Thermal Debonder ("A" -Company, San Diego, CA) debonding unit was used. See photograph #4. The Allure brackets were not debonded electrothermally because it wasn't a recommended method of debonding by GAC. The debonding force applied to these teeth was 100 Nmm turning force as suggested by **Sernetz and Kraut (1991)**. A pilot study was conducted to determine that this force would be adequate for electrothermal and laser debonding. This force was applied via a custom made instrument for each bracket type. This instrument surrounded the bracket base and had a lever arm from which the torsional force was applied (see photographs #5 and 6).

To keep the forces applied to the brackets equal during electrothermal and laser debonding, a grid was used to measure the distance of displacement of the debonding instrument handle. The distance of displacement to produce the optimal force of 100 Nmm was marked on the grid. The debonding instrument handle was moved to this marked spot before application of the electrothermal or laser energy. The distance of displacement needed was determined before hand by using the Chatillon Digital Torque Gauge (Chatillon, Greensboro, NC).

An infrared CO_2 laser, of 10.6mm wavelength (Luxar Corporation, Bothell, WA) was selected for the laser debonding due to the favorable results obtained by **Strobl, et al. (1992)**. In this previous study, it was recommended that an energy of 28 joules, 14 watts for 2 seconds be used for effective bracket debonding. However, in a pilot study in the current investigation, it was found that both types of brackets debonded in less than 2 seconds at 11 watts. Therefore, both the Starfire and Allure brackets were debonded with the CO_2 laser set on continuous mode at 11 watts. The laser was applied to the brackets at a distance of 1mm from the center of the bracket for 2 seconds or until the bracket debonded, whichever came first.

Upon debonding, the site of bond failure was recorded either as a cohesive failure of the bonding agent, an adhesive failure between the enamel and bonding agent, or an adhesive failure between the bracket and bonding agent. This was recorded where at least 2/3rds of the fracture site was located. Bracket fractures and enamel damage were also recorded. After debonding, the adhesive was removed from the laser debonded groups in order to evaluate the condition of the enamel. This was accomplished with the ETM 346 direct-bond removing pliers and the Starfire TMB debonding pliers for the Allure and Starfire brackets, respectively. All teeth were evaluated under light microscopy to check for any enamel alterations. Data was recorded as a presence or absence of enamel changes.

To measure the heat transferred to the pulp chamber during the debonding processes, a Series 4500 Microscribe Strip Chart Recorder (The Recorder Company, San Marcos, TX) was used to record any changes in temperature over time. A thermal probe connected to the X-T recorder was inserted into the pulp chamber via the proximal prep. The pulp chamber was filled with the .1% Thymol/H_2O solution and sealed with wax. After debonding the temperature was allowed to return to pre-debonding temperature before removing the probe.

To keep the teeth as close to 37°C before electrothermal and laser debonding, they were kept in an oven in the .1% thymol/ H_2O solution at 37°C. During the debonding, the teeth were filled with this same solution and then the experiment was performed under a heat lamp. The temperature was checked to make sure it was constant over time before the debonding procedure was performed.

Due to the unexpected finding of severe laser induced enamel damage, 10 teeth (5 from each laser debonding group) were rebonded on the lingual with the same type of brackets as had previously been bonded to the buccal of these teeth. Then these brackets were again removed with the CO_2 laser set at 11 watts. The brackets were held in place with a Tweed band seating plier #803-0123 (AEZ/Ormco, Glendora, CA) and lased for 2 seconds, for a total energy of 22 joules. The composite was again removed from these teeth with the mechanical debonding pliers and the enamel was observed under light microscopy for evidence of damage.

Results

The time for each bracket to debond after application of the energy source and the increases in pulp chamber temperatures for the electrothermal and two laser debonding groups, are presented in tables I - III. Table IV is a comparison of the temperature changes and debonding times for the three groups (presenting the number of samples, mean, range, and standard deviation of each group). The mean temperature changes for both of the laser debonded brackets were lower than that of the electrothermally debonded brackets. The debonding times for the laser debonded groups were also lower than those seen for electrothermal debonding.

Statistically, a 2-way ANOVA was utilized in conjunction with a Tukey multiple comparisons analysis to evaluate differences in mean temperature changes and in mean debonding times. No significant difference was shown between the mean intrapulpal temperature changes. However, there was a significant difference in mean debonding times, with both of the laser debonded groups exhibiting a significantly ($p = .05$) shorter debonding time.

Evaluation of the sites of bond failure for the mechanical, electrothermal, and laser debonded brackets are listed in tables V - IX. All of the electrothermally debonded monocrystalline brackets exhibited bond failure at the bond/bracket interface with all of the resin left on the tooth. None of these brackets fractured or splintered during the debonding process. In addition, the laser debonded monocrystalline and polycrystalline brackets didn't have any bracket failures during debonding and all but one bond failed at the bond/bracket interface. Sample number 10 of the monocrystalline, Starfire, bracket group displayed a cohesive bond failure.

In the mechanical debonding groups, the results were more variable. Eight of the monocrystalline brackets exhibited a cohesive failure within the bond material. Of these eight, two brackets fractured into two pieces. The remaining two brackets of this group showed an adhesive failure between the bond and the bracket. The polycrystalline group also had the majority of bond failures of the cohesive type, with seven of the ten bonds failing within the resin. One bracket debonded at the bond/bracket interface and two brackets debonded at the tooth/bond interface. None of the polycrystalline brackets fractured during mechanical debonding. Table X presents the percentages of bond failures occurring of the bracket/adhesive interface of the five groups.

The results of the evaluation of the enamel after debonding are shown in tables XI - XV. Enamel damage was not detected under light microscopy for either one of the mechanical debonding groups or the electrothermal debonding group. However, enamel damage, ranging from mild to severe, was seen in all but two of the laser debonded brackets. In general, the damage was less severe in the teeth bonded with the Allure brackets. This damage was seen as small cracks and chips in the enamel, and also included some pitted areas (see photographs #7 and 8). The teeth bonded with the Starfire brackets were seen to have extensive cracking and cratering of the enamel surface (see photographs #9, 10, and 11). The two teeth that didn't exhibit evidence of enamel damage were in the Allure bracket group (see photograph #12). SEM evaluation of one of the more severely damaged teeth is displayed in photos #13 - 16.

Since enamel damage wasn't anticipated, the procedure of laser debonding in this investigation was questioned. Due to the force system applied to the brackets, the brackets didn't stay in place once the bond failed. The laser was operated manually and was terminated at two seconds or when the bracket debonded. Since all of the brackets debonded before two seconds there was a possibility of direct laser application to the adhesive after the bond failed and before the laser was terminated. If indeed the laser was being directly applied to the adhesive and tooth, once the bracket debonded, then there should not have been any difference between the monocrystalline and polycrystalline groups in the amount of damage seen. To better evaluate these results, a second trial was run with 10 teeth divided into two groups, as previously described in the materials and methods, in order to see if enamel damage occurs with a bracket in place.

The results of this second trial are shown in table XIV. All of these brackets, except one, debonded at the bond/bracket interface. Sample #4 of the Allure, polycrystalline brackets, had an cohesive bond failure. Also two of the Starfire, monocrystalline brackets fractured at the end of laser application while being held with the Tweed band seating plier. None of the Starfire bracketed teeth exhibited any enamel alterations, but one of the Allure bracketed teeth did have some minor changes. This change appeared as a white opacity located gingival to the center of where the bracket had been. Under S.E.M. evaluation this area was revealed to have enamel damage consistent with what previous studies exhibited as enamel tear outs from mechanical debonding (see photographs #17, 18, and 19).

From these results thermal debonding ceramic brackets proved to be beneficial in preventing bracket fracture and in keeping the site of bond failure at the bracket/bond interface, thereby decreasing the chance for enamel damage from the mechanical stresses of debonding. As in previous research, electrothermal debonding exhibited successful removal of the brackets with a minimal intrapulpal temperature increase that was well within the physiologic limits established by **Zach and Cohen (1965)**. This study established that the thermal insult from laser debonding was also well within this physiologic limit. The actual thermal insult from the laser debonding was less than that seen with electrothermal debonding, although the difference wasn't statistically significant.

The main problem seen in the laser debonding was enamel damage. However, this damage was a result of the experimental design. The follow-up laser study failed to demonstrated inconclusively whether or not enamel damage could be expected with laser debonding. The one tooth out of ten that demonstrated enamel damage could have been damaged during the removal of the resin after bracket removal.

An additional problem seen in the follow-up study was the fracture of two of the five monocrystalline brackets during laser application. Bracket fracture is typically associated with mechanical debonding, as this study seemed to validate. However, holding the bracket in place with a plier during laser application to prevent enamel damage appears to put enough stress on the monocrystalline brackets to also cause bracket fracture.

Discussion

The amount of thermal insult seen from the laser debonding of both types of ceramic brackets establishes debonding with a continuous wave CO_2 laser as safe, in regard to thermal insult to the pulp. The temperature increases seen were less than those seen with electrothermal debonding, and yet this should actually be a worse case scenario for thermal insult with laser debonding. Since the laser was obviously being applied directly to the adhesive after the bracket debonded it can be assumed that the thermal insult would only be smaller if the bracket were held in place to shield the tooth from direct laser application.

In comparison of the results of this study to previous laser studies in which the laser energy was applied directly to the enamel, the present findings exhibit a lower temperature increase intrapulpally. **Powell, et al. (1990)** found temperature increases of less than 6°F (3.3°C) with laser energies of only 8 joules, while **Miserendino, et al. (1989)** found measurable thermal changes at power levels of 2 watts for exposures greater than .5 seconds (1 joule). This suggests that the actual amount of time that the laser beam was allowed to contact the adhesive, and enamel, was very minimal.

The mean time to debond the brackets with the laser was significantly shorter than the mean debonding time of the electrothermally debonded group. As suggested by **Jost-Brinkmann, et al. (1992)** and **Strobl, et al. (1992)** a shorter debonding time should provide for less time for the heated bracket to transmit heat through the tooth to the pulp. However, in this investigation, even though the thermal changes in the laser debonded groups were lower than the electrothermal group, the difference wasn't significant. Perhaps the direct application to the adhesive is responsible for this lack of significance.

Of note is the fact that the temperature increases for the two teeth in group C that did not exhibit any enamel damage were very similar to the temperature changes seen in all the rest of the samples of that group. These temperatures are actually within one standard deviation of the mean temperature increase for the entire group. This also suggests that the data obtained in this investigation are not different than what could be expected from laser debonding without incidental lasing of the adhesive and enamel.

One possible explanation for the temperature changes to be similar in teeth that were lased and those that weren't is the postulate of **Stern, et al. (1972)**, whereby heat transfer to the pulp is not expected to be very significant since the optical absorption of enamel is very similar to that of the CO_2 laser wavelength. Supposedly this would nearly eliminate heat transfer to the pulp since the heat should be dissipated within a few micrometers of the surface. However, this doesn't seem probable since some of the more recent investigations involving the CO_2 laser and teeth have shown that intrapulpal temperature increases do occur.

The presence of enamel alterations provides one clear message, that is the importance of controlling the laser beam. At the level of energy needed to effectively remove ceramic brackets, the laser is capable of producing severe enamel damage within times of less than one second. **Powell, et al. (1990)** demonstrated that enamel damage occurs at power levels of 10 watts in as little as .1 second. This in itself could be enough of a contraindication to prohibit the use of the laser as a debonding instrument. Trying to hold brackets with a plier and apply a laser beam through the center of a bracket could prove difficult intraorally on some patients.

Ninety-seven percent of the thermally debonded ceramic brackets debonded at the bracket/adhesive interface, compared to a total of fifteen percent for the combined mechanically debonded groups. Debonding at the bracket/adhesive interface virtually eliminates the possibility of enamel tear-outs from the debonding procedure itself. However, the adhesive has to be removed from these teeth after the bracket is removed. The adhesive removal also has the potential to create enamel defects.

The damage seen in the tooth exhibiting a tear-out in the second laser study group could possibly be caused from the removal of the adhesive for evaluation of the enamel. There is no way to tell if the enamel had been damaged prior to the adhesive removal. But, since there was no enamel damage evident in the mechanically debonded group, it certainly raises a question as to the possibility of enamel weakened from the laser, which tore out once the adhesive was removed. Further research needs to be carried out in regard to enamel damage from laser debonding.

As demonstrated by several studies in the past, bracket fracture is one of the problems associated with debonding of ceramic brackets.[5,11,31,43,44] Four brackets in the present investigation exhibited fracture during debonding. All four of these were monocrystalline Starfire brackets. Two of the brackets fractured during mechanical debonding with the manufacturers recommended plier. The other two brackets fractured at the end of laser application while being held with the Tweed band seating plier during the follow-up laser study. None of the polycrystalline brackets fractured. Possibly this is due to differences in bracket design between the Starfire and Allure brackets as suggested by **Bishara and Trulove, (1990)**.

Summary and Conclusions

Fifty-one human premolars were bonded with polycrystalline Allure and monocrystalline Starfire brackets. Twenty of these teeth were debonded with a continuous wave CO_2 laser and compared to 11 electrothermally debonded teeth (Starfire brackets), and 20 mechanically debonded teeth. The thermal conductance to the pulp chamber in both types of porcelain brackets was lower for teeth debonded with the laser than those debonded electrothermally, although the mean difference wasn't statistically significant.

In a follow-up study using 10 teeth, enamel damage was shown to occur in one tooth that was laser debonded. However, the cause of enamel damage was not identifiable. It can only be speculated whether the laser damaged the tooth or if the removal of the adhesive for the enamel evaluation caused the damage.

It is clear from the data obtained in this study that laser debonding is relatively safe in regard to thermal insult to the pulp. However, this study was inconclusive in regard to the potential for enamel damage from laser debonding. Further investigation into the possibility of enamel damage from laser debonding is needed.

TABLE I
Data for group A
(electrothermal debonding of Starfire brackets)

	Temperature(°C)				**Time**(sec.)
Sample	**Initial**	**Debond**	**Peak**	**Change**	**Debond**
1	32.0	32.5	34.5	2.5	4.2
2	35.5	35.5	36.5	1.0	5.4
3	35.5	35.5	37.0	1.5	2.1
4	35.5	36.0	37.0	1.5	2.4
5	35.5	35.5	37.5	2.0	3.0
6	36.0	36.0	38.0	2.0	6.6
7	35.5	35.5	36.5	1.0	1.2
8	35.0	35.0	37.0	2.0	2.1
9	35.5	35.5	38.5	3.0	3.0
10	35.0	35.0	36.5	1.5	1.8
11	35.0	35.0	37.0	2.0	2.1

TABLE II
Data for group B
(laser debonding of Starfire brackets)

	Temperature(°C)				**Time**(sec.)
Sample	**Initial**	**Debond**	**Peak**	**Change**	**Debond**
1	35.5	35.5	36.5	1.0	1.2
2	35.0	35.0	36.5	1.5	1.3
3	35.0	35.0	35.5	0.5	1.5
4	36.0	36.0	37.5	1.5	1.5
5	35.0	35.0	37.0	2.0	1.2
6	36.0	36.0	37.0	1.0	1.1
7	35.5	35.5	36.0	0.5	1.5
8	35.0	35.0	37.0	2.0	1.5
9	36.0	36.5	39.5	3.5	1.1
10	35.5	35.5	37.5	2.0	1.2

TABLE III
Data for group C
(laser debonding of Allure bracket)

	Temperature(°C)				**Time**(sec.)
Sample	**Initial**	**Debond**	**Peak**	**Change**	**Debond**
1	35.0	35.0	37.5	2.5	1.3
2	35.5	35.5	37.0	1.5	1.7
3	35.0	35.0	36.0	1.0	1.2
4	34.5	34.5	36.5	2.0	1.7
5	34.5	34.5	36.0	1.5	1.2
6	35.5	35.5	36.5	1.0	1.7
7	35.0	35.0	37.0	2.0	1.2
8	36.0	36.0	37.5	1.5	1.1
9	36.0	36.0	37.0	1.0	1.0
10	35.0	35.0	36.0	1.0	1.1

TABLE IV
MEAN AND RANGE DATA FOR GROUPS A, B, AND C.

		Temperature Changes °C			Debond Times (sec.)		
Group	N	Mean	Range	S.D.	Mean	Range	S.D.
A	11	1.82	1-3.0	.575	3.08	1.2-6.6	1.58
B	10	1.55	.5-3.5	.85	1.31	1.1-1.5	.164
C	10	1.50	1-2.5	.5	1.32	1.0-1.7	.26

TABLE V
Site of bond failure for group A
(electrothermal debonding of Starfire brackets)

Sample	Bracket/Adhesive	Cohesive	Enamel/Adhesive
1	X		
2	X		
3	X		
4	X		
5	X		
6	X		
7	X		
8	X		
9	X		
10	X		
11	X		

* no brackets fractured

TABLE VI
Site of bond failure for group B
(laser debonding of Starfire brackets)

Sample	Bracket/Adhesive	Cohesive	Enamel/Adhesive
1	X		
2	X		
3	X		
4	X		
5	X		
6	X		
7	X		
8	X		
9	X		
10		X	

* no brackets fractured

TABLE VII
Site of bond failure for group C
(laser debonding of Allure brackets)

Sample	Bracket/Adhesive	Cohesive	Enamel/Adhesive
1	X		
2	X		
3	X		
4	X		
5	X		
6	X		
7	X		
8	X		
9	X		
10	X		

* no brackets fractured

TABLE VIII
Site of bond failure for group D
(mechanical debonding of Starfire brackets)

Sample	Bracket/Adhesive	Cohesive	Enamel/Adhesive
1		X	
2		X	
3		X	
4		X	
5	X		
6		X	
7		X	
8		X	
9		X	
10	X		

* brackets #1 and #9 fractured

TABLE IX
Site of bond failure for group E (mechanical debonding of Allure brackets)

Sample	Bracket/Adhesive	Cohesive	Enamel/Adhesive
1			X
2		X	
3		X	
4		X	
5		X	
6	X		
7		X	
8		X	
9			X
10		X	

* no brackets fractured

TABLE X
Comparisons of percentages of bond failures occurring at the bracket/adhesive interface between groups.

GROUP OR GROUPS	PERCENTAGE OF BOND FAILURES AT THE BRACKET/ADHESIVE INTERFACE
A Starfire (electrothermal)	100%
B Starfire (laser)	90%
C Allure (laser)	100%
D Starfire (mechanical)	20%
E Allure (mechanical)	10%
A,B, & C (thermal)	97%
D & E (mechanical)	15%

TABLE XI
ENAMEL DAMAGE FOR GROUP A
(electrothermal debonding of Starfire brackets)

Sample	1	2	3	4	5	6	7	8	9	10	11
Presence											
Absence	X	X	X	X	X	X	X	X	X	X	X

TABLE XII
ENAMEL DAMAGE FOR GROUP B
(laser debonding of Starfire brackets)

Sample	1	2	3	4	5	6	7	8	9	10
Presence	X	X	X	X	X	X	X	X	X	X
Absence										

TABLE XIII
ENAMEL DAMAGE FOR GROUP C
(laser debonding of Allure brackets)

Sample	1	2	3	4	5	6	7	8	9	10
Presence	X	X	X		X	X	X	X	X	
Absence				X						X

TABLE XIV
ENAMEL DAMAGE FOR GROUP D
(mechanical debonding of Starfire brackets)

Sample	1	2	3	4	5	6	7	8	9	10
Presence										
Absence	X	X	X	X	X	X	X	X	X	X

TABLE XV
ENAMEL DAMAGE FOR GROUP E
(mechanical debonding of Allure brackets)

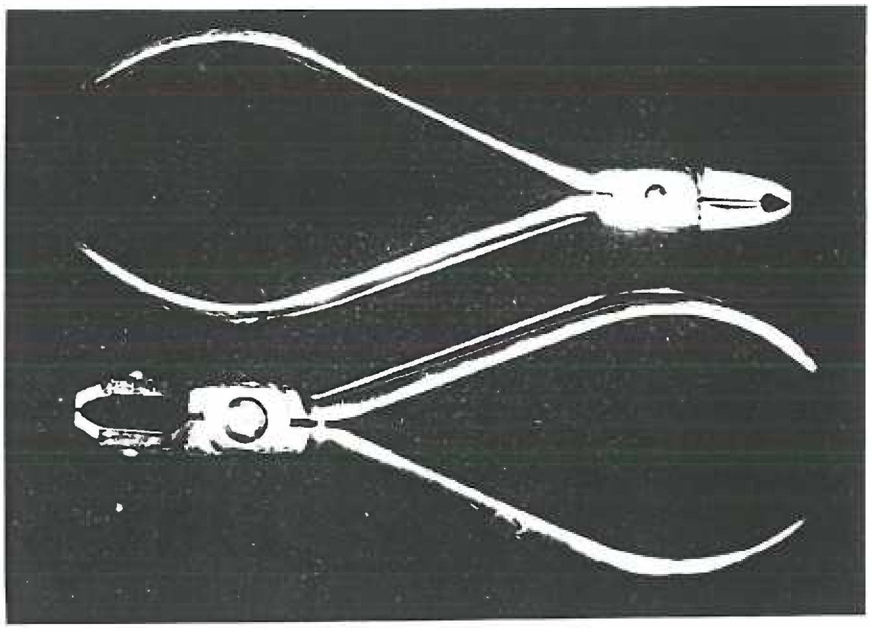
Sample	1	2	3	4	5	6	7	8	9	10
Presence										
Absence	X	X	X	X	X	X	X	X	X	X

TABLE XVI
ENAMEL DAMAGE FOR GROUPS F AND G
(laser debonding of Starfire and Allure brackets)
(these brackets were held in place during lasing)

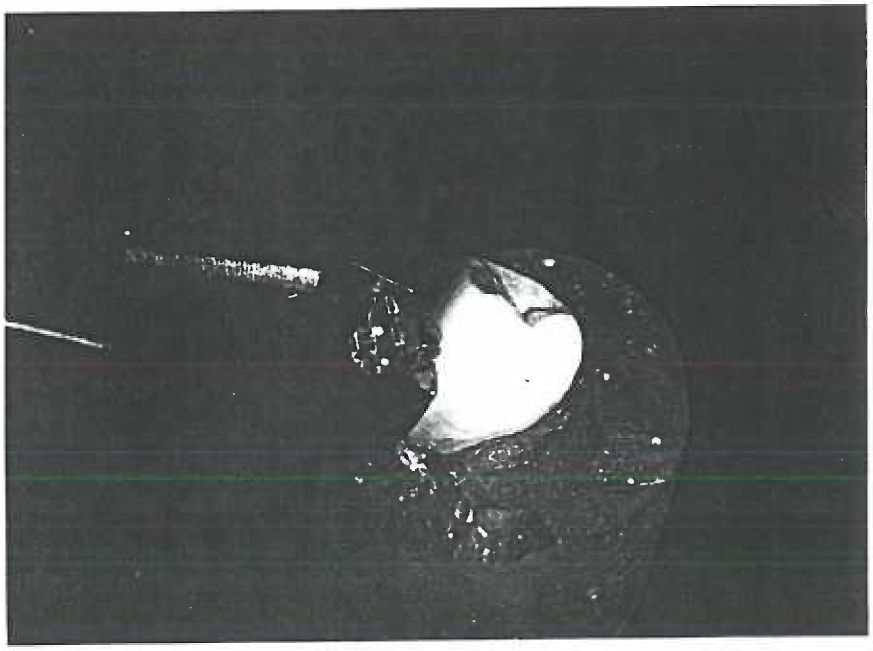
	Sample	1	2	3	4	5
Group F (Starfire)	Presence					
	Absence	X	X	X	X	X
Group G (Allure)	Presence					X
	Absence	X	X	X	X	

* all brackets except #4 of group F debonded at the bracket/bond interface (#4 of group F exhibited an cohesive bond failure

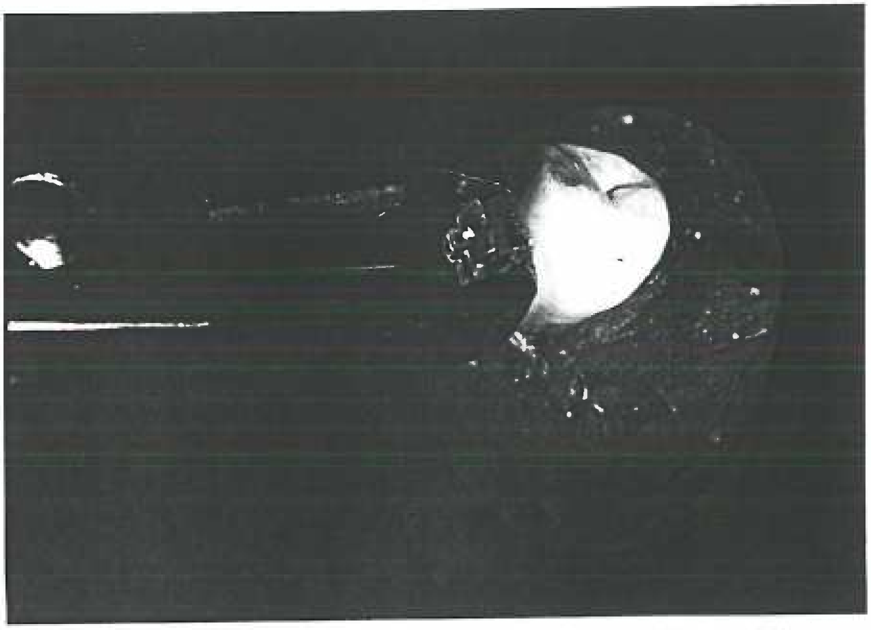
** two Starfire brackets (#2 & #5) fractured while being lased



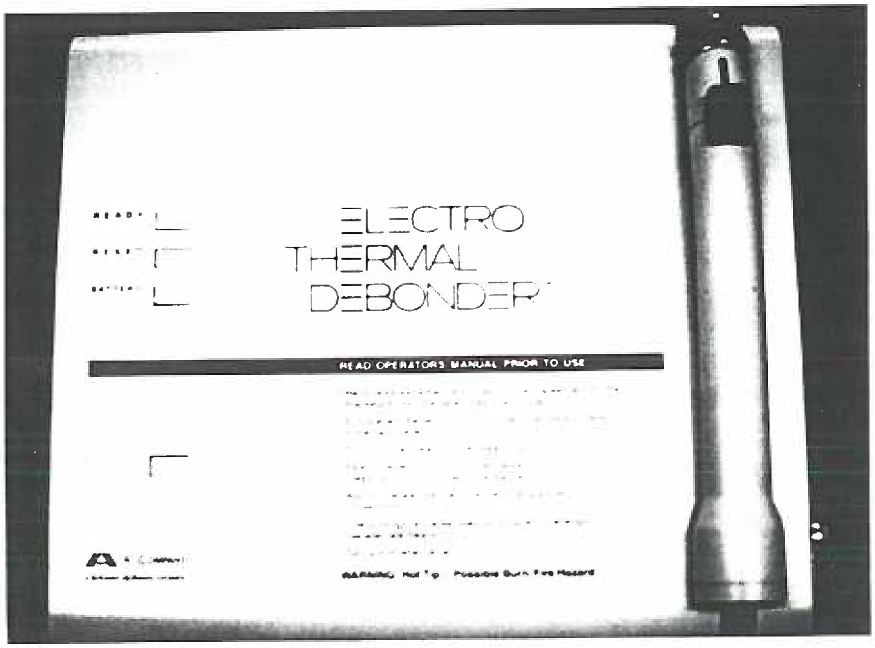
Photograph #1: ETM 346 direct-bond bracket removing plier and the Starfire TMB debonding plier.



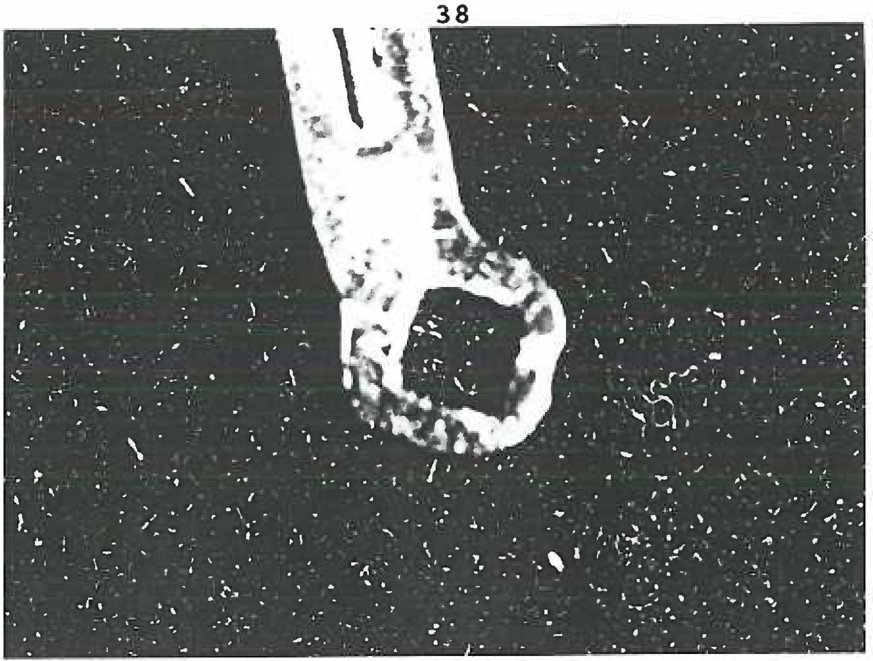
Photograph #2: ETM 346 direct-bond bracket removing plier engaged on an Allure bracket.



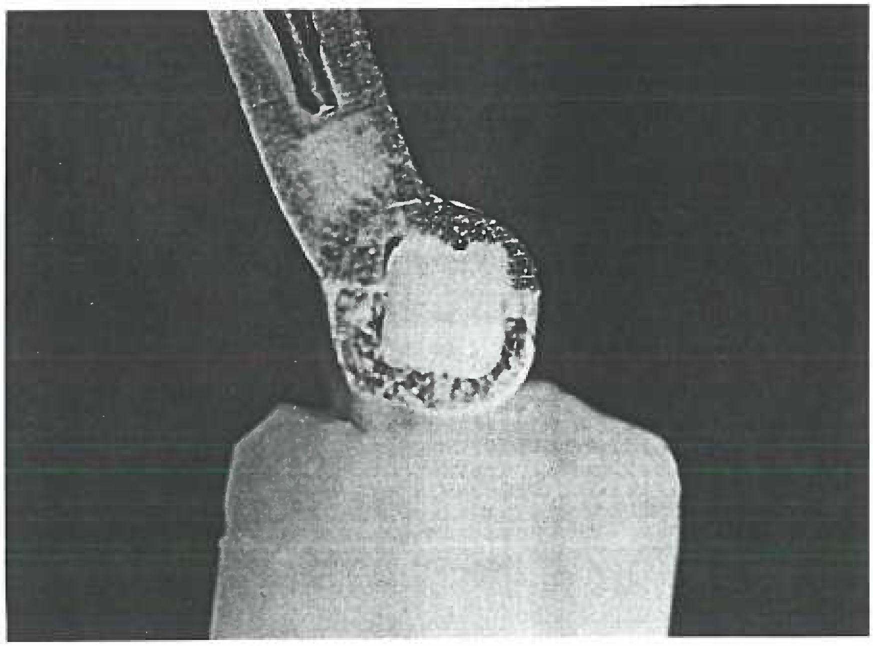
Photograph #3: Starfire TMB debonding plier engaged on a Starfire bracket.



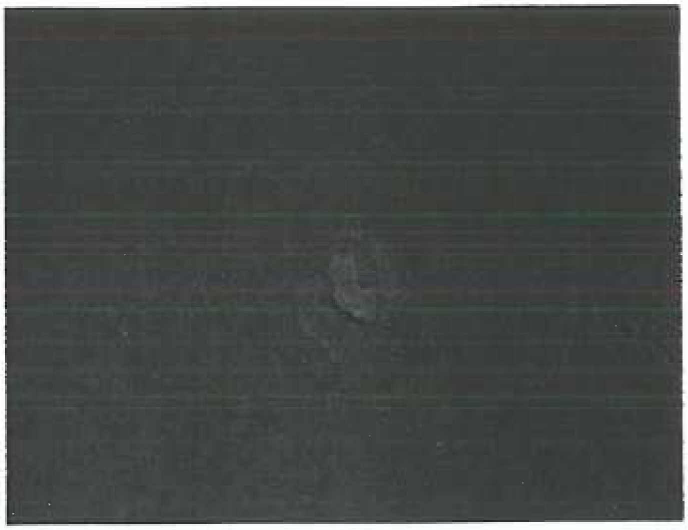
Photograph #4: Electro-thermal Debonder, for electrothermal debonding of Starfire brackets.



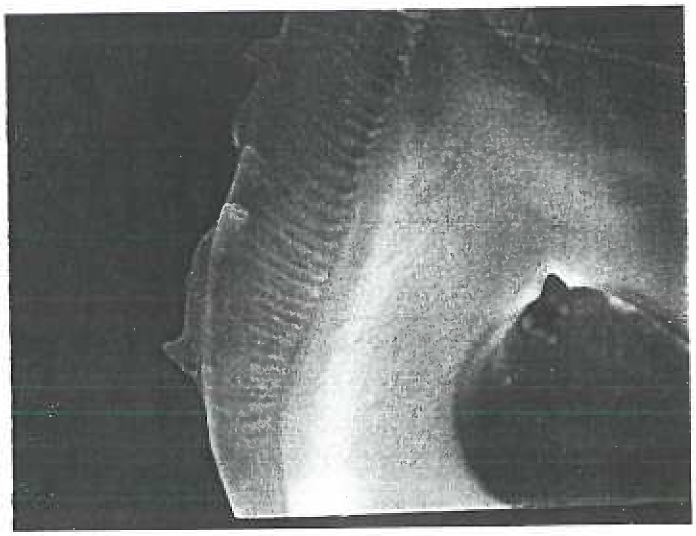
Photograph #5: Custom made instrument for application of torsional force to the base of the brackets during electrothermal and laser debonding.



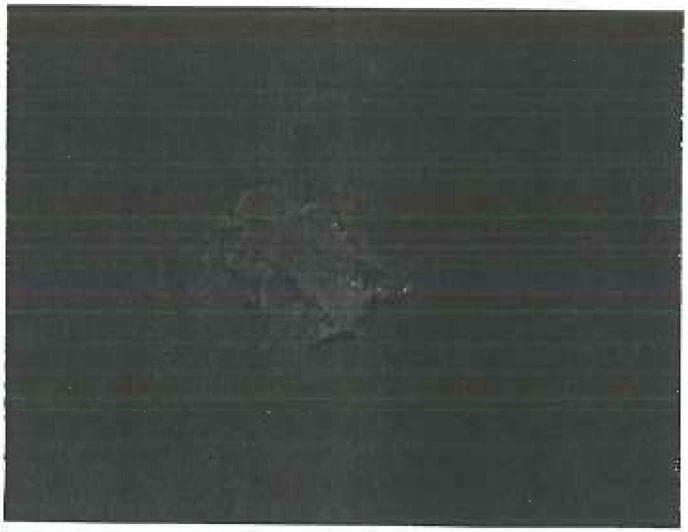
Photograph #6: Custom made instrument engaged around the base of an Allure bracket.



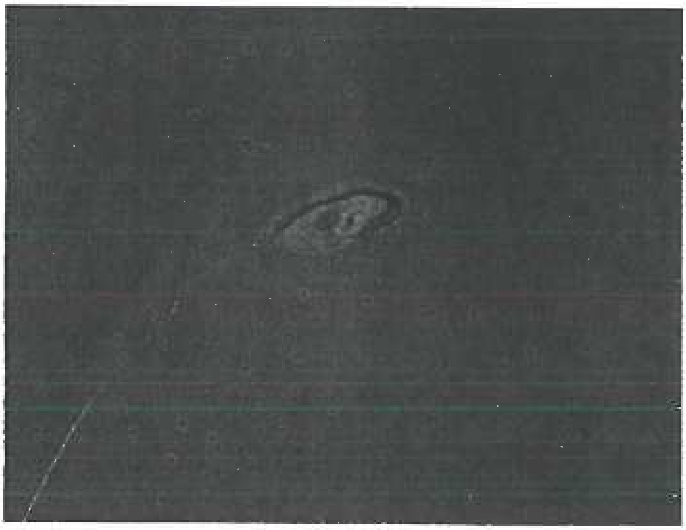
Photograph #7: Enamel damage seen in sample #1 of the laser debonded, Allure bracket group.



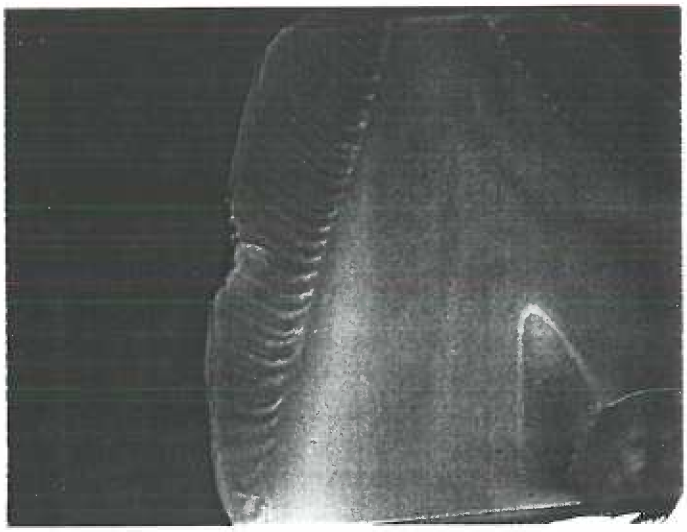
Photograph #8: Enamel damage seen in sample #2 of the laser debonded, Allure bracket group.



Photograph #9: Enamel damage seen in sample #10 of the laser debonded, Starfire bracket group.

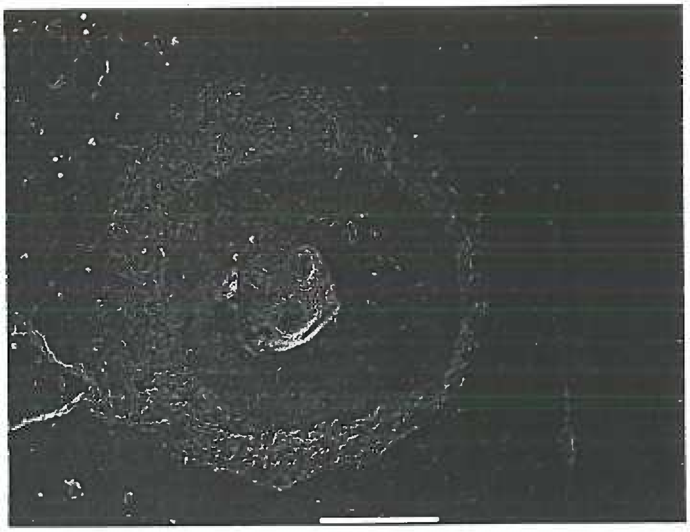


Photograph #10: Enamel damage seen in sample #7 of the laser debonded, Starfire bracket group.

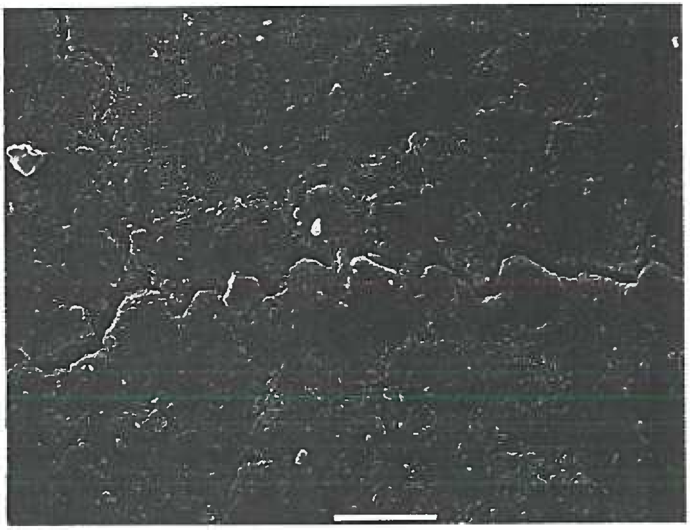


Photograph #11: Enamel damage seen in sample #6 of the laser debonded, Starfire bracket group.

Photograph #12: Sample #10 of the Allure bracketed, laser debonded group in which no enamel damage was evident.

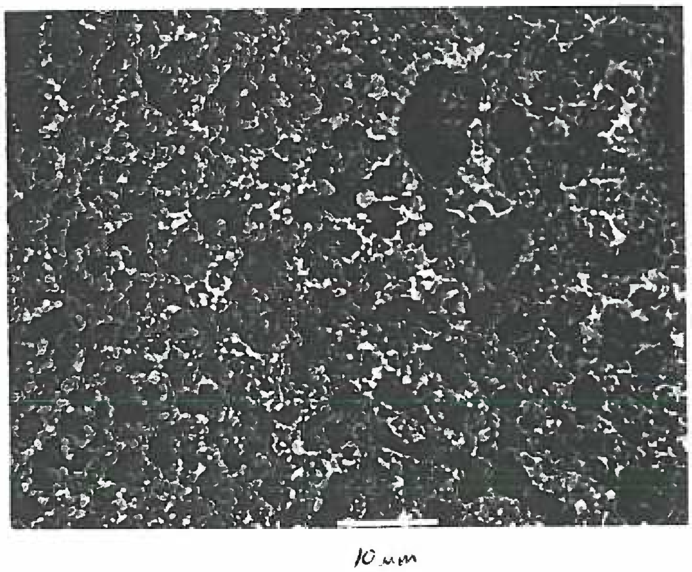


Photograph #13: S.E.M. view of enamel damage of sample #8 of the Starfire bracketed, laser debonded group. (Magnification 35x)

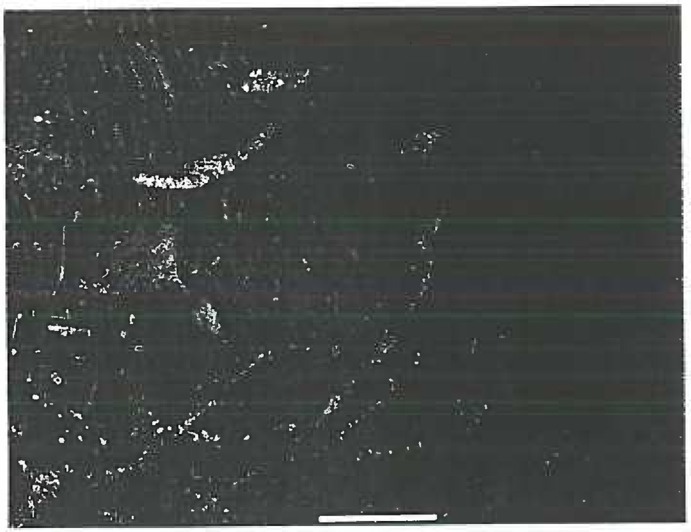


Photograph #14: Enamel cracking exhibited after laser application to sample #8 of the Starfire group. (Magnification 1500x)

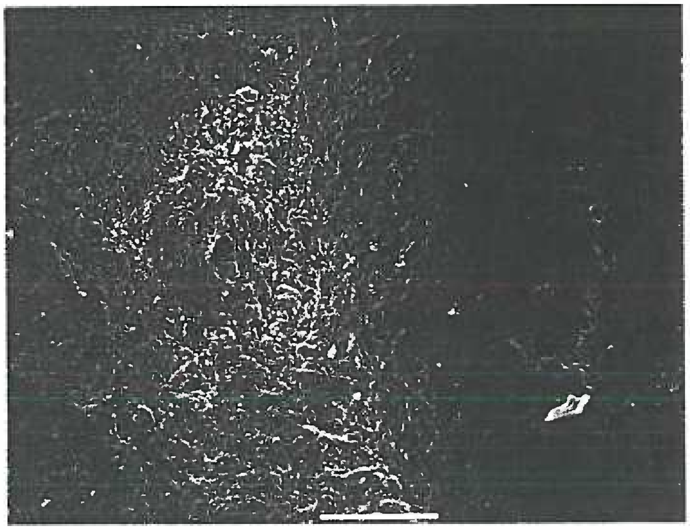
Photograph #15: Cratered and fractured enamel surface from laser debonding of sample #8 of the Starfire bracketed group. (Magnification 350x)



Photograph #16: Exposed enamel rods within the cratered enamel surface of Starfire bracketed sample #8. (Magnification 1500x)

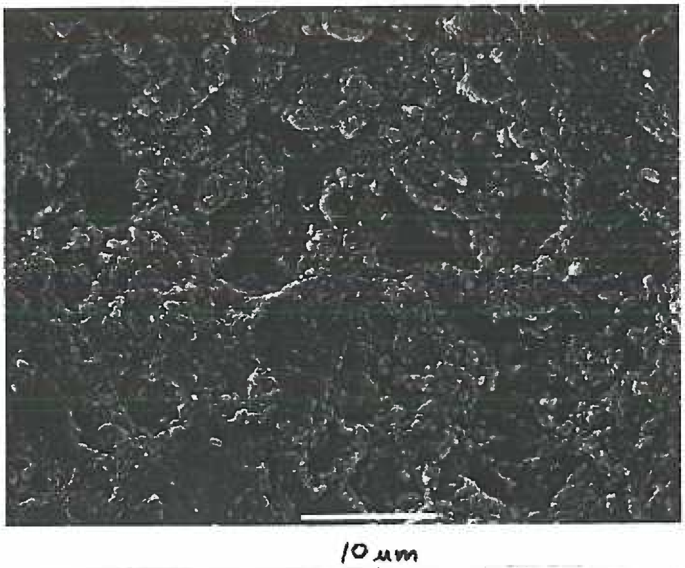


Photograph #17: Enamel tearout of sample #5 of the second laser debonding group of Allure bracketed teeth. This defect shows up as the white spot to the left of the picture, which is located gingival to the center of where the bracket was bonded, and where the laser was applied. (Magnification 35x)



50 um

Photograph #18: Enamel tearout of sample #5 of the second laser debonded Allure bracket group. (Magnification 350x)



Photograph #19: Enamel tearout of sample #5 of the second laser debonded Allure bracket group. (Magnification 2000x)

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