Ceramic Brackets: Something Old, Something New, A Review

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This article reviews some of the characteristics of ceramic brackets that are of particular interest to the clinician. Various factors that may significantly influence bond strength and bracket removal are discussed. The information provided should enable the clinician to debond ceramic brackets safely applying available scientific information. (Semin Orthod 1997;3:178-188.) ***Copyright © 1997 by W.B. Saunders Company***

As the number of adults seeking orthodontic care increased, orthodontists felt the need to provide their patients with more esthetically "appealing" appliances. This perceived need motivated manufacturers to provide acceptable esthetic brackets, including the ceramic brackets.

Ceramics are materials that are both very rigid and brittle, that is, nonductile. Because of this, debonding pressure on the bracket base often results in partial or complete bracket failure or fracture. The residual bracket remnants frequently require removal using a diamond bur in a high-speed handpiece.

Initial removal of most ceramic brackets from enamel is often accomplished using specially designed pliers, however, some clinicians suggest removal by electrothermal and ultrasonic methods.[1] An experimental laser debonding approach has been reported.[1a]

Enamel fractures, cracks, and flaking have been reported as complications of the mechanical debonding procedures.[2] Pulp irritation has been reported as a potential complication of the heat-producing devices.[3] Tooth or pulp tissue damage are major concerns to the clinicians using ceramic brackets.

An understanding of the characteristics of ceramic brackets that influence bond strength and bracket removal should assist the clinician in the use of these brackets.

The Effect of the Manufacturing Process on the Physical Characteristics of Ceramic Brackets

Although the term *ceramics* encompasses different compounds, most currently available ceramic brackets are composed of aluminum oxide. Two basic types of brackets exist, based on two different manufacturing processes.[4]

The polycrystalline brackets are made of sintered or fused aluminum oxide particles. The process begins by blending the particles with a binder. This mixture is then molded into a shape from which the critical parts of the brackets can be cut. The molded part is then fired at a temperature that allows the binder to be burnt out and the aluminum oxide particles to fuse but not melt. This firing process is called sintering.

This molding/sintering process is relatively inexpensive, making it a popular manufacturing technique. Unfortunately, the process results in both structural imperfections at grain boundaries and the incorporation of trace amounts of impurities. These slight imperfections and impurities, even in quantities as low as 0.001%, can serve as foci for crack propagation under stress. This could lead to fracturing of the bracket.[4]

Monocrystalline ceramic brackets also are manufactured from aluminum oxide. In this process, the oxide particles are melted and then cooled slowly, permitting complete crystallization. This process minimizes the stress-inducing impurities and imperfections found in the polycrystalline brackets.

The orthodontic bracket is then milled into shape from the single crystal of aluminum oxide. This is a more difficult and expensive manufactur-

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ing process, because of the hardness of the ceramic material.[4] Milling and the presence of sharp corners introduce their own stresses on the material and also predispose the bracket to fracture.

Optical Properties of Ceramic Brackets

The optical properties of ceramics provide the only advantage over stainless steel brackets.[5,6] The larger the ceramic grains, the greater the clarity becomes. However, when the grain size reaches about 30 µm, the ceramic material becomes weaker.

The grain boundaries and impurities that are present in polycrystalline ceramics reflect light, resulting in some degree of opacity. The monocrystalline brackets, however, are essentially clear. The clear appearance is the result of two factors: reduction of grain boundaries and having fewer impurities introduced during the manufacturing process.[4]

Whether the difference between the optical properties of the opaque and clear ceramics is significant from an esthetic point of view is based on the personal preference of the clinician. This is particularly true because ecause ceramic brackets in the oral environment can be affected by color pigments for example, in tea, coffee, and wine.

The Effects of Hardness of Ceramics on Various Aspects of Orthodontic Treatment

Four important side effects that ceramic brackets have on orthodontic treatment have been identified:

1. Ceramic is the third hardest material known to humans.[4] Therefore, brackets in contact with opposing teeth can cause wear of the relatively softer enamel.[7,8]
2. Because aluminum oxide is much harder than stainless steel, the slot in the ceramic bracket shows minimum wear during sliding mechanics. However, nicks occur in the relatively softer metal arch wires, which increases friction.
3. When using sliding mechanics, the relatively rough surfaces of the ceramic slot significantly increases frictional resistance when compared with stainless steel brackets.[9,10] A decrease in the efficiency of canine retraction was estimated at 25% to 30% when ceramic and stainless steel brackets were compared.
4. The "fracture toughness" (the ability of a material to resist fracture) of ceramic brackets is much lower than metals. For example, the elongation (deformation) of stainless steel is approximately 20% before it finally fails, and the elongation of sapphire before failure does not exceed 1%.[5] Compared with a metal bracket, the ceramic bracket is more susceptible to fracture when orthodontic forces are applied to it. As a result, stresses introduced during ligation and arch wire activation, forces of mastication and occlusion, and forces applied during bracket removal are all capable of creating cracks in the ceramic brackets which may initiate failure.

Types of Retention Mechanisms Incorporated in the Ceramic Bracket Base

Aluminum oxide, from which ceramic brackets are made, is an inert material. As a result, it cannot chemically adhere directly to any of the currently available bonding resins. For these reasons, two different basic mechanisms were developed by which ceramic brackets could be attached to the adhesive.

The first method is by mechanical retention achieved by indentations or recesses in the bracket base, much like the mesh on the base of metal brackets. These indentations provide a mechanical interlocking with the resin adhesive. The second method is by employing an intermediate layer of glass on the bracket base and using a silane coupler to obtain a chemical bond between the bracket and the adhesive. There are therefore three different retention mechanisms by which ceramic brackets can be attached to the bonding agent, chemical retention using silane, mechanical retention, and a combination of both methods.

The Effects of the Retention Mechanism on Bond Strengths

The possibility of enamel damage when debonding ceramic brackets may be attributable to many factors. A significant factor is the increased bond strength at the bracket-adhesive interface. A number of studies have shown that chemically retained ceramic brackets produce a significantly stronger bond strength, compared with conventional metal brackets.[11-16] Increased bond strength with ceramic brackets resulted in bond failure at the enamel-adhesive interface, rather than at the "safer" bracket-adhesive interface, which is fairly common with metal brackets. Failure at the enamel-adhesive interface results in an increased incidence of enamel fractures.[2,14,17-20] The latter is of concern to patients and clinicians, as well as to manufacturers. As a result, some manufacturers have added grooves, recesses, or a rough surface onto the base of their ceramic brackets to increase the surface area and allow for more mechanical interlocking and less need for chemical adhesion between the bracket and the adhesive. Guess et al[21] suggested that the mechanical interlocking in the bracket base provided adequate strength and that the additional chemical bond provided by the silane was unnecessary.[21]

As debonding complications occurred, partly because of the high bond strengths, some manufacturers developed ceramic brackets designed to reduce the bond strengths of the brackets. Their brackets have mechanical retention only, or the silane coupler was applied only in the mechanical recesses. Some investigators contend that the use of a silane coupler, in combination with the mechanical retention, increased the bracket's bond strength.[15] Others considered that this combination of chemical and mechanical retention does not alter the tensile strength[13,16] but significantly decreased the shear strength when compared with that of the chemically backed ceramic brackets.[13,16,17]

The Effect of Enamel Surface Conditioning on Bond Strength

A number of factors related to surface conditioning may influence bond strength. These include acid etching and crystal growth.

Acid Etching

Adhesion of the resin to the etched enamel surface occurs through mechanical retention. Etching the enamel surface with acid leaves a microscopic honeycomb lattice appearance. This is the result of preferential dissolution between the prism periphery and its core, producing microspaces or porosities in the enamel surface. Along with increasing the total enamel surface area available for mechanical bonding, acid etching increases the wettability of the surface. This facilitates the flow of the resin material over the enamel surface, allowing greater penetration of resin tags into the undercuts of the etched surface. After polymerization, the adhesive resin tags form a tightly interlocking mechanical bond with the etched tooth structure.[22]

It has been suggested that reducing either acid etching concentrations or etching time may decrease bond strengths.[23] Research has shown that varying acid etching concentrations from 5% to 37% did not significantly affect bond strength.[23-25] Furthermore, reducing etching times from 60 to 15 seconds,[23-25] and even to 10 seconds,[26] did not significantly change either the bond strength or the bond failure of ceramic brackets. However, reducing the etching time to 5 seconds resulted in an inadequate bond.[26] These results indicate that reducing etching time will not significantly aid the clinician at the time of the debonding of ceramic brackets (unless times are reduced to less than 5 seconds).

Crystal Growth

Smith proposed an alternative method for preparing the enamel surface for the direct bonding of orthodontic attachments, which he called crystal growth.[27] It has been shown that polyacrylic acid, containing residual sulfate ions, reacted with the enamel surface to produce a deposit of white spherulitic crystalline calcium sulfate to which the adhesive resin bonds. The crystals were identified as calcium sulfate dihydrate, $CaSO_4 \cdot H_2O$ (gypsum).[27] The crystal growth bonding technique has several advantages over the phosphoric acid etch technique; (1) the enamel surface is not significantly damaged, (2) debonding and enamel cleanup are easier, (3) there is minimal loss of the outer fluoride-rich enamel layer, and (4) few if any resin tags are left in the enamel after debonding.[27,28]

Maijer and Smith[28] compared the conditioning of enamel by the acid-etch technique with the crystal growth method. They concluded that conditioning with polyacrylic acid had a bond strength comparable to that of acid-etching with phosphoric acid, both in the laboratory[27,29,30] and clinically.[28] However, other researchers found that bond strengths with the use of crystal growth conditioning was much weaker than that of the conventional acid etching techniques.[31-33] It should be noted that the polyacrylic acids used in the latter experiments were not of the same formula as that used by Maijer and Smith.

One problem with the crystal growth technique is that it is operator sensitive. Inadequate washing will not completely remove the polyacrylic acid solution and this will result in a weaker bond. It has also been suggested that rinsing too vigorously may remove the crystals and therefore reduce bond strength.[28] Burkey[34] found that the bond strengths obtained with the use of polyacrylic acid are nearly equal to those obtained by conventional acid etching techniques, even when the crystalline structure was not preserved.[34] Although it is recommended that a 30-second rinse be used, others found that it took approximately 1 minute to ensure the complete removal of the polyacrylic acid and still preserve the crystals.[35] The addition of red coloring to the polyacrylic acid product made it possible to assure the removal of all the excess polyacrylic acid.

In general, the use of polyacrylic enamel conditioner in the crystal growth technique resulted in a reduced debonding strength when compared with the use of phosphoric acid in the conventional acid etch technique.[35] However, the "reduced" strength was still above the minimum bond strength of 60 kg/cm^2 recommended by Reynolds[36] as being adequate for clinical usage. This relative reduction in bond strength might be advantageous when debonding ceramic brackets, because it reduces the stress on the enamel surface.[37]

With the use of the crystal growth enamel conditioning method, bond failure still occurs at the enamel-adhesive interface. In general, this is considered the least desirable location for bond failure because of the increased risk for enamel damage. However, with the use of polyacrylic acid conditioner, the bond actually fails within the crystals and not at the enamel surface,[27,33,37] minimizing the probability of enamel damage.

The Effect of the Adhesive Composition on Bond Strength

There are essentially two groups of adhesives used for bonding orthodontic brackets to enamel, acrylic and diacrylic resins.

Acrylic Resins

Acrylic resins consist of a methylmethacrylate monomer and an ultrafine polymer powder. Similar to self-curing acrylic, activation is usually achieved by a catalyst. Some investigators believe that acrylic resins are relatively poor orthodontic bracket adhesives because they do not possess adequate bond strength.[18,38]

Diacrylic Resins

Diacrylic resins are based on an acrylic modified epoxy resin, generally referred to as bis-GMA (bisphenol A glycidyl dimethacrylate). The major difference between diacrylic and acrylic resins is that the latter can form only linear polymers. However, the diacrylic resins may be polymerized also by cross-linking into a three-dimensional network. This cross-linking contributes to the greater strength, low water absorption, and less polymerization shrinkage of the diacrylic resins.[38,39]

The Effects of the Adhesive Additives on Bond Strength

Diacrylic resin adhesives are available in either filled or unfilled forms. Often an orthodontic bonding system will contain both types. The best example of the unfilled resin is the sealant that is placed on the etched enamel surface. In most cases for bracket bonding this step is followed by applying a filled resin that provides for increased bond strength.[36]

The filler is usually an inorganic material and is used mainly to minimize the deformation and strengthen the matrix of the adhesive. The dimensionally stable filler is combined with the dimensionally unstable resin to reduce the coefficient of thermal expansion of the resin matrix for it to approximate that of enamel.[39] The filler can vary in composition, size of particle, and amount added. These factors, plus any added chemical modifiers, can significantly influence abrasion resistance, viscosity, and hardness of the different resins.[40]

The fillers currently used in orthodontic adhesives are composed of either quartz or silica glass. The quartz is a harder material, lending itself to less wear of the composite.[39] This is an important factor in operative dentistry but less so in orthodontics. The softer silica glass may be advantageous in orthodontics at the time of debonding, because it may cause less wear of the debonding plier and also make it easier for the clinician to clean the residual adhesive from the enamel surface.

The particle size of the filler can significantly influence the properties of the adhesive. Orthodontic adhesives may contain one of two types of fillers, large particles of highly variable diameter ranging from 3 to 20 μm, ie, macrofilled, or submicron filler particles with an average diameter ranging between 0.2 and 0.3 μm, ie, microfilled. The macrofilled resins impart abrasion resistance properties, and the microfilled resins are more prone to abrasion, therefore yielding a smoother surface.[38,41] Zachrisson and Brobakken[41] showed clinically that bonding brackets with a microfilled adhesive was more hygienic because of less plaque retention on the smoother adhesive surface.[41]

Adhesives also can vary in the percentage of filler incorporated. The earlier orthodontic adhesives were heavily filled composites (60% to 75% filled). This caused an increase in the strength of the adhesive. More recently, lightly filled adhesives (20% to 30% filled) were developed to overcome some of the difficulties encountered during the removal of ceramic brackets.[42]

It has been repeatedly demonstrated when debonding metal brackets that highly filled diacrylic resins, when compared with lightly filled resins, provided higher bond strengths.[41,43,44] Although many practitioners use heavily filled adhesives because of their added strength, the recent trend has been toward the use of lightly filled adhesives.[45]

In general, when using polyacrylic acid enamel conditioner, the type of adhesive used, whether filled or unfilled, was of secondary importance in influencing bond strength. When using a phosphoric acid etch, highly filled adhesive provided a debonding strength twice that of the lightly filled adhesive.[35] However, the findings have also indicated that some unfilled adhesives may have a debonding strength comparable to those of the highly filled adhesives.[35,43]

Interestingly, the clinical performance of the lightly and heavily filled adhesives, when used on anterior teeth and measured by the failure rate of brackets, seems comparable. However, the heavily filled adhesives may be more effective clinically when bonding the posterior teeth, where the forces of mastication are heavier.[42] Because ceramic brackets are usually used on anterior teeth, it may be advantageous to use lightly filled adhesives when etching with phosphoric acid.

It should be noted that most research experiments on adhesives have been conducted in vitro. After recent improvements in resin performance, the "operator's technique" has been suggested as being the weakest link in the process, ie, it is the source of the greatest amount of variability when bonding brackets in vivo.[34,40] It is therefore imperative for the orthodontist to consistently follow the manufacture's instructions.

Debonding Issues

The clinician should be aware of some important variables that could influence success when debonding ceramic brackets.

Force Magnitudes Applied During Debonding

The mean bond strength for the different bracket, adhesive, and enamel conditioner combinations ranged from a low of 40 kg/cm^2 to highs in excess of 190 kg/cm^2. Most debonding stresses are between 60 and 115 kg/cm^2 [26,25,46]; however, some investigators have reported forces in excess of 300 kg/cm^2.[11,12,16] With metal brackets, the critical question for the clinician was whether the bond was too weak to withstand the forces of orthodontic treatment. With ceramic brackets, clinicians are concerned with whether the bond was too strong for safe debonding. Reynolds[36] suggested that a minimum bond strength of 60 to 80 kg/cm^2 was adequate for most clinical orthodontic needs.

The maximum limit for bond strength has been considered. Retief[47] reported that enamel fractures can occur with bond strengths as low as 138 kg/cm^2. This is comparable with the mean linear tensile strength of enamel of 148 kg/cm^2

as reported by Bowen and Rodriguez.[48] Therefore, it would seem to be advisable to avoid tensile bond strengths that are greater than 130 kg/cm^2.

Force Range Related to Debonding

When the "mean" debonding forces in various studies were evaluated,[26,35,46] it became evident that most of the means fall below the upper limits of what are considered as safe debonding forces.[36] However, the potential for clinical disasters lie in the range of forces that these means actually describe (Table 1). The lower values of these ranges (36.0 to 44.0 kg/cm^2) pose only one complication, specifically, the bracket will likely fail during treatment and will need to be rebonded. However, the higher values of the range (246.0 to 292.0 kg/cm^2) are almost twice as high as the forces that have the potential for causing significant damage to the enamel surface.

It is important to note that these wide ranges of forces occurred regardless of the adhesive tested or the bracket used. Unfortunately the clinician when debonding ceramic brackets cannot predict which of the brackets will have these extremely high bond strengths. This poses a clinical dilemma. In the same patient one could successfully remove all the brackets except for one tooth. On that one tooth, enamel cracks or fractures could occur as a result of the excessive bond strength and the excessive debonding forces required.

It should be remembered that moisture, temperature, and other oral variables are known to weaken bond strength at the enamel-adhesive interface.[38,40,45,49] Therefore, in vitro bond strength values may be higher than those obtained in vivo. This may be an advantage when using ceramic brackets.

Table 1. Descriptive Statistics on Various Debonding Forces Recorded

	x *(kg/cm²)*	*S.D.* *(kg/cm²)*	*Range* *(kg/cm²)*
Adhesive A	126.0	67.0	36.0-292.0
Adhesive B	122.0	44.0	44.0-247.0
Adhesive C	133.0	64.0	37.0-246.0

Data from Bishara et al,[35] Bishara and Fehr,[46] and Fonseca et al.[52]

Combinations of Brackets and Adhesives That Will Provide the Clinician With an Optimal Debonding Force

There are combinations of brackets and adhesives the clinician should not use. With a phosphoric acid enamel conditioner and conventional debonding pliers, the combinations that produced unacceptably large debonding forces included chemically or chemically/mechanically retained ceramic brackets bonded with an unfilled adhesive. Similar results were obtained when the chemically/mechanically retained bracket were bonded with a highly filled adhesive. These combinations produced mean debonding force values exceeding 175 kg/cm^2. Some investigators have found that some chemically retained ceramic brackets have mean bond strengths ranging between 198 and 329 kg/cm^2.[11,12,16,37] All other combinations produced mean debonding forces less than 115 kg/cm^2, which would appear to be safe debonding forces.[35]

With polyacrylic acid enamel conditioning (crystal growth), neither the type of adhesive nor the bracket used was found to be as critical. This is because bond failure occurs within the crystals themselves, thus minimizing the stresses transmitted to the enamel.

Manufacturing companies should be encouraged to provide the orthodontists with agreed-on, standardized information about their products. For example, the product of a company should have information that states the magnitude of forces generated from testing a specific metal or ceramic bracket with a specific etching material and a particular adhesive system.

Effectiveness of Various Debonding Methods

Because of the brittle nature of ceramic brackets, earlier methods of mechanical debonding often cause bracket or enamel fracture. As a result, manufacturers, clinicians, and researchers have attempted to develop new debonding techniques specifically designed for ceramic brackets; these include mechanical, ultrasonic, electrothermal, and laser debonding.

Mechanical Debonding

The earliest types of debonding instruments used on ceramic brackets applied heavy shear-torsion forces to the already sensitive and mobile teeth. The sudden nature of bracket failure associated with such methods had the potential of causing enamel fracture or cracks.[2,14,17] Swartz[17] stated, "This method of force concentration is analogous to the delamination of two pieces of bonded wood. Attempting to twist one piece from the other will require great forces. Wedging a chisel at the interface of the two will usually be less destructive and require significantly less force to separate."

Currently one of the most popular mechanical debonding techniques used for ceramic brackets involves applying the blades of a debonding plier near the enamel surface but within the adhesive.[50,51] In the typical in vitro shear bond strength test, the force is applied on one side of the bracket.[11-17,19,21,37] More recently an attempt was made to simulate the clinical situation and measure the actual force applied by the pliers during debonding by applying the force at the bracket-adhesive interface on both sides of the bracket.[46] Applying the load to the two sides simultaneously with the pliers increases the chances of creating a crack in the brittle adhesive. The results indicated that this method transmits one third less force to the enamel compared with a pure shear force. This is a very significant reduction in the debonding force and places much less stress on the enamel surface, thereby reducing the risk of fracture damage.

The width of the plier blades and debonding forces. When debonding a ceramic bracket with a sharp-edged debonding instrument, the clinician can use either the 2.0-mm narrow blades or the 3.2-mm wide blades. The use of narrow blades results in a lower debonding stress (120 kg/cm^2) than with the wider blades (150 kg/cm^2).[46] In other words, there is a reduction in the debonding force when using narrow plier blades.

The incidence of enamel cracks after mechanical debonding. In a recent study,[52] transillumination was used to evaluate damage to enamel surfaces after debonding. The changes evaluated included enamel cracking and crazing. Each facial or buccal tooth surface was divided into nine equal vertical and horizontal zones for detailed mapping of the enamel cracks. Most of the teeth, 82%, showed no increase in enamel cracks after debonding, whereas approximately 18% of the teeth showed an increase in enamel cracks. After debonding, the lateral incisors showed the greatest increase in the number of cracks, 41%. The molars showed the least increase, 7%.

Teeth bonded with the same adhesive but used in different forms, for example, either precoated or as a paste, showed different damage after debonding. For example, teeth that had precoated brackets showed the highest increase in the number of cracks (33%), whereas those bonded with the same adhesive but used as a paste showed the least (3%).[52] The difference probably had to do with the consistency and homogeneity of the precoated adhesives, which provided for a stronger bond. It is important to note that the teeth that showed an increase in the number of cracks had bonds with a significantly higher mean bond strength (113 kg/cm^2) than had those teeth that showed no increase in the number of cracks after debonding (73 kg/cm^2). In other words, the stronger the bond strength, the greater the probability of enamel cracks occurring.[52]

Clinical Precautions When Using Mechanical Debonding Techniques

Under ideal laboratory conditions, all of the conventional mechanical debonding techniques were effective. However, the potential for causing damage is higher if the integrity of the tooth is already compromised as a result of preexisting developmental defects, enamel cracks, large restorations, or with the relatively brittle nonvital teeth. Therefore, placement of ceramic brackets should be avoided in these situations.

The debonding forces result in various degrees of patient discomfort. Clinically these heavy forces are applied at the end of the active phase of orthodontic treatment to teeth that are often mobile and sensitive. To minimize the discomfort and pain, the teeth should be well protected during bracket removal. It has been suggested that either the orthodontist should support the tooth with his or her fingers, or have the patient bite firmly into a cotton roll to minimize discomfort.

The likelihood of bracket fracture can be minimized if the excess composite flash is first removed from around the bracket. This will allow the debonding instrument to be fully seated at the base of the bracket, allowing the plier to transmit the debonding forces through the strongest and bulkiest part of the bracket, namely, the bracket base.

Bracket fracture, when it occurs, is usually quick. Consequently, fragments could injure the oral mucosa or the clinician. Furthermore, whole brackets or fractured bracket particles could become ingested or aspirated by the patient, creating a significant medical emergency. To minimize such occurrences, it is advisable to remove the brackets while the mouth is closed and with a piece of gauze behind the teeth, to catch any loose fragments. In addition, the "flying" projectiles may cause eye injury to the patient or the clinician. Therefore, protective eyewear should be used by both the clinician and patient. Some pliers have a protective sheath that covers the working end of the instrument. The sheath decreases the probability of any loose bracket fragments becoming accidentally discharged into the patient's mouth.

Plier blades progressively lose their sharpness, especially as the blades are abraded from contact with the much harder ceramic material. As the plier blades become dull, the debonding efficiency is significantly reduced. It is therefore recommended to use new blades after debonding 50 brackets. Pliers with nonexchangeable blades should be sharpened on a regular basis.

Alternative Debonding Methods

Alternative methods of debonding ceramic brackets have been designed to minimize the potential for bracket fracture or trauma to the enamel surface. The main purpose of these new methods is to reduce the force levels during the debonding process.

Three debonding techniques have been proposed: ultrasonic, electrothermal, and laser.

Ultrasonic debonding. The ultrasonic technique uses specially designed tips applied at the bracket-adhesive interface to erode the adhesive layer between the enamel surface and bracket base.[53,54] The resulting force magnitudes needed with the ultrasonic approach are significantly lower than those required for the conventional methods of bracket removal. However, the ultrasonic technique has a major disadvantage. Debonding time using this technique is 30 to 60 seconds per bracket, compared with 1 to 5 seconds for other bracket removal methods.[1] In addition, there is excessive wear of the relatively expensive ultrasonic tips. This wear is the result of the friction between the softer steel tip moving against the much harder ceramic surface.[1] There is also the potential for gouging the enamel surface during the erosion process. Consequently, this method of ceramic bracket removal is not yet recommended for clinical use.

Electrothermal debonding. Electrothermal debonding instruments are essentially rechargeable, cordless heating devices that are placed in contact with the bracket. The instrument transfers heat through the bracket, softening the adhesive and allowing bond failure between the bracket base and the adhesive resin.[1,55,56] This method is a quick and effective way to debond a bracket. Its major disadvantage is related to the relatively high temperatures generated at the heated tip. Pulpal damage and mucosal burns are possible.[1,57]

Laser debonding. Debonding ceramic brackets was attempted using both CO_2 and YAG lasers[58] in combination with mechanical torque. The use of a laser is conceptually similar to the use of the electrothermal approach, that is, through heat generation to soften the adhesive. With the laser, the torque force needed to debond polycrystalline brackets was lowered by a factor of 27 for molars and a factor of 16 for incisors when compared with the mechanical debonding forces used without the laser. The polycrystalline brackets were illuminated for 2 seconds with a focused CO_2 laser beam of 14 W, whereas the monocrystalline brackets needed only half that amount of energy.

The laser approach, although still experimental, is more precise with regard to time and amount of heat application, and therefore would have better control of the amount of heat transmitted to the tooth. A major disadvantage, in addition to the effects of the thermal energy on the pulp, is the high cost of the instrument.

The Effects of Heat Application on the Pulpal Tissues

The short- and long-term effects of electrothermal debonding on the underlying pulp as well as the degree of patient discomfort, were evaluated.[57] Forty-eight premolars planned for orthodontic extraction were bonded with monocrystalline brackets and debonded using the electrothermal instrument. Seventeen premolars were not etched or bracketed and served as controls. Patients were questioned as to sensations during debonding. Teeth were extracted at 1 or 4 weeks after bracket removal and were then histologically examined. The findings indicated that at the end of 1 week, the predominant inflammatory cells were lymphocytes, with no pulpal necrosis observed. At 4 weeks chronic inflammation decreased over time, indicating repair of the damaged areas. The odontoblastic layer was intact, although some evidence of the earlier damage remained (an infrequent calciotraumatic line and formation of a mildly irregular secondary dentin) in 12% of the specimens. A similar reaction occurs when a tooth has a cavity preparation. The histological evidence indicated that the pulp damage was mostly reversible and the pulp injury, when it occurred, was relatively mild in the premolar teeth. In the clinical tests, the patients experienced minimum discomfort. Generally, the sensation was described as "warmer than normal body temperature," but was well tolerated.[57]

An important question that was not answered by the study was whether the pulp response of premolars would be similar to that of other groups of teeth. Premolars have an average enamel/dentin thickness of 3.6 mm,[58] which essentially acts as insulation protecting the pulpal tissues. Incisors have significantly less insulation. According to data reported by Crispin,[58] at the middle of the labial surface, the maxillary central incisors have only 64% as much enamel as the premolars, whereas the mandibular incisors have only 51% as much enamel. Although the pulp changes were fairly mild in the premolar specimens, there is a need for further investigations on the effects of the procedure on the incisors.

Rueggeberg and Lockwood[59] also suggested that the temperature needed to debond brackets varied significantly, depending on the type of adhesive used. They suggested that highly filled adhesives will need more heat to soften and debond.

Conclusions

Ceramic brackets have one main advantage, esthetics.

On the other hand, ceramic brackets have numerous disadvantages, including:

1. Ceramic brackets have a higher incidence of fracture during debonding, particularly with the conventional debonding techniques.
2. Ceramic brackets are unable to withstand strong torsional forces, especially after the bracket surface has been nicked during treatment.
3. The use of ceramic brackets should be avoided on compromised teeth. Therefore, clinicians should conduct a thorough pretreatment and posttreatment examination of the surface characteristics of enamel using transillumination. This is carried out to detect cracks, fractures, or other defects that may serve as enamel fracture sites during debonding. This examination is preventive risk management by the orthodontist.
4. Enamel wear occurs if ceramic brackets contact opposing tooth surfaces. Therefore, placement of ceramic brackets is contraindicated on the lower anterior teeth in cases with deep overbite and minimal overjet. In such cases, sufficient overjet has to be created before bonding the lower incisors. Similarly, during maxillary incisor retraction, the overbite should be reduced first so that the maxillary incisors do not contact the mandibular ceramic brackets.
5. Ceramic brackets can cause nicks in the arch wires, resulting in more friction between the bracket and the arch wire. This can decrease the efficiency of tooth movement.
6. The use of ceramic brackets in patients who will undergo orthognathic surgery should be discouraged. The fracture of the brackets before, during, or after surgery creates the potential for undesirable and avoidable complications.
7. Because of potential fracture of the bracket or enamel, the clinician should not delegate the removal of ceramic brackets to auxiliaries.

There is a demand from patients for ceramic brackets because of their desirable esthetics, but there is a need to continue improving current debonding methods and develop new techniques or design concepts that are better suited for the removal of ceramic brackets. The new techniques need to be reliable and safe, to both the patient and the orthodontist. The debonding approach should be tailored to the type of bracket base retention, bracket design, enamel conditioner, and/or adhesive used. The stronger the bond strength between the ceramic bracket and the enamel, the more critical it is to consider alternative methods for bracket removal. Debonding should occur either within the adhesive, or at the bracket-adhesive interface rather than from the adhesive-enamel interface.

References

1. Bishara SE, Trulove TS. Comparisons of different debonding techniques for ceramic brackets: An in vitro study. Parts I and II. Am J Orthod Dentofacial Orthop 1990;98: 145-153, 263-273.
1a. Strobl K, Bahns TL, Wilham L, et al. Laser-aided debonding of orthodontic ceramic brackets. Am J Orthod Dentofacial Orthop 1992;152-159.
2. American Association of Orthodontist. Summary of AAO ceramic bracket survey. The Bulletin Supplement 1989;7: (Winter).
3. Dovgan JS, Walton RE, Bishara SE. Electrothermal debracketing of orthodontic appliances: Effects on the human pulp. J Dent Res 1990;69:300 (abstr 1531).
4. Swartz ML. Ceramic brackets. J Clin Orthod 1988;22: 82-88.
5. Scott GE. Fracture toughness and surface cracks: The key to its understanding ceramic brackets. Angle Orthod 1988;58:5-8.
6. Kusy RP. Morphology of polycrystalline alumina brackets and its relationship to fracture toughness and strength. Angle Orthod 1988;58:197-203.
7. Viazis AD, DeLong R, Bevis RR, et al. Enamel abrasion from ceramic orthodontic brackets under an artificial oral environment. Am J Orthod Dentofacial Orthop 1990;98:103-109.
8. Viazis AD, DeLong R, Bevis RR, et al. Enamel surface abrasion from ceramic orthodontic brackets: A special case report. Am J Orthod Dentofacial Orthop 1989;96: 514-518.
9. Pratten DH, Popli K, Germane N, et al. Frictional resistance of ceramic and stainless steel orthodontic brackets. Am J Orthod Dentofacial Orthop 1990;98:398-403.
10. Angolkar PV, Kapila S, Duncanson MG, et al. Evaluation of friction between ceramic brackets and orthodontic wires of four alloys. Am J Orthod Dentofacial Orthop 1990;98:499-506.
11. Odegaard J, Segner D. Shear bond strength of metal brackets compared with a new ceramic bracket. Am J Orthod Dentofacial Orthop 1988;94:201-206.
12. Gwinnett AJ. A comparison of shear bond strengths of metal and ceramic brackets. Am J Orthod Dentofacial Orthop 1988;93:346-348.
13. Ripley KT. In vitro comparative study of shear and tensile bond strengths for stainless steel and ceramic orthodontic brackets. Masters Thesis, University of Iowa, 1988.
14. Joseph VP, Rossouw PE. The shear bond strengths of stainless steel and ceramic brackets used with chemically and light-activated composite resins. Am J Orthod Dentofacial Orthop 1990;97:121-125.
15. Iwamoto H, Kawamoto T, Kinoshita Z. Bond strength of new ceramic brackets as studied in vitro. J Dent Res 1987;66:928 (abstr).
16. Hyer KE. An in vitro study of shear and tensile bond strengths comparing mechanically and chemically bonded ceramic brackets with three bonding agents. Masters Thesis, University of Iowa, 1989.
17. Swartz ML, Ormco Corporation. A technical bulletin on the issue of bonding and debonding ceramic brackets. #070-5039, 1988.
18. Viazis AD, Cavanaugh G, Bevis RR. Bond strength of ceramic brackets under shear stress: An in vitro report. Am J Orthod Dentofacial Orthop 1990;98:214-221.
19. Harris AMP, Joseph VP, Rossouw E. Comparison of shear bond strengths of orthodontic resins to ceramic and metal brackets. J Clin Orthod 1990;24:725-728.
20. Storm ER. Debonding ceramic brackets. J Clin Orthod 1990;24:91-94.
21. Guess MB, Watanabe LG, Beck FM, et al. The effect of silane coupling agents on the bond strength of a polycrystalline ceramic bracket. J Clin Orthod 1988;22:788-792.
22. Retief DH. The mechanical bond. Int Dent J 1978;28: 18-27.
23. Barkmeier WW, Gwinnett AJ, Shaffer SE. Effects of reduced acid concentration and etching time on bond strength and enamel morphology. J Clin Orthod 1987;21: 395-398.
24. Legler LR, Retief DH, Bradley EL, et al. The effects of phosphoric acid concentration and etch duration on the shear bond strength of an orthodontic bonding resin to enamel: An in vitro study. Am J Orthod Dentofacial Orthop 1989;96:485-492.
25. Sadowsky PL, Retief DH, Cox PR, et al. Effects of etchant concentration and duration on the retention of orthodontic brackets: An in vivo study. Am J Orthod Dentofacial Orthop 1990;98:417-421.
26. Olsen ME, Bishara SE, Boyer D, et al. Effect of varying etching time on the bond strength of ceramic brackets. J Dent Res 1994;73:197 (abstr 766).
27. Smith DC, Cartz L. Crystalline interface formed by polyacrylic acid and tooth enamel. J Dent Res 1973;52: 1155.
28. Maijer R, Smith DC. Crystal growth on the outer enamel surface: An alternative to acid etching. Am J Orthod 1986;89:183-193.
29. Smith DC, Bennett G, Peltoniemi R, et al. Further studies of bonding to enamel through crystal growth. J Dent Res 1980; Special Issue B, 995 (abstr 435).
30. Smith DC, Lux J, Maijer R. Crystal bonding to enamel. J Dent Res 1981;60:Special Issue A, 178 (abstr 231).
31. Artun J, Bergland S. Clinical trials with crystal growth conditioning as an alternative to acid-etch enamel pretreatment. Am J Orthod 1984;85:333-340.
32. Read MJF, Ferguson JW, Watts DC. Direct bonding:

crystal growth as an alternative to acid-etching? Eur J Orthod 1986;8:118-122.

33. Farquhar RB. Direct bonding comparing a polyacrylic acid and a phosphoric acid technique. Am J Orthod 1986;90:187-194.
34. Burkey PS. Enamel conditioning with acid etch and crystal bonding techniques: Tensile and shear strength comparisons and scanning electron microscopic observations. Masters Thesis, University of Iowa, 1985.
35. Bishara SE, Fonseca JM, Fehr DE, et al. Debonding forces applied to ceramic brackets simulating clinical conditions. Angle Orthod 1994;64:277-282.
36. Reynolds IR. A review of direct orthodontic bonding. Br J Orthod 1979;2:171-178.
37. Maskeroni AJ, Meyers CE, Lorton L. Ceramic bracket bonding: A comparison of bond strength with polyacrylic acid and phosphoric acid enamel conditioning. Am J Orthod Dentofacial Orthop 1990;97:168-175.
38. Gorelick L, Masunaga G, Thomas RG, et al. Round table on bonding. J Clin Orthod 1978;12:695-714, 761-778, 825-842.
39. Phillips RW. Science of Dental Materials (ed 8). Philadelphia, PA: Saunders, 1982.
40. Phillips HW. JCO/Interviews. J Clin Orthod 1980;14:391-411.
41. Zachrisson BU, Brobakken BO. Clinical comparison of direct versus indirect bonding with different bracket types and adhesives. Am J Orthod 1978;74:62-78.
42. Council on Dental Materials, Instruments, and Equipment: State of the art and science of bonding in orthodontic treatment. J Am Dent Assoc 1982;105:844-849.
43. Buzzitta VA, Hallgren SE, Powers JM. Bond strength of orthodontic direct-bonding cement-bracket systems as studied in vitro. Am J Orthod 1982;81:87-92.
44. Faust JB, Grego GN, Fan PL, et al. Penetration coefficient, tensile strength, and bond strength of thirteen direct bonding orthodontic cements. Am J Orthod Dentofacial Orthop 1987;73:512-525.
45. Silverman E, Cohen M, Gwinnett AJ. JCO/Interviews. J Clin Orthod 1979;13:236-251.
46. Bishara SE, Fehr DE. Comparisons of the effectiveness of pliers with narrow and wide blades in debonding ceramic brackets. Am J Orthod Dentofacial Orthop 1993; 103:253-257.
47. Retief DH. Failure at the dental adhesive-etched enamel interface. J Oral Rehabil 1974;1:265-284.
48. Bowen RL, Rodriguez MS. Tensile strength and modulus of elasticity of tooth structure and several restorative materials. J Am Dent Assoc 1962;64:378.
49. Mitchem JC, Turner LR. The retentive strength of acid-etched retained resins. J Am Dent Assoc 1974;89: 1107-1110.
50. Bennett CG, Chiayi S, Waldron JM. The effects of debonding on the enamel surface. J Clin Orthod 1984;18: 330-334.
51. Oliver RG. The effect of different methods of bracket removal on the amount of residual adhesive. Am J Orthod Dentofacial Orthop 1988;93:196-200.
52. Fonseca J, Bishara S, Boyer D, et al. A comparative study of the debonding strengths of three ceramic brackets. J Dent Res 1993;72:176 (abstr 578).
53. Englehardt G, Boyer D, Bishara S. Debonding orthodontic ceramic brackets by ultrasonic instrumentation. J Dent Res 1993;72:139.
54. Krell KV, Coury JM, Bishara SE. Orthodontic bracket removal using conventional and ultrasonic debonding techniques: Enamel loss and time requirements. Am J Orthod Dentofacial Orthop 1993;103:258-265.
55. Sheridan JJ, Brawley G, Hastings J. Electrothermal debracketing. Part I. An in vitro study. Am J Orthod 1986;89:21-27.
56. Sheridan JJ, Brawley G, Hastings J. Electrothermal debracketing. Part II. An in vivo study. Am J Orthod 1986;89:141-145.
57. Dovgan JS, Walton RE, Bishara SE. Electrothermal debracketing: patient acceptance and the effects on the dental pulp. Am J Orthod Dentofacial Orthop 1995 (In press).
58. Crispin BJ. Esthetic moieties. J Esthetic Dent 1993;5:37.
59. Rueggeberg FA, Lockwood P. Thermal debracketing of orthodontic resins. Am J Orthod Dentofacial Orthop 1990;98:56-65.