Comparison of Bond Strength and Degree of Conversion of a Metal, Polycrystalline and Monocrystalline Bracket by use of Sheer Bond-Strength Testing and Micro-FTIR.

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TABLE OF CONTENTS

ABSTRACT

With the increase in adult orthodontics, there has been an increase in the use of transparent ceramic brackets. Past studies of ceramic brackets revealed higher bond strengths than their metal counterparts, but there has been no firm explanation as to why these brackets differ in their mechanical properties. One hypothesis states that an increase in degree of conversion (DC) of the adhesive under the translucent bracket leads to an increase in bond strength. The purpose of this study was to compare the bond-strength and DC between a metal bracket, a polycrystalline ceramic bracket and a monocrystalline ceramic bracket.

Sixty teeth were prepared for either shear bond-strength testing or micro-FTIR testing. For both tests, ten teeth were bonded with metal brackets, ten teeth with a polycrystalline bracket and ten teeth a monocrystalline bracket. The teeth subjected to the micro-FTIR testing did not undergo acid etch in order to remove the bracket with the maximum cement intact.

The results showed that there was a significant difference in bond strength between the metal bracket and the two ceramic brackets. However, there was no significant difference found in the DC between the three brackets after micro-FTIR testing. Additionally, the monocrystalline bracket was noted to have three cohesive failures of the bracket itself during bond-strength testing, possibly due to increased crack propagation within the more brittle single crystal bracket.

Although not statistically significant, the more translucent sapphire bracket exhibited a higher DC compared to the polycrystalline and metal bracket and the

polycrystalline bracket displayed a slightly higher bond-strength that its ceramic counterpart. It is recommended that care be taken when debonding ceramic brackets, particularly monocrystalline brackets as their single crystal structure may induce increased crack propagation within the bracket.

INTRODUCTION AND REVIEW OF THE LITERATURE

A. <u>Historical Aspects of Orthodontic Bonding</u>

The bonding of orthodontic brackets to tooth enamel has been a principal subject in orthodontic research since the time a stable bond between the enamel and its associated bracket was first introduced. The bond required the transfer of a load applied to the bracket to a relatively inelastic surface. Engagement of an activated archwire into the bracket could not exceed the bond strength in the bracket/tooth relationship. The low bond- strength of the brackets quickly became a primary concern of clinicians due to the repeated and time-consuming bonding procedures during the course of treatment.

Before the advent of the bonded bracket, metallic bands with welded brackets attached were bonded to enamel by the use of zinc phosphate cement. Not only were there esthetic issues to this approach, but other disadvantages included:

- Extensive chair time required to separate and band each tooth.

- Increased risk of caries or decalcification of the underlying tooth structure.

- Increased periodontal health risk due to gingival irritation by cements.

- Additional arch space of up to 3-4 mm to provide placement of the bands, thereby affecting the final debonding placement of the dentition due to interdental spacing.

These disadvantages plainly presented a need for an alternative treatment modality that would provide retention of the bracket to the tooth.

Buonocore[1] first introduced the use of acid etching applied to the enamel surface of a tooth. Due to this prominent discovery in 1955, the bonding of the bracket to enamel has driven orthodontic bonding research to what it is today. At first, direct bonding of orthodontic attachments to teeth were used with epoxy resins. This was followed by the use of epoxy-acrylates and the more recent utilization of Bis-GMA composite resins. Although there is an argument as to when the "first bonding in Orthodontics," occurred, the use and strength of polymeric resins has increased significantly. Diacrylate resins, or more specifically, bisphenol A glycidyl dimethacrylate was designed to improve bond strength and increase dimensional stability by cross-linking[2].

In 1977, the first detailed post-treatment evaluation of direct bonding in orthodontics during a full treatment period and using a large sample size was published[3]. The study concluded that acid etching and bonding with filled composite resins would produce a major revolution in the profession of orthodontics. A survey taken approximately two years after Zachrisson's paper found that 93% of orthodontists used chemically cured resin bonding for bracket placement[4]. However, a major drawback of this system was the inability of the practitioner to manipulate the setting time of the composite resin. The clinician must position the brackets correctly on the teeth to assure a functional end result[5]. This must be done rapidly when the chemically cured resins are used, because polymerization starts immediately on mixing. If the resin were left on the tooth, the excess would lead to plaque accumulation and enamel decalcification[6-8]. Additionally, the clinician must wait to remove the excess resin so as not to mix air in the composite which could lead to a

weakening of the bond strength of the resins as well as creating porosities on the resin surface[9].

The late 70's and early 80's introduced the use of light activated resins[10-12.] Polymerization of the light activated resin can improve the accuracy of bracket positioning and thus minimize the need for difficult finishing bends or the realigning of teeth after debonding[12]. Furthermore, the clinician has the ability to remove excess resin before curing, thus reducing the amount of resin attached to the tooth that could cause enamel decalcification.

Because of these relatively recent discoveries, the majority of the studies in the area of orthodontic bonding have focused on an evaluation of the physical and mechanical properties of the adhesive resins used for direct bracket bonding. These studies included evaluations of the early and long-term bond strength, the enamel condition and the appearance of the teeth after debonding.

B. Statement of the problem

With the advent of visible light-cured orthodontic adhesives, orthodontic bonding research has focused on the physical properties of the bonding systems mentioned previously. It is clear to see the reasoning for this objective as these materials provide a very convenient means of achieving clinically acceptable results. The visible light-cured adhesives are particularly attractive for use with the relatively recent introduction of the transparent or translucent alumina ceramic brackets. These ceramic brackets have lead to a trend of cosmetic orthodontics and a greater increase of adult orthodontic treatment and general patient acceptance. However, ceramic brackets pose several clinical complications, most significantly, a greater chance of

enamel damage during debonding[13-17]. Subsequently, an increase in enamel fractures compared to traditional metallic brackets has become evident[13-17]. Various methods have been tested which would either alter the debonding technique used with ceramic brackets[18-20] or would change the base of the bracket[21]. Eliades examined the light transmittance through ceramic brackets and found that the structure, morphology and composition of the ceramic brackets affected the light transmission significantly. He also stated that such clinical factors as diffuse transmittance, enamel reflectance or light directed about the edges of the bracket might affect the polymerization and physical properties of the light cured adhesive resin[22].

Although previous studies have revealed considerable information about the bond strength provided by light-cured adhesive systems and their use with ceramic brackets, very little information is currently available about the polymerization, or, more specifically, the degree of cure of the resin and their relationship with such brackets.

The importance of the degree of cure as a factor affecting the clinical characteristics of a composite resin has been demonstrated. Mechanical properties such as flexural modulus, tensile strength and compressive strength have been found to be correlated with the degree of cure of the resin[23-30]. Furthermore, physical properties such as solubility, wear, and biocompatibility of the resin have shown to be influenced by its degree of conversion, or the amount of polymerization[30-33].

The appropriate experimental approach is a significant factor for study of the curing efficiency of dental composite resin systems. Indirect techniques such as hardness and bond strength tests may provide valuable information about the clinical

performance of these materials, yet yield little insight into the complex issue of resin polymerization.

A direct method of relating DC to a material's polymerization efficiency in adhesive bonding systems has become available. Through this study it is hoped to gain insight into this relationship and partially determine the reasons why ceramic brackets have higher shear bond strengths than metallic brackets. Thus, the specific aims of this investigation are to:

1. Study the polymerization efficiency in two representative light-cured and chemically-cured adhesive resins bonded to a monocrystalline and polycrystalline ceramic brackets and a stainless steel bracket which serves as a control. A direct approach is employed to evaluate the polymerization efficiency, or DC. This will be accomplished by a direct determination of the percent of remaining carbon-carbon ($C=C$) double bonds through the use of micro-Fourier transform infrared spectroscopy.

2. Investigate the correlation between the adhesive/bracket polymerization efficiency and the bond strengths of these units.

The null hypothesis tested in this project are:

1. The degree of cure in the light-cured adhesive is independent of the extent of bracket-induced light blockage.

2. The polymerization of the adhesive does not significantly affect the bond strength of the bracket.

C. Current Bonding Systems

Dental composite resin materials are mixtures of polymers and glass particles. Polymers are large, long-chain organic molecules. The molecules contain thousands of carbon atoms linked together like beads on a string. In addition to the polymers and filler or glass particles, the composites also contain chemicals to begin the hardening reaction (polymerization initiators), color pigments to produce the different shades to match a diversity of teeth, accelerators to speed the reaction once it has begun, inhibitors to obstruct the reaction before its time. The filler particles are coated with a substance called silane, which enhances the bonding between filler particles and the surrounding polymer matrix. In addition to the principal composite resin material, a fluid resin of relatively low viscosity (bonding agent) is initially placed in contact with the acid etched enamel during the bonding procedure[34].

1. Monomer Systems

Monomers play the major role in the formulation of the orthodontic resins, since these components provide the initial rheological properties for the clinical application of the material prior to polymerization and also the origin for the subsequent polymer structure. Dimethacrylate systems currently used in orthodontic adhesives polymerize to form a three-dimensional matrix network. The internal structure that results from the formation of linear polymers is amorphous (Figure 1). Residual unsaturated groups in the form of unpolymerized dimethacrylate monomers contribute to the development of structural defects and compromised properties of these materials. The resultant polymeric structure can many times be characterized as branched, individual and discrete units. However, some monomers contain two functional C=C groups per molecule instead of only one. This extra C=C unit can

combine with two other monomers, forming bonds to link two individual polymer chains, thus creating a cross-linked or networked structure (Figure 2). This network presents higher resistance to potential polymeric degradation reactions, as well as exposure to heat and radiation[34].

2.   Filler Systems

A number of filler systems have been used for composite resins. Strontium, barium, and alumino-borosilicate glasses, as well as crystalline quartz, and pre-polymerized composite resin particles have been listed as the main filler systems[35]. The reason for the utilization of these filler systems is to increase the mechanical properties of the composite by decreasing the volume fraction of the weaker resin phase. Properties such as the modulus of elasticity, tensile strength and compressive strength have been found to depend upon the volume fraction of the filler particles. The elastic modulus of the matrix for a Bis-GMA/TEGDMA-based composite resin has been calculated to be 3.7 GPa, while the filler elastic modulus has been found to be approximately 60 GPa. However, in order to cause a substantial change in the overall elastic modulus of the composite resin, a filler volume fraction of about 60% is required. Modern heavily filled dental composite resins have filler volume fractions in the range of 56-70%[36].

3.   Bonding Agents

Unfilled resins have traditionally been utilized as bonding agents in dental composite resin bonding systems. The basic difference between these fluid bonding resins and the composite resins is the absence of filler particles in the former. The compositions of these systems differ from those of their composite counterparts in the

12

increased proportion of the TEGDMA monomer relative to the Bis-GMA monomer. The use of these unfilled resins is due to their lower viscosity and therefore their exceptional diffusion into both the polymer network and the enamel rods, resulting in improved bonding after polymerization[37].

4. Initiator Systems in Orthodontic Adhesives

a. Chemically-activated systems

Chemically activated orthodontic adhesives employ an initiator called benzoyl peroxide, which is activated by a tertiary aromatic amine. Initiation occurs from mixing of the paste and liquid components of these systems, and peroxide radicals are formed by a multistep process according to the general reaction[38]:

$$I + A = R$$

Where,

I: Initiator,

A: Amine,

R: Free radical.

In chemically-cured systems, polymerization defects such as surface porosity and air voids in the bulk material are accentuated by the prolonged exposure to atmospheric air and the entrapment of air bubbles during mixing[39]. Merkel[40] found that this porosity and the voids created by mixing compromised the properties of these materials. He showed that mixed composites demonstrated severely porous surfaces and air voids. Reinhardt[41] discovered that mixing composite material caused porosity to reach nearly 50% of the materials total volume.

"No-mix" bonding systems were introduced to orthodontics with the intent to minimize the mixing-induced defects as well as reduce the steps that were essential for the application of the material. However, these systems utilized a catalyst on the primed enamel surface, thus creating an inconsistent polymerization gradient. The polymerization gradient worked its way towards the brackets through the process of diffusion. This diffusion gradient of the catalyst decreased the cross-linking network, thereby decreasing the strength of the material as well[42].

b.   Light-cured bonding systems

Camphoroquinone is the typical photoinitiator utilized in visible light-cured systems. Light from the light source provides the impetus for the resin complex to evolve into an excited state (exiplex). As the exiplex decomposes, it produces free radicals which, in turn propagate polymerization. The extent of the polymerization of the resin depends upon the following criteria:

1. the curing light exposure time

2. the filler volume fraction

3. the photoinitiator used, and

4. the intensity of the curing light at the specific peak absorbance wavelength of the photoinitiator.

Work by Chamberlain[43] has shown that varying the total energy density, i.e., the product of intensity and exposure time, of a composite can have a significant effect on the degree of conversion of the resin. The clinical significance of this is that greater total energy density leads to increased composite strength, as more crosslinking of the structure is formed. However, light scattering at the filler surface

can reduce the intensity of the incident light reaching the bulk material, producing decreased conversion in thick composite specimens. Therefore, filler size of the material is a crucial component of the composite and maximum scattering of light occurs when the filler size is one-half the wavelength of the incident light, or $\lambda/2$.

c.   Dual-cured systems

The dual-curing approach combines the advantages of rapid initiation for photopolymerizing resins and high conversion rates for chemically-cured resins throughout the bulk of the material. For these systems, activation of polymerization is induced through surface exposure of the material to a visible light source, and polymerization in the bulk material occurs by a chemical curing process. Therefore, both improved surface and bulk material properties would be expected. However, there is little clinical data to support these claims.

D. Conversion and Polymerization Issues

1. Polymerization extent

Degree of conversion (DC) is a term used to describe the extent of conversion of the $C = C$ double bonds to single bonds during polymerization of crosslinked network. Degree of polymerization (DP) would be a misnomer as oxidation of unreacted particles takes place with prolonged exposure to the environment over time. Additionally, DP relates more to linear polymers, not cross-linked systems. Thus, terms such as degree of cure, degree of conversion, or simply conversion are used instead. DC is calculated as the number of carbon double bonds reacted as a percent of the total number of carbon double bonds originally present.

2. Polymerization inhibitors

Inhibition of polymerization for orthodontic resins is deliberately provided by manufacturers to allow ample working time in such clinical situations as bracket placement. In light-cured systems, the working time is partially operator-controlled, since initiation of significant polymerization does not occur until the clinician allows exposure to the intense photocuring light.

3. Conversion and Mechanical Properties

It has been shown that mechanical properties such as hardness, flexural modulus, wear resistance, bulk strength and bond strength of the dental composite resins depend on the degree of conversion[23-33]. Lower degree of conversion results in the formation of polymer chains that contain an increased number of unsaturated methacrylate groups. This further produces a reduction of the cross-linking density of the network. The polymer structure therefore has less rigidity and reduced mechanical properties.

MATERIALS AND METHODS

Instron Bond Test

Thirty maxillary central incisors were collected. Selection criteria included noncarious, intact tooth surfaces. The teeth were cleaned and stored in distilled water at room temperature before being randomly assigned to one of the two test groups. Ten maxillary central metal brackets (Roth Omniarch, GAC International, Central Islip, NY), ten maxillary central monocrystalline ceramic brackets (Roth Inspire, Ormco, Sybron Dental Specialties, Orange, CA) and ten maxillary central polycrystalline ceramic brackets (Roth Clarity, 3M Unitek Corp., Monrovia, CA) were used. The thirty central incisor teeth were sectioned from the roots and the buccal surfaces were sanded flat using 600 grit silicon carbide paper to achieve a uniform flat enamel area large enough to bond a central incisor bracket. The crowns were then placed in acrylic molds with the proper diameter to fit the Instron machine, and filled with self-curing acrylic. Care was taken so that the flat, sanded facial surfaces of the teeth were flush with the acrylic (Figure 1). This resulted in an exposed tooth surface that was exactly 90 degrees to the long axis of the acrylic mold, which would later allow the shear force from the Instron machine to be applied to the base of the bonded bracket. The prepared samples were then stored in 100% humidity at room temperature.
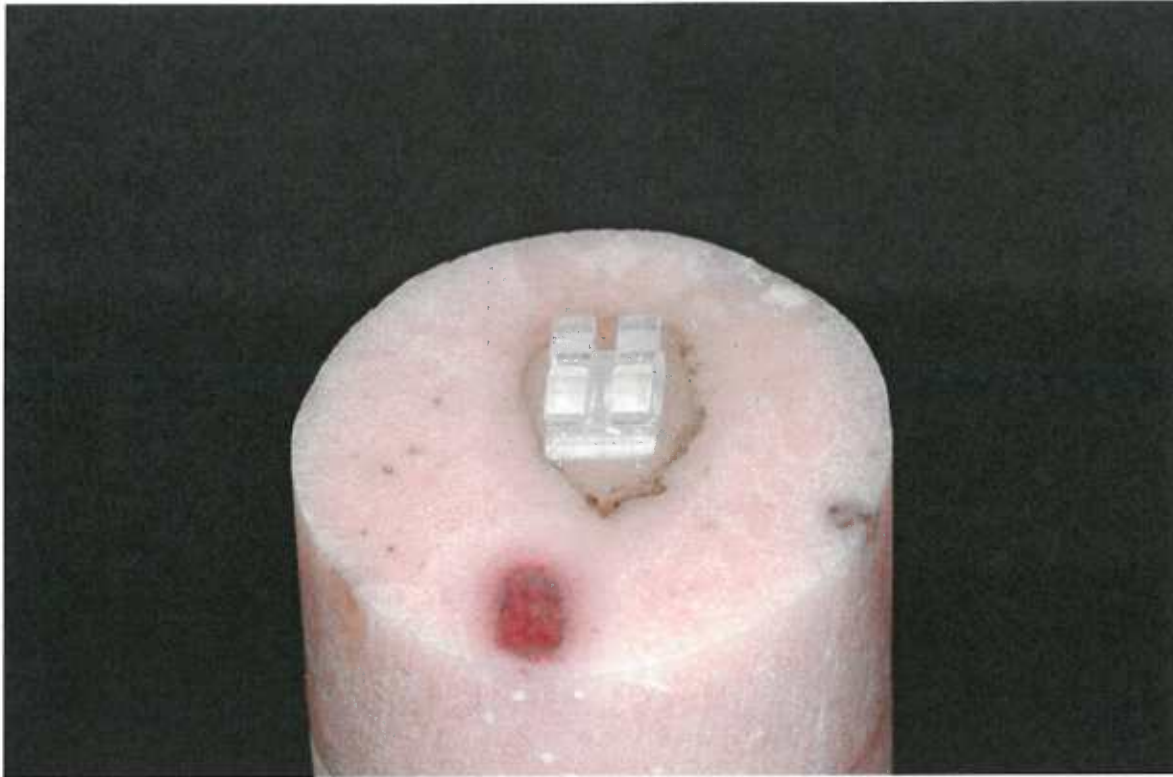
Figure 1

Preparation

All samples were thoroughly cleansed using pumice. Afterward they were

rinsed and air-dried. The samples were acid-etched with 37% phosphoric acid for 30

seconds, rinsed with water for 10 seconds and dried with an air syringe.   A light

cured adhesive primer (Transbond XT; 3M Unitek Corp.) was applied to the tooth

surfaces and light cured for 10 seconds, according to the manufacturers specifications

Figure 2. A thin layer of composite (Transbond XT; 3m Unitek Corp.) was applied to

the base of each bracket, which were then pressed onto the facial surfaces of the teeth

using cotton forceps. Excess material was removed with an explorer. The specimens

were then light-cured from the incisal aspect for ten seconds as well as from the

mesial and distal aspects for ten seconds each, for a total of 30 seconds. An Optilux

XT (3M Unitek Corp., Monrovia, CA) was used for all the specimens tested. The adequacy of the unit irradiance was confirmed using a radiometer prior to photo polymerization. The irradiance was confirmed at 596 mW.

Figure 2

The Instron machine (Instron Corp., Canton, Mass.) was utilized to apply a shear force to each bracket until bond failure. The cross-head speed was set at 2.54 mm per minute. The acrylic mounted teeth were placed in a holding apparatus with the brackets uniformly oriented as much as possible (Figure 3). A debonding jig was fit over the gingival wings of each sample and force was applied by the Instron machine until failure (Figure 4). Shear bond force and the site of failure were recorded for each sample. Shear bond strength was calculated as the force divided by the bracket area.
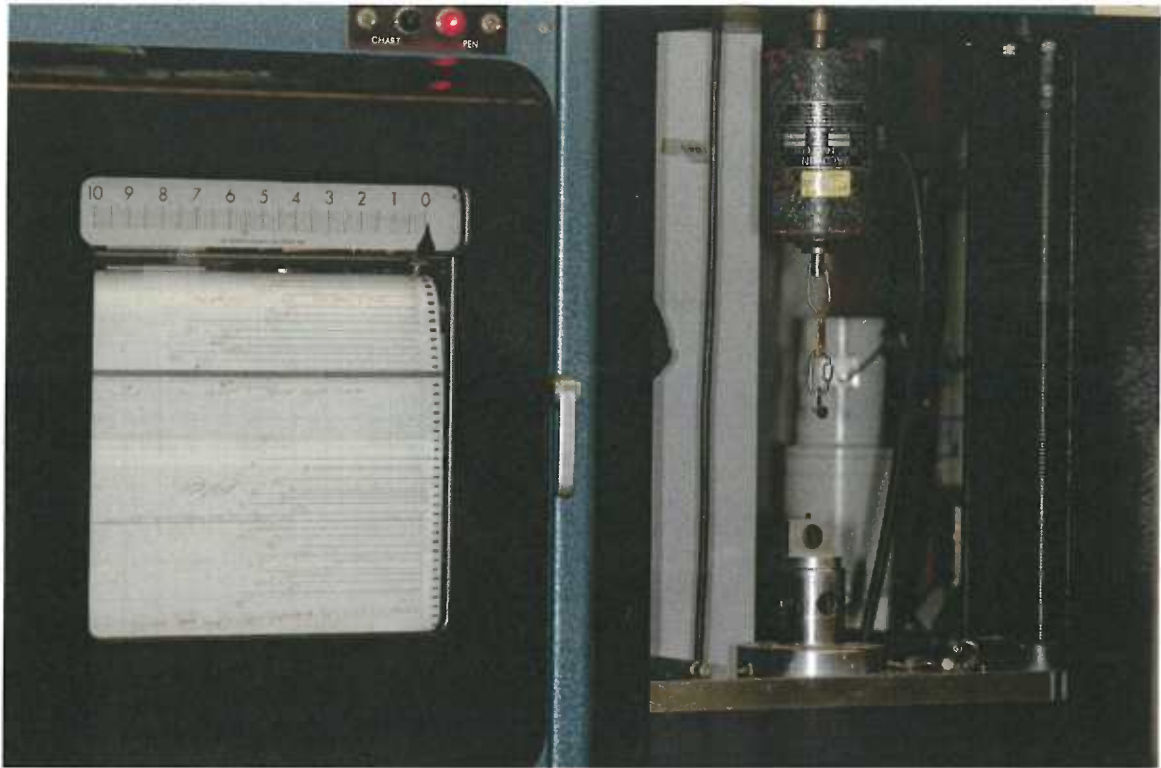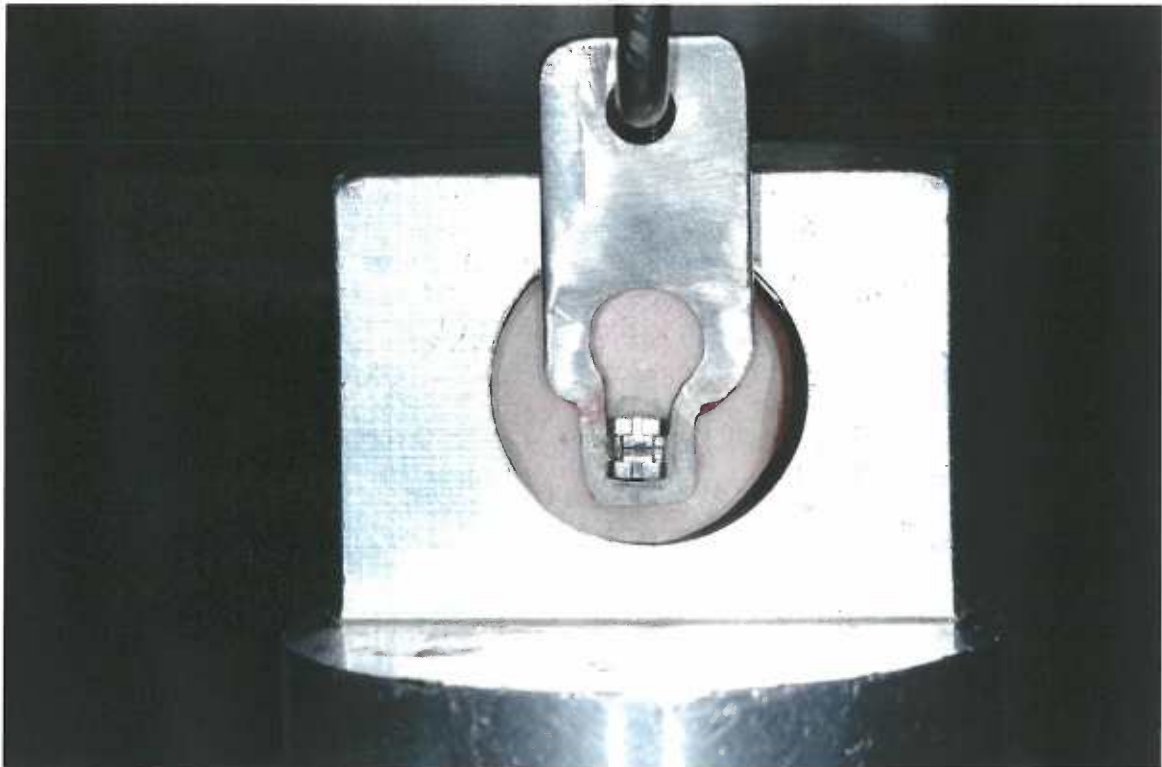
Figure 3

Figure 4

DC Test

Thirty extracted human premolars were selected. Selection criteria included noncarious, intact tooth surfaces. The teeth were cleaned and stored in distilled water at room temperature before being randomly assigned to one of the three test groups. The teeth were placed in a mold of self-curing acrylic with the roots embedded in the acrylic (Figure 5). Since these teeth were not being subjected to the Instron machine, it was not necessary to grind the facial surfaces flat and place the surfaces flush to the acrylic. The teeth were cleaned and stored in distilled water at room temperature before being randomly assigned to one of the three test groups. Ten maxillary central metal brackets (Roth Omniarch, GAC International, Central Islip, NY), ten maxillary central monocrystalline ceramic brackets (Roth Inspire, Ormco, Sybron Dental Specialties, Orange, CA) and ten maxillary central polycrystalline ceramic brackets (Roth Clarity, 3M Unitek Corp., Monrovia, CA) were used.
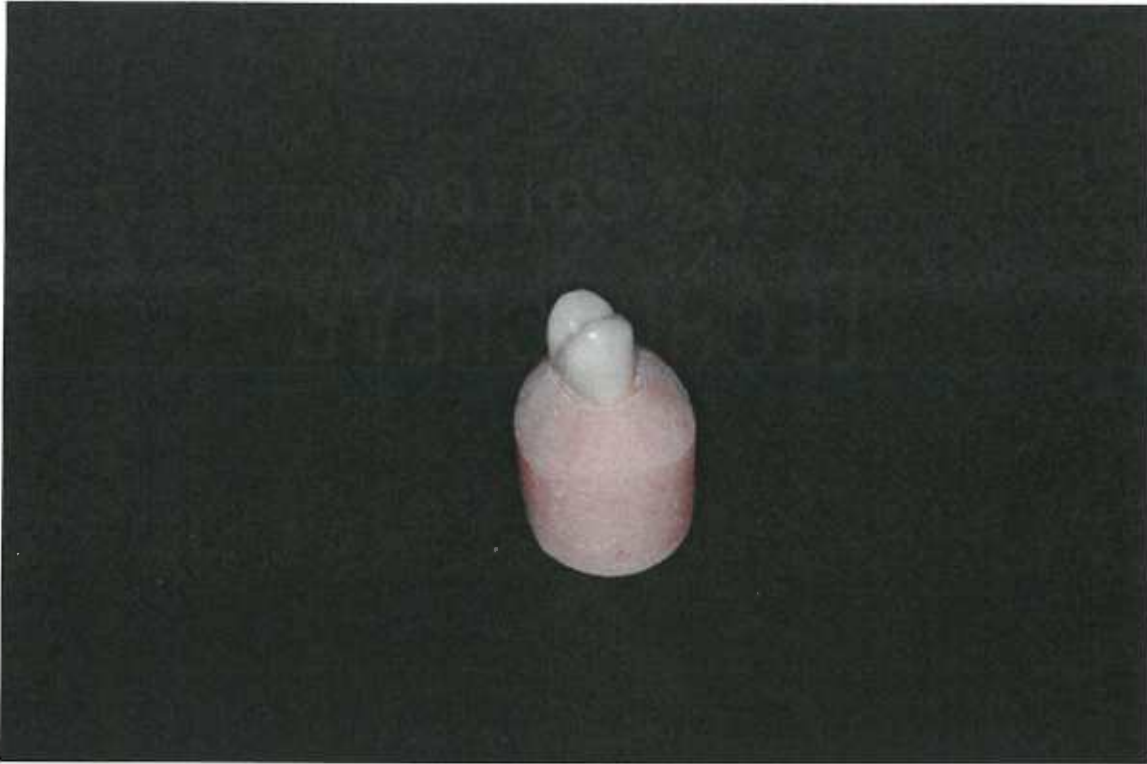
Figure 5

Preparation

The teeth were prepared for bonding as described above except the samples were not acid-etched with 37% phosphoric acid in order to remove the bracket with the maximum cement intact. The thirty samples were bonded as previously described. The teeth were then stored in distilled water for 24 hours prior to being subjected to micro-FTIR testing.

Micro-FTIR

Micro-FTIR was performed on an Analect DS20 (Figure 6). The thirty brackets were removed from the teeth after being stored in distilled water for 24 hours. The bases of the brackets were sanded with 400 grit silicon carbide paper 6-8 times. A KCl salt crystal and a bracket with cured composite were placed underneath

a 10x microscope (Bausch and Lomb) and, using forceps to hold the specimen in place, a scalpel was used to chip off 5-10 tiny fragments of the cured composite approximately 0.5mm in size (Figure 7). The specimens were placed on the KCl salt chip and seated in the XAD microscope. A background was taken of the KCl after which the micro scanner was focused on one of the transparent pieces of composite where a spectrum was acquired. The KCl salt was cleaned once again with acetone and the process was repeated for each specimen. Analect FX90 software was used to calculate the conversion and absorption of each specimen.

Figure 6

Figure 7

A baseline was taken by using an average C=C/Benzyl ratio of five uncured composite samples and placing them on a KCl salt-crystal for use in the micro-FTIR. Readings of the C=C/Benzyl peaks were read at approximately $1635cm^{-1}$ and $1610cm^{-1}$, respectively (Figure 8). For each specimen, the ratio of C=C/Benzyl was divided by the average ratio of the uncured composite and multiplied by 100. This gave the percentage of composite that was not converted. Subtraction of the percent unconverted by 100 gave the percent conversion, or DC, of the composite.
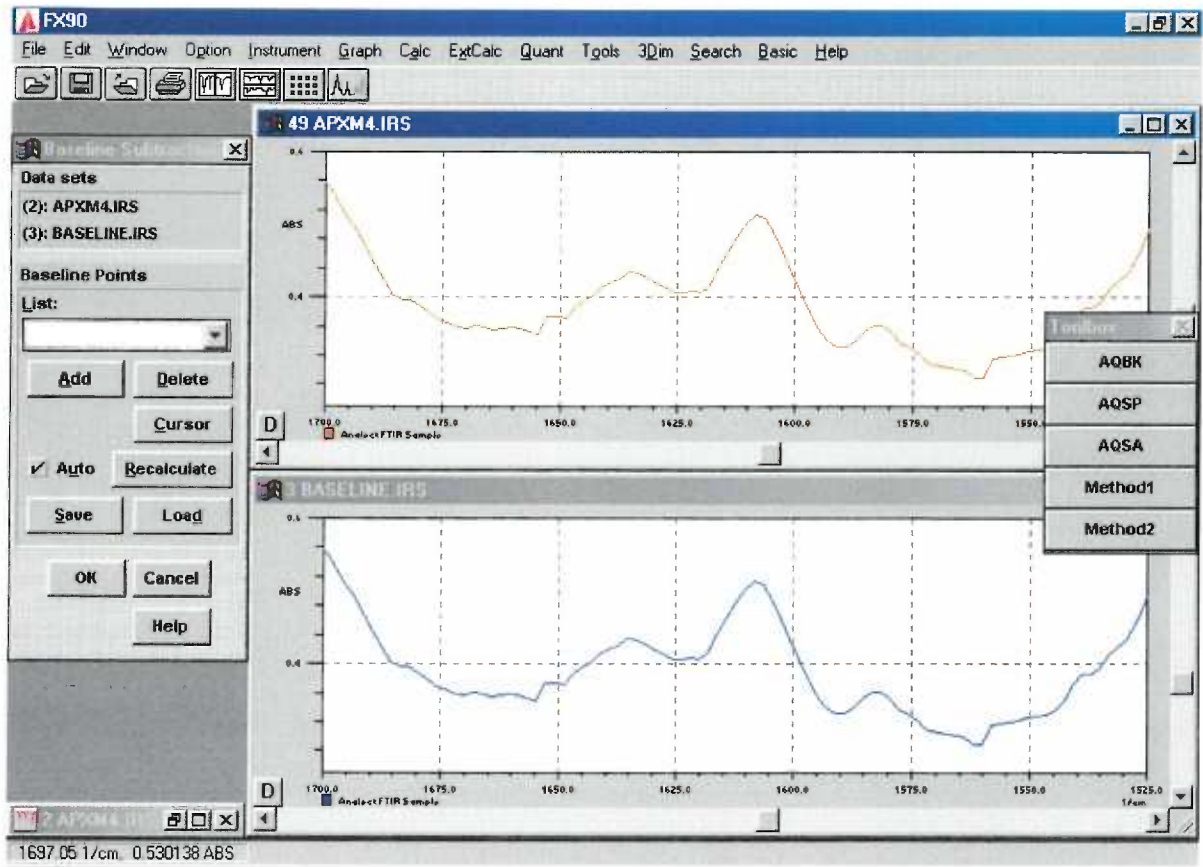
Figure 8

ANOVA and Tukey's multiple comparison test were used to determine statistical significance of differences between groups ($\alpha=0.05$).

RESULTS

An ANOVA table for statistical comparisons of bracket type and sheer bond strength is provided in Figure 9/Table 1. The highest value for sheer bond strength was in the polycrystalline bracket (Unitek Clarity bracket), followed closely by the monocrystalline bracket (Ormco Inspire bracket). These two were significantly different from the metal bracket (GAC OmniArch bracket). Failure occurred at the bracket/adhesive interface on six samples and at the tooth/adhesive interface on the other four samples of the polycrystalline bracket. For the metal bracket, failure occurred at the tooth/adhesive interface on four samples with failure at the bracket/adhesive interface on five samples and one cohesive failure. The monocrystalline bracket showed failure at the bracket/adhesive interface on seven samples and cohesive failure within the ceramic bracket itself on three samples.
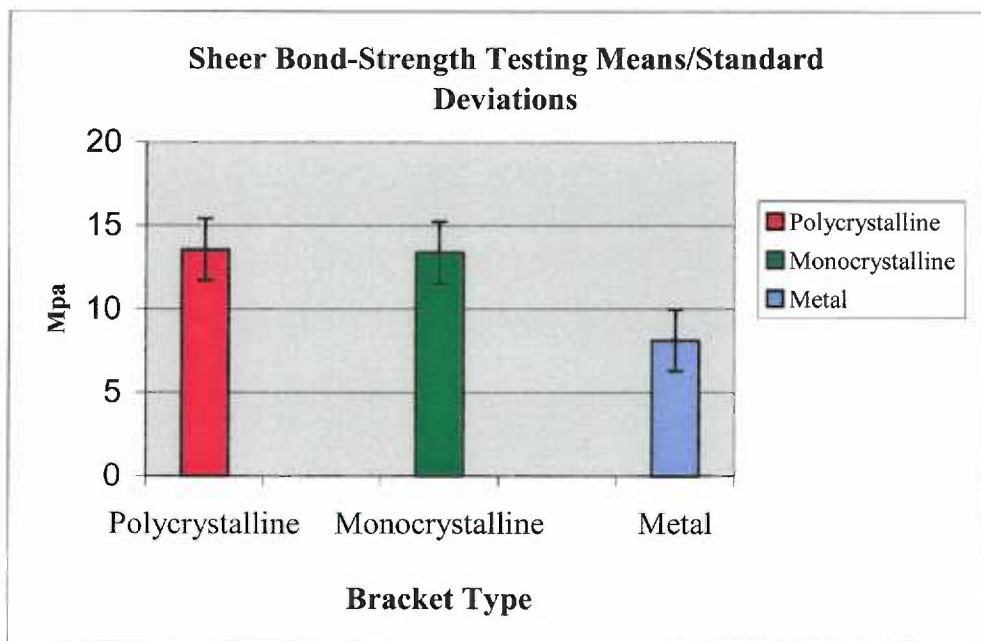

Figure 9

	Polycrystalline	Monocrystalline	Metal
Mean	13.57	13.39	8.12
St. Dev.	1.4	2.27	1.91
n	10	10	10

Table 1

The DC results for the adhesive bonded to the three bracket types is shown in Figure 10/Table 2. The highest values for these were found with the monocrystalline bracket followed by the polycrystalline bracket. The smallest DC was found with the metal bracket, although the differences between the three were not significant.

Figure 10

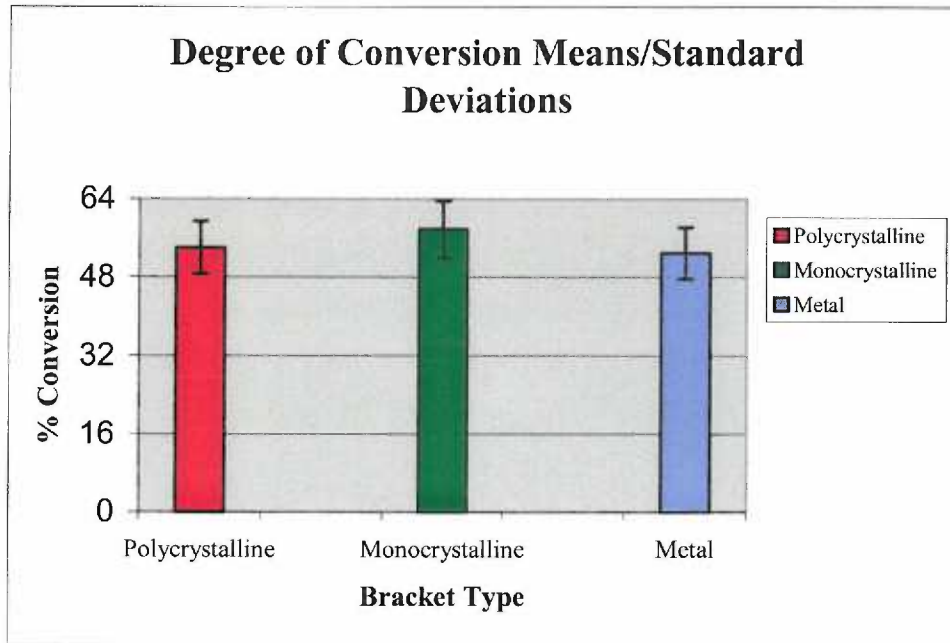|	Polycrystalline	Monocrystalline	Metal
Mean	54.06	57.82	52.97
St. Dev.	3.84	6.28	4.46
n	10	10	10

Table 2

DISCUSSION

This study examined three different brackets types: polycrystalline, monocrystalline and metal. The metal bracket base configuration included a mesh backing design. The polycrystalline as well as the monocrystalline brackets had a rough surface design. All three were able to provide micromechanical retention with the resin adhesive.

The single-crystal Inspire brackets are reported to be initially manufactured in block rod form, from which the individual brackets are machined. Although this sapphire bracket is very hard, in the past, single crystal brackets have been shown to undergo high rates of cohesive fracture when debonding from the enamel[22]. Crack propagation is relatively unrestrained in these brackets compared with the polycrystalline brackets which have irregular paths of crack propagation. This result may explain the occurrence of the three cohesive failures during shear bond-strength testing of the monocrystalline brackets.

Polycrystalline ceramic brackets are reported to be either sintered directly or machined from raw stock material. These brackets are less hard compared to the monocrystalline and they have been described to withstand greater loads during orthodontic wire engagement and debonding[44]. In the current study, although there was no significant difference found between the bond strengths of the two brackets, the average strength of the polycrystalline bracket was slightly higher than the monocrystalline bracket. Additionally, the polycrystalline microstructure has been said to have a decreased light transmittance through the brackets, compared to the

more transparent single crystal bracket[22]. Again, this could be related to the current study in which the monocrystalline bracket did exhibit a slightly higher DC compared with the monocrystalline bracket and even more so when compared to the metal bracket.

Metal brackets are known to be less rigid than their ceramic counterparts. The decreased bond strength could be due to the decrease in rigidity, or, conversely, the increase in deformation at the bracket during debonding. In this way, the metal bracket is able to 'peel' itself off the enamel surface. Previous research has alluded to this difference and the current research seems to support this hypothesis[16]. This correlates to clinical findings where metal brackets have been shown to have lower bond strength and thus are less hazardous to the enamel surface during debonding[14-15].

The micro FTIR spectroscopy technique utilized in this study, examined the degree of carbon-carbon double bond conversion of the adhesive along the tooth/adhesive interface. Although the curing was done with ten second curing along the incisal, mesial and distal aspects of the bracket, the curing light beam would have to be scattered either through the bracket and then penetrate the entire thickness of the adhesive before reaching the resin surface which was analyzed, or would have to be scattered and refracted indirectly through the enamel rods to the adhesive surface. This latter method of light transmittance is shown to be sufficient as the DC of the opaque metal bracket was not significantly different from the other more translucent brackets.

The unpredictable character of the relationship between the DC and bond strength is evident from the results of this study. Although the bond strengths of the

metal bracket were significantly less than the ceramic brackets, the DC was not found to be different. Thus, the assumption that the bond strength is proportional to the DC was not confirmed.

SUMMARY

A comparison of three orthodontic brackets were evaluated for bond-strength and degree of conversion by the use of a shear bond-strength testing machine and micro-FTIR.

The results showed a significant difference in the bond strengths between the two ceramic brackets and the metal bracket but showed no difference in the degree of conversion between the three brackets.

The monocrystalline sapphire bracket was noted to have three cohesive failures of the bracket itself during bond strength testing, possibly due to increased crack propagation within the more brittle single crystal.

Although not statistically significant, the more translucent sapphire bracket exhibited a higher DC compared to the polycrystalline and metal bracket. Additionally, the polycrystalline bracket displayed a slightly higher bond strength than the ceramic counterpart.

CONCLUSION

Ceramic brackets have significantly higher bond strengths than metal brackets. However, it was not shown that the difference in bond strength was due to a difference in cure of the bonding adhesive under the bracket.

It is recommended that care be used when debonding ceramic brackets, particularly monocrystalline brackets as their single crystal structure may induce increased crack propagation within the bracket.

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