

**Comparison of tensile bond strength between  
Microetched woven mesh and Laser structured base  
retention brackets - An in vitro study**

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## **CERTIFICATE**

This is to certify that this dissertation titled “**COMPARISON OF TENSILE BOND STRENGTH BETWEEN MICROETCHED WOVEN MESH AND LASER STRUCTURED BASE RETENTION BRACKETS – AN INVITRO STUDY**” is a bonafide record of work done by **Dr. K.S.NAGACHANDRAN** under my guidance during his postgraduate study period between 2002-2005.

This dissertation is submitted to **THE TAMIL NADU Dr. M.G.R. MEDICAL UNIVERSITY**, in partial fulfillment for the degree of **Master of Dental Surgery in Branch V –Orthodontia.**

It has not been submitted (partially or full) for the award of any other degree or diploma.

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## INTRODUCTION

Bonding orthodontic brackets to teeth has been a common procedure for more than 25 years. Bracket bond strength depends on several factors, which includes the bracket base design, bonding adhesive material and its curing method and the type of enamel conditioner used.

Bracket base retention mechanisms can be chemical or mechanical or a combination of both systems. Mesh pad is the system most commonly used for retention. The foil mesh type of base has been most widely used and can result in bond strengths in tension and shear, which are adequate for clinical use. Later their retentive capacity has been increased by other procedures like microetching, spraying metal alloy onto the base and double mesh base. Non-mesh bases, such as those obtained through chemical etching, sandblasting, or undercut milling, are not as widely accepted and are expensive.

Recently the retention mechanism of non-mesh brackets has been improvised by introduction of a new type of laser structured base retention. These laser structured base retention brackets are made of AISI 316L stainless steel by the process of metal injection molding. The smooth surface of the bracket base is then treated by a sufficiently powerful Nd: YAG (Neodymium: Yttrium-Aluminum-Garnet) laser to create retentions for the adhesive. The laser beam is scanned over the base surface, melting and evaporating the metal and burning hole shaped retentions in the base.

The chemically cured composites (self-curing acrylics) were the first systems developed for orthodontic bracket bonding. To improve the ease of

use, clinical handling and increase the working time, curing methods have been improved, the method of light curing the resin. Both light-cured and chemically cured composites have been shown to be clinically acceptable and effective.

Interest has developed in the use of glass ionomer cements as orthodontic bonding agents because of their potential advantages over conventional composite resins. The advantages claimed include excellent wetting capacity that allows the cement to adhere to the tooth surface without the need for acid etching; adhesion in a wet field; fluoride-releasing action that could reduce the risk of decalcification at the periphery of the brackets; less damage to the enamel surface in debonding; and shorter and more comfortable chair time for the patient. However studies demonstrate lower mean shear bond strength values for glass ionomer cement than for bonding resins and question the suitability of glass ionomer cements for orthodontic purposes.

Recently, a light-cured resin reinforced glass ionomer was introduced as an alternative direct bonding agent which exhibits greater shear bond strength than the traditional chemical cure glass ionomer cements.

The aims of this study were to,

- 1) compare the tensile bond strength between microetched woven mesh base retention bracket with laser structured base retention bracket using two adhesive systems and
- 2) determine the site of bond failure after debonding

## **REVIEW OF LITERATURE**

The direct bonding of orthodontic attachments to etched enamel surfaces with dental adhesives has become an accepted clinical procedure in orthodontics. The bond strength of the bonding adhesives to etched enamel

must be able to withstand the forces being applied to the teeth via the orthodontic appliances.

Various factors that influence the bond strength of orthodontic brackets include, etching technique, the conditioner used, bracket base design, type of adhesive material and its curing method.

## **ENAMEL PROPHYLAXIS**

Ideally, a prophylaxis paste should be sufficiently abrasive to remove all types of accumulations from the enamel surface without abrasion. However, 50 to 60 percent by weight of prophylactic paste is abrasive. The remaining 40 to 50 percent consists of water, humectants, and binders. As the most common abrasives are pumice, silica, and zirconium silicate, all of which are harder than enamel, it is to be expected that there will be some enamel loss when these materials are used.

**Mark Daniel Pus and David C. Way [1980]**<sup>31</sup> determined the enamel loss during initial prophylactic procedure and difference between the use of a bristle brush and of a rubber cup. Fifty human premolars were treated with zirconium silicate and water on a rotating bristle brush for 10 to 15 seconds and another set of fifty teeth were similarly treated with a rotating rubber cup. He found that the use of zirconium silicate on a rotating bristle brush causes significantly more enamel loss than when a rubber cup is used and concluded that rubber cup is preferred for routine dental prophylaxis.

**Robert Edward Thompson and David C. Way [1981]**<sup>44</sup> evaluated the enamel loss due to prophylactic procedure and multiple bonding and debonding procedures. They used both bristle brush and rubber cup with commercially available four different prophylaxis pastes. The results showed that an average of 14.2  $\mu\text{m}$  of enamel was lost when prophylaxis with

zirconium silicate on a rotating bristle brush was done for 30 seconds, which was significantly greater than the loss with the rubber cup (6.9µm). They concluded that rubber cup prophylaxis using a paste containing fine to medium-sized particles is considerably less destructive to enamel than bristle brush prophylaxis using coarse pastes with large particles.

**Franklin Gracia-Godoy et al [1991]**<sup>13</sup> evaluated the effect of pumice prophylaxis on shear bond strength of direct bonding orthodontic brackets. Three groups of teeth underwent prophylaxis by using fine slurry of pumice, fluoridated prophylaxis paste and non-fluoridated prophylaxis paste. They found that none of the three prophylaxis treatments had adverse effect on the shear bond strength of the brackets.

**Steven J. Lindauer, Henry Browning and Bhavna Shroff [1997]**<sup>54</sup> determined whether pumice prophylaxis, performed before acid etching, enhances the shear bond strength and retention rate of orthodontic brackets and using scanning electron microscopy (SEM) evaluated the surface characteristics of teeth that have been etched with and without prior pumice prophylaxis. They concluded that in vitro shear bond strengths were similar in pumiced and nonpumiced samples as were the etching patterns observed under SEM. and pumiced surfaces showed scratches under SEM, whereas nonpumiced surfaces showed retained plaque and debris in some areas after etching.

#### **ENAMEL PREPARATION AND ACID ETCHING:**

Enamel preparation prior to direct bonding aids in increased retention of orthodontic brackets to tooth surface. Various methods used include,

- 1) Air abrasion or sandblasting – uses a high-speed stream of aluminum oxide particles, propelled by air pressure

- 2) Air-powder polisher – uses a stream of fine sodium bicarbonate particles and
- 3) Acid etching – uses different acids at various concentrations

### **Air abrasion or sandblasting**

**Karen R. Reisner, Harvey L. Levitt and Francis Mante [1997]** <sup>24</sup> in their invitro study compared the surface roughness of human enamel that resulted using four different prebonding preparations and compared the shear bond strengths associated with the four prebonding enamel preparations. Four techniques used include sandblasting alone with 50 µm aluminum oxide particles at 65 to 70 psi pressure for 2 to 3 seconds, sandblasting followed by acid etching using 37% phosphoric acid for 30 seconds, surface abrasion using fluted bur at slow speed followed by acid etching and a fine pumice slurry with rubber cup for 10 seconds followed by acid etching. The results indicated that sandblasting without acid etching produces lower bond strengths than sandblasting followed by acid etching. They concluded that sandblasting should be followed by acid etching to produce enamel surfaces with comparable bond strengths and sandblasting can be used as a substitute for polishing with pumice and it does not appear to damage the enamel surface, however more in vivo tests are needed.

**Marc E. Olsen, Samir E. Bishara and Paul Damon [1997]** <sup>29</sup> compared the shear bond strength and surface structure between conventional acid etching and air-abrasion of human enamel. Conventional acid etching was carried out using 37% phosphoric acid for 30 seconds and air abrasion technique utilized two particle sizes of 50 µm and 90 µm aluminum oxide at 160 psi pressure for 3 seconds at a distance of 10 mm to enamel surface. The results indicated that the enamel surface preparation using air-abrasion results in significantly lower and clinically unacceptable

shear bond strength, regardless of the particle size. They concluded that the air-abrasion technique for enamel surface preparation results in the irreversible removal of both the inorganic and organic components of the enamel matrix. Consequently, air-abrasion of the enamel surface as a substitute protocol for acid etching and bonding orthodontic brackets is not advocated for routine clinical use.

### **Air-powder polisher**

**Laurence R. Gerbo, Caren M. Barnes and Karl F. Leinfelder [1993]** <sup>25</sup> described the application of the air-powder polisher in the orthodontic practice for surface preparation of the tooth before bracket placement. This system operates by delivering a controlled stream of fine sodium bicarbonate particles onto the tooth surface through a water spray and compressed air and primary advantages over the conventional rubber cup and pumice are that there is no generation of heat, there is greater effectiveness, and less time is required to carry out the procedure. They also suggested that the instrument should be held approximately 4 to 5 mm from the tooth surface, at a 60° angle for anterior smooth surfaces, at an 80° angle for posterior smooth surfaces, and at a 90° angle for occlusal surfaces. A constant circular motion should be used, with an exposure time of 30 to 60 seconds.

### **Acid etching**

In **1955**, **Buonocore** demonstrated the increased adhesion produced by acid pretreatment, using 85% phosphoric acid. In **1965**, **Newman** applied these findings to direct bonding of orthodontic attachments.

Various authors proposed different concentrations of acids for etching,

- 1) **Buonocore (1955)** – 85% phosphoric acid for 30 seconds

- 2) **Miura, Nakagawa and Ishizati (1973)** – 65% phosphoric acid for 30 Seconds
- 3) **Retief (1974)** - 50% phosphoric acid for 60 seconds
- 4) **Silverstone (1974)** – 30% phosphoric acid for 60 seconds
- 5) **Moser, Dowling and Marshall (1976)** – 50% phosphoric acid for 60 seconds

Acid dissolution of the enamel surface creates microporosities that results in a micromechanical bond. The etching of an enamel surface with a strong acid causes loss of surface contour together with a roughening of the enamel, which is necessary for proper adhesion of the bonding agent.

The mean loss of enamel in depth after application of phosphoric acid solutions in concentrations of 30%-50% was found to be approximately 3-10 $\mu$ m after a 1-minute exposure and up to 15 $\mu$ m after 2 minutes. The penetration of the adhesive into etched enamel has achieved a depth of up to 80 $\mu$ m and in some cases of more than 100  $\mu$ m.

**Mark Daniel Pus and David C. Way [1980]** <sup>31</sup> treated 50 human premolars with 43% gel orthophosphoric acid for 90 seconds and 50 premolars with 37% liquid orthophosphoric acid for 90 seconds. They concluded that the average loss of enamel tissue was 7.5 and 6.5  $\mu$ m in the two groups, respectively and no statistical difference between gel and liquid forms.

**Nordenvall and Brännström [1980]** <sup>23</sup> compared the effects of 15 and 60 seconds of etching with a 37 percent phosphoric acid solution on enamel surfaces from deciduous and young and old permanent teeth studied in the scanning electron microscope. The results indicated that for deciduous teeth, no difference was found in effect between the etching periods studied. For young permanent teeth, 15 seconds of etching created more retentive

conditions than 60 seconds. For old permanent teeth, the 60-second period was more effective. The most retentive conditions were found for the deciduous teeth, regardless of etching time.

**Peter Diedrich [1981]**<sup>36</sup> using scanning electron microscope studied the enamel alterations from bracket bonding and debonding. The etching agent used was 50 percent unbuffered phosphoric acid gel for ½, 1, 2, 3, 4, and 5 minutes. The results of varying the etching time suggested that the peripheral etching pattern represents an advanced stage of acid attack after fracture or breakdown of the marginal ridges. A 2-minute etching with 50 percent phosphoric acid gel was found optimum to provide a consistently uniform distribution of retentive microroughnesses on the entire conditioned enamel surface.

**Lehman and Davidson [1981]**<sup>40</sup> investigated the loss of surface enamel after acid etching procedures and its relation to fluoride content. It was shown that fluoridated enamel has a highly acid-resistant layer 2 to 4 microns in thickness. At least 2 minutes of etching with phosphoric acid (50 wt. percent) was necessary to remove such a layer and to expose a surface with the same solubility and etch pattern as nonfluoridated enamel.

**Brännström, Malmgren, and Nordenvall [1982]**<sup>28</sup> evaluated the effect of 15 seconds of etching of young permanent teeth in vitro with a phosphoric acid gel (50 percent) using the scanning electron microscope (SEM). It was found that there is no difference in the degree of surface irregularity after etching with an acid solution as compared with an acid gel and that it is possible to create good retentive conditions on the enamel of young permanent teeth after 15 seconds of etching. It was also concluded that extra etching time is not necessary when teeth have been pretreated with fluoride.

**W. J. Mardaga and I. L. Shannon [1982]** <sup>60</sup> determined the degree to which etching time can be reduced without affecting the tensile bond strength at the resin-enamel interface. Enamel surfaces were etched with 37% phosphoric acid for 15, 20, 30 or 60 seconds. They concluded that to meet the clinical needs, 30 second etch procedure with 37% phosphoric acid is suggested for clinical trial.

**Artun and Bergland [1984]** <sup>22</sup> in their clinical study compared the failure rates of orthodontic brackets that were bonded to enamel surface treated with two different conditioning solutions. In their first part of the experiment, they used 37% phosphoric acid for 60 seconds and a crystal growth conditioner which is an ion solution containing 1% sulfuric acid buffered to pH 1.5 and 15% anhydrous sodium sulfate for 90 seconds for etching the enamel surface. Scanning electron microscopic evaluation showed that teeth etched with crystal growth conditioner exhibited round and flat crystal deposits spread evenly over the enamel surface. Clinically the force needed to debacket teeth treated with crystal growth conditioner was much weaker than that needed to debacket teeth conditioned with phosphoric acid. So in their second part of the experiment they used crystal growth conditioner containing 10% phosphoric acid. They found that addition of phosphoric acid in the crystal growth conditioner improved the bond strength significantly, but not to the extent of clinical applicability. They concluded that crystal growth could produce enough retention for the brackets and the advantages might be,

- Easier and quicker debonding with little damage to the enamel surface
- Minimal effect on the outer, fluoride containing enamel surface
- No resin tags left behind in the enamel surface and

- Possibility in the future of incorporating fluoride in the crystal interface to provide an anticariogenic action

**Carstensen [1986]**<sup>64</sup> evaluated the clinical failure rate of a direct bonding technique of etching using etching times of 15-20 seconds and 30-35 seconds and performed a controlled clinical comparison of the two etching times. Results indicated that the effectivity of etching with a 37% phosphoric acid solution for either 15 or 30 seconds is similar and he concluded that a 15-second etching appears to be sufficient for the bracket bonding of anterior teeth.

**Russell Bert Farquhar [1986]**<sup>47</sup> compared the polyacrylic acid technique (crystal bonding) with a conventional phosphoric acid etching technique for the preparation of teeth for bonding. He used polyacrylic acid for 30 seconds and 43% phosphoric acid for 90 seconds. Stainless steel mesh based bracket were bonded using highly filled resin adhesive and shear bond strength was evaluated. He concluded that teeth etched with phosphoric acid had greater shear bond strength of almost three times than that of teeth etched with polyacrylic acid but the enamel loss was 4.5  $\mu\text{m}$  for polyacrylic acid group, which is less than that of the phosphoric acid group.

**Bryant, Retief, and Russell [1987]**<sup>48</sup> determined the tensile bond strengths of three two-paste bonding systems using different etching procedures and compared the tensile bond strengths of attachments bonded by two two-paste and two one-paste systems to enamel surfaces subjected to different etching procedures. Tensile bond strengths were evaluated 15 minutes and 24 hours after specimen preparation. They concluded that, the tensile bond strengths of the bonded brackets determined 24 hours after specimen preparation were always greater than the bond strengths recorded after 15 minutes. Also tags or resin extensions into etched enamel were not

essential to obtain adequate bonding after short periods of water immersion, but warned that in the clinical situation in which the bond is subjected to stress, interfacial failure due to the ingress of water at the resin/etched enamel interface may occur. It is therefore, in the clinical situation, etching with 15% phosphoric acid for 30 seconds should be preferred over etching with 5% phosphoric acid for 15 seconds.

**Sadowsky and Retief et al [1990]**<sup>34</sup> in their clinical study evaluated the effects of acid concentration and duration on the retention of orthodontic brackets. They used 37% phosphoric acid for 60 seconds and 15 seconds. They concluded that reducing the etching time of 37% H<sub>3</sub>PO<sub>4</sub> from 60 seconds to 15 seconds or reducing the acid concentration from 37% to 15% H<sub>3</sub>PO<sub>4</sub> applied for 60 seconds had no significantly different effect on the retention of bonded orthodontic attachments.

**Wang and Lu [1991]**<sup>62</sup> evaluated the tensile bond strengths of an orthodontic resin cement and compared for 15-, 30-, 60-, 90-, or 120-second etching times, with a 37% phosphoric acid solution on the enamel surfaces of young permanent teeth. From the results they found that there were no statistically significant differences in bond strength among the 15-, 30-, 60-, or 90-second etching times. However, the 120-second group showed significantly less bond strength. The enamel fragments were dramatically increased whenever the etching time was longer than 30 seconds (i.e., the amount of enamel fragments increased in proportion to the length of etching time). They proposed that the optimal etching time should be 15 seconds.

**Der Horng and Sheen [1993]**<sup>11</sup> analyzed the tensile bond strength and debonding failure mode in younger and older permanent teeth after etching for 15 and 60 seconds. They concluded that a 15-second etch with 37% phosphoric acid solution is preferable to a 60-second etch for older or

younger permanent teeth. The bond strength of older permanent teeth was stronger than that of younger teeth, with either 15- or 60-second etching time and enamel detachment was found on teeth etched for 60 seconds.

**Wang and Lin et al [1994]** <sup>63</sup> evaluated the effect of varying the phosphoric acid concentration used for acid etching on the tensile bond strength. The concentration of phosphoric acid used were, 2%, 5%, 10%, 20%, 30%, 40%, 50%, 60%, 70% and 80% by weight for 15 seconds and grooved retention base brackets were bonded with a chemical cured adhesive. The results showed that lower (2% to 5%) and higher (70% to 80%) concentrations of phosphoric acid solution resulted in lower bond strengths with debonding interfaces between the resin and enamel and enamel detachment was found as the concentrations of phosphoric acid solution increased above 30%. They concluded that 10% to 30% concentrations of phosphoric acid solution applied for 15 seconds etching resulted in bond strength adequate for clinical bonding with minimal enamel detachment.

**Marc E. Olsen and Samir E. Bishara [1997]** <sup>30</sup> compared the shear bond strength of orthodontic brackets using 37% Phosphoric acid and 10% Maleic acid for etching enamel surface and evaluated the site of bond failure. They concluded that the use of maleic acid enamel surface conditioner maintains clinically useful bond strength and there is a significant change in bond failure location to a more unfavourable site (enamel/adhesive interface) with the use of maleic acid.

**Senay Canay et al [2000]** <sup>52</sup> compared the conventional acid-etch technique using 37% orthophosphoric acid with an air abrasion surface preparation technique in which 50µm aluminium oxide was used. He studied four groups of which samples in first group was acid etched with 37%

phosphoric acid for 15 seconds, second group was sandblasted with 50µm aluminum oxide, third group was polished with pumice followed by acid etching with 37% phosphoric acid for 15 seconds and fourth group were sandblasted with 50µm aluminum oxide followed by acid etching with 37% phosphoric acid for 15 seconds. The results showed that the sandblasting followed by acid etching group had significantly higher bond strength values when compared to the other 3 groups. He concluded that sandblasting should be followed by acid etching to produce enamel surfaces with comparable bond strength and enamel surface preparation using sandblasting with a microetcher alone results in a significantly lower bond strength and should not be advocated for clinical use as an enamel conditioner.

**Rudolfo M. Valente et al [2002]** <sup>46</sup> investigated the different acid etch preparations and concentrations that affect the tensile bond strength of a visible light-cured resin-modified glass ionomer cement for bonding orthodontic attachments. Various acid etchants used were 37% phosphoric acid with silica and silica-free, 10% phosphoric acid silica-free, 10% polyacrylic acid and unetched enamel. He concluded that the etchants used did not affect tensile bond strength of visible light cured resin-modified glass ionomer cement. It is still necessary to prepare the tooth surface with an etchant before bonding since lower bond strength was achieved in nonetched enamel condition. Also he concluded that resin cement's tensile bond strength was superior to that of RMGIC but unlike resin cements, RMGIC can bond effectively to etched teeth under moist conditions without the need for an additional bonding agent to promote bond strength.

### ***BRACKET BASE DESIGN***

To enhance the retention of the adhesive to the metal base of orthodontic brackets, various chemical and mechanical retentive designs

have been suggested. Mechanical retention was enhanced by placing undercuts in the cast bracket bases or by welding different diameter mesh wires to the bracket base as well as incorporating different designs in the mesh itself.

Originally metal brackets were fabricated with perforated backings, from 12-16 holes per bracket. The bonding resin would seep through these perforations and secure the bracket. This type of mechanical retention is essential because there can be no adhesion of the bonding resins to metal. Later metal brackets with mesh pad backings were introduced. These create a greater potential for mechanical interlock of the resin to the metal bases. In fact, in some brackets the increase of the interlocks is estimated to be approximately 10,000 areas per square inch, a tremendous improvement when compared to 16 or more perforations of the original metal brackets.

Further improvements have been made in the mesh pads backings. The mesh was firmly united to the brackets so it could not be separated. This created a great advantage in debonding procedures. The entire bracket with the mesh pads backing comes off in one piece, leaving only the resin residue to be removed from the tooth surface. Originally, the strands within the mesh backing were welded to each other and to the back of the bracket. During the welding process a great number of flattened joints were created and this flattened areas encroached upon the space to be occupied by the bonding resin. To eliminate this problem, instead of welding the mesh strands they are united by a special process called braising that does not flatten the wires.

**James I. Lopez [1980]**<sup>17</sup> evaluated the shear bond strength of sixteen commercially available bracket bases at 24hours and 30 days period. He concluded that one of the foil mesh bases tested for shear strength was

significantly superior to the two other base designs (indents with undercuts and solid bases with perforations) and mechanical retention of the attachment bases to the adhesive was not significantly affected after being placed in distilled water at 37° C either for 24 hours or for 30 days.

**Dickinson [1980]** <sup>37</sup> evaluated tensile bond strengths for fourteen direct-bonding bracket bases. The different bracket bases evaluated were Trim line base, Ultra-trim line base, Laminated perforated base, Laminated mesh base, Mini-mesh base, Ormesh wide central, Foil mesh base, Micro-lok base, Lok-mesh base, Mini-Dyna bond base, Dyna bond base, Micromesh base and Peripheral perforated bases. The sizes of the wire mesh used in the manufacturing of the various mesh type bases were 40, 60, 80, and 100 mesh. The results showed that Ultra-Trim line base and Mini-mesh base had the highest values of tensile bond strength, while Laminated mesh base and Peripheral perforated base had the lowest values. Bond strength was independent of the nominal area and mesh size for the bases tested and all bond failures occurred at the base adhesive interface.

**Maijer and Smith [1981]** <sup>41</sup> evaluated seven different bracket pads using scanning electron micrographs and identified a number of variables and observations that might affect the bond strength of brackets. They used lightly filled composite resin, Dynabond as adhesive and evaluated the shear bond strength. They concluded that,

- Weld spots could reduce the retentive area
- Weld spurs could be responsible for lower bond strengths in some foil-mesh samples
- Weld spots on the edges of attachment bases should be avoided to prevent a poor marginal resin-mesh seal

- Bracket bases should be designed to prevent air entrapment under the base

The best resin penetration and bond strength were obtained with a fine mesh bracket base of the woven mesh type.

**Smith and Maijer [1983]**<sup>9</sup> improved mechanical retention of metal brackets by fusing metallic or ceramic particles onto the bracket base. Particulate-coated bases were prepared by sintering stainless steel or cobalt-chromium beads of various mesh sizes onto the bases at approximately 1,100° C for 4 hours in an inert atmosphere. Ceramic coatings were applied by similar sintering techniques or with a chemical bonding agent to the stainless steel. One advantage of a porous-coated base is that ready penetration of bonding resin occurs through capillary action and strong mechanical interlocking results, with concomitant high bond strength if the porous coating is firmly bonded to the base. The conventional mesh-base bracket showed failure at the mesh surface. The ceramic-coated base showed failure partly in the ceramic coating and partly at the resin and bracket interfaces. They concluded that the advantages of ceramic-coated base are the absence of corrosion at the resin interface and the ability to incorporate releasable fluoride into the ceramic layer, thus providing a local anticariogenic and possible remineralization effect.

**Hanson and Gibbon [1983]**<sup>15</sup> used bracket bases coated with porous metal powder and compared its bond strength with foil mesh base. Stainless steel powder consisting of small particles was used to coat the bracket base. A special sintering process was used to fuse the particles to one another and to orthodontic attachments to create strongly cohesive coatings roughly 0.005 inch thick. The manner in which the particles are joined creates highly irregular pores varying in size up to 100 mm across their major dimension.

They concluded that the large surface area and intricate microscopic void network of the powder coating provide better mechanical keying with orthodontic cement than does mesh, with a corresponding significant increase in bond strength.

**Siomka and Powers [1985]** <sup>27</sup> determined the effect of surface treatments on the tensile bond strength of three direct bonding metal bases namely Mini mesh base, photo etched Micro-lok base and grooved Dyna lok bracket base. The surface treatments included etching, silanation, surface activation, etching plus silanation, and etching plus surface activation. They concluded that the grooved Dyna lok base had the highest tensile bond strength in the nontreatment condition. Etching improved the bond strength of the grooved bracket by 56%. Silanation improved the bond strength of the mesh bracket by 28%. Surface treatments did not improve the bond strength of the photo-etched bracket.

**MacColl and Rossouw et al [1998]** <sup>14</sup> studied the effects of sandblasting bracket base surfaces, reducing base surface area, and etching enamel with various acid types on the shear bond strength. They used SPEED brackets with four different base sizes with foil mesh type base as untreated, microetched, sandblasted for bonding using unfilled chemical cured resin. Microetching was done by the bracket manufacturer with a patented grit-blasting procedure and sandblasting was done as a laboratory procedure using 50µm aluminum oxide particles for 5 seconds at 90 psi pressure. to evaluate the difference between gel and solution forms of etchants, they used 37% phosphoric acid and 10% maleic acid in gel forms and aqueous solutions were prepared using liquid orthophosphoric acid and maleic acid crystals. They concluded that,

- Significant reduction in shear bond strength occurs with smaller base areas, which may detrimentally influence the bond strength
- The retention of foil-meshed brackets is significantly enhanced if they are either microetched or sandblasted before bonding to the teeth
- An aqueous solution of 10% maleic acid produces an etching pattern that leads to statistically significantly higher shear bond strengths
- Gel preparation residues do not impair resin penetration into etched enamel surfaces and they do not differ from aqueous solutions.

**Knox et al [2000]** <sup>20</sup> evaluated the influence of bracket base design and adhesive type on the tensile strength of the bracket-adhesive interface. The tensile strength tests were performed for brackets with 60, 80 and 100 single mesh bases, a double mesh base, the Dyna lock and Mini Twin bases using four adhesives that included two chemically cured resins, a visible light cured resin and a visible light cured glass ionomer cement. He concluded that the orthodontic bonding agent selected would appear to largely determine the bond strength achieved with a particular bracket base design. Particular base designs may allow improved cement penetration or improved penetration of curing light. Alternatively, the dimension and distribution of resin tags prescribed by one base could promote a stress distribution that was better resisted by a particular adhesive.

**Corey C. Conrad [2000]** <sup>8</sup> evaluated the shear bond strength of light cured resin-modified glass ionomer cement with five different bracket designs. The brackets studied were Dentaurem Discovery titanium brackets

with laser-etched pads, GAC MicroArch twin brackets with Supermesh, a 200-gauge foil mesh layer covered by a 100-gauge foil mesh layer, Unitek Miniature Twin stainless steel brackets with cast stainless steel pads, Ormco Diamond full-size twin brackets with Ormesh 100-gauge foil mesh pads, Ormco Mini Diamond twin brackets with Optimesh, a 100-gauge foil mesh that has been metallic-coated and silanated. The results showed that Ormco Ormesh bracket had highest shear bond strength and the adhesive remnant index indicated that the Dentaaurum Discovery brackets left the least adhesive remnant on the enamel, and the GAC Supermesh brackets left the greatest amount of adhesive which had the least shear bond strength value.

**Knox et al [2001]** <sup>18</sup> evaluated the influence of bracket base morphology on the stresses generated in the bracket-cement-tooth interface by shear/peel load case using finite element method of stress analysis. Brackets with single mesh and double mesh base were modeled as three-dimensional computer generated model. The result showed that for the single-mesh designs, increasing wire diameter (100–400  $\mu\text{m}$ ) resulted in a decrease in enamel and cement stresses. Increases in wire mesh spacing (200–750  $\mu\text{m}$ ) increased the major principal stress recorded in the enamel and adhesive at all wire diameters. Within the bracket, the major principal stress increased significantly at wire spacing above 400–500  $\mu\text{m}$ . When the double-mesh bracket base was considered, the combined mesh layers resulted in a decrease in the stresses recorded in the most superficial (coarse) mesh layer and an increase in the stresses recorded in the deepest (fine mesh) layer when compared with the single-layer designs in isolation. They concluded that modification of single mesh spacing and wire diameter influences the magnitude and distribution of stresses within the bracket-

cement-tooth interface and the use of a double mesh design results in a reduction in the stresses recorded in the most superficial mesh.

**Samir E. Bishara et al [2004]** <sup>49</sup> studied the effect of variation in mesh-base design on shear bond strength of orthodontic brackets. Two metallic brackets, one with single mesh bracket base (Victory series) and the other bracket with a double mesh base called Super-mesh (Ovation) were compared using a light cured adhesive. Shear bond strength testing was performed within half an hour from the time of initial bonding to approximate the timing of tying the initial archwires to the teeth. They concluded that single mesh and double mesh bracket bases have comparable shear bond strength and bracket failure modes but whether these results will hold at 24 hours after the time of initial bonding or after thermocycling still needs to be determined.

## **ORTHODONTIC ADHESIVE**

The orthodontic adhesive and its curing method also influence the bond strength of the brackets to the tooth surface. Since the introduction of bonding adhesives the resin systems contained the two-paste catalyst-base systems and the "nomix" primer-paste systems. Once activated, these chemically cured resin systems set rapidly, severely limiting the working time and consequently the number and accuracy of bracket placements with each mix. Later to overcome this disadvantage light activated resin systems were developed. Both chemically activated and light activated composite resin adhesives required acid etching enamel preparation and a completely dry field of operation since moisture contamination greatly lowered the bond strength clinically.

Resin modified glass ionomer cements gained popularity as adhesive for bonding orthodontic brackets through its advantages like bonding even in

presence of moisture, fluoride release and reduction in enamel decalcification.

**Buzzitta, Hallgren, and Powers [1982]** <sup>58</sup> evaluated the tensile bond strength and bond failure location for three types of direct bonding cements (unfilled, low filled, and highly filled resins) with three types of brackets (polycarbonate, stainless steel, and ceramic). The results indicated that highly filled diacrylate resin gave the highest bond strength for the metal brackets and bond failure occurred at the bracket-adhesive interface with the stainless steel brackets with all three types of resin cements.

**Evans and Powers [1985]** <sup>26</sup> evaluated the effects of cement thickness and time of exposure of primer to a simulated oral environment on tensile bond strength for three no-mix cements and a two-paste cement. They concluded that there was a gradual decrease in tensile bond strength as cement thickness increased for the two-paste adhesive system. The failure site was essentially at the cement-base interface. Also when film thickness was increased and failure occurred within the cement, there was incomplete polymerization at the failure interfaces of the no-mix cements.

**Klockowski and Davis et al [1989]** <sup>43</sup> evaluated the shear bond strength and durability of three glass ionomer cements (Ketac-Fil, Ketac-Cem, and Chelon) when used as a bonding agent in the placement of orthodontic brackets and compared with a chemically cured resin adhesive (Rely-A-Bond). They concluded that glass ionomer cements exhibited lower shear bond strength than the chemical cured resin adhesive.

**Fajen and Duncanson et al [1990]** <sup>59</sup> evaluated the tensile bond strength of three commercially available glass ionomer cements (Ketac-Cem, Fuji I, Precise) and compared with chemically cured resin adhesive (Concise) using mesh-backed medium twin brackets to enamel surfaces. The

effect of three different enamel surface preparations on bond strength were also evaluated. The results of the study indicate the following:

- A large variation exists between the bond strength of three glass ionomer cements tested. Ketac-Cem showed the highest bond strength, followed by Fuji-I and Precise cements.
- The bond strength of glass ionomer cements was significantly less than that of Concise resin.
- Pretreatment of enamel surface with 45% polyacrylic acid or 1.23% acidulated phosphate fluoride solution did not significantly affect the bond strength of glass ionomer cements.

They concluded that the glass ionomer cement the Ketac-Cem cement may have adequate bond strength for clinical use.

**Wang and Meng [1992]**<sup>61</sup> evaluated the effectiveness of a visible light source in curing the composite resin under a solid metal bracket and compared the tensile bond strength between visible light-cured resin and chemical-cured resin. They concluded that visible light has the capability to diffuse and to cure the visible light-activated orthodontic composite resin under solid metal brackets and the bond strength of light-cured resin is stronger than that of the chemical-cured resin.

**Compton et al [1992]**<sup>4</sup> evaluated the shear bond strength of a light-cured glass ionomer (Zionomer) and compared with a rapidly setting chemically cured glass ionomer cement (Ketac-Bond) tested at 60 minutes and 24 hours. The results showed that the mean shear bond strength of the light-cured glass ionomer is greater than that of the chemically cured glass ionomer at 1 and 24 hours. The mean shear bond strength of both glass ionomers increases from 1 to 24 hours and the mean shear bond strength of the light cured glass ionomer is not significantly different from 1 to 24

hours, but the shear bond strength of the chemically cured glass ionomer cement is different. They concluded that because of the convenience of the faster setting reaction of the light-cured glass ionomer and its higher initial and sustained shear bond strength, it was suggested as a direct bonding alternative to the traditional composite resins.

**John P. Fricker [1994]** <sup>21</sup> performed a 12-month clinical evaluation of a light-activated glass polyalkenoate cement (Fuji II LC) compared with a chemical cured composite resin adhesive. Glass polyalkenoate cements have the unique properties of physicochemically bonding to enamel and base metals and to leach fluoride over prolonged periods. These cements have been modified to provide a dual setting with both light activation and chemical cure to produce a more rapid set. He concluded that there was no significant difference in failure rates of direct bonded orthodontic brackets cemented with light-activated glass polyalkenoate cement compared with composite bonding resin.

**McCarthy and Hondrum [1994]** <sup>32</sup> evaluated the mechanical and bond strength properties of a commercially available light-cured glass ionomer cement (Zionomer) and of a chemically cured glass ionomer cement (Ketac-Bond). The shear bond strengths of the two cement types were evaluated at 1 hour, 24 hours, and 7 days. The results showed the following:

- The light-cured cement achieves maximum tensile strength faster than the chemically cured material.
- The bond strengths of both chemically cured and light-cured glass ionomer cements increase with time. The bond strength of light-cured cement was greater than the proposed minimum level for clinical success at all test times; the bond strength of

chemically cured materials did not reach minimum levels until after 24 hours.

- The bond failures of the glass ionomer cements are primarily cohesive, light-cured more than chemically cured.
- There is a high correlation between the diametral tensile strength and the bond strength for glass ionomer cements at 1 hour and 24 hours.

**Silverman and Cohen [1995]** <sup>12</sup> evaluated the new light-cured glass ionomer cement that bonds brackets to teeth and discussed the advantages of this cement over composite resins. They concluded that the light-cured glass ionomer cement exhibited all the necessary qualities needed to bond brackets, without etching and in the presence of saliva. The tensile strength of this cement exhibited enough resistance to forces needed to move teeth. The debonding procedures were also completely undamaging to the underlying enamel surfaces. Fluoride release protects teeth against decalcification.

**Sejal B. Jobalia and Rudolfo M. Valente [1997]** <sup>51</sup> conducted tensile strength tests with a visible light cured glass ionomer cement under six different enamel surface conditions - dry nonetched, moist etched, moist nonetched, moist nonetched rebonded, moistened with saliva substitute and moistened with human saliva. They concluded that glass ionomer cement approaches the strength observed for conventional resin adhesives and is suitable for rebonding brackets. It favors the presence of moisture on the enamel surface in the form of water, saliva, or saliva substitute and this cement required the presence of moisture on the enamel surface for optimal performance.

**Akira komori and Haruo Ishikawa [1997]** <sup>1</sup> evaluated the tensile and shear bond strength of resin reinforced glass ionomer cement and compared with conventional glass ionomer cement and chemical cured resin. The adhesives used included a dual setting resin reinforced glass ionomer cement (Fuji Ortho) that sets by acid-base and free radical polymerization process, a conventional glass ionomer cement (Ketac-Cem) and a chemically cured resin (Rely-a-Bond) for bonding mesh backed stainless steel brackets. Glass ionomer groups were etched with 10% polyacrylic acid for 20 seconds and resin group was etched with 37% buffered phosphoric acid for 30 seconds. Tensile and shear testing were performed after 24 hours. The results indicated that the tensile and shear bond strength of the resin reinforced glass ionomer cement is greater than the conventional GICs but less than that of the chemically cured resin. They concluded that the resin reinforced glass ionomer cement might be useful as an alternative to composite resin for the bonding of orthodontic brackets.

**Samir E. Bishara, Marc E. Olsen, Paul Damon and Jane R. Jakobsen [1998]** <sup>50</sup> compared the shear bond strength of light-cured bonding system that used a hybrid adhesive containing a resin reinforced glass ionomer with a more traditional light-cured bonding system that contained resin material only. The results showed that, with etched enamel, even when contaminated with water or saliva before bonding, the newly introduced light-cured resin-reinforced glass ionomer adhesive system has comparable shear bond strength, as the traditional light-cured composite resin systems. With unetched enamel, the shear bond strength of the resin-reinforced glass ionomer adhesive is significantly reduced by a third to a half. This reduction in bond strength is critical and should be taken into consideration by the

clinician, because the residual bond strength might not be able to withstand the forces produced during routine clinical orthodontic procedures.

**Stephen J. Lippitz, Robert N. Staley and Jane R. Jakobsen [1998]**<sup>53</sup> compared the shear bond strength of three resin modified glass ionomer cements with that of a chemical cured resin. They used Ormesh type mesh-based brackets which were bonded using three resin modified glass ionomers namely Advance, Fuji Duet and Fuji Ortho LC and a chemical cured resin, Concise and 24 hour and 30 day shear bond strength were evaluated. Teeth that were bonded with Fuji Ortho LC had both non-etching and etching with 10 % polyacrylic acid for 20 seconds. They concluded that resin modified ionomer cements Advance, Fuji Duet, and Fuji Ortho LC had 24-hour and 30-day shear bond strengths that were statistically equivalent to those of the composite resin when used to bond mesh-backed stainless-steel brackets to the enamel surfaces of human premolars and Fuji Ortho LC had 24-hour and 30-day shear bond strengths that were lower than the composite resin bonding adhesive when the enamel surfaces were not etched with polyacrylic acid.

**Chun-Hsi Chung et al [1999]**<sup>5</sup> compared the shear bond strength of chemical cured resin adhesive (Concise) and light-cured resin reinforced glass ionomer cement (Fuji Ortho LC) under different bonding conditions namely Concise-etched and dry, Fuji Ortho LC-etched and dry, Fuji Ortho LC-etched and wet, Fuji Ortho LC-unetched and dry and Fuji Ortho LC - unetched and wet. They used 37% phosphoric acid for etching all the groups for 20 seconds. The results showed that Concise-etched and dry and Fuji Ortho LC-etched and dry groups showed comparable mean shear bond strength while the other three groups had considerably lower values. The site of bond failure was between bracket and adhesive in all etched groups and

between adhesive and enamel in the unetched groups. They concluded that enamel surface etching is required for light cured resin modified glass ionomer cement to achieve optimum bond strength and moisture does not affect its bond strength significantly.

**Akira komori and Haruo Ishikawa [1999]** <sup>2</sup> evaluated the effect of delayed light exposure between material mixing and curing of light cured resin reinforced glass ionomer cement and light cured resin on tensile and shear bond strength. Stainless steel brackets with mesh backing were bonded using light cured resin reinforced glass ionomer cement (Fuji Ortho LC) and a light cured resin (Transbond XT). Tensile and shear bond strength of the adhesives were assessed after immediate light exposure (time interval, 5 minutes) and at 10, 20, and 40 minutes after material mixing. The results showed that light cured resin reinforced glass ionomer cement and light cured resin subjected to immediate light exposure showed similar tensile and shear bond strength. The tensile and shear bond strength of light cured resin reinforced glass ionomer cement was not affected by the timing of visible light exposure but for the light cured resin, the bond strength decreased as the time intervals increased. They concluded that light cured resin reinforced glass ionomer cement serve as an advantageous alternative to composite resin for bracket bonding.

**Ana Rosa Flores [1999]** <sup>3</sup> evaluated the debonding strength of photopolymerizable resin-modified glass ionomer adhesive with and without acid etching using 37% orthophosphoric acid and compared with photopolymerizable resin. The results showed that the photopolymerizable resin-reinforced glass ionomer with acid etching of enamel offers a higher but nonsignificant debonding strength and fewer enamel changes than the photopolymerizable resin with acid etching. He also concluded that the use

of photopolymerizable resin-reinforced glass ionomer with acid etching on enamel is a favorable option in bracket bonding because the debonding strength significantly increases and there is less damage observed in the enamel surface.

**Knox et al [2000]** <sup>19</sup> using finite element analysis, evaluated the stresses generated in a bonded orthodontic attachment by three different load conditions namely masticatory load, peel force and twisting couple. Three dimensional computer model of the bracket tooth interface was developed and from the finite element model they inferred that the maximum principal stresses resulting from occlusal and twisting forces are distributed toward the adhesive periphery, peel forces applied to the bracket tie wing are concentrated beneath the bracket stem and twisting forces result in the highest enamel stresses. They concluded that the quality of orthodontic attachment can be explained by the magnitude and distribution of major principal stresses within the cement and impregnated bracket base. Shear and shear/peel forces are most likely to induce crack propagation within the adhesive layer. However, when a twisting action is used to remove orthodontic brackets, enamel failure is most likely.

**George V. Newman and Richard A. Newman [2001]** <sup>16</sup> compared the shear bond strength of light cured glass ionomer cement (Fuji Ortho LC) with light cured resin (Contacto Lite) adhesive. The effects of the commercially available new adhesive, with a system of etching (Expt AF) and using adhesive promoters (Megabond) on the tooth enamel, as well as microetching the brackets, were analyzed. The results showed that the newly formulated adhesive system that uses resin-modified hybrid glass ionomer cement (Expt AF), the adhesion promoter Megabond, and includes microetching the mesh brackets and etching the teeth, produced the highest

bond strength of the combinations tested. They concluded that Fuji Ortho LC can be used to bond under moist conditions, and it produces adequate bond strength when compared with conventional light cured no-mix composite resin adhesives and Fuji Ortho Light Cure produced a higher bond strength when tooth surfaces were etched with 10% polyacrylic acid before bonding.

### **TENSILE BOND STRENGTH TESTING**

**Thomas R. Katona and Keith Moore [1994]** <sup>55</sup> using a finite element model of the bracket-tooth interface studied the effects of load misalignment on tensile load testing of direct bonded orthodontic brackets and assessed the stress distribution in the system when bracket removing forces are applied. The results indicate that peak stress values increase as the load deflection angulation increases. If the tensile load is inadvertently applied entirely on one wing of the bracket, the stress components nearly double in magnitude.

**Katona and Chen [1994]** <sup>56</sup> in their experimental analysis determined how the construction of a ligature wire harness affects the alignment of the applied load during tensile strength testing of direct bonded orthodontic brackets. An engineering model was developed to explain these deviations. The results indicated that it is virtually impossible to evenly apply tensile loads to the bracket and they proposed that long harnesses constructed with thin ligature wire, prestressing the harness and lubrication may reduce some of the effects of unavoidable load-bracket misalignment.

**Thomas R. Katona [1997]** <sup>57</sup> using finite element model compared the stresses developed in tension, shear peel and torsion strength testing of direct bonded orthodontic brackets. The finite element model computations depict the load mode dependency of cemental layer stress component

distributions and ratios. This suggests that loading method can influence relative strength measurements. He concluded that the manner of loading affects the strength measurements and that the average stress does not adequately characterize bond strength.

**Robert L. Thomas [1999]** <sup>45</sup> compared the tensile and shear stresses in the orthodontic attachment adhesive layer with finite element analysis using a three-dimensional model and calculated the effect of misalignment of the tensile and shear forces. The results indicated that a typical tensile load induces predominantly tensile stresses in the cement interface and that the test is relatively insensitive to minor misalignment errors. In contrast, the shear load produces both tensile stresses and compressive stresses in the cement interface that are of comparable magnitude or greater as compared to the shear stress. He concluded that the tensile test method is a robust testing method with low sensitivity to misalignment of the applied load.

### **RESIDUAL ADHESIVE AND ADHESIVE REMNANT INDEX (ARI)**

After debonding the orthodontic bracket, to determine the site of bond failure, the amount of residual adhesive remaining on the tooth surface is assessed using Adhesive Remnant Index (ARI). **Artun and Bergland [1984]** <sup>22</sup> developed the Adhesive Remnant Index (ARI) on the basis of a pilot study on twenty extracted teeth. This assessment system consists of 4-point scale with scores ranging from 0 to 3. The criteria are as follows:

Score 0 = No adhesive left on the tooth.

Score 1 = Less than half of the adhesive left on the tooth.

Score 2 = More than half of the adhesive left on the tooth.

Score 3 = All adhesive left on the tooth, with distinct impression of the bracket mesh

Adhesive Remnant Index originally developed by **Artun and Bergland**<sup>22</sup> consisted of four-point scale. Later **Samir E. Bishara [1998]**<sup>50</sup> suggested the modified adhesive remnant index that consisted of 5-point scale with scores ranging between 5 and 1, which was scored with respect to the amount of adhesive adhering to the enamel surface. The criteria are as follows:

Score 5 = No adhesive remained on the enamel

Score 4 = Less than 10% of adhesive remained on the tooth surface

Score 3 = More than 10% but less than 90% of the adhesive remained on the tooth surface

Score 2 = More than 90% of the adhesive remained on the tooth surface

Score 1 = All the adhesive remained on the tooth surface

Some of the methods used for examining the tooth or bracket base surface include use of 5X or 10X magnifying lens, dental light and mouth mirror, stereomicroscope and scanning electron microscope.

## **SUMMARY AND CONCLUSION**

The purpose of this study was to, (1) compare the tensile bond strength between microetched woven mesh base retention bracket with laser structured base retention bracket using two adhesive systems and (2) determine the site of bond failure after debonding.

Sixty extracted human premolar teeth were used in this study that was divided into two main groups and teeth from each group were bonded using one of the two types of brackets, Dentaurem 'Discovery' (laser structured

base) and 3M ‘Gemini’ (microetched woven mesh base) brackets. Further these two groups were subdivided into four subgroups of which two types of adhesives, a chemically cured resin (3M ‘Unite’) and light cured resin modified glass ionomer adhesive (GC Fuji Ortho LC) were used to bond two types of brackets.

Tensile bond strength testing was performed for all the four groups and the results were calculated in Megapascals (Mpa). Our results indicated that laser structured base retention brackets exhibited highest tensile bond strength when compared with microetched woven mesh base brackets. This suggested that the bond strength of orthodontic brackets is greatly influenced by the bracket base design and this new type of laser structured base brackets might provide good bond strength for its clinical use.

Bracket-adhesive combination comparison revealed that laser structured base retention brackets exhibited high tensile bond strength when bonded with chemical cured resin adhesive. Also when adhesive systems were compared, chemically cured resin had greater bond strength than the light cured resin modified glass ionomer cement. Even though resin adhesives provide higher bond strength than the light cured resin modified glass ionomer cement, bonding brackets with resin adhesives needs entirely dry enamel surface. Since light cured RMGICs can be used under moist conditions, an attempt was made to assess whether the use of laser structured base retention mechanism with a light cured resin modified glass ionomer can provide optimal bond strength. Results of our study showed that light cured resin modified glass ionomer cement when used for bonding laser structured base retention brackets provide adequate bond strength with the added advantage that it can be used even in moist enamel surface which promises the clinical use of this combination.

The site of bond failure was evaluated using adhesive remnant index (ARI) scores and our results indicated that for laser structured base brackets, 76% of the bond failure occurred between the enamel-adhesive interface which shows less cleanup procedure required after debonding. But for microetched woven mesh base brackets, 70% of the bond failure occurred between the bracket-adhesive interface indicating extensive removal of residual adhesive from the tooth surface after debonding.

Thus from the results of our study we infer that the stainless steel bracket made of single piece injection molded technique with a laser structured retention base is advantageous over microetched woven mesh backed bracket and when used with light cured resin modified glass ionomer cement, it can provide clinically acceptable bond strength with etched enamel surface and even under moist conditions.

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