Comparative bond strengths of stainless steel orthodontic brackets bonded with different bonding agents

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Summary

The aim of this project was to compare the shear bond strengths of three light cure orthodontic adhesive resins with three different stainless steel molar brackets.

Materials and methodolgy

The adhesive resins used were:

- Transbond XT (3M Unitek, Monrovia, CA 91016. U.S.A),
- Enlight (Ormco, Orange, CA 92867. U.S.A),
- Sure Ortho Light Bond (Sure Orthodontics, Geneva 3. Switzerland).

The maxillary molar brackets used were:

- Victory Series (3M Unitek, Monrovia, CA 91016. U.S.A),
- Optimesh XRT (Ormco, Orange, CA 92867. U.S.A),
- GAC (GAC, Bohemia, NY 11716. USA).

One hundred and forty four (144) extracted human maxillary molar teeth were selected according to a protocol. These teeth were randomly divided into nine groups of sixteen teeth each. Each of these nine groups of teeth was randomly assigned to a different bracket/adhesive resin combination for testing.

The enamel specimens were etched and the brackets were bonded with their assigned adhesive resin, according to the instructions of each resin manufacturer. The bonded teeth were stored in a thymol solution at 4 degrees centigrade for twenty four hours prior to being exposed to a process of temperature cycling. The specimens were then placed in cylinders and debonded using a Zwick universal tester (Matterialprufung, 1446, Germany). The debonded specimens were inspected and indexed according to the amount of adhesive remaining on each tooth after debonding.

Results

On debonding the highest average shear bond strength of 11.8 MPa was exhibited by the 3M bracket/Transbond XT adhesive resin. When debonding the GAC and Ormco bracket groups the highest average shear bond strengths were exhibited by the Sure Ortho Light Bond adhesive resin (11.7 and 7.6 MPa respectively).

Enlight adhesive resin had the lowest average shear bond strength of the three adhesive resins irrespective of which bracket base design it was combined with. The 3M bracket/Enlight adhesive resin combination had a average shear bond strength of 9.8 MPa. The GAC bracket/Enlight adhesive resin combination exhibited an average shearbond strength of 9.2 MPa. The Ormco bracket/Enlight adhesive resin combination exhibited the lowest overall average shear bond strength of 5.8 MPa. The Kruskal-Wallis multiple comparison test showed the GAC bracket/Enlight adhesive resin combination to be significantly weaker than the GAC bracket/Sure Ortho Light Bond adhesive resin combination.

Overall there were 23 incidents of enamel damage on debonding, 16 of these were significant. These 16 instances all occurred in association with GAC brackets. The Chi-squared test showed this to be statistically significant with a p-value < 0.001. The double mesh base of the GAC brackets could account for a higher bond strength at the bracket/ adhesive interface.

The three different brackets each exhibited a different contact surface design. The 3M and Ormco brackets both had a single mesh design while the GAC bracket had a patented double mesh design. The Ormco bracket had the smallest surface area, combined with the thickest mesh strands and smallest mesh aperture of the three bases. According to the Kruskal-Wallis and Tukey-Kramer multiple comparison tests this base design resulted in significantly weaker shear bond strengths in association with all three adhesive resins.

There was no clear advantage found in using bracket/adhesive resin combinations from the same manufacturer when comparing the shear bond strengths in this study. These combinations did however show an advantage in that they caused no enamel damage.

The shear bond strength of Sure Ortho Light Bond adhesive resin proved in this study to be comparable to that of Transbond XT and Enlight adhesive resins.

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Keywords:

Bond strength

Resin.

Orthodontics.

Brackets.

Molar

Steel

4-META

Clinical Relevance:

- The shear bond strength of the new material (Sure Ortho Light Bond) was found to be comparable with that of Transbond XT and Enlight adhesive resins.
- With the exception of the Ormco bracket/Enlight adhesive resin combination molar bonding should be successful in selected cases.
- Successful bonding was found to be dependant on the contact surface size and design of the bracket and this should not be overlooked by the practitioner when choosing brackets.

Declaration

I the undersigned declare that *Comparative bond strengths of stainless steel orthodontic brackets bonded with different bonding agents* is my own work and that it has not been submitted before for any degree or examination in any other university.

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October 2007

Signed: ....

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Chapter 1

Introduction

In 1928 Dr Angle developed the Edgewise system which has served as a blueprint for subsequent orthodontic bracket systems. The original Edgewise appliances involved attaching the orthodontic brackets to the teeth by means of stainless steel bands. The bracket was welded to the band prior to band cementation around each tooth. This was a time consuming process for both the patient and the practitioner. Not only were the bands unaesthetic and unhygienic but their use also entailed creating interdental spaces at the beginning of the treatment in order to fit the bands. These same spaces required closure at the end of treatment once the bands were removed (Moyers 1988).

The introduction of the orthodontic acid etch bonding technique has led to some dramatic changes in the practice of orthodontics (Newman 1964 cited by Komori and Ishikawa, 1999). By 1979 a survey in the United States showed that 93% of orthodontists used bonding techniques for bracket attachment (Graber and Swain 1990). In 1996 a US survey showed that more than 90% of orthodontists were using a direct bonding, as opposed to an indirect technique (Gottlieb *et al* 1996). Bishara *et al* (1999a) summarised the advantages of bonding as multifactorial. The ease of plaque control, minimal soft tissue inflammation, the absence of post treatment band spaces, the ability to bond partially erupted teeth, the easier monitoring for caries and enhanced aesthetics.

Some practitioners bond bracket attachments directly to all the teeth (including molars) whilst others (a common practice) use bands on the molars and sometimes on the second premolars (Sperber *et al* 1999). The space and time advantage of not having to use bands has made treatment objectives more attainable as less space needs to be created and the patient requires fewer visits (Matasa 2003a, Tsibel and Kuftinec 2004, Banks and Macfarlane 2007). Whilst bands are more resistant to the debonding forces (Banks and Macfarlane 2007) associated with normal function, consideration needs to be given to the hygiene aspect and the associated possibility of periodontal damage (Sperber *et al* 1999, Tsibel and Kuftinec 2004, Millett and Mc Cabe 1996, Gillgrass *et al* 2001).

Hobson *et al* (2002a) stated a overall orthodontic bond failure rate of between 0.5% and 16%. Millett *et al* (2001) claimed that despite the hygiene advantages of direct bonding it was a less frequently adopted practice in the molar region due to a bond failure rate in excess of 21% when compared to the bonding success associated with the more anteriorly placed teeth. They attributed this to:

- an inferior etch pattern obtained on the molars,
- potentially a greater chance of moisture contamination,
- greater masticatory forces in the posterior regions,
- an uneven bonding agent layer between the enamel surface and the base (due to variations in the anatomy of the buccal surface of the molars).

Banks and Macfarlane (2007) added to the list of contributing factors:

- fewer enamel prisms evident in the enamel microstucture of the buccal enamel of molars,
- the age of the patient,
- inter-operator sensitivities and
- treatment mechanics.

Hobson *et al* (2002a) found that the upper first right molar (in vivo) had the highest bond failure rate of all the teeth and reported that the bond on molar bonded teeth fractured consistently. Maxillary molars failed on average after 105 days whilst mandibular molars averaged 140 days compared to an average bond survival on all other teeth of 326 days. This is significant considering that the average duration of orthodontic treatment is between 547 and 730 days.

However, Tsibel and Kuftinec (2004) claimed that the majority of todays fixed appliances are routinely bonded from second molar to second molar with a great deal of success. Thus, it would appear as though orthodontic treatment is moving away from molar bands to bonding as techniques, bonding agents and the adhesive bracket bases are evolving and improving.

The rapid pace of advancement in materials science can see some materials come and go in a relatively short space of time. This may be as a result of quality control, research and/or design shortcomings. A dilemma in the field of dentistry is that it is a challenge for the clinician to keep abreast of technological advancements and to become familiar with new materials and methods, some of which show no advantages over existing technology (Eliades 2006).

1.1 The aim of this study was:

- To test and compare the shear bond strengths of three different light cure fluoride releasing resin bonding agents using three different stainless steel maxillary molar brackets.

1.2 The objectives of this study were:

- To asses whether the new adhesive resin (Sure Ortho Light Bond) is comparable to those already on the market. (Sure Ortho Light Bond, at time of testing, was not yet commercially available and its shear bond strength was compared to that of the other bonding agents (Transbond XT and Enlight) in these tests. The remaining two bonding agents are widely used in practice and currently both claim to enjoy a significant market share.)
- To assess whether same manufacturer ('in house') combinations of brackets and adhesive resins exhibited greater bond strengths than a random mix of bonding agents and brackets?
- To comparatively assess the amount of each bonding agent remaining on the enamel after debonding – by means of adhesive remnant indexing.
- To assess importance of the size and design of the bracket base adhesive surfaces and the role this plays in the shear bond strength of the various materials?
- To assess whether molar bonding displays sufficient bond strength in order for it to be considered routine in orthodontic treatment.

Chapter 2

Literature review

2.1 Introduction

O'Brien (2005) reviewed the orthodontic literature spanning the previous ten years to reveal that twenty percent of all orthodontic research involved the materials science of orthodontic bonding.

As early as 1988 Matasa published "Adhesion and its ten commandments". He quoted these as:

"A. The adhesive

1. Shall resist ambient environment, at the same time protecting the interfaces.
2. Shall be fluid enough.
3. Shall set hard and tough.
4. Shall tolerate/dissolve tiny amounts of impurities.
5. Shall not cure slowly, unduly shrink or allow discontinuities.

B. The substrate / interfaces

6. Shall be clean.
7. Shall be firm.
8. Shall allow air to escape

C. The System

9. The adhesive has to 'love' both substrates.
10. Have a thin 'glue line'."

Clinically there are many variable factors that are associated with the shear bond strength of any adhesive material (Eliades and Brantley 2000, Thomas *et al* 1999, Aljouni *et al* 2004). Attempting to compare different materials through *in vitro* testing is a common procedure. However attempting to gain any clinical significance from such tests remains controversial. The variable factors associated with shear bond testing need to be carefully analysed, in order to produce a reliable testing protocol for the results to be in any way meaningful (Elliades and Brantley 2000).

Bishara *et al* (1999a) stated that the variables associated with shear bond strength were:

- The enamel surface and its preparation.
- The different bonding agents.
- The size, design and surface treatment of the adhesive surface of the brackets.
- The duration, intensity and direction of the light cure source.
- The size, speed and direction of the debonding force.
- Time period between bonding and debonding.
- The effects of thermocycling.
- In the clinical scenario the clinicians' skills as well as management of the oral environment play an important role in the success of the bond between the enamel and the bracket.

Currently with all the advances in bonding to enamel there are a whole new set of materials and techniques that have developed in the last decade. There are different options for enamel preparation prior to bonding, different options for bonding as in single delivery systems, moisture resistant adhesives as well as generation 5, 6 and 7 adhesives (Eliades 2006).

2.2 The enamel surface and its preparation

Routine clinical practice sees enamel surfaces cleaned with a slurry of pumice prior to etching, in order to remove the pellicle. There is no reported difference in failure rate of the bond in cases where the polishing of enamel was excluded (Barry 1995, Eliades 2006). Prophylaxis pastes are contra-indicated as the fluoride content or the oils and flavoring agents added to these pastes are believed to have a detrimental effect on the bond strength (Garcia-Godoy *et al* 1991).

Many studies in the literature were performed on teeth where the buccal surfaces had been flattened prior to etching. Hadad *et al* (2006) found that bond strengths to subsurface enamel produced significantly greater bond strengths when compared to surface enamel. Therefore they recommended that all testing conditions mimic that of the clinical situation as closely as possible.

Enamel etching is an accepted procedure even though there is enamel decalcification and loss (Flores *et al* 1999). Hosein *et al* (2004) confirmed that enamel was lost with etching prior to treatment with a further loss after debonding, at the clean-up stage. The amount of enamel lost was dependent on the instrumentation used for the post operative removal of residue adhesive.

Since the advent of enamel etching various acids, chelating agents and the use of lasers have been explored in an attempt to achieve the same result (Usumez *et al* 2002). Enamel conditioning agents other than phosphoric acid have shown weaker or less effective bond strengths (Usumez *et al* 2002, Gardener and Hobson 2001).

The ideal etch pattern can be achieved by a thirty second exposure to thirty seven percent phosphoric acid (Gardner and Hobson 2001). Research done in the 1990's showed, that both acid concentration and etching time may be reduced without significant effects on the bond strength (Eliades and Brantley 2000). Reports that an etchant with a phosphoric acid concentration of as low as two percent was adequate for bonding contradict other recommendations that range from concentrations of ten percent to thirty seven percent phosphoric acid (Johnston *et al* 1996). Johnston *et al* (1998) by means of scanning electron microscopic analysis showed that in order to get a satisfactory enamel etch pattern on molars an etching time of 30 seconds with 37% phosphoric acid was needed. They found a significant difference in the quality of etch pattern depending on whether the molars were etched for 15 or 30 seconds. They found that increasing the etching time to 60 seconds did not affect the etch pattern in any significant way, when compared to enamel that had been exposed to etchant for 30 seconds. Summers *et al* (2004) reported resin tags to a depth of 80µm after etching with 37% phosphoric acid.

Millett *et al* (2001) claimed that one of the possible causes for the poor performance of molar bonding was an inferior etch pattern attained on the buccal surfaces of molars. Hobson and McCabe (2002b) refer to four types of etched enamel; type A, B, C and D:

- Type A: Etched enamel represents 'a well developed etch pattern with well defined prisms'.
- Type B: Refers to apparent prisms which are poorly defined.
- Type C: Refers to a situation where there is no prism definition but surface

roughening has occurred.

- Type D: Enamel shows no apparent effect of the etchant on the enamel.

They showed that an ideal etch pattern occurred in less than 5% of the overall bonding area while most of the area was occupied by a type C etched enamel pattern. Their *in vivo* study went on to show that the greater the area of type A or B etch pattern the longer the bond lasted. This result contrasts with earlier laboratory tests where Hobson showed that there was no correlation between the bond strength and the quality of the etch pattern (Hobson 2000 unpublished thesis cited by Hobson and McCabe 2002b).

Irregularities in the enamel surface shape, particularly on the molars, are thought to play a role in the bond strength of bonding agents as this allows inconsistencies in the thickness of the layer of adhesive between the enamel and the bracket base (Swanson *et al* 2004).

Self etching primers have recently been introduced with results also indicating a weaker bond strength whilst exhibiting a chair time saving (Ireland *et al* 2003) and less enamel loss (Hosein *et al* 2004).

The effect that the presence of enamel fluorosis has on bond strength is significant (Duan *et al* 2006). Severely fluorosed enamel is reported not to etch consistently. Most practitioners avoid direct bonding in cases of severe fluorosis opting for bands instead.

Enamel cracks and chips as a result of extraction pose a problem that is not associated with the clinical scenario. Rix *et al* (2001) reported a 7% to 10% incidence of *in vivo* enamel cracks in premolars. They referred to their study which showed enamel cracking of the buccal surface in 46% of the enamel specimens after extraction. Should these cracks pass undetected prior to *in vitro* testing they could be responsible for enamel fractures on debonding (Schaneveldt and Foley 2002).

The microhardness of enamel has been shown to vary. This hardness may vary by 15% from one point to another. These softer enamel areas may potentially place the enamel at risk according to S. R. Grobler (personal communication September 2007).

2.3 The Bonding agents

Intra-orally, dental cements and adhesive resins are used to attach fixed orthodontic devices to the teeth. Whereas some cements bond chemically to enamel they are not suitable to bond brackets because their brittleness allows them to fracture cohesively. Cements are used to attach orthodontic bands to teeth. Adhesive resins have the advantage of low solubility and improved physical characteristics over cements. These resins penetrate the etched enamel as well as the adhesive surface of the bracket pad effecting mechanical retention between the tooth and the bracket. The resins are less susceptible to fracture than the cements resulting in higher bond strengths. Resins, however, do not bond well as a result of moisture contamination. Resin adhesives can be either light cured, chemically cured or dual cured. Hybridised adhesive materials combine the advantages of both cements and resins, but are not without disadvantages (Ewoldsen and Demke 2001). These hybridised materials were not part of this study and therefore will not be reviewed.

In order to maximise their advantages composite resins are a combination of materials of differing properties (Matasa 2005). These advantages are improved mechanical properties, aesthetics, reduced polimerisation shrinkage and a reduced coefficient of expansion (Aljouni *et al* 2004).

The main categories of composite are:

- dispersion-strengthened,
- particle strengthened,
- laminar (sandwich) and
- fibre re-inforced.

Almost all resin dental adhesives available are particle strengthened and the filler particles exceed 25% of the composition of the composite. These particles have a strengthening effect in the composite. Chemically these material components display distinct boundaries between their particles (Matasa 2005).

Little has changed in the composition of the composite resins in the last 50 years, because of the consistant reliabilty of the bond achieved. They are still a mixture of bis-GMA (Bisphenylglycidal-methacrylate) diluted with a less viscous acrylate (Matasa

2003a, Aljouni *et al* 2004).

Eppelbaum *et al* (1995) categorized dental bonding agents into four generations of development:

First generation

The first adhesive material in dentistry was methylmethacrylate (MMA) polimerised with tri-N-butylborane. Other active agents in this group are glycidyl-methacrylate (GMA), N-phenylglycine(NPG) and 2-hydroxyethyl-methacrylate (HEMA). Adhesion using these materials is obtained by infiltration and mechanical interlocking. Tensile adhesion strength in the region of 2 to 3 MPa may be achieved using these materials.

Second generation

Bisphenylglycidyl-methacrylate (bis-GMA) and tetraethyl-glycidal-methacrylate (TEGDMA) bond ionically to calcium. These bonding agents were capable of achieving a bond of between 6 to 9 MPa. These bonding agents were found to be sensitive to moisture and thermal shock.

Third generation

These materials evolved as a result advancing adhesive technology and insight into the organisation and function of the smear layer and its role as a barrier. Some of these materials are N-tolylglycineglycidyl-methacrylate (NTG-GMA), maleic acid/2 HEMA system, 4-methacryloxyethyl-trimellitic acid (4-META). Bond strengths of between 10 and 18 MPa can be achieved. 4-META is a coupling agent of multifunctional molecules responsible for obtaining adhesion between the curing polymer and any hydrophylic surface.

Fourth generation

The fourth generation was as a result of the quest for a simple multipurpose adhesive system with the following requirements:

- Compatibility with enamel, dentine, various alloys, amalgam and dental composites.
- Bond strengths in the region of 20 MPa are attainable.
- The ability to penetrate the smear layer, but not significantly affect the hydroxyapetite of the tooth.
- Display minimal shrinkage whilst remaining aesthetic.
- Exhibit hydrolytic stability.

4-META based systems are included in this generation due to their high bond strength to a variety of substrates. 4-META is a difunctional monomer which exhibits its difunctionality through:

- a hydrophobic methacrylate group which is able to combine with the resins in composite adhesives and
- hydrophilic aromatic anhydride group which promotes adhesion to the tooth and oxidised surfaces (Clark *et al* 2003).

Subsequently other generations have been described by various authors.

Fifth generation (Farah and Powers 2004, Bishara *et al* 2004a)

The emerging trend in orthodontic adhesives is the use of new self etching bonding systems. An *in vivo* study done by House *et al* (2005) using a GAC product Ideal 1 showed unacceptably high bond failure rates of up to 72.4%. This was in contrast to what Bishara *et al* (2004a) found which showed Ideal 1 to be comparable to Transbond in bond strength. The fewer steps employed in the bonding procedure can save chair time and reduce the chances of error and contamination (Bishara *et al* 2004a).

Sixth generation (Farah and Powers 2004)

Type I – A self-etching primer and adhesive in a two bottle system. Liquid 1 is an acidic primer and liquid 2 is the adhesive.

Type II – Is a self-etching adhesive that is a 2 bottle system, a drop of each is mixed and applied to the tooth surface to be bonded.

It is stated that for both types that unprepared (uncut) enamel may need to be etched with phosphoric acid.

Seventh generation (Farah and Powers 2004)

This is a no-mix, self etching adhesive which requires uncut enamel to be etched.

Van Meerbeek *et al* (2005) concluded that one step self etch adhesives are user friendly but do have major shortcomings, the most important of which is the strength of the bond. However Pandis *et al* (2006) showed self etching and conventional etching to have similar success rates *in vivo* in the molar region. Faltermeier *et al* (2007) showed 1 component adhesives to have significantly lower bond strengths than the 2 and 3 component adhesive systems. They showed the 2 and 3 component adhesive systems to have similar bond strengths.

One of the three adhesives tested in this study contains 4-META filled bis-GMA. In the covering letter attached to the official test results of this new material a warning was issued regarding the strength of this new material and the possibility of enamel damage (Yasuda 19 April 2007). The official test results show Sure Ortho Light Bond to be approximately one and a half times stronger than Transbond XT (3M Unitek) (Sato and Yasuda 17 April 2007 attached to Yasuda 19 April). An e-mail from Dr Barry Zalsman (Zalsman 1 April 2007) representing the manufacturers (BJM Laboratories) of this material anticipates that because of 4-META this adhesive should be one and a half times stronger than its conventional resin based competitors. He also claims that, because of the 4-META adhesion promoter, chemical and mechanical adhesion to etched enamel is obtained. Adhesives containing 4-META were shown by Clark *et al* (2003) to have significantly higher bond strengths than ordinary adhesive composites. These authors also warned that MCP Bond which contains 4-META may be potentially clinically unacceptable for fear of enamel damage.

An area for clinical improvement of direct bonding would be to improve on the moisture sensitivity of bonding agents (Schaneveldt and Foley 2002). Moisture contamination can occur at one or both of two critical stages:

- After the tooth has been etched.
- After the primer has been applied.

Conventional composite resins contain hydrophobic functional monomers that have little affinity for enamel or metal oxides. A reduction in bond strength of moisture contaminated resins has frequently been reported on. Resin modified glass ionomer cements have a competitive advantage because of their abilities in moist conditions. In response to this moisture insensitive primers and hydrophilic resins have been developed as a result of the advances in restorative materials and are currently in their fifth generation providing one-bottle systems. These systems work more effectively if the contamination takes place after the primer has been applied as opposed to before (Webster *et a*l 2001). Saayman (2005) found that saliva contamination did not significantly increase microleakage at the resin enamel interface when 37% phosphoric acid was used as opposed to a no rinse conditioner in preparation of the enamel. Hobson and Meechan (2001) showed different bond strengths for teeth contaminated with moisture compared to those contaminated with body fluids. According to their research body fluid contaminated enamel affected the bond strength to a greater extent than did moisture contamination when using a moisture insensitive primer.

A wide variety of orthodontic resin bonding agents are available and there are a formidable set of criteria required for them to be successful (Proffit and Fields 2000). Ideally they should be:

- Dimensionally stable.
- Fluid enough to penetrate etched enamel and the retentive surface of the bracket base.
- Strong enough to withstand the forces experienced in the mouth.
- Viscous enough to prevent the bracket moving on the tooth surface subsequent to placement and prior to curing.
- User friendly.

Some disadvantages to bonding have, however, emerged through use:

- Bonded brackets have a weaker attachment to the tooth surface than cemented bands (used prior to the bonding technique) (Graber and Swain 1990).
- The bond strengths of some bonding adhesives have been shown to be not sufficiently strong enough or strong enough for certain applications (Graber and Swain 1990).
- The resins are moisture sensitive, potential allergens, have been found to be cytotoxic, are suspected of having an estrogenic effect (Matasa 2000, 2002, Aljouni *et al* 2004, Grobler *et al* 2007b) and
- Often they have an unpleasant taste (Ortendahl and Ortengren 2000).
- Bonded molar attachments fail almost twice as frequently as banded attachments with a survival time of almost half of the banded attachment *in vivo* (Banks and Macfarlane 2007).

Seven mega Pascals is regarded to be the minimum bond strength required for a clinically effective bond (Ortendahl and Ortengren 2000). Orthodontic forces are thought to be between three and almost eight MPa (Swanson *et al* 2004).

Good bond strength, clinically, is dependent on (Sfondrini *et al* 2004):

- Avoiding moisture contamination of the etched enamel.
- Undisturbed polimerisation of the bonding agent.
- Using a bonding agent with sufficient strength.
- Minimising occlusal stress (Banks and Macfarlane 2007)

Chung and Piatti (2000) reported that orthodontic adhesive composite resins have a low incidence of bond failure. These resins do increase the probability of a plaque build-up and may be associated to an enamel demineralisation immediately adjacent to the adhesive. Enamel demineralisation has been reported on one or more teeth in 50% of orthodontic patients with banded or bonded appliances. Because of this composite resins with a low sustained fluoride release have been developed. This has been shown to reduce demineralisation by some authors whilst some report no reduction in the incidence of white spot formation as a result of the fluoride release of orthodontic resins (Chung and Piatti 2000). The fluoride is thought to be released through one of two ways. The first way is fluoride release through material dissolution which could compromise the bond strength of the resin. The second form of release is via an ion exchange with other anions in the oral environment – with the material retaining its properties. Chung and Piatti (2000) showed that there was no significant difference in bond strength of composite resins without fluoride release when compared to ion exchange fluoride releasing composite resins. All three of the resin adhesives used in this series of tests are flouride releasing agents.

Traditionally orthodontic bonding has been done with either chemical or light cure resins. Light cured resins are conveniently dispensed as a single component system stored in an opaque container, thus eliminating mixing inconsistencies that may be associated with the mixing of the chemical cure agents.

2.4 The bracket base

A wide variety of orthodontic brackets and bonding agents are available. Orthodontists choose orthodontic brackets according to various treatment related factors (Proffit and Fields 2000, Alexander 1986). The effectiveness of the adhesive surface is just as important as any other consideration as all treatment results depend on the success and stability of the bond between the enamel and the bracket. In the attempt to improve bond strength the focus of development has been on the adhesive pad (Matasa 2003a).

There are many variations in the adhesive surface design of orthodontic brackets. Some brackets are manufactured with grooves, some with perforations, some have a stainless steel wire mesh brazed onto the adhesive pad while some bases are laser formed. Each manufacturer claims its own unique 'in house' adhesive surface design, trademarks and/or patents but at the same time providing very little information regarding their dimensions (Matasa 2003a). Both the enamel and the bracket base bond to the bonding agent by means of mechanical retention. Therefore the bracket base design, size and surface treatment are important variables when it comes to bond strength testing

(Sharma-Sayal *et al* 2003). The improvement in the bond strengths of the bonding agents since inception has been significant. This coupled with the aesthetic demands of an aesthetically conscious society and the refinement of bracket base design has allowed manufacturers to decrease the size of the bases, without sacrificing bond strength. Matasa (2003a) claims the size of the adhesive surface has been reduced by 75% in recent years. Orthodontic metal brackets have an average adhesive base size of 9 to $12mm^2$ (Alexander 1986, Bishara *et al* 1999b, Sorel *et al* 2002) and rely on mechanical retention for the bond strength to the bracket. The size of the base is important because of the oral hygiene ramifications, bond strength and aesthetic considerations (Sharma-Sayal *et al* 2003). The effectiveness (design) of the adhesive surface is important for the stability, the strength of the bond, the ease of debonding, as well as the amount of bonding agent left on the enamel after debonding. Since the inception of bonding, it has been the bracket base/adhesive agent interface that has been the weak link in orthodontic bonding (Sharma-Sayal *et al* 2003). Sorel *et al* (2002) found 75% of brackets with a simple foil mesh base underwent bond failure at the bracket adhesive interface. Cozza *et al* (2006) demonstrated that retentive surface enlargement improved adhesion but also increased the risk of fracture at the bracket/adhesive interface because of surface variability. This substantiated the finding of MacColl *et al* (1998) that shear bond strength was independent of the base size once the surface area of the bracket exceeded $7mm^2$.

Sharma-Sayal *et al* (2003) found that bracket bases with a 60 gauge mesh or an integral machined base with undercuts produced the highest shear bond strengths. Wang et al (2004) showed that the Tomy bracket with its base of circular concavities produced a higher shear bond strength than the foil based brackets it was compared to. The mesh based brackets with larger mesh spaces (apertures) provided a greater shear bond strength than did bases with smaller mesh apertures. The number of openings per unit of area of the bracket base is determined by the wire diameter and the mesh spacing. For resin to penetrate the base effectively air needs to be able to escape and this is determined by the free volume between the mesh and the bracket base. Bishara *et al* (1999a) and Grubisa *et al* (2004) used forces of 300 to 400 grams applied to the bracket after placement and prior to light curing to ensure maximal penetration of the adhesive into the base.

Both mesh and non mesh base surfaces have undergone contact surface treatments in order to increase shear bond strengths. The various types of treatment have entailed micro-etching, sandblasting, polymer coating or spraying with fine particles of molten metal (Matasa 2003a, MacColl *et al* 1998). There are still further possibilities for improving base retention by incorporating a wetting agent, thus facilitating better penetration of the adhesive. Bis-GMA is a hydrophobic non-polar compound (has a hydrophilic-lipophilic balance of +7.4) and does not penetrate the highly polar surfaces (hydrophilic) of etched enamel or oxide (impervious chromium oxide) covered attachments. To counter this chemical effect pressure application to the attachment prior to polimerisation is of utmost importance in order to ensure maximum penetration of adhesive into the mesh of the bracket pad (Matasa 2004). Presently most stainless steel attachments use a fine mesh of sorts (Wang *et al* 2004). The two areas in which improvements have taken place are in the structure of the mesh as well as bond enhancing metal surface treatments (Matasa 2003b, MacColl *et al* 1998). As far as the mesh design is concerned Matasa (2003a) claimed that mesh number and wire diameter of the mesh are the most important influencing factors. *Mesh number* is the number of openings per lineal inch measured from the centre of the wire to the centre of the wire. The mesh *wire diameter* is almost as important in that if it is too thin it could break, whilst if too thick it could limit sufficient amounts of adhesive penetration. The size of the *aperture* in the mesh plays a role in that it can prevent the coarser particles of the adhesive from penetrating the mesh. Currently the trend is for a less dense mesh to be used so as to ensure a larger aperture or open area in the base.

Certain bracket/adhesive combinations exhibit greater shear bond test results. This is thought to be as result of the fact that the base design enhances or restricts adhesive penetration and or light exposure. The distribution of certain resins within a certain base design may better resist debonding because of a more favourable stress distribution (Knox *et al* 2000). Knox *et al* (2001) found mesh design to affect stress distribution at debonding mainly by influencing the flexibility of the base of the bracket. Double mesh bases showed less stress in the superficial mesh as opposed to the deeper mesh layer thus allowing increased flexibility of the base, when compared to single mesh designs. Wire diameter and mesh spacing of the single mesh brackets affect the size and location of the stresses both adhesively and cohesively. Bishara *et al* (2004b) concluded that single and double mesh bases have similar bond strength and bracket failure modes.

Laser structured base retention surfaces have reached the market and these brackets show a bond strength that is approximately double that of the traditional foil mesh attachment base with equal safety with regard to the enamel surface. Of clinical significance is that these showed a trend for all the adhesive to remain on the bracket with debonding as opposed to the mesh design where most of the adhesive tends to remain on the enamel surface (Sorel *et al* 2002).

Cucu *et al* (2002) found no statistically significant difference in bond strengths between conventional size brackets and mini brackets. Their tests showed that the site of bond failure was mostly at the adhesive bracket interface. Clinical observations show bond failure to occur usually at the enamel adhesive interface (Cucu *et al* 2002). This suggests that factors such as moisture contamination play a large part in the bond failure of the orthodontic brackets in clinical practice. Banks and Macfarlane (2007) claimed that there is no apparent relationship between the size of the adhesive pad and bond strength.

2.5 The Light curing process

Light cured bonding agents have taken over from the chemically cured agents and are now routinely used in orthodontic practice because of ease of use and the time saved (Klocke *et al* 2003). The most common and affordable light source commercially available and thus the instrument of choice since the seventies, has been the conventional halogen light. These lights display a wide intensity spectrum ranging from, approximately, 400 mW/cm^2 to 1000 mW/cm^2 (Kauppi and Combe 2003, Swanson *et al* 2004). Halogen bulbs have a life span of approximately 50 hours and manufacturers recommended that they be replaced on a six monthly basis in practice. This however appears not to be a standard practice (Swanson *et al* 2004). Kauppi and Combe (2003) established that conventional as well as high intensity halogen curing lights show a drop in light intensity after 30 seconds of continuous use.

Mitton and Wilson (2001) conducted a study of curing lights in general practice with alarming results. For the purposes of the study they accepted 300 mW/mm^2 , as minimum, for sufficient light output. The study showed 28% of lights delivered an insufficient light output. Thirty five percent of lights had material adhering to the exit light portal and forty seven percent were found to be damaged or to have had repairs. The question has to be asked what percentage of bond failures in clinical practice are as result of light units with an inadequate intensity output to achieve the required initial polymerization?

Maximum conversion of monomer, in the bonding agent, to polymer is required to achieve optimum bond strength. The thickness of the adhesive layer (which is considerably thinner than 2mm) is largely determined by the amount and size of filler particles in the resin, its viscosity, tooth surface irregularities and the bracket placement technique. This thin adhesive layer between the bracket base surface and the enamel surface should therefore convert to polymer easily. The bond strength depends on the composition of the bonding agent as well as the intensity of and exposure to the light source as well as time elapsed after exposure (Swanson *et al* 2004).

Studies have been done to compare the shear bond strength of various bonding agents and various types of light. Up to forty seconds of exposure per metal bracket is recommended using a conventional tungsten quartz halogen light source. Lasers effectively cure composite adhesives with a five to ten second exposure per bracket while the exposure of two to nine seconds per bracket is recommended for plasma arc curing lights (Klocke *et al* 2003). 'Intensity is the key to faster curing times.' (Kauppi and Combe 2003). However this higher intensity does not significantly affect the degree of chemical conversion within the bonding agent, as shown in their research. Standt *et al* (2006) showed that greater power density (mW/mm^2) created better adhesion at the mesh/resin interface. But a level of polymerization (saturation level) is reached which cannot be increased by increasing the power density (Standt *et al* 2006).

Uzel *et al* (2005) showed that there was a temperature increase in the pulp chamber of teeth as a result of light curing the adhesive agent during orthodontic bracket bonding. The lights tested were quartz tungsten halogen, xenon plasma arc and light emitting diodes. It was found that the temperature increase did not reach the 5.5^0C mark which is regarded as the critical threshold after which pulpal health may be challenged.

Komori and Ishikawa (1999) provided evidence that light cure composite resin adhesives should be light cured as soon as possible after mixing as delays in illumination can have a detrimental effect on the bond strength. The single tube delivery system has an advantage in that mixed bonding agent need not be exposed to environmental light unduly with very little wastage.

Thind *et al* (2006) stated "There appears to be no reason why any of the three light (Halogen, plasma-arc or a light emitting diode) sources cannot be used in orthodontics". They found polymerization to be equally effective with all three types of light and the only difference amongst them was the time saving offered by the plasma-arc and LED lights.

Light intensity appears not to effect polymerization shrinkage significantly. No significant difference was found using two well used brands of resin adhesive (Transbond and Lightbond) cured with high intensity quartz tungsten halogen or quartz tungsten halogen light curing units (Sener *et al* 2006).

Staudt *et al* (2005) found that a power density of 300 mW/cm^2 for thirty seconds with a halogen lamp, provided sufficiently strong shear bond strength for metallic brackets. They also found that an increase in the power density improved the adhesion at the bracket adhesive interface as shown by the interpretation of the adhesive remnant index.

Research evidence suggests that the effects of halogen irradiation lights on the tissues might alter or affect cell functions, apart from potential retinal damage (Eliades 2006). Suggesting that this irradiation should be kept to a minimum as well as also raising questions regarding the 'biologic' safety of the newer high intensity lights.

2.6 The debonding force

Normal orthodontic forces applied to the brackets are estimated to produce stresses in the region of 3 to 7.8 MPa. For an adhesive system to have a clinically acceptable performance *in vitro* should be between 6 and 8 MPa (Clarke *et al* 2003, Webster *et al* 2001). Environmental forces increase these stresses, particularly in the molar region (Swanson *et al* 2004). Bishara *et al* (2003) stated that forces as a result of chewing increased the further posterior the teeth are situated in the mouth. Sonneson and Bakke (2005) using a load transducer found pre-orthodontic thirteen year old children to have a maximum mean bite force of 362 Newtons in the molar region. This value was obtained by testing the bite in 88 sequentially admitted pre-orthodontic children.

In vivo failure rates of bonded molar tubes were shown to be 14.8% with second molars debonding twice as often as the first molars. In this study, lower molars also debonded in 21% of cases as opposed to 7.5% debonding of the maxillary molar tubes. The first time failures were recorded within a range of 23 to 29 months with a mean of 26 months (Pandis *et al* 2005). Molar tube bonding with self etching adhesives compared to conventional acid etching have shown similar success rates (Pandis *et al* 2006).

Laboratory shear bond strength depends on several factors including the bracket base retention mechanisms, the bonding system, the type of enamel conditioner used, the etch pattern of the enamel, the point of force application, direction and crosshead speed of the force applied (Eliades and Brantley 2000, Klocke *et al* 2003). *In vivo* shear bond strength tests show signifcantly lower bond strengths than *in vitro* tests (Pickett *et al* 2001).

Shear bond forces should be applied to the base of the attachment (Klocke and Kahl-Nieke 2005 c), as force applied to any other part of the attachment may corrupt comparative results and this may be a reflection of the bracket design variability (resulting in varying force vectors) not the base design or adhesive material (Eliades and Brantley 2000, Klocke and Kahl-Nieke 2005a).

Bishara *et al* (2005) deemed it important to keep parameters like crosshead speed constant for the sake of comparison. However, Klocke and Kahl-Nieke (2005 b) claim that crosshead speed does not appear to influence the amount of force applied to debond or the adhesive failure mode. They compared various speeds ranging from 0.1 to 5 mm per second. Eliades and Brantley (2000) concluded that 0.5mm per second cross head speed adds consistency to the test, but it does not simulate clinical conditions. Clinically debonding incidents are as a result of sudden high impact situations. Low cross head speeds do not test this viscoelastic property of the adhesive agent. With a low crosshead speed the impact factor is non existent.

With debonding the metal bracket bases are distorted causing the separation of the bracket from the tooth. This separation can occur at one of four sites (Sperber *et al* 1999, Ortendahl and Ortengren 2000, James *et al* 2003):

- At the bracket / adhesive interface,
- in the adhesive material,
- at the adhesive / enamel interface or

- in the enamel.

A fracture at the adhesive/enamel surface interface can cause damage to the enamel (Bishara *et al* 2004b). Retief (1974) demonstrated *in vitro* enamel damage at 9.7MPa. Stratmann *et al* (1996) demonstrated enamel damage consistantly with debonding fractures occurring at the enamel/adhesive interface. This was done by a microprobe analysis of the debonded resin which showed mineral enamel particles in the resin. Wang *et al* (2004) concluded that most debonding fractures were at the bracket adhesive or adhesive enamel interface. In order to make comparisons between the various materials on trial adhesive remnant indexing can be done in an attempt to simulate expectations in a clinical scenario (Eliades and Brantley 2000). From a chair time perspective it would be ideal to have no adhesive left on the tooth after debonding. The greater the strength of the bonding agent (or effectiveness of the pad design), the greater is the risk of enamel fracture. The failure at the bracket/adhesive interface decreases the probability of enamel damage or crazing (Bishara *et al* 2004b) but necessitates the removal of residual adhesive after debonding (Bishara *et al* 1997). Summers *et al* (2004) found that *in vivo* bond failure occurred in most cases at the resin/bracket interface. This was ascribed to incomplete polimerisation of the adhesive resin because of the metal base not allowing light penetration, as well as the entrapment of air in the mesh base could affect polimerisation.

Eliades and Brantley (2000) commented on *in vitro* debonding as follows; "The simulation of clinical conditions is a task that is not seen to be attainable in the near future". Clinically brackets can be debonded with special debonding forceps, ligature cutters, electrothermal debonding, debracketing instruments, ultrasonic or laser debonding. A squeezing force applied to the bracket by means of debonding pliers (recommended by the supplier), causing a tensile failure, is considered by most to be the safest and most effective technique of bracket removal with regard to the enamel integrity (Mundstock *et al* 1999). This technique leaves almost all the resin on the tooth surface with minimal bracket distortion. The remaining resin can be cleaned of by means of a finishing bur or by using air abrasion (Socker *et al* 2005). Summers *et al* (2004) reported 80µm resin tags as a result of etching therefore resin must remain in the enamel with the potential to discolour with time.

2.7 Time – post cure

Bishara *et al* (1999a) demonstrated that the initial bond strength of composite resins more than doubled in the first 24 hours using Transbond adhesive resin. They also showed that resin reinforced glass ionomer adhesives bond strength increased approximately twenty times within the first 24 hours. Sharma-Sayal *et al* (2003) also found an increase in the shear bond strength of Transbond adhesive resin but not to the same extent as Bishara and co-workers (1999a). Okemwa *et al* (2002) showed that the shear bond strength of Transbond after 24 hours and after 7 days remained constant at 123 Newtons on premolars.

Daub *et al* (2006) found a significant reduction in shear bond strength after exposure to thermocycling. Bishara *et al* (2003) showed that thermocycling reduced the shear bond strength of a cyanoacrylate orthodontic adhesive by as much as eighty percent.

2.8 Data analysis and presentation

The actual surface contact area of the bracket cannot be accurately estimated (Eliades and Brantley 2000). The conversion of the units of force to units of stress requires the accurate calculation of the three dimensional contact surface area of the bracket adhesive surface. A simple geometric calculation grossly underestimates the contact surface area, because of the curvature of the base (to fit the anatomy of the tooth surface) and the design of the adhesive surface (single mesh or double mesh).

The base designs are all different therefore the base adhesive interface load distributions cannot be uniform, because of the different thicknesses of the adhesive (Knox *et al* 2000). Therefore, the determined stress values may not be relevant to the size of the debonding force.

Statistical analysis and interpretation of data units of force are inconsistent with that of the same data converted units of stress. Because of this stress values may not be a reliable reference for the clinical situation (Eliades and Brantley 2000). Klocke and Kahl-Nieke (2005a) cautioned against interpreting shear bond strength values from *in vitro* tests for clinical relevance, as these values may be affected more by the methodology of the tests than the materials.

Eliades (2006) a strong critic of what he calls 'presumptuous' laboratory research noted that there has been a recent move to clinical trials as a means of assessing material performance, made possible by what he termed:

- Adapted modern instrumentation,
- advanced analytical techniques and
- more thorough statistical methods.

2.9 Summary / overview

Certain conditions in the laboratory may be controlled to such a degree that they may be considered consistent. These are:

- The concentration of the etchant.
- The etching time.
- The intensity and time exposure of the curing light.
- The time elapsed post curing.
- The thermocycling protocol.
- The position, size and angulation of the debonding force applied.
- The cross-head speed of the debonding force.

The variables then must be:

- The hardness variables within enamel.
- The soundness of the post extraction enamel.
- The etch pattern obtained on the enamel.
- The different ingredients of the bonding agents.
- The bracket adhesive base size and design.

Chapter 3

Research design and methodology

3.1 Sample description

Extracted human maxillary molar specimens were collected from the extraction clinic at University of the Western Cape's Tygerberg dental faculty. One hundred and forty four upper molar enamel specimens were selected according to a selection protocol (3.1.1). These selected teeth were prepared for bonding.

Three light cure orthodontic adhesive resin were acquired. Two of these resins are established, commercially available products available from two of the major orthodontic manufacturers. The third material at time of testing was not yet commercially available. This material was released commercially in May 2007.

Sixty maxillary molar stainless steel orthodontic brackets from each of three different manufacturers were obtained. A total of one hundred and eighty brackets were donated for use in this study.

3.1.1 Enamel specimen selection protocol

Only extracted human maxillary molars were used. The enamel selection criteria were such that the following teeth were discarded;

- Teeth with caries affecting or underming the buccal enamel
- Teeth exhibiting fluorosis
- Teeth that had enamel damage as result of the extraction. The enamel was inspected at ten times magnification for any signs of enamel damage.
- Each enamel specimen was then checked in order to identify any unacceptable morphology of the buccal surface of any of the enamel specimens. This was done by placing an example of its assigned bracket with its base positioned in the prescribed position on the buccal enamel. If there was any doubt regarding

the closeness of the 'fit' of the base to the tooth, the tooth was excluded from any further testing and another specimen was assessed and used if found to be suitable. This was done in an attempt to minimise the variation of the thickness of the adhesive layer as much as possible.

The selected teeth were sectioned in such a way as to remove the roots this was done by means of a water cooled high speed turbine handpiece. The sectioned crowns were stored in water at four degrees centigrade with a few crystals of thymol added (as an anti-bacterial agent).

3.1.2 Sample distribution

The teeth were randomly assigned to three groups, one group (forty eight specimens) for each of the bracket makes. Each group was stored separately in labeled specimen bottles.

Each group of these assigned teeth was then divided into three groups of sixteen teeth each and bottled (9 bottles) separately. Each of these bottles was labeled with the assigned bracket/adhesive resin combination. This was done with a view to ensure that sixteen brackets of each manufacturer would be bonded with the each of the three adhesive agents (16x3x3 combinations).

3.1.3 Manufacturers of the brackets used in the study

Ormco	1717 West Collins Avenue, Orange, CA 92867. U.S.A.
3M Unitek	2724 South Peck Road, Monrovia, CA 91016. U.S.A.
GAC	355 Knickerbocker Ave., Bohemia, NY 11716. USA.

3.1.4 Adhesive resins used in the study

The adhesive resins tested were:

Transbond XT	3M Unitek, Monrovia, CA 91016. U.S.A.
Enlight	Ormco, Orange, CA92867. U.S.A.
Sure Ortho Light Bond	Sure Orthodontics, Geneva. Switzerland.

All three adhesives used were light cure, fluoride release and packaged in ready mixed single delivery syringes. In the literature Transbond XT has been commonly used as a reference in comparative tests with a wide variety of other materials (Sato and Yasuda 2007, Bishara *et al* 1997, 1999a, 1999b, 2004b, 2005). Both Transbond XT and Enlight are established and well used adhesives in the market place. Sure Ortho Light Bond (Sure Orthodontics) is a new product which was released commercially in mid 2007.

Table 3.1.4a:

Materials, manufacturers and composition of each.

Adhesive Resin	***Composition***	***Manufacturer***
Enlight *(Figure 3.1.4a)*	Bisphenylglycidyl-methacrylate (bis-GMA), moisture displacing fluoride releasing sealant/bond enhancer, dark-cure mechanism. (Ormco catalog 2007)	Ormco
Transbond XT *(Figure 3.1.4b)*	Bisphenylglycidyl-methacrylate (bis-GMA), Bisphenylethyl-methacrylate (bis-EMA), fillers (silanated quartz and sub-micron silica). (Bishara *et al* 2002)	3M Unitek
Sure Ortho Light Bond *(Figure 3.1.4c)*	4-Methacryloxyethyl-trimellitic acid (4-META), Urethane Diacrylate Oligomers, Polimerisation accelerators, Triethylenglycoldimethacrylate, 2-Hydroxyethylmethacrylate, Photo-initiators, Barium aluminoborosilicate glass, Nano Silica. (Zalsman 9^{th} October 2007)	Sure Orthodontics (BJM Laboratories)

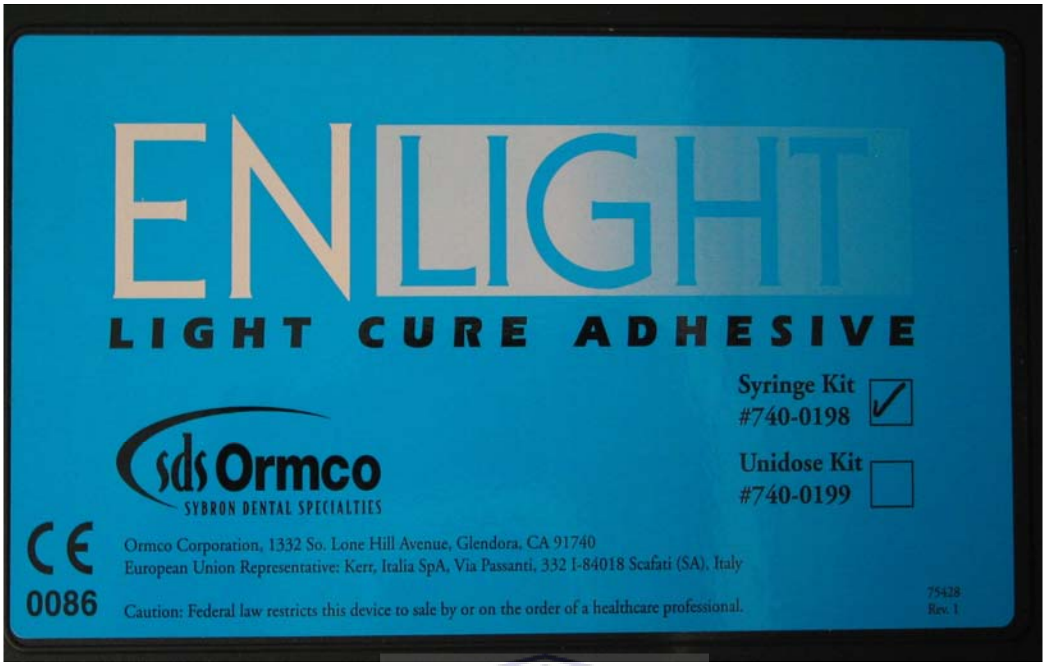


Figure 3.1.4a

The Enlight adhesive kit: Containing etching solution, Ortho solo sealant, resin and applicators.

Figure 3.1.4b

Transbond XT resin and adhesive primer kit.

Figure 3.1.4c

The Sure Ortho Light Bond kit: Containing etchant, bonding solution, resin and applicators

3.1.5 Brackets used in the study

Currently the manufacturers Ormco, 3M Unitek and GAC enjoy a large share of the worldwide orthodontic bracket market. In 1994 a quarterly publication of the Ortho Cycle company did a comparative market share for orthodontic bracket manufacturing companies. The above mentioned companies enjoyed a considerable share of the market.

Ormco	24.9%
Unitek	9.4%
GAC	17%

The remainder of the market at that time was shared by approximately twenty five other manufacturers.

Manufacturers   Attachments to be tested

Ormco (Figure3.1.5a)   Optimesh XRT (upper left molar).
Assembly recorder no: 342-2106,
PEERLESS TM
LOT: 06D238D

3M Unitek (Figure 3.1.5b)   Victory Series bondable molars (upper right).
REF 068-8242
LOT 998186100

GAC (Figure 3.1.5c)   Bondable upper right molar attachment.
REF 68-171-24
LOT B375
US mesh patent 4,889,485

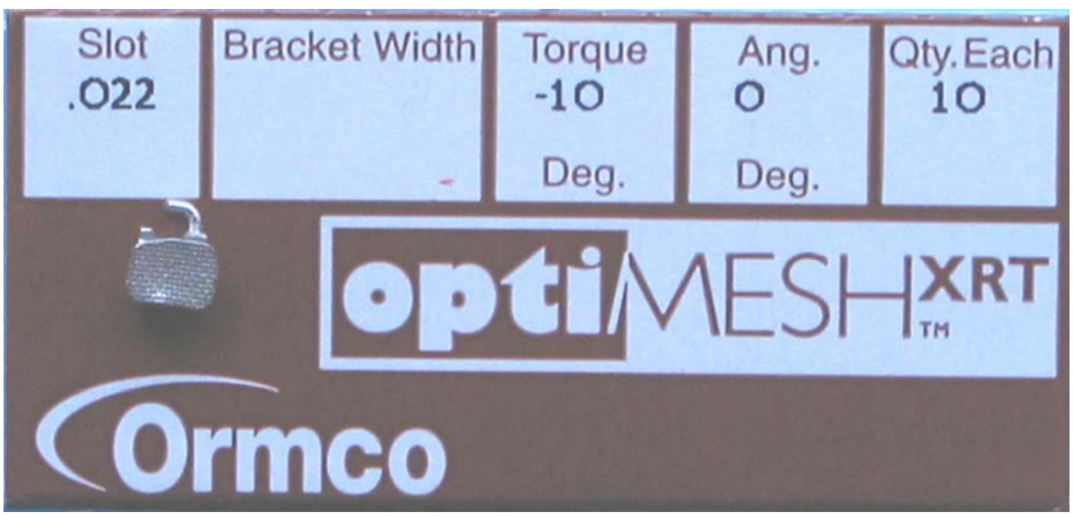


Figure 3.1.5 a
The Ormco Optimesh XRT bracket container.

Figure 3.1.5 b

The 3M Unitek Victory Series bracket container.

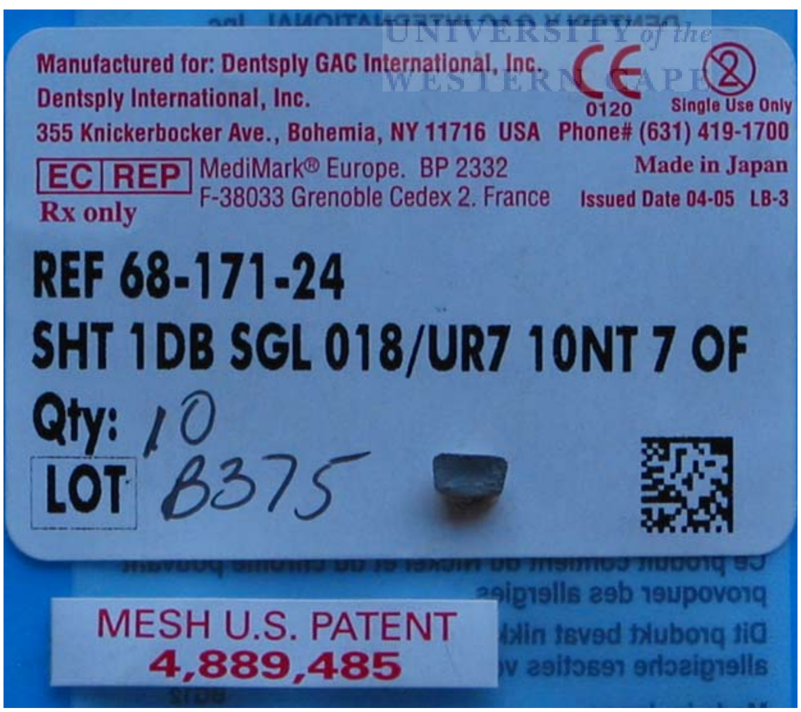


Figure 3.1.5 c

The GAC bracket container.

Table 3.1.5a:

Allocation of brackets, adhesives and teeth.

Bottle labels	*Transbond XT resin adhesive*	*Enlight resin adhesive*	*Sure Ortho Light Bond resin adhesive*
3M brackets	16 teeth	16 teeth	16 teeth
Ormco brackets	16 teeth	16 teeth	16 teeth
GAC brackets	16 teeth	16 teeth	16 teeth

3.1.5.1 Bracket base designs:

Each of the three bracket bases has a different mesh design. These meshes are brazed to the adhesive surface of the bracket pad in order to increase the contact surface area as well as to create a form of mechanical retention. This mechanical retention is enhanced by the fact that the adhesive surface and the mesh of the base are treated during the manufacturing process.

- The Ormco bracket contact surface is treated with 'Optimesh XRT' coating.
- The 3M bracket contact surface is micro-etched.
- The GAC bracket contact surface is sandblasted.

Both the 3M and Ormco bracket adhesive surfaces are constructed using a single layer of mesh. The Ormco bracket base exhibits a mesh with strands that run vertically and horizontally (figure4.5a). The 3M Unitek Victory Series bracket has a mesh which runs diagonally from corner to corner of the base (figure 4.5b). The aperture space of the Ormco mesh appears to be smaller as well as the mesh appearing to have a largely smooth and shiny surface. The GAC brackets have a double mesh structure (figure 4.5c) on the base which they claim will enhance the bond at the bracket/adhesive interface as well as serve to reduce the amount of residual adhesive left on the enamel. The bracket is constructed in such a way that mesh material becomes wider and rougher toward the adhesive/bracket interface (GAC US patent 4889485).

3.1.5.2 *Base sizes of brackets used*

Each of the three brackets had their contact surface area measured individually making use of a reflex microscope (Prior S2000 Reflex Microscope, 9 Whitehall Park, London. N19. No 001). This microscope, courtesy of the University of Cape Town's Photogrammetry Unit, is attached to a desktop computer and the Real Term Serial capture programme was used to register the x, y and z co-ordinates. The following port settings on the programme were used:

- Band; 2400
- Port: 1
- Stop Bits: 2
- Data Bits: 8
- Parity: None

The x, y and z co-ordinates obtained by this equipment were fed into a Microsoft Excell worksheet. This information was then used to calculate the contact surface area of the adhesive pad of the bracket.

Two different bases of each type of bracket were measured using this device in order to ensure averaging out of any differences that may occur. The measurement readings on each base numbered between three and four thousand readings per base. Each base was measured on the same day by a single operator.

The perimeter of each of the brackets was also measured and the base area calculated mathematically assuming simple rectangular geometry of a flat surface. This way of measuring the surface area is inaccurate as it does not take the base curvature or the three dimensional surface of the mesh into consideration.

The mesh wire diameter of each bracket was measured in microns using the Zwick/Roell ZHV microhardness tester (Indentec hardness testing machines limited, West Midlands, DY9 8HX). The aperture size was also measured using the same apparatus and the open space or aperture area was calculated. Each bracket was measured randomly in five locations for both mesh strand thickness and for the size of the open spaces or apertures.

The data generated is presented in the results chapter. The data was also submitted for statistical analysis.

3.2 Bonding

The brackets were stored in their sealed containers until they were ready to be used. Each make of attachment was bonded to enamel with each of the three bonding agent options. Each combination (bracket/adhesive) was repeated 16 times (16 x 3 x 3) on the advice of the statistical consultant.

All the enamel specimens were gently polished (for 10 seconds) with a oil free, fluoride free pumice solution to clean the enamel thus simulating the removal the pellicle as in the clinical scenario.

All the brackets to be bonded with the same bonding agent, were bonded in one session by the same operator. The brackets were thus bonded to the teeth in groups of 48. Transbond XT was the first bonding agent to be used. Sixteen 3M Unitek brackets were bonded to their assigned teeth with Transbond XT. This was followed by 16 Ormco brackets and then 16 GAC brackets being bonded to their assigned teeth with Transbond XT. This was followed by bonding the abovementioned brackets (16 of each make) to 48 teeth with Enlight and then the remaining 48 were bonded by using Sure Ortho Light Bond. The brackets were at all times handled with bonding tweezers in order to prevent skin oil contamination.

3.2.1 Transbond XT bonding

The enamel of each tooth was etched according to the instructions of the manufacturer, with a thirty seven percent solution of phosphoric acid for thirty seconds. The etchant was then rinsed for twenty seconds with water. The enamel surface was then dried to a frosty white appearance with clean oil and water free compressed air for 15 seconds. The etched enamel was then primed with a thin layer of the Transbond XT primer applied by means of a small brush. This was followed by applying the adhesive paste from the syringe to the base of the bracket, under pressure, to ensure that the paste would have the best possible penetration into the base of the bracket. The bracket was positioned on the tooth, by means of bracket tweezers, and then a force of four hundred grams was applied by means of a Dontrix gauge (American Orthodontics, Sheboygan, Wisconsin, WI53081. U.S.A.) to ensure a consistently close fit between the base and enamel surface, as well as maximal penetration of adhesive into the mesh design. Prior to light curing the excess adhesive agent was removed from around the base of the bracket with a sharp probe. The Transbond XT on each tooth was light cured for thirty seconds (10 seconds from a mesial direction, 10 seconds from an occlusal direction and 10 seconds from distal of the bracket). The exit portal of the light curing was held as close as possible to the bracket. Each bonded specimen was placed back into the water/thymol solution in its designated bottle and stored for twenty four hours at room temperature.

3.2.2 Enlight bonding

Enlight was the next adhesive used to bond the 3M, Ormco and GAC brackets to their designated teeth. The enamel was etched according to the instructions of the manufacturer, for thirty seconds, with the etchant supplied in the Enlight kit (37% phosphoric acid). The etchant was rinsed off for 20 seconds with water. The etched surface was then dried with clean oil and water free air for 15 seconds. This was followed by an application of the Enlight primer (Ortho Solo sealant) by means of the brushes supplied in the kit to cover the etched area. Enlight paste was applied to the bracket base under pressure from the syringe to ensure maximum adhesive penetration. The bracket was positioned with bracket tweezers and placed under four hundred grams of pressure with a Dontrix guage. The excess adhesive was cleaned off with a scaler and then the adhesive was cured for thirty seconds in the same manner as the Transbond specimens (10 seconds from mesial, 10 seconds from occlusal and 10 seconds from a distal direction). Each bonded specimen was placed back into the water/thymol solution in its designated bottle and stored for twenty four hours at room temperature.

3.2.3 Sure Ortho Light Bond

Sure Ortho Light Bond was the next adhesive used to bond the forty eight remaining 3M Unitek Victory Series, Ormco Optimesh XRT and GAC brackets to their designated teeth. The enamel was etched according to the instructions of the manufacturer, for thirty seconds, with the etchant supplied in the Sure Ortho Light Bond kit. The enamel surface was rinsed with water for twenty seconds and dried for fifteen seconds with oil free compressed air. This was followed by an application of the brand primer (according to manufacturer's instruction) by spreading the primer by means of a gentle stream of air from the air syringe. The Sure Ortho Light Bond paste was applied to the bracket base under pressure from the syringe to ensure maximum penetration of the adhesive into the base. The bracket was positioned with bracket tweezers and placed under four hundred grams of pressure with a Dontrix guage. The excess adhesive was removed from the tooth surface around the base of the bracket with a probe. The adhesive was light cured in the same manner as the Transbond XT and Enlight adhesives for thirty seconds, as described above. Each bonded specimen was placed back into the water/thymol solution in its designated bottle and stored for twenty four hours at room temperature.

3.3 The curing light

A standard standard tungsten quartz halogen curing light (figure 3.3b) (Optilux 501, Demetron Research Corporation), set at an intensity of 460 milliwatt per square centimeter (mW/cm^2) was used to cure the bonding agents. The intensity of the light was checked after every 8 exposures with a minimum setting of $440mW/cm^2$ allowed. Thus an intensity range of between 440 and 480 mW/cm^2 was used. A Dentsply light intensity meter (Cure Rite Meter, Dentsply, Caulk.) was used to ensure this consistent intensity (figure 3.3a).

Figure 3.3a

The Cure Rite light intensity meter (Dentsply)

Figure 3.3b

The Optilux 501 curing light (Demetron Research Corporation)

3.4 The testing procedure.

Each bonded specimen was stored in the water with a few crystals of thymol for twenty four hours and then exposed to a temperature cycling procedure (figure 3.4a). This entailed each specimen being exposed to 500 cycles of heat and cold. The specimens were exposed to a temperature high of 55^{o} C as opposed to a low of 5^{o} C, in cycles of 15 seconds with a dwell time of 30 seconds (Saayman *et al* 2005, Grobler *et al* 2007a).

In order to ensure that all the specimens were easily and quickly exposed to the temperature changes the specimens were placed in a plastic mesh bag. Following the temperature cycling the enamel specimens were stored in their respective adhesive/bracket combination groups. The bonded enamel specimens were then embedded in plastic cups with cold curing acrylic resin (figure 3.4b). The specimens were positioned by means of a jig in such a way that the entire buccal enamel surface stood proud of the embedding material and the plastic cup (figure 3.4b). The jig was constructed from saliva ejectors, acrylic and rectangular, stainless steel orthodontic wire (figure 3.4b and 3.4c).

Figure 3.4a

The temperature cycling apparatus used

Figure 3.4b

The jig used to replicate the position of each tooth in the acrylic

The tooth specimen (with its bonded attachment) was placed in the plastic cup in such a way that the bracket/enamel interface was positioned at ninety degrees to the long axis of the plastic cup (figure 3.4c).

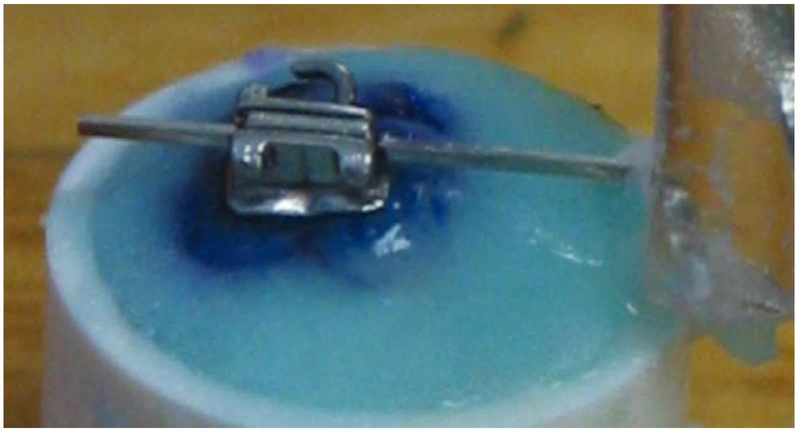


Figure 3.4c

Tooth specimen with attachment in a plastic cup with the bracket and enamel surface proud of the acrylic

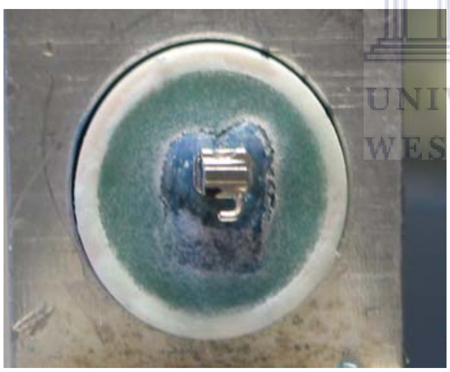


Figure 3.4d

The specimen in its plastic cup clamped into the base of the Zwick universal tester.

The specimens were clamped (figure 3.4d) to the base of the Zwick Universal testing machine (Matterialprufung, 1446, Germany). A shear load was applied in an occluso-gingival direction to the attachment, with the debonding force parallel to the bracket/adhesive interface (figure 3.4e and 3.4f).

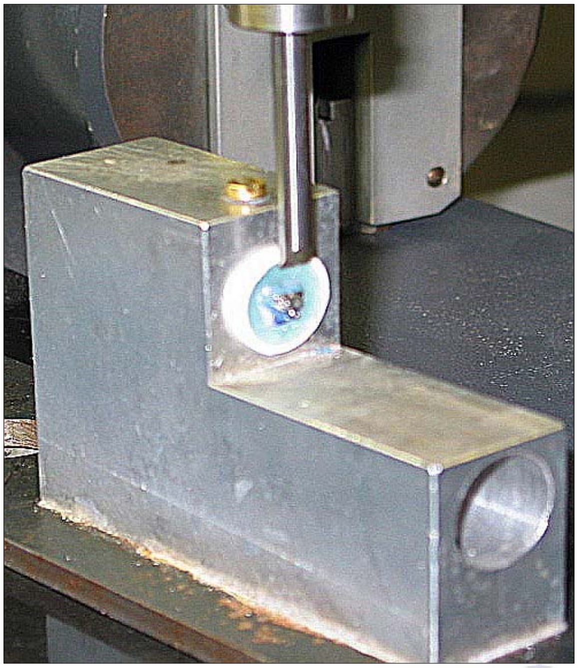


Figure 3.4e

The base of the Zwick universal tester

Figure 3.4f

The blade of the Zwick universal tester contacting the base of a GAC bracket

This load was applied by means of a knife-edged rod at a crosshead speed of 0.5 mm per minute. The force applied to the attachments was consistently from the same direction and position on each bracket. Shear bond strengths were registered in Newtons to be calculated and expressed in mega pascals (MPa). The debonding was done in groups according to the bracket/adhesive resin combinations. All the specimens were numbered and kept together in sequence after the debonding in order to facilitate adhesive remnant investigations of each specimen (figure 3.4g and 3.4h).

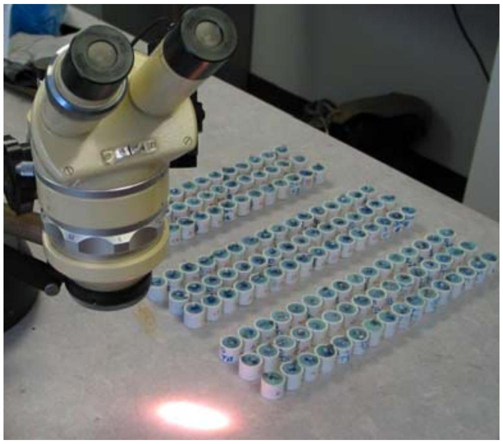


Figure 3.4g

The debonded specimens grouped for adhesive remnant indexing under magnification (10 times).

Figure 3.4h

Debonded specimens numbered and grouped for the adhesive remnant indexing procedure.

After debonding the enamel surface was inspected at 10x magnification (figure 3.4g) with a view to assessing the amount of bonding agent remaining on the tooth. This was assessed according to an Adhesive Remnant Index (ARI) as described in table 3.4a (Kirovski and Madzarova 2000).

The ARI was estimated by the author of this thesis in one sitting. The assessment was a percentage wise estimation as to where the locations of the debonding fracture occurred.

- Adhesive fractures at the bracket/adhesive resin interface were estimated as a percentage of the fracture and entered into a data spreadsheet in a column designated as b/a %.
- The percentage of each fracture that was cohesive was registered in the column designated a%.
- The percentage of each fracture that occurred at the enamel/adhesive resin interface was entered into a column designated a/e%.

Table 3.4a

The description of each category of the adhesive remnant index.

ARI	***Description***
0	0% of the bonding agent remaining on the enamel specimen surface.
1	less than 50% of the bonding agent remaining on the enamel specimen surface.
2	50% or more of the bonding agent remaining on the enamel specimen surface.
3	100% of bonded enamel covered by a layer of bonding agent
4	Enamel damage as a result of debonding.

Chapter 4

Results

4.1 Presentation of raw data

Each of the bracket/adhesive resin combinations were grouped and presented in groups (tables 4.1b to 4.1j). Each of these mentioned tables (4.1b to 4.1j) has fourteen columns. The abbreviation for each column heading is explained in table 4.1a.

Table 4.1a:
Abbreviations used in tables 4.1b – j

#	Specimen number
Bracket base size 1	Contact surface area measured with the reflex microscope
Bracket base size 2	Contact surface area calculated mathematically
MPa 1	Mega Pascals - stress values calculated using the three dimensional base size (using the reflex microscope measurements).
MPa 2	Mega Pascals - stress values calculated using the two dimensional base sizes (using the mathematical calculation of height x width).
b/a %	% of the debond fracture at the base adhesive interface.
a %	% of the debond fracture in the adhesive (cohesive failure)
a/e %	% of the debond fracture at the enamel adhesive interface.
ARI	Adhesive remnant index
*	Denotes incidents of enamel damage

Table 4.1b:

Results of the 3M bracket/Transbond XT adhesive resin combination.

#	adhesive agent	bracket	bracket base size 1	bracket base size 2	light intensity	force Newton	MPa 1	MPa 2	fracture location b/a %	a %	a/e %	ARI	
1	Transbond XT	3M	25.05	16	476	85.51							
2	Transbond XT	3M	25.05	16		387.86	15.48	24.2	5		95	1	
3	Transbond XT	3M	25.05	16		276.13	11.02	17.3	20		80	1	
4	Transbond XT	3M	25.05	16		260.95	10.42	16.3	30		70	1	
5	Transbond XT	3M	25.05	16		158.31	6.32	9.8	15		85	1	
6	Transbond XT	3M	25.05	16		320.11	12.78	20.0	5	55	40	2	
7	Transbond XT	3M	25.05	16		334.77	13.36	20.9	5		95	1	
8	Transbond XT	3M	25.05	16	480	282.2	11.27	17.6	100			3	
9	Transbond XT	3M	25.05	16		313.92	12.53	19.6	90		10	2	
10	Transbond XT	3M	25.05	16		138.25	5.52	8.6	10		90	1	
11	Transbond XT	3M	25.05	16		292.64	11.68	18.3	5		95	1	
12	Transbond XT	3M	25.05	16		311.91	12.45	19.5	5	90	5	2	
13	Transbond XT	3M	25.05	16		399.48	15.95	24.9	5	5	90	1	
14	Transbond XT	3M	25.05	16		314.81	12.57	19.6	10	10	80	1	
15	Transbond XT	3M	25.05	16		288.22	11.51	18.0	5	80	15	2	
16	Transbond XT	3M	25.05	16		344.39	13.75	21.5	5		95	1	

Abbreviations in tables 4.1b – j

#	Specimen number
Bracket base size 1	Contact surface area measured with the reflex microscope
Bracket base size 2	Contact surface area calculated mathematically
MPa 1	Stress values calculated using the reflex microscope measurements
MPa 2	Stress values calculated mathematically
b/a %	% of the debond fracture at the base adhesive interface.
a %	% of the debond fracture in the adhesive (cohesive failure)
a/e %	% of the debond fracture at the enamel adhesive interface.
ARI	Adhesive remnant index
*	Denotes incidents of enamel damage

Table 4.1c:

Results of the Ormco bracket/Transbond XT adhesive resin combination.

#	adhesive agent	bracket	bracket base size 1	bracket base size 2	light intensity	force Newton	MPa 1	MPa 2	fracture location b/a %	fracture location a %	fracture location a/e %	ARI	
17	Transbond XT	Ormco	20.9	14.3	470	125.29	5.99	8.76	80	20		3	
18	Transbond XT	Ormco	20.9	14.3		82.32	3.94	5.76	100			3	
19	Transbond XT	Ormco	20.9	14.3		154.35	7.39	10.79	100			3	
20	Transbond XT	Ormco	20.9	14.3		114.8	5.49	8.03	100			3	
21	Transbond XT	Ormco	20.9	14.3		162.97	7.80	11.40	5	95		3	
22	Transbond XT	Ormco	20.9	14.3		143.38	6.86	10.03	99	1		3	
23	Transbond XT	Ormco	20.9	14.3		294.56	14.09	20.60	70		30	2	
24	Transbond XT	Ormco	20.9	14.3	460	181.7	8.69	12.71	85	1	14	2	
25	Transbond XT	Ormco	20.9	14.3		90.61	4.34	6.34	100			3	
26	Transbond XT	Ormco	20.9	14.3		129.37	6.19	9.05	70		30	2	
27	Transbond XT	Ormco	20.9	14.3		142.27	6.81	9.95	80		20	2	
28	Transbond XT	Ormco	20.9	14.3		97.36	4.66	6.81	100			3	
29	Transbond XT	Ormco	20.9	14.3		108.55	5.19	7.59	75		25	2	
30	Transbond XT	Ormco	20.9	14.3		236.04	11.29	16.51	60		40	2	
31	Transbond XT	Ormco	20.9	14.3		170.2	8.14	11.90	75		25	2	
32	Transbond XT	Ormco	20.9	14.3		119.69	5.73	8.37	30	50	20	2	

Abbreviations in tables 4.1b – j

#	Specimen number
Bracket base size 1 Bracket base size 2	Contact surface area measured with the reflex microscope Contact surface area calculated mathematically
MPa 1	Stress values calculated using the reflex microscope measurements
MPa 2	Stress values calculated mathematically
b/a %	% of the debond fracture at the base adhesive interface.
a %	% of the debond fracture in the adhesive (cohesive failure)
a/e %	% of the debond fracture at the enamel adhesive interface.
ARI	Adhesive remnant index
*	Denotes incidents of enamel damage

Table 4.1d:

Results of the GAC bracket/Transbond XT adhesive resin combination.

#	adhesive agent	bracket	bracket base size 1	bracket base size 2	light intensity	force Newton	MPa 1	MPa 2	fracture location b/a %	fracture location a %	fracture location a/e %	ARI	
33	Transbond XT	GAC	26.2	16.1	459	258.68	9.87	16.07			100	0	
34	Transbond XT	GAC	26.2	16.1		259.81	9.92	16.14	5	5	90	1	
35	Transbond XT	GAC	26.2	16.1		277.04	10.57	17.21	5	5	90	1	
36	Transbond XT	GAC	26.2	16.1		286.16	10.92	17.77		100		3	
37	Transbond XT	GAC	26.2	16.1		279.41	10.66	17.35	5	40	55	4	*
38	Transbond XT	GAC	26.2	16.1		324.87	12.40	20.18		20	80	1	
39	Transbond XT	GAC	26.2	16.1		318.94	12.17	19.81		5	95	1	
40	Transbond XT	GAC	26.2	16.1	480	304.98	11.64	18.94	10	10	80	4	*
41	Transbond XT	GAC	26.2	16.1		307.53	11.74	19.10	5		95	1	
42	Transbond XT	GAC	26.2	16.1		301.85	11.52	18.75		100		3	
43	Transbond XT	GAC	26.2	16.1		259.51	9.90	16.12			100	0	
44	Transbond XT	GAC	26.2	16.1		243.48	9.29	15.12	5		95	1	
45	Transbond XT	GAC	26.2	16.1		280.7	10.71	17.43	2		98	1	
46	Transbond XT	GAC	26.2	16.1		104.2	3.98	6.47	50	50		3	
47	Transbond XT	GAC	26.2	16.1		220.66	8.42	13.71			100	0	
48	Transbond XT	GAC	26.2	16.1		333.86	12.74	20.74	10		90	1	

Abbreviations in tables 4.1b – j

#	Specimen number
Bracket base size 1	Contact surface area measured with the reflex microscope
Bracket base size 2	Contact surface area calculated mathematically
MPa 1	Stress values calculated using the reflex microscope measurements
MPa 2	Stress values calculated mathematically
b/a %	% of the debond fracture at the base adhesive interface.
a %	% of the debond fracture in the adhesive (cohesive failure)
a/e %	% of the debond fracture at the enamel adhesive interface.
ARI	Adhesive remnant index
*	Denotes incidents of enamel damage

Table 4.1e:

Results of the 3M bracket/Enlight adhesive resin combination.

									fracture location				
#	adhesive agent	bracket	bracket base size 1	bracket base size 2	light intensity	force Newton	MPa 1	MPa 2	b/a %	a %	a/e %	ARI	
49	Enlight	3M	25.05	16	460	266.34	10.63	16.65	15	85		3	
50	Enlight	3M	25.05	16		244.86	9.77	15.30	30	45	15	2	
51	Enlight	3M	25.05	16		274.42	10.95	17.15	45	55		3	
52	Enlight	3M	25.05	16		179.99	7.19	11.25	50	50		3	
53	Enlight	3M	25.05	16		261.26	10.43	16.33	20		80	1	
54	Enlight	3M	25.05	16		253.3	10.11	15.83	25	25	50	2	
55	Enlight	3M	25.05	16		291.31	11.63	18.21	100			3	
56	Enlight	3M	25.05	16	470	240.12	9.59	15.01	40	60		3	
57	Enlight	3M	25.05	16		330.52	13.19	20.66	10	20	70	4	*
58	Enlight	3M	25.05	16		252.57	10.08	15.79	20	10	70	1	
59	Enlight	3M	25.05	16		347.08	13.86	21.69	60	40		3	
60	Enlight	3M	25.05	16		196.48	7.84	12.28	10	10	80	1	
61	Enlight	3M	25.05	16		212.03	8.46	13.25	30	20	50	2	
62	Enlight	3M	25.05	16		204.75	8.17	12.80	40	60		3	
63	Enlight	3M	25.05	16		257.52	10.28	16.10	20	20	60	1	
64	Enlight	3M	25.05	16		117.68	4.70	7.36	20		80	1	

Abbreviations in tables 4.1b – j

#	Specimen number
Bracket base size 1	Contact surface area measured with the reflex microscope
Bracket base size 2	Contact surface area calculated mathematically
MPa 1	Stress values calculated using the reflex microscope measurements
MPa 2	Stress values calculated mathematically
b/a %	% of the debond fracture at the base adhesive interface.
a %	% of the debond fracture in the adhesive (cohesive failure)
a/e %	% of the debond fracture at the enamel adhesive interface.
ARI	Adhesive remnant index
*	Denotes incidents of enamel damage

Table 4.1f:

Results of the Ormco bracket/Enlight adhesive resin combination.

									fracture location				
#	adhesive agent	bracket	bracket base size 1	2	light intensity	force Newton	MPa 1	MPa 2	b/a %	a %	a/e %	ARI	
65	Enlight	Ormco	20.9	14.3	477	134.2	6.42	9.38	100			3	
66	Enlight	Ormco	20.9	14.3		127.69	6.11	8.93	100			3	
67	Enlight	Ormco	20.9	14.3		141.82	6.79	9.92	97	3		3	
68	Enlight	Ormco	20.9	14.3		134.83	6.45	9.43	95	5		3	
69	Enlight	Ormco	20.9	14.3		145.11	6.94	10.15	90	5	5	2	
70	Enlight	Ormco	20.9	14.3		120.76	5.78	8.44	95	5		3	
71	Enlight	Ormco	20.9	14.3		141.45	6.77	9.89	100			3	
72	Enlight	Ormco	20.9	14.3	470	106.14	5.08	7.42	100			3	
73	Enlight	Ormco	20.9	14.3		113.75	5.44	7.95	50	10	40	2	
74	Enlight	Ormco	20.9	14.3		105.01	5.02	7.34	100			3	
75	Enlight	Ormco	20.9	14.3		120.21	5.75	8.41	90		10	2	
76	Enlight	Ormco	20.9	14.3		104.86	5.02	7.33	100			3	
77	Enlight	Ormco	20.9	14.3		120.99	5.79	8.46	80		20	2	
78	Enlight	Ormco	20.9	14.3		96.58	4.62	6.75	100			3	
79	Enlight	Ormco	20.9	14.3		153.97	7.37	10.77	90		10	2	
80	Enlight	Ormco	20.9	14.3		77.16	3.69	5.40	100			3	

Abbreviations in tables 4.1b – j

#	Specimen number
Bracket base size 1	Contact surface area measured with the reflex microscope
Bracket base size 2	Contact surface area calculated mathematically
MPa 1	Stress values calculated using the reflex microscope measurements
MPa 2	Stress values calculated mathematically
b/a %	% of the debond fracture at the base adhesive interface.
a %	% of the debond fracture in the adhesive (cohesive failure)
a/e %	% of the debond fracture at the enamel adhesive interface.
ARI	Adhesive remnant index
*	Denotes incidents of enamel damage

Table 4.1g:

Results of the GAC bracket/Enlight adhesive resin combination.

#	adhesive agent	bracket	bracket base size 1	bracket base size 2	light intensity	force Newton	MPa 1	MPa 2	fracture location b/a %	fracture location a %	fracture location a/e %	ARI	
81	Enlight	GAC	26.2	16.1	460	152.46	5.82	9.47	40	50	10	4	*
82	Enlight	GAC	26.2	16.1		273.38	10.43	16.98	10	20	70	4	*
83	Enlight	GAC	26.2	16.1		245.83	9.38	15.27	20	80		3	
84	Enlight	GAC	26.2	16.1		246.63	9.41	15.32	5	30	65	4	*
85	Enlight	GAC	26.2	16.1		272.26	10.39	16.91		95	5	2	
86	Enlight	GAC	26.2	16.1		112.3	4.29	6.98	50	10	40	2	
87	Enlight	GAC	26.2	16.1		186.71	7.13	11.60			100	0	
88	Enlight	GAC	26.2	16.1	470	299.53	11.43	18.60	5	40	55	4	*
89	Enlight	GAC	26.2	16.1		208.3	7.95	12.94	60	40		3	
90	Enlight	GAC	26.2	16.1		228.31	8.71	14.18	20	80		3	
91	Enlight	GAC	26.2	16.1		356.01	13.59	22.11	10	20	70	4	*
92	Enlight	GAC	26.2	16.1		357.18	13.63	22.19	20	80		3	
93	Enlight	GAC	26.2	16.1		261.61	9.99	16.25		90	10	2	
94	Enlight	GAC	26.2	16.1		245.79	9.38	15.27		50	50	4	*
95	Enlight	GAC	26.2	16.1		163.41	6.24	10.15		100		3	
96	Enlight	GAC	26.2	16.1		266.2	10.16	16.53	25	30	45	4	*

Abbreviations in tables 4.1b – j

#	Specimen number
Bracket base size 1	Contact surface area measured with the reflex microscope
Bracket base size 2	Contact surface area calculated mathematically
MPa 1	Stress values calculated using the reflex microscope measurements
MPa 2	Stress values calculated mathematically
b/a %	% of the debond fracture at the base adhesive interface.
a %	% of the debond fracture in the adhesive (cohesive failure)
a/e %	% of the debond fracture at the enamel adhesive interface.
ARI	Adhesive remnant index
*	Denotes incidents of enamel damage

Table 4.1h:

Results of the 3M bracket/Sure Ortho Light Bond adhesive resin combination.

#	adhesive agent	bracket	bracket base size 1	base size 2	light intensity	force N	MPa 1	MPa 2	fracture location b/a %	a %	a/e %	ARI	
97	Sure Bond	3M	25.05	16	460	347.99	13.89	21.75	20	40	40	4	*
98	Sure Bond	3M	25.05	16		268.84	10.73	16.80	100			3	
99	Sure Bond	3M	25.05	16		292.34	11.67	18.27	80	20		3	
100	Sure Bond	3M	25.05	16		285.07	11.38	17.82	90	10		3	
101	Sure Bond	3M	25.05	16		265.23	10.59	16.58	50	50		3	
102	Sure Bond	3M	25.05	16		217.98	8.70	13.62	40	60		3	
103	Sure Bond	3M	25.05	16		284.31	11.35	17.77	100			3	
104	Sure Bond	3M	25.05	16	463	347.05	13.85	21.69		20	80	4	*
105	Sure Bond	3M	25.05	16		339.13	13.54	21.20	100			3	
106	Sure Bond	3M	25.05	16		371.63	14.84	23.23	15	85		3	
107	Sure Bond	3M	25.05	16		297.08	11.86	18.57	70	10	20	2	
108	Sure Bond	3M	25.05	16		248.86	9.93	15.55	70		30	2	
109	Sure Bond	3M	25.05	16		170	6.79	10.63	60	40		3	
110	Sure Bond	3M	25.05	16		251.34	10.03	15.71		80	20	2	
111	Sure Bond	3M	25.05	16		216.13	8.63	13.51		60	40	4	*
112	Sure Bond	3M	25.05	16		151.92	6.06	9.50	20	10	70	4	*

Abbreviations in tables 4.1b – j

#	Specimen number
Bracket base size 1	Contact surface area measured with the reflex microscope
Bracket base size 2	Contact surface area calculated mathematically
MPa 1	Stress values calculated using the reflex microscope measurements
MPa 2	Stress values calculated mathematically
b/a %	% of the debond fracture at the base adhesive interface.
a %	% of the debond fracture in the adhesive (cohesive failure)
a/e %	% of the debond fracture at the enamel adhesive interface.
ARI	Adhesive remnant index
*	Denotes incidents of enamel damage

Table 4.1i:

Results of the Ormco bracket/Sure Ortho Light Bond adhesive resin combination.

									fracture location				
	adhesive	bracket	bracket base size		light	force	MPa	MPa	b/a	a	a/e	ARI	
#	agent		1	2	intensity	N	1	2	%	%	%		
113	Sure Bond	Ormco	20.9	14.3	470	99.6	4.77	6.97	60	30	10	2	
114	Sure Bond	Ormco	20.9	14.3		118.58	5.67	8.29	80		20	2	
115	Sure Bond	Ormco	20.9	14.3		163.89	7.84	11.46	40	20	40	2	
116	Sure Bond	Ormco	20.9	14.3		120.99	5.79	8.46	20		80	1	
117	Sure Bond	Ormco	20.9	14.3		154.04	7.37	10.77	90	10		3	
118	Sure Bond	Ormco	20.9	14.3		113.3	5.42	7.92	100			3	
119	Sure Bond	Ormco	20.9	14.3		200.08	9.57	13.99	90	10		3	
120	Sure Bond	Ormco	20.9	14.3	465	172.2	8.24	12.04	90	10		3	
121	Sure Bond	Ormco	20.9	14.3		290.95	13.92	20.35	90	10		3	
122	Sure Bond	Ormco	20.9	14.3		359.81	17.22	25.16	60	10	30	2	
123	Sure Bond	Ormco	20.9	14.3		138.13	6.61	9.66	80		20	2	
124	Sure Bond	Ormco	20.9	14.3		120.31	5.76	8.41	100			3	
125	Sure Bond	Ormco	20.9	14.3		145.02	6.94	10.14	100			3	
126	Sure Bond	Ormco	20.9	14.3		152.06	7.28	10.63	90	10		3	
127	Sure Bond	Ormco	20.9	14.3		75.61	3.62	5.29	100			3	
128	Sure Bond	Ormco	20.9	14.3		123.15	5.89	8.61	100			3	

Abbreviations in tables 4.1b – j

#	Specimen number
Bracket base size 1	Contact surface area measured with the reflex microscope
Bracket base size 2	Contact surface area calculated mathematically
MPa 1	Stress values calculated using the reflex microscope measurements
MPa 2	Stress values calculated mathematically
b/a %	% of the debond fracture at the base adhesive interface.
a %	% of the debond fracture in the adhesive (cohesive failure)
a/e %	% of the debond fracture at the enamel adhesive interface.
ARI	Adhesive remnant index
*	Denotes incidents of enamel damage

Table 4.1j:

Results of the GAC bracket/Sure Ortho Light Bond adhesive resin combination.

#	adhesive agent	bracket	bracket base size 1	base size 2	light intensity	force N	MPa 1	MPa 2	fracture location b/a %	a %	a/e %	ARI	
129	Sure Bond	GAC	26.2	16.1	470	303.28	11.58	18.84		25	75	4	*
130	Sure Bond	GAC	26.2	16.1		375.24	14.32	23.31		100		3	
131	Sure Bond	GAC	26.2	16.1		338.34	12.91	21.01	10	60	30	4	*
132	Sure Bond	GAC	26.2	16.1		270.25	10.31	16.79		70	30	4	*
133	Sure Bond	GAC	26.2	16.1		281.7	10.75	17.50	10		90	1	
134	Sure Bond	GAC	26.2	16.1		361.04	13.78	22.42		100		3	
135	Sure Bond	GAC	26.2	16.1		253.2	9.66	15.73	20	80		3	
136	Sure Bond	GAC	26.2	16.1	480	290.29	11.08	18.03	10	90		3	
137	Sure Bond	GAC	26.2	16.1		284.02	10.84	17.64		40	60	4	*
138	Sure Bond	GAC	26.2	16.1		325.88	12.44	20.24		40	60	4	*
139	Sure Bond	GAC	26.2	16.1		325.64	12.43	20.23		100		3	
140	Sure Bond	GAC	26.2	16.1		286.86	10.95	17.82		20	80	4	*
141	Sure Bond	GAC	26.2	16.1		318.29	12.15	19.77		10	90	4	*
142	Sure Bond	GAC	26.2	16.1		244.77	9.34	15.20		30	70	4	*
143	Sure Bond	GAC	26.2	16.1		255.9	9.77	15.89		100		3	
144	Sure Bond	GAC	26.2	16.1		382.9	14.61	23.78		20	80	4	*

Abbreviations in tables 4.1b – j

#	Specimen number
Bracket base size 1	Contact surface area measured with the reflex microscope
Bracket base size 2	Contact surface area calculated mathematically
MPa 1	Stress values calculated using the reflex microscope measurements
MPa 2	Stress values calculated mathematically
b/a %	% of the debond fracture at the base adhesive interface.
a %	% of the debond fracture in the adhesive (cohesive failure)
a/e %	% of the debond fracture at the enamel adhesive interface.
ARI	Adhesive remnant index
*	Denotes incidents of enamel damage

4.2 Statistical treatment of shear bond strengths in Newtons:

The data in Newtons obtained from the tests performed with Zwick Universal Tester were statistically analysed and presented as follows.

Table 4.2a:

Abbreviations used in the statistical analyses.

Abbreviation	***Description***
Ormco or Oc	Ormco Optimesh XRT stainless steel molar brackets.
GAC	GAC stainless steel molar brackets.
3M	3M Unitek Victory Series stainless steel molar brackets.
Enl	Enlight adhesive resin.
SB	Sure Ortho Light Bond adhesive resin.
Tb or Tc	Transbond XT adhesive resin.

Table 4.2b:

Pivot table of shear bond strengths (average, standard deviation, minimum and maximum) of each bracket/adhesive resin combination in Newtons.

	3M			GAC			Ormco			All
	Enl	SB	Tb	Enl	SB	Tb	Enl	SB	Tb	groups
Count	16	16	15	16	16	16	16	16	16	143
Average	245.6	272.2	294.9	242.2	306.1	272.6	121.5	159.2	147.1	228.6
Standard deviation	56.1	62.8	70.8	67.3	43.0	54.5	20.4	72.5	55.2	85.8
Minimum	117.7	151.9	138.3	112.3	244.8	104.2	77.2	75.6	82.3	75.6
Maximum	347.1	371.6	399.4	357.2	382.9	333.9	154.0	359.8	294.6	399.4

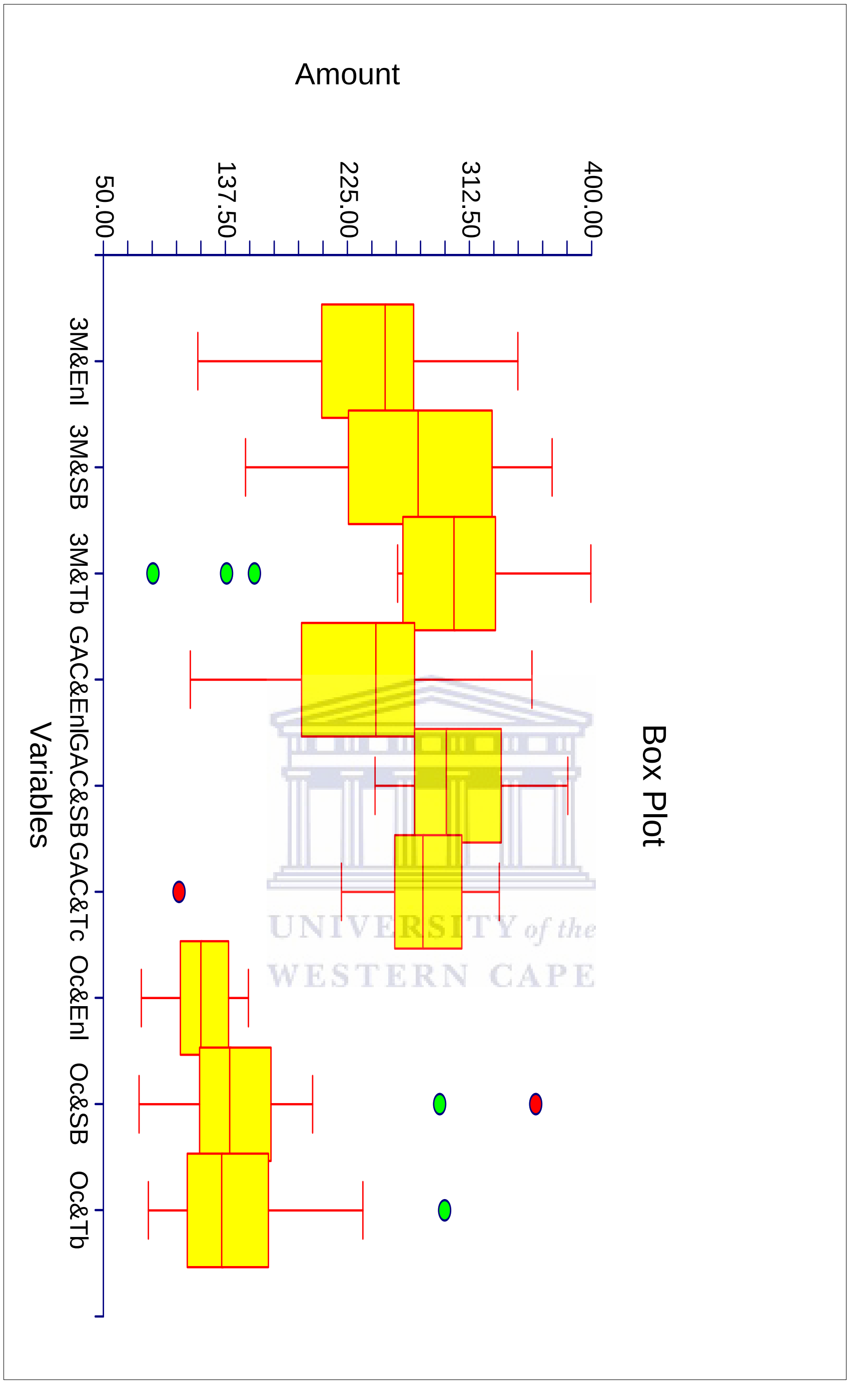


Figure 4.2a:

Box plot showing the shear bond strengths in Newtons (Amount) of each bracket/adhesive Combination (Variables).

Each box represents (the interquartile area) 50% of the readings for each combination.

The red line in each box represents the median.

The green and red dots are representative of extreme values obtained

4.2.1: The analysis of variance report (ANOVA): Shear bond strengths (Newtons)

Group	Oc&Enl	Oc&Tb	Oc&SB	GAC&Enl	3M&Enl	3M&SB	GAC&Tb	3M&Tb	GAC&S
Mean	121.5	147.1	159.2	242.2	245.6	272.2	272.6	281.8	306.1

Figure 4.2.1a:
A simplified diagram summarising the Tukey-Kramer multiple comparison test (Newtons).

The figure 4.2.1a shows two distinct groupings indicated as black boxes. All the Ormco bracket/adhesive resins combinations fell into the same group which was significantly different from all the 3M and GAC bracket/adhesive resin combinations.

Highlighted in yellow are the average shear bond strengths (from table 4.2b) of all the GAC and 3M bracket/adhesive resin combinations showing the extent of the differences (in Newtons) between the two groupings.

Abbreviation	*Description*
Ormco	Ormco Optimesh XRT molar brackets.
GAC	GAC molar brackets.
3M	3M Unitek Victory Series molar brackets.
Enl	Enlight adhesive resin.
SB	Sure Ortho Light Bond adhesive resin.
Tb or Tc	Transbond XT adhesive resin.

Table 4.2.1a:

Kruskal-Wallis One-Way ANOVA on Ranks

Hypotheses
Ho: All medians are equal.
Ha: At least two medians are different.

Test Results

Method	**DF**	**Chi-Square (H)**	**Prob Level**	**Decision(0.05)**
Not Corrected for Ties	8	72.28906	0.000000	Reject Ho
Corrected for Ties	8	72.28921	0.000000	Reject Ho
Number Sets of Ties	1			
Multiplicity Factor	6			

Group Detail

Group	**Count**	**Sum of Ranks**	**Mean Rank**	**Z-Value**	**Median**
3M&Enl	16	1245.00	77.81	0.5403	252.935
3M&SB	16	1498.00	93.63	2.1486	276.575
3M&Tb	16	1602.00	100.13	2.8097	302.275
GAC&Enl	16	1236.00	77.25	0.4831	246.23
GAC&SB	16	1759.00	109.94	3.8078	296.785
GAC&Tb	16	1494.00	93.38	2.1232	280.055
Oc&Enl	16	365.50	22.84	-5.0505	120.875
Oc&SB	16	673.50	42.09	-3.0926	141.575
Oc&Tb	16	567.00	35.44	-3.7696	135.82

Means and Effects Section

Term	**Count**	**Mean**	**Standard Error**	**Effect**
All	144	227.6076		14.22547
A: Br_Combo_Ad				
3M&Enl	16	245.6394	15.03782	231.4139
3M&SB	16	272.1812	15.03782	257.9558
3M&Tb	16	281.8412	15.03782	267.6158
GAC&Enl	16	242.2444	15.03782	228.0189
GAC&SB	16	306.1	15.03782	291.8745
GAC&Tb	16	272.605	15.03782	258.3795
Oc&Enl	16	121.5331	15.03782	107.3077
Oc&SB	16	159.2325	15.03782	145.007
Oc&Tb	16	147.0912	15.03782	132.8658

Abbreviation	***Description***
Ormco or Oc	Ormco Optimesh XRT molar brackets.
GAC	GAC molar brackets.
3M	3M Unitek Victory Series molar brackets.
Enl	Enlight adhesive resin.
SB	Sure Ortho Light Bond adhesive resin.
Tb or Tc	Transbond XT adhesive resin.

Table 4.2.1b:

A summary of the rankings from lowest to the highest according to the median, the mean shear bond strength and the average rank of each combination.

Median	***Mean.***	***Av Rank***
Oc & Enl	Oc & Enl	Oc & Enl
Oc & Tb	Oc & Tb	Oc & Tb
Oc & SB	Oc & SB	Oc & SB
GAC &Enl	GAC &Enl	GAC & Enl
3M & Enl	3M & Enl	3M & Enl
3M & SB	3M & SB	GAC & Tb
GAC &Tb	GAC &Tb	3M & SB
GAC & SB	3M & Tb	3M & Tb
3M & Tb	GAC & SB	GAC & SB

The yellow highlights show rankings that follow the same order.

Abbreviation	***Description***
Ormco or Oc	Ormco Optimesh XRT molar brackets.
GAC	GAC molar brackets.
3M	3M Unitek Victory Series molar brackets.
Enl	Enlight adhesive resin.
SB	Sure Ortho Light Bond adhesive resin.
Tb or Tc	Transbond XT adhesive resin.

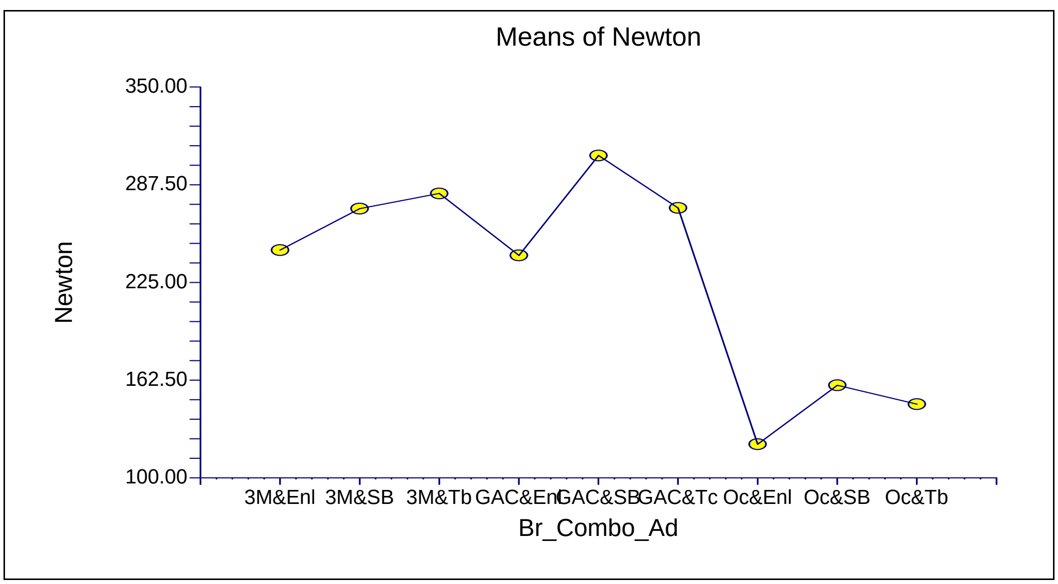


Figure 4.2.1b

The graphic plot of the Means section of the bracket/adhesive combinations (Br_Combo_Ad) of the Kruskal-Wallis one way ANOVA expressed in Newtons.

Table 4.2.1c:

Kruskal-Wallis Multiple-Comparison chart (Z-Value Test) – Newtons.

Newtons	3M&Enl	3M&SB	3M&Tb	GAC&Enl	GAC&SB	GAC&Tb	Oc&Enl	Oc&SB	Oc&Tb
3M&Enl	0	1.0722	1.5129	0.0381	2.1783	1.0552	3.7272	2.4220	2.8733
3M&SB	1.0722	0	0.4407	1.1103	1.0161	0.0170	4.7994	3.4941	3.9455
3M&Tb	1.5129	0.4407	0	1.5511	0.6654	0.4577	5.2402	3.9349	4.3862
GAC&Enl	0.0381	1.1103	1.5511	0	2.2164	1.0934	3.6891	2.3838	2.8352
GAC&SB	2.1783	1.1061	0.6654	2.2164	0	1.1230	5.9055	4.6002	5.0516
GAC&Tb	1.0552	0.0170	0.4577	1.0934	1.1230	0	4.7825	3.4772	3.9285
Oc&Enl	3.7272	4.7994	5.2402	3.6891	5.9055	4.7825	0	1.3053	0.8539
Oc&SB	2.4220	3.4941	3.9349	2.3838	4.6002	3.4772	1.3053	0	0.4513
Oc&Tb	2.8733	3.9455	4.3862	2.8352	5.0516	3.9285	0.8539	0.4513	0

The highlighted blocks show the intrabracket combinations.

The Regular test shows the medians to be significantly different from one another when the z-value is greater than 1.9600.

The Bonferroni test shows the medians to be significantly different from one another when the z-value is greater than 3.1970. This Bonferroni test is a stronger test that is used to show a more substantial statistical difference.

Abbreviation	***Description***
Ormco or Oc	Ormco Optimesh XRT molar brackets.
GAC	GAC molar brackets.
3M	3M Unitek Victory Series molar brackets.
Enl	Enlight adhesive resin.
SB	Sure Ortho Light Bond adhesive resin.
Tb or Tc	Transbond XT adhesive resin.

4.3 Statistical treatment of shear bond strengths mega Pascals.

The contact surface area of each bracket was calculated in two different ways. The first way was by means of a reflex microscope in order to account for the concavity of the adhesive surface as well as the 3 dimensional topography the mesh design. The second method of contact surface area calculation was by means of the length and breadth of the bracket base. From these two measurements the units of stress were calculated separately and presented in the pivot tables below.

The remaining analyses were done only on the values obtained from the reflex microscopic readings.

Table 4.3a:

A pivot table of shear bond strength expressed in MPa for the three dimensional contact surface area (average, standard deviation, minimum and maximum).

	3M			GAC			Ormco			
	Enl	SB	Tb	Enl	SB	Tb	Enl	SB	Tb	
Count	16	16	15	16	16	16	16	16	16	143
Average	9.8	10.9	11.8	9.2	11.7	10.4	5.8	7.6	7.0	9.3
Standard deviation	2.2	2.5	2.8	2.6	1.6	2.1	1	3.5	2.6	3.1
Minimum	4.7	6.1	5.5	4.3	9.3	4	3.7	3.6	3.9	3.6
Maximum	13.9	14.8	16.0	13.6	14.6	12.7	7.4	17.2	14.1	17.2

Table 4.3b:

A pivot table of shear bond strengths expressed in MPa for the two dimensional contact surface area (average, standard deviation, minimum and maximum).

	3M			GAC			Ormco			
	Enl	SB	Tb	Enl	SB	Tb	Enl	SB	Tb	
Count	16	16	15	16	16	16	16	16	16	143
Average	15.4	17.0	18.4	15.0	19.0	16.9	8.5	11.1	10.3	14.6
Standard deviation	3.5	3.9	4.4	4.2	2.7	3.4	1.4	5.1	3.9	5.1
Minimum	7.4	9.5	8.6	7	15.2	6.5	5.4	5.3	5.8	5.3
Maximum	21.7	23.2	25	22.2	23.8	20.7	10.8	25.2	20.6	25.2

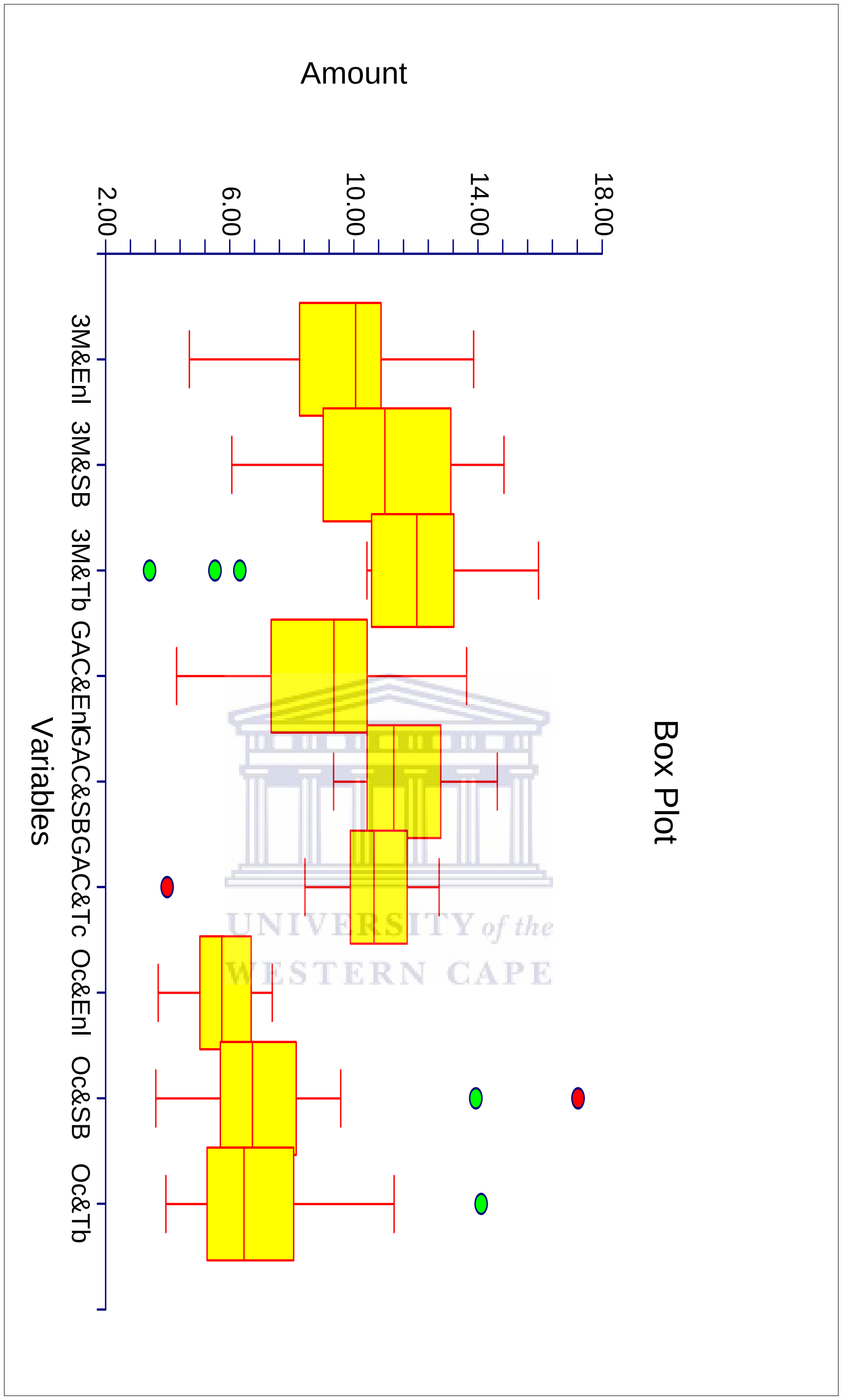


Figure 4.3a:

A box plot showing the shear bond strengths in MPa (Amount), of each bracket/adhesive combination (variables).

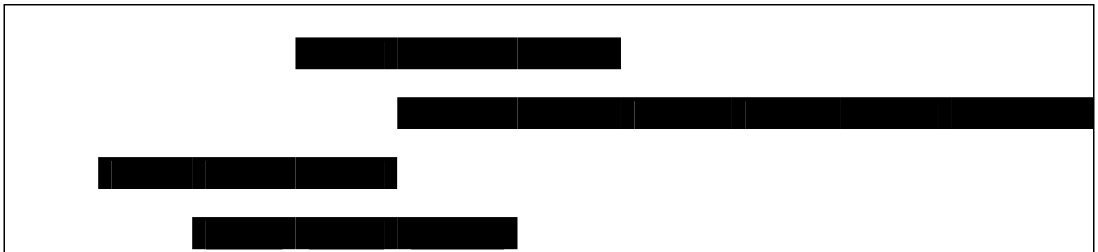
Each box represents (the interquartile area) 50% of the readings for each combination.

The red line in each box represents the median of each combination.

The green and red dots are representative of extreme values obtained.

4.3.1 The analysis of variance report (ANOVA):

Shear bond strengths (MPa)

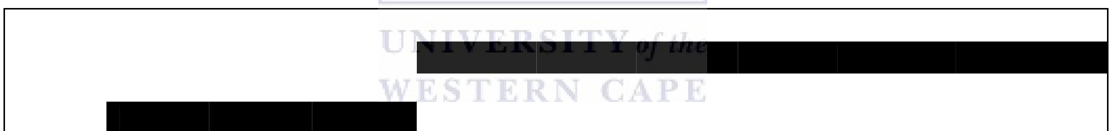


Group	Oc&Enl	Oc&Tb	Oc&SB	GAC&Enl	3M&Enl	GAC&Tb	3M&SB	3M&Tb	GAC&SB
Mean	5.8	7.0	7.6	9.2	9.8	10.4	10.9	11.3	11.7

Figure 4:3.1a

A simplified diagram summarising the Tukey-Kramer Multiple-Comparison Test using the three dimensional base size.

The black boxes indicate distinct groupings of shear bond strengths of bracket/adhesive combinations. Some bracket/adhesive combinations occur in three of shear bond strength groups. Sure ortho Light bond and transbond in combination with either the 3M or GAC brackets show significantly different shear bond strengths from the other combinations in this study.



Group	Oc&Enl	Oc&Tb	Oc&SB	GAC&Enl	3M&Enl	3M&SB	GAC&Tb	3M&Tb	GAC&SB
Mean	8.5	10.3	11.1	15.0	15.4	17.0	16.9	18.4	19.0

Figure 4.3.1b:

A simplified diagram summarising the Tukey-Kramer Multiple-Comparison Test using the two dimensional base size.

Depending on how the base size was determined different groupings appeared. The three dimensional base measurements show different groupings from the two dimensional base.

Abbreviation	*Description*
Ormco	Ormco Optimesh XRT molar brackets.
GAC	GAC molar brackets.
3M	3M Unitek Victory Series molar brackets.
Enl	Enlight adhesive resin.
SB	Sure Ortho Light Bond adhesive resin.
Tb or Tc	Transbond XT adhesive resin.

Table 4.3.1a:

The Kruskal-Wallis One-Way ANOVA on Ranks based on three dimensional contact surface area (the Reflex Microscopic readings).

Hypotheses

Ho: All medians are equal.

Ha: At least two medians are different.

Test Results

Method	**DF**	**Chi-Square (H)**	**Prob Level**	**Decision(0.05)**
Not Corrected for Ties	8	58.2118	0.000000	Reject Ho
Corrected for Ties	8	58.21192	0.000000	Reject Ho

Number Sets of Ties	1
Multiplicity Factor	6

Group Detail

Group	**Count**	**Sum of Ranks**	**Mean Rank**	**Z-Value**	**Median**
3M&Enl	16	1260.00	78.75	0.6357	10.09721
3M&SB	16	1508.00	94.25	2.2122	11.04092
3M&Tb	16	1598.00	99.88	2.7843	12.06687
GAC&Enl	16	1129.00	70.56	-0.1971	9.398091
GAC&SB	16	1684.00	105.25	3.3310	11.32767
GAC&Tb	16	1415.00	88.44	1.6210	10.68912
Oc&Enl	16	409.50	25.59	-4.7708	5.783493
Oc&SB	16	760.50	47.53	-2.5396	6.773923
Oc&Tb	16	676.00	42.25	-3.0767	6.498565

Means and Effects Section

Term	**Count**	**Mean**	**Standard Error**	**Effect**
All	144	9.303133		0.5814458
A: Br_Combo_Ad				
3M&Enl	16	9.805964	0.6273584	9.224517
3M&SB	16	10.86552	0.6273584	10.28407
3M&Tb	16	11.25115	0.6273584	10.6697
GAC&Enl	16	9.245969	0.6273584	8.664523
GAC&SB	16	11.68321	0.6273584	11.10176
GAC&Tb	16	10.40477	0.6273584	9.823325
Oc&Enl	16	5.814982	0.6273584	5.233536
Oc&SB	16	7.61878	0.6273584	7.037334
Oc&Tb	16	7.037859	0.6273584	6.456413

Abbreviation	*Description*
Ormco	Ormco Optimesh XRT molar brackets.
GAC	GAC molar brackets.
3M	3M Unitek Victory Series molar brackets.
Enl	Enlight adhesive resin.
SB	Sure Ortho Light Bond adhesive resin.
Tb or Tc	Transbond XT adhesive resin.

Table 4.3.1b :

A summary of the rankings from lowest to highest according to the median, the mean shear bond strength and the average rank of each combination based on the three dimensional contact surface area of each bracket.

Median	**Mean**	**Av Rank**
Oc&Enl	Oc&Enl	Oc&Enl
Oc&Tb	Oc&Tb	Oc&Tb
Oc&SB	Oc&SB	Oc&SB
GAC&Enl	GAC&Enl	GAC&Enl
3M&Enl	3M&Enl	3M&Enl
GAC&Tb	GAC&Tb	GAC&Tb
3M&SB	3M&SB	3M&SB
GAC&SB	3M&Tb	3M&Tb
3M&Tb	GAC&SB	GAC&SB

The yellow highlights show rankings that follow the same order.

Abbreviation	*Description*
Ormco	Ormco Optimesh XRT molar brackets.
GAC	GAC molar brackets.
3M	3M Unitek Victory Series molar brackets.
Enl	Enlight adhesive resin.
SB	Sure Ortho Light Bond adhesive resin.
Tb or Tc	Transbond XT adhesive resin.

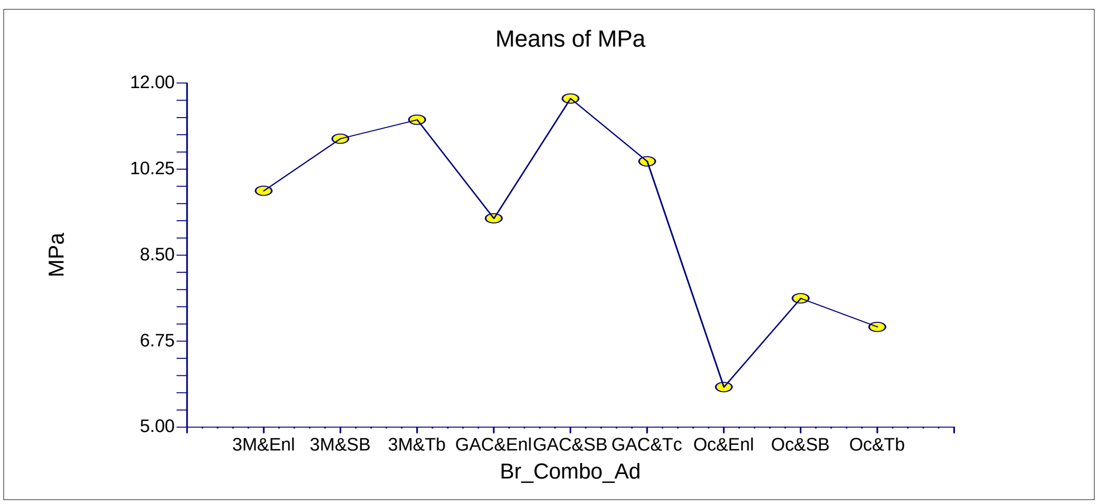


Figure 4.3.1c

The graphic plot of the Means section of all the bracket/adhesive combinations (Br_Combo_Ad) of the Kruskal-Wallis one way ANOVA expressed in MPa.

Table 4.3.1c

The Kruskal – Wallis multiple comparison chart (Z-value test) for stress values.

MPa	3M&Enl	3M&SB	3M&Tb	GAC&Enl	GAC&SB	GAC&Tb	Oc&Enl	Oc&SB	Oc&Tb
3M&Enl	0	1.051	1.4324	0.5552	1.7969	0.6569	3.6043	2.1168	2.4749
3M&SB	1.051	0	0.3814	1.6062	0.7459	0.3941	4.6553	3.1678	3.5259
3M&Tb	1.4324	0.3814	0	1.9876	0.3645	0.7755	5.0367	3.5492	3.9073
GAC&Enl	0.5552	1.6062	1.9876	0	2.352	1.212	3.0492	1.5617	1.9198
GAC&SB	1.7969	0.7459	0.3645	2.352	0	1.14	5.4012	3.9137	4.2718
GAC&Tb	0.6569	0.3941	0.7755	1.212	1.14	0	4.2612	2.7737	3.1318
Oc&Enl	3.6043	4.6553	5.0367	3.0492	5.4012	4.2612	0	1.4875	1.1294
Oc&SB	2.1168	3.1678	3.5492	1.5617	3.9137	2.7737	1.4875	0	0.3581
Oc&Tb	2.4749	3.5259	3.9073	1.9198	4.2718	3.1318	1.1294	0.3581	0

The highlighted blocks show the intrabracket combinations.

The Regular test shows the medians to be significantly different from one another when the z-value is greater than 1.9600.

The Bonferroni test shows the medians to be significantly different from one another when the z-value is greater than 3.1970. This Bonferroni test is the stronger test and is used to show a more substantial statistical difference.

Abbreviation	*Description*
Ormco	Ormco Optimesh XRT molar brackets.
GAC	GAC molar brackets.
3M	3M Unitek Victory Series molar brackets.
Enl	Enlight adhesive resin.
SB	Sure Ortho Light Bond adhesive resin.
Tb or Tc	Transbond XT adhesive resin.

4.4 <u>The adhesive remnant index results</u>

Table 3.4a

The description of each category of the adhesive remnant index.

ARI	***Description***
0	0% of the bonding agent remaining on the enamel specimen surface.
1	less than 50% of the bonding agent remaining on the enamel specimen surface.
2	50% or more of the bonding agent remaining on the enamel specimen surface.
3	100% of bonded enamel covered by a layer of bonding agent
4	Enamel damage as a result of debonding.

Table 4.4a:

Analysis of the adhesive remnant index:

Contingency Table

	3M Brackets			GAC Brackets			Ormco Brackets			
ARI	Enlight	Surebond	Transbond	Enlight	Surebond	Transbond	Enlight	Surebond	Transbond	TOTAL
0	0	0	0	1	0	3	0	0	0	**4**
1, 2 & 3	15	12	15	8	7	11	16	16	16	**116**
4	1	4		7	9	2				**23**
Total	**16**	**16**	**15**	**16**	**16**	**16**	**16**	**16**	**16**	*143*

Test Statistic CHI-Squared = 62.1438
P-Value = 0

The row indicating enamel damage (ARI 4) is highlighted. The green highlights indicate a statistically significant incidence of enamel damage associated with two of the bracket/adhesive resin combinations.

The 3M bracket/Transbond XT adhesive resin had only 15 specimens analysed as the incorrect crosshead speed was used on specimen number 1 (table 4.1b).

Table 4.4b
The Spearman rank correlations all groups

	Newton	MPa	B_a_	a_	a_e_	ARI	
Newton	1	0.994	-0.617	0.360	0.371	0.037	Correlation (N)
	0	0.00000	0.00000	0.00002	0.00001	0.67137	p-value
	135	135	135	135	135	135	number tested
MPa	0.994	1	-0.565	0.329	0.348	0.017	
	0.00000	0	0.00000	0.00010	0.00004	0.84744	
	135	135	135	135	135	135	
B_a_	-0.617	-0.565	1	-0.511	-0.607	0.085	
	0.00000	0.00000	0	0.00000	0.00000	0.31240	
	135	135	143	143	143	143	
a_	0.360	0.329	-0.511	1	-0.231	0.421	
	0.00002	0.00010	0.00000	0	0.00541	0.00000	
	135	135	143	143	143	143	
a_e_	0.371	0.348	-0.607	-0.231	1	-0.449	
	0.00001	0.00004	0.00000	0.00541	0	0.00000	
	135	135	143	143	143	143	
ARI	0.037	0.017	0.085	0.421	-0.449	1	
	0.67137	0.84744	0.31240	0.00000	0.00000	0	
	135	135	143	143	143	143	

This table shows:

- **The correlation in MPa and Newtons.**

  This correlation is expressed as a value between –1 and 1.

  A negative value indicates a negative correlation between the pairs.

  A positive value indicates a positive correlation between the pairs.

  A value of zero indicates no correlation between the pairs.

- **The p-value.**

  The value indicates the risk of error.

  A p-value of 0.0001 indicates a chance of 1 in 10000 of making an error.

- **The number tested**

  The number of specimens tested.

B_a_ Represents the correlation at the bracket adhesive interface, including the p-value and the number tested.

a_ Represents the correlation for cohesive fractures, including the p-value and the number tested.

a_e_ Represents the correlation at the adhesive enamel interface, including the p-value and the number tested.

Table 4.4c

The Spearman rank Correlation matrices for 3M Unitek bracket/Transbond adhesive resin combination.

	Newton	MPa	B_a_	a_	a_e_	ARI
Newton	1	1.000	-0.601	0.091	0.530	-0.293
	0	0	0.02968	0.76789	0.06243	0.33048
	13	13	13	13	13	13
MPa	1.000	1	-0.601	0.091	0.530	-0.293
	0.00000	0	0.02968	0.76789	0.06243	0.33048
	13	13	13	13	13	13
B_a_	-0.601	-0.601	1	-0.456	-0.491	0.164
	0.02968	0.02968	0	0.08761	0.06310	0.55995
	13	13	15	15	15	15
a_	0.091	0.091	-0.456	1	-0.443	0.435
	0.76789	0.76789	0.08761	0	0.09837	0.10544
	13	13	15	15	15	15
a_e_	0.530	0.530	-0.491	-0.443	1	-0.838
	0.06243	0.06243	0.06310	0.09837	0	0.00009
	13	13	15	15	15	15
ARI	-0.293	-0.293	0.164	0.435	-0.838	1
	0.33048	0.33048	0.55995	0.10544	0.00009	0
	13	13	15	15	15	15

This table shows:

- **The correlation in MPa and Newtons.**

  This correlation is expressed as a value between –1 and 1.

  A negative value indicates a negative correlation between the pairs.

  A positive value indicates a positive correlation between the pairs.

  A value of zero indicates no correlation between the pairs.

- **The p-value.**

  The value indicates the risk of error.

  A p-value of 0.0001 indicates a chance of 1 in 10000 of making an error.

- **The number tested**

  The number of specimens tested.

B_a_ Represents the correlation at the bracket adhesive interface, including the p-value and the number tested.

a_ Represents the correlation for cohesive fractures, including the p-value and the number tested.

a_e_ Represents the correlation at the adhesive enamel interface, including the p-value and the number tested.

Table 4.4d

The Spearman rank correlation matrices for Ormco bracket/Transbond adhesive resin combination.

	Newton	MPa	B_a_	a_	a_e_	ARI
Newton	1	1.000	-0.419	0.382	0.244	-0.322
	0	0	0.13586	0.17744	0.40044	0.26116
	14	14	14	14	14	14
MPa	1.000	1	-0.419	0.382	0.244	-0.322
	0.00000	0	0.13586	0.17744	0.40044	0.26116
	14	14	14	14	14	14
B_a_	-0.419	-0.419	1	-0.392	-0.665	0.621
	0.13586	0.13586	0	0.13370	0.00495	0.01030
	14	14	16	16	16	16
a_	0.382	0.382	-0.392	1	-0.294	0.149
	0.17744	0.17744	0.13370	0	0.26867	0.58304
	14	14	16	16	16	16
a_e_	0.244	0.244	-0.665	-0.294	1	-0.929
	0.40044	0.40044	0.00495	0.26867	0	0.00000
	14	14	16	16	16	16
ARI	-0.322	-0.322	0.621	0.149	-0.929	1
	0.26116	0.26116	0.01030	0.58304	0.00000	0
	14	14	16	16	16	16

This table shows:

- **The correlation in MPa and Newtons.**

  This correlation is expressed as a value between –1 and 1.

  A negative value indicates a negative correlation between the pairs.

  A positive value indicates a positive correlation between the pairs.

  A value of zero indicates no correlation between the pairs.

- **The p-value.**

  The value indicates the risk of error.

  A p-value of 0.0001 indicates a chance of 1 in 10000 of making an error.

- **The number tested**

  The number of specimens tested.

B_a_ Represents the correlation at the bracket adhesive interface, including the p-value and the number tested.

a_ Represents the correlation for cohesive fractures, including the p-value and the number tested.

a_e_ Represents the correlation at the adhesive enamel interface, including the p-value and the number tested.

Table 4.4e

The Spearman rank correlation matrices for GAC bracket/Transbond adhesive resin combination

	Newton	MPa	B_a_	a_	a_e_	ARI
Newton	1	1.000	0.188	0.346	-0.499	0.456
	0	0	0.50123	0.20624	0.05820	0.08748
	15	15	15	15	15	15
MPa	1.000	1	0.188	0.346	-0.499	0.456
	0.00000	0	0.50123	0.20624	0.05820	0.08748
	15	15	15	15	15	15
B_a_	0.188	0.188	1	0.008	-0.317	0.450
	0.50123	0.50123	0	0.97600	0.23142	0.07995
	15	15	16	16	16	16
a_	0.346	0.346	0.008	1	-0.913	0.788
	0.20624	0.20624	0.97600	0	0.00000	0.00029
	15	15	16	16	16	16
a_e_	-0.499	-0.499	-0.317	-0.913	1	-0.880
	0.05820	0.05820	0.23142	0.00000	0	0.00001
	15	15	16	16	16	16
ARI	0.456	0.456	0.450	0.788	-0.880	1
	0.08748	0.08748	0.07995	0.00029	0.00001	0
	15	15	16	16	16	16

This table shows:

- **The correlation in MPa and Newtons.**

  This correlation is expressed as a value between –1 and 1.

  A negative value indicates a negative correlation between the pairs.

  A positive value indicates a positive correlation between the pairs.

  A value of zero indicates no correlation between the pairs.

- **The p-value.**

  The value indicates the risk of error.

  A value of 0.0001 indicates a chance of 1 in 10000 of making an error.

- **The number tested**

  The number of specimens tested.

B_a_ Represents the correlation at the bracket adhesive interface, including the p-value and the number tested.

a_ Represents the correlation for cohesive fractures, including the p-value and the number tested.

a_e_ Represents the correlation at the adhesive enamel interface, including the p-value and the number tested.

Table 4.4f

The Spearman rank correlation matrices for the 3M brackets/Enlight adhesive resin combination.

	Newton	MPa	B_a_	a_	a_e_	ARI
Newton	1	1.000	0.050	-0.162	-0.085	0.336
	0	0	0.85866	0.56472	0.76339	0.22082
	15	15	15	15	15	15
MPa	1.000	1	0.050	-0.162	-0.085	0.336
	0.00000	0	0.85866	0.56472	0.76339	0.22082
	15	15	15	15	15	15
B_a_	0.050	0.050	1	0.269	-0.755	0.428
	0.85866	0.85866	0	0.31323	0.00073	0.09783
	15	15	16	16	16	16
a_	-0.162	-0.162	0.269	1	-0.745	0.596
	0.56472	0.56472	0.31323	0	0.00092	0.01479
	15	15	16	16	16	16
a_e_	-0.085	-0.085	-0.755	-0.745	1	-0.741
	0.76339	0.76339	0.00073	0.00092	0	0.00103
	15	15	16	16	16	16
ARI	0.336	0.336	0.428	0.596	-0.741	1
	0.22082	0.22082	0.09783	0.01479	0.00103	0
	15	15	16	16	16	16

This table shows:

- **The correlation in MPa and Newtons.**

  This correlation is expressed as a value between –1 and 1.

  A negative value indicates a negative correlation between the pairs.

  A positive value indicates a positive correlation between the pairs.

  A value of zero indicates no correlation between the pairs.

- **The p-value.**

  The value indicates the risk of error.

  A value of 0.0001 indicates a chance of 1 in 10000 of making an error.

- **The number tested**

  The number of specimens tested.

B_a_ Represents the correlation at the bracket adhesive interface, including the p-value and the number tested.

a_ Represents the correlation for cohesive fractures, including the p-value and the number tested.

a_e_ Represents the correlation at the adhesive enamel interface, including the p-value and the number tested.

Table 4.4g

The Spearman rank correlation matrices for the Ormco bracket/Enlight adhesive resin combination.

	Newton	MPa	B_a_	a_	a_e_	ARI
Newton	1	1.000	-0.396	0.302	0.227	-0.307
	0	0	0.12899	0.25612	0.39716	0.24722
	16	16	16	16	16	16
MPa	1.000	1	-0.396	0.302	0.227	-0.307
	0.00000	0	0.12899	0.25612	0.39716	0.24722
	16	16	16	16	16	16
B_a_	-0.396	-0.396	1	-0.562	-0.876	0.863
	0.12899	0.12899	0	0.02332	0.00001	0.00002
	16	16	16	16	16	16
a_	0.302	0.302	-0.562	1	0.210	-0.196
	0.25612	0.25612	0.02332	0	0.43539	0.46585
	16	16	16	16	16	16
a_e_	0.227	0.227	-0.876	0.210	1	-0.979
	0.39716	0.39716	0.00001	0.43539	0	0.00000
	16	16	16	16	16	16
ARI	-0.307	-0.307	0.863	-0.196	-0.979	1
	0.24722	0.24722	0.00002	0.46585	0.00000	0
	16	16	16	16	16	16

This table shows:

- **The correlation in MPa and Newtons.**

  This correlation is expressed as a value between –1 and 1.

  A negative value indicates a negative correlation between the pairs.

  A positive value indicates a positive correlation between the pairs.

  A value of zero indicates no correlation between the pairs.

- **The p-value.**

  The value indicates the risk of error.

  A value of 0.0001 indicates a chance of 1 in 10000 of making an error.

- **The number tested**

  The number of specimens tested.

B_a_ Represents the correlation at the bracket adhesive interface, including the p-value and the number tested.

a_ Represents the correlation for cohesive fractures, including the p-value and the number tested.

a_e_ Represents the correlation at the adhesive enamel interface, including the p-value and the number tested.

Table 4.4h

The Spearman rank correlation matrices for the GAC bracket/Enlight adhesive resin combination.

	Newton	MPa	B_a_	a_	a_e_	ARI
Newton	1	1.000	-0.193	0.041	0.212	0.332
	0	0	0.47287	0.87894	0.42992	0.20916
	16	16	16	16	16	16
MPa	1.000	1	-0.193	0.041	0.212	0.332
	0.00000	0	0.47287	0.87894	0.42992	0.20916
	16	16	16	16	16	16
B_a_	-0.193	-0.193	1	-0.287	-0.303	0.172
	0.47287	0.47287	0	0.28184	0.25339	0.52315
	16	16	16	16	16	16
a_	0.041	0.041	-0.287	1	-0.766	-0.211
	0.87894	0.87894	0.28184	0	0.00054	0.43272
	16	16	16	16	16	16
a_e_	0.212	0.212	-0.303	-0.766	1	0.334
	0.42992	0.42992	0.25339	0.00054	0	0.20580
	16	16	16	16	16	16
ARI	0.332	0.332	0.172	-0.211	0.334	1
	0.20916	0.20916	0.52315	0.43272	0.20580	0
	16	16	16	16	16	16

This table shows:

- **The correlation in MPa and Newtons.**

  This correlation is expressed as a value between –1 and 1.

  A negative value indicates a negative correlation between the pairs.

  A positive value indicates a positive correlation between the pairs.

  A value of zero indicates no correlation between the pairs.

- **The p-value.**

  The value indicates the risk of error.

  A value of 0.0001 indicates a chance of 1 in 10000 of making an error.

- **The number tested**

  The number of specimens tested.

B_a_ Represents the correlation at the bracket adhesive interface, including the p-value and the number tested.

a_ Represents the correlation for cohesive fractures, including the p-value and the number tested.

a_e_ Represents the correlation at the adhesive enamel interface, including the p-value and the number tested.

Table 4.4i
The Spearman rank correlation matrices for the 3M bracket/Sure Ortho Light Bond adhesive resin combination.

	Newton	MPa	B_a_	a_	a_e_	ARI
Newton	1	1.000	0.102	-0.045	-0.081	0.028
	0	0	0.70638	0.86949	0.76506	0.91831
	16	16	16	16	16	16
MPa	1.000	1	0.102	-0.045	-0.081	0.028
	0.00000	0	0.70638	0.86949	0.76506	0.91831
	16	16	16	16	16	16
B_a_	0.102	0.102	1	-0.782	-0.631	-0.359
	0.70638	0.70638	0	0.00035	0.00872	0.17236
	16	16	16	16	16	16
a_	-0.045	-0.045	-0.782	1	0.048	0.137
	0.86949	0.86949	0.00035	0	0.86081	0.61258
	16	16	16	16	16	16
a_e_	-0.081	-0.081	-0.631	0.048	1	0.402
	0.76506	0.76506	0.00872	0.86081	0	0.12250
	16	16	16	16	16	16
ARI	0.028	0.028	-0.359	0.137	0.402	1
	0.91831	0.91831	0.17236	0.61258	0.12250	0
	16	16	16	16	16	16

This table shows:

- **The correlation in MPa and Newtons.**
  This correlation is expressed as a value between –1 and 1.
  A negative value indicates a negative correlation between the pairs.
  A positive value indicates a positive correlation between the pairs.
  A value of zero indicates no correlation between the pairs.
- **The p-value.**
  The value indicates the risk of error.
  A value of 0.0001 indicates a chance of 1 in 10000 of making an error.
- **The number tested**
  The number of specimens tested.

B_a_ Represents the correlation at the bracket adhesive interface, including the p-value and the number tested.

a_ Represents the correlation for cohesive fractures, including the p-value and the number tested.

a_e_ Represents the correlation at the adhesive enamel interface, including the p-value and the number tested.

Table 4.4j
The Spearman rank correlation matrices for the Ormco bracket/Sure Ortho Light Bond adhesive resin combination.

	Newton	MPa	B_a_	a_	a_e_	ARI
Newton	1	1.000	-0.171	0.464	-0.126	0.205
	0	0	0.55946	0.09477	0.66853	0.48107
	14	14	14	14	14	14
MPa	1.000	1	-0.171	0.464	-0.126	0.205
	0.00000	0	0.55946	0.09477	0.66853	0.48107
	14	14	14	14	14	14
B_a_	-0.171	-0.171	1	-0.479	-0.882	0.881
	0.55946	0.55946	0	0.06056	0.00001	0.00001
	14	14	16	16	16	16
a_	0.464	0.464	-0.479	1	0.114	-0.097
	0.09477	0.09477	0.06056	0	0.67530	0.72142
	14	14	16	16	16	16
a_e_	-0.126	-0.126	-0.882	0.114	1	-0.981
	0.66853	0.66853	0.00001	0.67530	0	0.00000
	14	14	16	16	16	16
ARI	0.205	0.205	0.881	-0.097	-0.981	1
	0.48107	0.48107	0.00001	0.72142	0.00000	0
	14	14	16	16	16	16

This table shows:

- **The correlation in MPa and Newtons.**

  This correlation is expressed as a value between –1 and 1.

  A negative value indicates a negative correlation between the pairs.

  A positive value indicates a positive correlation between the pairs.

  A value of zero indicates no correlation between the pairs.

- **The p-value.**

  The value indicates the risk of error.

  A value of 0.0001 indicates a chance of 1 in 10000 of making an error.

- **The number tested**

  The number of specimens tested.

B_a_ Represents the correlation at the bracket adhesive interface, including the p-value and the number tested.

a_ Represents the correlation for cohesive fractures, including the p-value and the number tested.

a_e_ Represents the correlation at the adhesive enamel interface, including the p-value and the number tested.

Table 4.4k

The Spearman rank correlation matrices for the GAC bracket/Sure Ortho Light Bond adhesive resin combination.

	Newton	MPa	B_a_	a_	a_e_	ARI
Newton	1	1.000	-0.225	0.101	-0.030	0.079
	0	0	0.40159	0.71005	0.91132	0.77214
	16	16	16	16	16	16
MPa	1.000	1	-0.225	0.101	-0.030	0.079
	0.00000	0	0.40159	0.71005	0.91132	0.77214
	16	16	16	16	16	16
B_a_	-0.225	-0.225	1	-0.010	-0.160	-0.433
	0.40159	0.40159	0	0.97128	0.55390	0.09374
	16	16	16	16	16	16
a_	0.101	0.101	-0.010	1	-0.980	-0.481
	0.71005	0.71005	0.97128	0	0.00000	0.05912
	16	16	16	16	16	16
a_e_	-0.030	-0.030	-0.160	-0.980	1	0.510
	0.91132	0.91132	0.55390	0.00000	0	0.04345
	16	16	16	16	16	16
ARI	0.079	0.079	-0.433	-0.481	0.510	1
	0.77214	0.77214	0.09374	0.05912	0.04345	0
	16	16	16	16	16	16

This table shows:

- **The correlation in MPa and Newtons.**
  This correlation is expressed as a value between –1 and 1.
  A negative value indicates a negative correlation between the pairs.
  A positive value indicates a positive correlation between the pairs.
  A value of zero indicates no correlation between the pairs.
- **The p-value.**
  The value indicates the risk of error.
  A p-value of 0.0001 indicates a chance of 1 in 10000 of making an error.
- **The number tested**
  The number of specimens tested.

B_a_ Represents the correlation at the bracket adhesive interface, including the p-value and the number tested.

a_ Represents the correlation for cohesive fractures, including the p-value and the number tested.

a_e_ Represents the correlation at the adhesive enamel interface, including the p-value and the number tested.

Table 4.4l

The Spearman special correlation between the incidence of debonding fracture at the adhesive enamel interface and the adhesive remnant index with each bracket adhesive combination.

Bracket/adhesive	*Correlation a_e & ARI*	*p-value*
3M & Tb	-0.838	0.00009
Oc & Tb	-0.929	0.00000
GAC & Tb	-0.880	0.00001
3M & Enl	-0.741	0.00100
Oc & Enl	-0.979	0.00000
GAC & Enl	0.334	0.20580
3M & SB	0.402	0.12250
Oc & SB	-0.981	0.00000
GAC & SB	0.510	0.04345

The interpretation of these correlation coefficients show:

- A negative value indicates a negative correlation between the force applied and the ARI, while a positive value indicates a positive correlation.
- Any value greater than 0.9 indicates a statistically significant correlation.

Yellow highlights

- These correlations had a p-value indicating a margin of error of between 4% and 20% (see tables 4.4j, 4.4k and 4.4m)

Pink highlights

- These correlations had a p-value < 0.001

4.5 The bracket base dimensions

Table 4.5a:

The average bracket base contact surface area size measured three dimensionally and two dimensionally.

Bracket make	3 dimensional surface area	2 dimensional surface area.
GAC	26.20mm^2	16.1mm^2
3M	25.05mm^2	16mm^2
Ormco	20.90mm^2	14.3mm^2

Table 4.5b

Comparison of bracket base mesh dimensions

	Bracket bases		
	3M	**GAC**	**Ormco**
Mesh aperture size (µm)	208.6 x 205	225.1 x 218.9	140.5 x 141
Aperture area (µm^2)	42640	49500	19600
Average thickness of the wire strands of the gauze (µm)	115.5	113.5	126.5

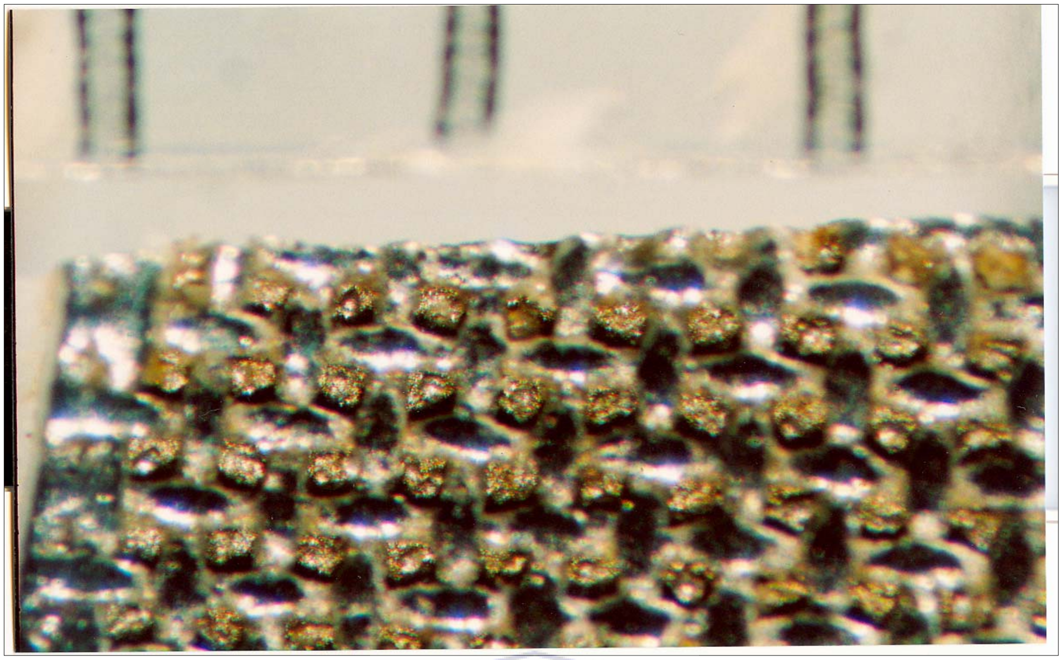


Figure 4.5a

The single mesh base of the Ormco bracket with a millimeter scale at the top of the photograph (62.5 X magnification).

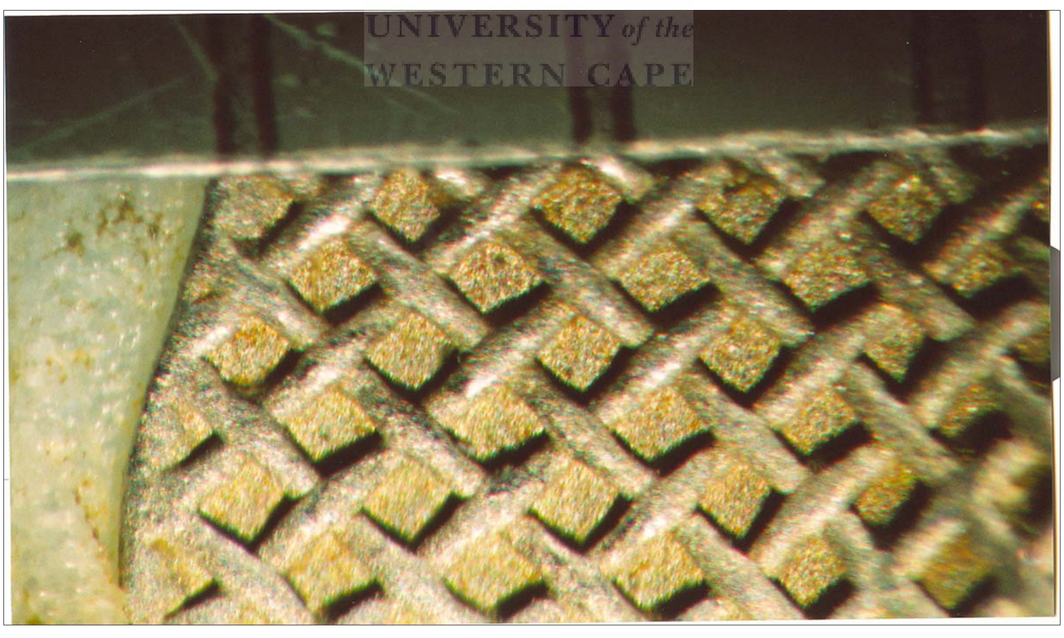


Figure 4.5b

The single mesh base of the 3M bracket with a millimeter scale at the top of the photograph (62.5 X magnification)

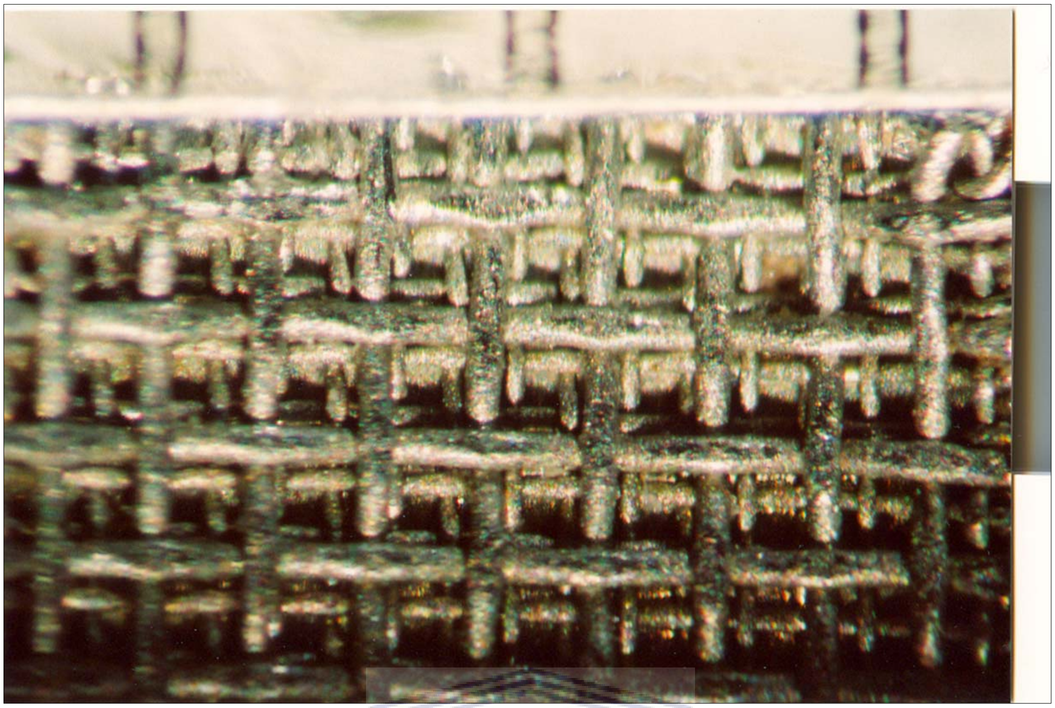


Figure 4.5c

The double mesh base of the GAC bracket with a millimeter scale at the top of the photograph (62.5 X magnification)

Chapter 5

Discussion

5.1 Introduction

The review of the literature of orthodontic bond strength testing reveals inconsistencies in the use of converted data units and the value of statistical analysis thereof. The 'inaccuracy' of base contact surface area determination cannot accurately allow for the transformation of units of force to units of stress. Once these units of stress have been calculated they cannot be accurately applied to the clinical situation (Eliades and Brantley 2000). However, it can give one an indication of what could happen in the clinical situation. Particularly, the comparative nature of the tests done in this study produced results that could be considered when acquiring materials for clinical practice.

Because of this the conversion of force to stress units have been calculated been in two ways.

1. Based on the three dimensional readings of the base registered with the reflex microscope.
2. Based on calculating the geometric symmetry of the base, assuming it to be a flat rectangular surface (Elliades and Brantley 2000, Summers *et al* 2004).

Looking at the results of this study the mega Pascal values calculated are vastly different from one another. Klocke and Kahl-Nieke (2005a) cautioned against interpreting shear bond strength values from *in vitro* tests for clinical relevance, as these values may be affected more by the methodology of the tests than the materials.

The statistical analysis of bond strength results have therefore been analysed in three ways:

1. Stress units calculated from the three dimensionally measured contact surface area.
2. Stress units calculated from the geometric dimensions of the various bases (Pivot table and the Tukey-Kramer multiple comparison test only, table 4.3b and figure 4.3.1b).
3. According to the force units applied (Newtons).

This type of testing however does not test the visco-elasticity of any of the materials. *In vivo* this visco-elasticity is an important consideration emanating from mastication and or the application of heavy rectangular wires (Eliades and Brantley 2000).

5.2 Comparative shear bond strengths of the bracket/adhesive resin combinations:

The aim of this study was to test and compare the shear bond strengths of three different light cure, fluoride release orthodontic resin bonding agents. This was done by using the adhesives in combination with three different makes of stainless steel maxillary molar orthodontic attachments. This allowed the assessment and comparison of:

- The adhesive resins with one another in combination with the same design of bracket base.
- The various bracket/adhesive resin combinations with one another, allowing the comparison of the effect of the size and design of the bracket base on the shear bond strength of the adhesive resin.

Figures 4.2a and 4.3a show box plots indicating the shear bond strengths of each bracket/adhesive resin combination. Figure 4.3a is a representation of shear bond strengths of the bracket/adhesive resin combinations expressed in MPa. Figure 4.2a is a representation of shear bond strengths of the bracket/adhesive resin combinations expressed in Newtons. Both of these plots show a similar spread.

Depending on how the contact surface area of each bracket base was calculated the average shear bond strength expressed in MPa showed vastly differing values (tables 4.3a and 4.3b).

- Using the three dimensional bracket contact surface area the shear bond strength of the 3M bracket/Transbond XT adhesive resin combination ranged from a minimum of 5.5 MPa to a maximum 15.9 MPa.

- Using the two dimensional bracket contact surface area showed that the shear bond strength of the same bracket/adhesive resin combination ranged from a minimum of 8.6 MPa to a maximum 25 MPa.

Elliades and Brantley (2000) and Klocke and Kahl-Nieke (2005a) cautioned that there was little reliability or relevance in attempting to project this type of result to the clinical situation. These differences highlight the importance of the methodology employed. All the comparisons and data analysed were derived from the 3 dimensional surface area values which is theoretically correct.

5.2.1 3M maxillary molar brackets:

Comparative shear bond strengths of the three adhesive agents

The results after debonding were compared (tables 4.2b and 4.3a). The average shear bond strength for the adhesives used with this bracket ranged from a low of 9.8 MPa (245.6 Newtons) when the bracket was combined with Enlight adhesive resin to a high of 11.8 MPa (294.9 Newtons) when combined with Transbond XT adhesive resin. The standard deviation in the shear bond strength displayed in the three groups was small even though the range between maximum and minimum values was large.

<u>The 3M bracket/Enlight adhesive resin combination</u> displayed the lowest shear bond strength of the three adhesives when combined with the 3M bracket. The average, the minimum and the maximum shear bond strengths of this combination were the lowest in the group. These values ranged from a minimum of 4.7 MPa (117.7 Newtons) to a maximum of 13.9 MPa (347.1 Newtons) with an average value of 9.8 MPa (245.6 Newtons). This combination displayed a standard deviation 2.2 MPa (56.1 Newtons).

<u>The 3M bracket/Sure Ortho Light Bond adhesive resin combination</u> displayed an average shear bond strength of 10.9 MPa (272.2 Newtons) which is roughly halfway between that of the 3M bracket combination with Transbond XT and Enlight (tables 4.2b, 4.3a, figures 4.2a and 4.3a). This combination however displayed the highest

minimum shear bond strength value. The shear bond strength values of this combination ranged from a minimum value of 6.1 MPa (151.9 Newtons) to a maximum shear bond strength of 14.8 MPa (371.6 Newtons). This combination displayed a standard deviation of 2.5 MPa (62.8Newtons).

The 3M bracket/Transbond XT adhesive resin combination displayed the highest average shear bond strength as well as the highest maximum reading in the group (tables 4.2b, 4.3a, figures 4.2a and 4.3a). These shear bond strength values ranged from a minimum value of 5.5 MPa (138.3 Newtons) to a maximum value of 16.0 MPa (399.4 Newtons) with an average value of 11.8 MPa (294.9 Newtons). The average shear bond strength of the Transbond XT combination exhibited a standard deviation of 2.8 MPa (70.8 Newtons). The result of the test on specimen number 1 (raw data table 4.1b) was disregarded as a result of an incorrect crosshead speed setting on the Zwick universal tester.

These three adhesives showed shear bond strengths of a similar magnitude with no differences of any statistical significance (tables 4.2.1c and 4.3.1c). Transbond XT adhesive resin displayed first, second, and third quartile values that were the closest together (figure 4.2a, 4.3a). Enlight adhesive resin displayed the lowest first, second and third quartile values in the group (figure 4.2a, 4.3a).

The adhesion advantages because of the inclusion of 4-META in Sure Ortho Light Bond did not prove (in this part of the study) to be a significant factor in the shear bond strength of the 3M bracket/Sure Ortho Light Bond adhesive resin combination. This was contrary to the manufacturer's expectations and the results of the official tests of the bond strength of Sure Ortho Light Bond (Sato and Yasuda 2007, Zalsman 1st April 2007). The shear bond strength of Sure Ortho Light Bond did not exceed the other materials by 1.5 times.

5.2.2 The GAC molar brackets:
Comparative shear bond strengths of the three adhesives

The results after debonding were compared (tables 4.2b and 4.3a). The average shear bond strength for the adhesives used with this bracket ranged from a low of 9.2 MPa (242.2 Newtons) when combined with Enlight adhesive resin to a high of 11.7 MPa

(306.1 Newtons) when combined with Sure Ortho Light Bond adhesive resin. The standard deviation in the shear bond strength displayed in the three groups varied but not significantly.

The GAC bracket/Enlight adhesive resin combination displayed the lowest average shear bond strength of the three adhesive resins in this group (9.2 MPa), similar to the value achieved in combination with the 3M brackets (9.8 MPa). The average and the minimum shear bond strengths of this combination were the lowest in the group (tables 4.2b and 4.3a). The lowest shear bond strength value of 4.3 MPa (112.3 Newtons) ranged to a maximum of 13.6 MPa (357.2 Newtons) with an average value of 9.2 MPa (242.4 Newtons). This combination showed the largest range within the group with a standard deviation of 2.6 MPa (67.3 Newtons).

The GAC bracket/Sure Ortho Light Bond adhesive resin combination displayed the highest average shear bond strength, as well as the highest maximum and the highest minimum reading in the group (tables 4.2b, 4.3a and figures 4.2a, 4.3a). A minimum shear bond strength of 9.3 MPa (244.8 Newtons) was achieved, this ranged to a maximum of 14.6 MPa (382.9 Newtons) with an average of 11.7 MPa (306.1 Newtons). Sure Ortho Light Bond displayed the lowest standard deviation 1.6 MPa (43.0 Newtons) in the group.

The GAC bracket/Transbond XT adhesive resin combination displayed an average shear bond strength of 10.4 MPa (272.6 Newtons). A minimum shear bond strength of 4 MPa (104.2 Newtons) was the lowest in the group. A maximum shearbond strength of 12.7 MPa (333.9 Newtons) was registered and was the lowest maximum in the group. The standard deviation was 2.1 MPa (54.5 Newtons) (tables 4.2b and 4.3a).

According to the Kruskal-Wallis multiple comparison test (tables 4.2.1c and 4.3.1c), the z-value of the GAC bracket/Sure Ortho Light Bond adhesive resin combination and the GAC bracket/Enlight adhesive resin combination were significantly different. The Regular test shows the medians to be significantly different if the z-value is greater than 1.9600. The z-value comparative of these two combinations was 2.352 using MPa values and 2.2164 using Newton values.

The Tukey-Kramer multiple comparison test using MPa values (figure 4.3.1a) confirmed this, while the Tukey-Kramer multiple comparison test for the Newton values (figure 4.2.1a) did not confirm this significant difference.

Of interest in this group was the fact that the minimum shear bond strength of the GAC bracket/Sure Ortho Light Bond combination was found to be more than double that of the other two combinations. A shear bond strength of 9.3 MPa (244.8 Newtons) was registered as opposed to 4.3 MPa (112.3 Newtons) for the GAC bracket/Enlight resin combination and 3.98 MPa (104.2 Newtons) for the GAC bracket/Transbond XT combination. Displaying the type of advantage expected by the manufacturer and experienced by the official tester (in this part of the study)

Sure Ortho Light Bond average shear bond strength was marginally the highest in this group but did not display the type of advantage as expected by the manufacturer or experienced by the official tester (in this part of the study) when compared to the average shear bond strength of either Transbond XT or Enlight.

5.2.3 The Ormco Optimesh XRT upper molar brackets: Comparative shear bond strengths of the three adhesives.

The results after debonding were compared (tables 4.2b and 4.3a). The average shear bond strength for the adhesive resins used with this bracket ranged from a low of 5.8 MPa (121.5 Newtons) when combined with Enlight adhesive resin to a high of 7.6 MPa (159.2 Newtons) when combined with Sure Ortho Light Bond adhesive resin. The standard deviation in the shear bond strength displayed in the three groups varied but not significantly.

In this part of the study the average shear bond strengths for each of three adhesives was in a range of 5.8 to 7.6 MPa. These average shear bond strengths were approximately half of that achieved when the same three adhesives were combined with either of the other two brackets.

<u>The Ormco bracket/Enlight adhesive resin combination</u> was responsible for the lowest minimum, maximum and average shear bond strength values in this group of combinations. The maximum shear bond strength value achieved for this combination was 7.4 MPa (154 Newtons). The first, second and third quartile values were the lowest

of the three Ormco brackets/resin combinations (figure 4.2a and 4.3a).

The Ormco bracket/Sure Ortho Light Bond adhesive resin combination achieved the highest average shear bond strength (7.6 MPa or 159.2 Newtons) of the three combinations, as well as the highest minimum and maximum shear bond strength values in this part of the study (tables 4.2b, 4.3a, figures 4.2a and 4.3a).

The Ormco bracket/Transbond XT adhesive resin combination achieved an average shear bond strength of 7 MPa (147.1 Newtons) with a maximum of 14.1 MPa and a minimum of 3.9 MPa.

According to the Regular Kruskal-Wallis multiple comparison z-value test (table 4.2.1c, 4.3.1c) each of the three adhesive resins tested with the Ormco brackets showed shear bond strengths that were significantly different from the shear bond strength values achieved when each of those adhesive resins were combined with either the 3M or GAC brackets. The comparative mean values had a z-value of greater than 1.9600 denoting a significant difference in every case.

The Bonferroni test (combined with the Kruskal-Wallis multiple comparison z-value test) which requires the compared medians to have a z-value of greater than 3.1970 to be significantly different from each other. This test confirmed this significant trend in almost every case. The Bonferroni test is used to identify differences of a greater or stronger statistical significance. The only exceptions were:

- The Ormco bracket/Sure Ortho Light Bond adhesive resin compared to the 3M bracket/Enlight adhesive resin combination. The z-value was 2.1168 (2.4220 Newton value).
- The Ormco bracket/Sure Ortho Light Bond adhesive resin compared to the GAC bracket/Enlight adhesive resin combination. The z-value was 1.5617 (2.3838 Newton value).
- The Ormco bracket/Transbond XT adhesive resin compared to the 3M Unitek bracket/Enlight adhesive resin combination. This z-value was 2.4749 (2.8733 Newton value).
- The Ormco bracket/Transbond XT adhesive resin compared to the GAC bracket/Enlight adhesive resin combination. The z-value was 1.9198 (2.8352 Newton value).

- Ormco bracket/Sure Ortho Light Bond resin combination compared to the 3M Unitek bracket/Sure Ortho Light Bond combination. The z-value for the stress values was 3.1678, the force (Newtons) z-value however, showed a significant difference in contrast to the MPa values.

The Kruskall-Wallis one way analysis of variance showed that all three adhesives combined with the Ormco brackets displayed the lowest mean, median and average rank values when compared to the results involving all three resins combined with the either of the other two bracket options (Table 4.2.1a, b and 4.3.1a, b). The Ormco bracket/Enlight adhesive resin combination displayed the lowest value followed by the Ormco/Transbond XT and Ormco/Sure Ortho Light Bond adhesive resin combinations which displayed the third lowest mean, median and average rank values.

The Tukey-Kramer multiple comparison test show distinct, different groupings which differed depending on whether the comparison was done in units of stress or force (figure 4.2.1a and 4.3.1a). In both stress and force units the Tukey-Kramer multiple comparison tests showed all the resin combinations with 3M and GAC brackets had mean shear bond strength values that occurred in a distinct group. This grouping of shear bond strength values was found to be significantly different from the grouping of mean shear bond strength values associated with all three Ormco bracket/resin combinations. The Tukey-Kramer multiple comparison test of the means (MPa values) also showed two other distinct groupings. These groups comprised the following combinations (figure 4.3.1a):

- The Ormco bracket/Transbond XT, the Ormco/Sure Ortho Light Bond and the GAC bracket/Enlight adhesive resin combinations.
- The Ormco/Sure Ortho Light Bond, GAC/Enlight and 3M Unitek/Enlight resin combinations.

Sure Ortho Light Bond had the highest shear bond strength of the adhesives in combination with the Ormco brackets. This adhesive in this part of the study did not live up to the expectation of its manufacturer, or the results of the official tests that it would display shear bond strengths 1.5 times greater than its competitors (Zalsman 1st April 2007, Sato and Yasuda 2007).

5.3 Shear bond strength of the Sure Ortho Light Bond

The first objective of this study was to assess whether the new adhesive (Sure Ortho Light Bond) was comparable to two other adhesives already available in the marketplace.

Transbond XT and Enlight adhesive resins are widely used and have been proven to be clinically successful adhesives. Transbond XT adhesive resin is widely referred to in the literature as a benchmark material to which other materials are often compared (Sato and Yasuda 2007, Bishara *et al* 1997, 1999a, 1999b, 2004b, 2005).

In this range of tests Sure Ortho Light Bond produced average shear bond strengths consistently higher than that of Enlight with all three bracket combinations (tables 4.2b and 4.3a). Using the Regular test associated with the Kruskal-Wallis multiple comparison z-value test the GAC bracket/Sure Ortho Light Bond adhesive resin combination was significantly stronger than the GAC bracket/Enlight adhesive resin with a z-value of 2,352 (table 4.3.1c), this significance is however not strong enough to be confirmed by the Bonferroni test.

The GAC bracket/Sure Ortho Light Bond adhesive resin combination displayed an average rank, median and mean values higher than that of the GAC bracket/Transbond XT adhesive resin (tables 4.2.1b and 4.3.1b).

The 3M bracket/Transbond XT adhesive resin combination produced a higher median value than the GAC bracket/Sure Ortho Light Bond adhesive resin combination (Tables 4.2.1b and 4.3.1b).

There was no statistically significant difference found between Transbond XT and Sure Ortho Light Bond in association with any of the brackets used in the tests (figure 4.2a and 4.3a). When compared to Transbond XT the shear bond strength of Sure Ortho Light Bond did not live up to the higher shear bond strength expectations of its manufacturer. The manufacturer claims that because of the 4-META in the product it should return bond strengths 1.5 times that of competitors containing conventional bis-GMA because of enhanced mechanical and chemical bonding with both the enamel and the metal surface (Zalsman 1st April 2007, Sato and Yasuda 2007).

When Sure Ortho Light Bond and Enlight adhesive resins are compared, the Sure Ortho Light Bond shows higher average shear bond strengths. In combination with the GAC bracket the difference is significant (Table 4.2.1c and 4.3.1c). This confirms the higher shear bond strength expectations of the manufacturer (Zalsman 1st April 2007), and the findings in the official test results (Sato and Yasuda 2007).

5.4 Same manufacturer bracket/adhesive resin combinations

The second objective of this study was to assess whether an 'in-house' combination of bracket and adhesive resin provided a stronger bond than a random mix of bonding agents and brackets.

The 3M bracket/Transbond XT (3M) adhesive resin combination produced the highest maximum and average shear bond strength when compared to either the 3M bracket/Enlight or the 3M bracket/Sure Ortho Light Bond adhesive resin combinations. The 3M ‘in-house’ combination did not display a statistically significantly greater shear bond strength when compared to either of the other two 3M bracket/adhesive resin combinations according to either the Regular or Bonferroni tests associated with the Kruskall-Wallis multiple comparisons (tables 4.2.1c and 4.3.1c).

The Tukey-Kramer multiple comparison tests showed all the 3M bracket/adhesive resin combinations to be grouped together (figure 4.2.1a and 4.3.1a). In figure 4.3.1a the shear bond strength values involving the 3M bracket/Enlight did occur in two distinct statistically significant groupings. This was as a result of the wide range of readings attained in this part of the study, pointing to inconsistencies in the bond strengths achieved.

The Ormco bracket/Enlight (Ormco) adhesive resin combination produced the lowest average shear bond strength of all the nine combinations tested as seen on the box plot (figure 4.2a and 4.3a). This Ormco 'in house' combination was shown to be significantly weaker than the combinations of 3M Unitek/Enlight (Ormco) resin or GAC bracket/Enlight (Ormco) resin, by both the Regular and Bonferoni tests associated with the Kruskal-Wallis multiple comparison z-value tests (tables 4.2.1c and 4.3.1c).

This Ormco combination also displayed the lowest average rank, mean and median values for both force and units of stress (tables 4.2.1b and 4.3.1b).

The Tukey-Kramer multiple comparison test showed the Ormco combination to be at the lower end of a distinct grouping that was different to the other bracket adhesive combinations.

The GAC bracket/Sure Ortho Light Bond adhesive resin combination displayed the highest average rank and mean values while the 3M Unitek and Transbond XT combination produced the highest median (tables 4.2.1b and 4.3.1b).

The results indicate that 'in-house' combinations do not offer any significant advantages with regard to shear bond strength. The 'in-house' combinations did however show no enamel damage on debonding (table 4.4a).

5.5 The adhesive remnant index (ARI)

The third objective was to comparatively assess the adhesive remnant index of each bracket/adhesive combination.

Table 3.4a

The description of each category of the adhesive remnant index.

ARI	***Description***
0	0% of the bonding agent remaining on the enamel specimen surface.
1	less than 50% of the bonding agent remaining on the enamel specimen surface.
2	50% or more of the bonding agent remaining on the enamel specimen surface.
3	100% of bonded enamel covered by a layer of bonding agent
4	Enamel damage as a result of debonding.

A zero percentage of adhesive remaining on the enamel surface (ARI 0) after debonding occurred in only 4 of the 143 specimens assessed. All four of these occurred in association with the GAC brackets. Stratman *et al* (1996) demonstrated consistent microscopic enamel damage in cases of the debonding fracture occurring at the adhesive/enamel interface.

The vast majority (116) of the 143 debonded teeth were assessed to have an adhesive remnant index (ARI) of one, two or three.

- 25 of the specimens assessed displayed an ARI of 1.
- 31 specimens were scored an ARI of 2.
- 16 of the 143 teeth assessed scored an ARI of 3.

Twenty three incidents of visible enamel damage were recorded scoring a 4 on the ARI. Sixteen of these were considered statistically significant. The *Chi*-squared test showed a value of 62.1438 with a p-value of 1.029×10^{-12} (table 4.4a).

- The GAC bracket/Sure Ortho Light Bond adhesive resin combination produced nine of these sixteen enamel fractures. This confirmed the fears that enamel fractures may occur as a result of the shear bond strength of the 4META in the new resin (Sato and Yasuda 2007, Clarke *et al* 2003).
- The GAC bracket/Enlight adhesive resin combination produced seven of the sixteen enamel fractures. This finding is not consistent with the results discussed so far in that Enlight has been the weakest adhesive on trial (figure 4.2a, 4.3a and tables 4.2b and 4.3a). This combination was also found to be significantly different from the stronger GAC/Sure Ortho Light Bond combination (tables 4.2.1c and 4.3.1c).

Of these twenty three cases of enamel damage:

- Eighteen of the twenty three were associated with the GAC brackets and involved all three adhesive resins.
- Thirteen of the twenty three were associated with Sure Ortho Light Bond adhesive resin. This occurred in association with both 3M brackets (4 of 13) and GAC brackets (9of 13).

The twenty three cases of enamel damage occurred as a result of a wide range of forces (Tables 4.1 b - j):

- The GAC bracket/Enlight adhesive resin combination produced 7 cases of enamel damage that occurred with shear bond strengths that ranged from 5.8

MPa to a maximum of 13.6 MPa.

- The GAC bracket/Sure Ortho Light Bond adhesive resin combination produced 9 cases of enamel damage with shearbond strengths that ranged from 9.34 MPa to a maximum of 14.61 MPa.
- The 3M bracket/Sure Ortho Light Bond adhesive resin combination produced enamel damage in 4 cases with shear bond strengths ranging from 6.06 MPa to a maximum of 13.89 MPa.
- The GAC bracket/Transbond XT adhesive resin combination produced 2 cases of enamel damage that occurred with the shear bond strengths 10.66 MPa and 11.64 MPa.
- The 3M bracket/Enlight adhesive resin combination produced a single case of enamel damage that occurred as result of a shear bond strength with the magnitude of 13.19 MPa.

Retief 1974 demonstrated *in vitro* enamel fracture at 9.7 MPa. Enamel fracture on debonding metal brackets is an occurrence that is not commonly associated with the clinical situation (Summers *et al* 2004, Pickett *et al* 2001, Banks and Macfarlane 2007). Rix *et al* (2001) state that it is well documented that laboratory testing procedures provide higher bond strengths than obtained in the clinical situation, because of the etch pattern achieved. Banks and Macfarlane (2007) confirmed that *in vivo* bond strengths were lower than *in vitro* results. This is thought to be as a result of the possibility of moisture contamination, access and inter-operator differences in the clinical arena. These instances of enamel damage could have occurred as a result of the etch pattern achieved on these 23 teeth. The fractures could also have occurred as a result of the variable hardness characteristics of surface enamel which have been found to vary by 15% from one random location to another according to S. R. Grobler (personal communication October 2007).

A covering letter with the official report of bonding tests performed with Sure Ortho Light Bond expresses concern with the regard to the strength of the material and the potential it poses for possible enamel damage (Sato and Yasuda 2007). In these official tests the average shear bond strength of Sure Ortho Light Bond combined with GAC metal brackets was found to be seventy Newtons (1.5 times) greater than those achieved with Transbond XT combined with the same brackets (Sato and Yasuda 2007). The manufacturer (BJM Laboratories) of Sure Ortho Light Bond substantiated this by suggesting that the combination of 4-META with bis-GMA would give shearbond strength of up to one and a half times that of the resins not containing 4-META (Zalsman 2007). The incidence of enamel fracture associated with Sure Ortho Light Bond was found, in this study, to be a cause for concern thus confirming the fears of Yasuda (19th April 2007).

The ARI of all resins associated with the use of the Ormco brackets showed the highest incidence of an ARI 3. Of the forty eight teeth bonded with Ormco Optimesh XRT brackets:

- Twenty nine debonded at the bracket adhesive interface (ARI 3).
- Eighteen left more than 50% of the bonding agent on the tooth surface (ARI 2).
- One left less than 50% of bonding agent on the tooth surface (ARI 1)

In this study the Ormco bracket proved to be the safest bracket to use from an enamel safety point of view. However the significantly weaker shear bond strength might not prove strong enough for success or reliability in the clinical arena.

The Spearman rank correlations require that the correlation coefficient be greater than +0.9 or less than -0.9 in order to be statistically significant. A positive value indicates a positive correlation between force applied and the ARI while a negative value is indicative of a negative correlation. This bi-variant interpretation shows a significant negative correlation for the Ormco brackets bonded with all three adhesive resins. It then holds true for these three combinations that the greater the debonding force the more adhesive remains on the enamel surface of the teeth in question (table 4.4l). In the case of these three combinations the p-value (<0.00001) of the correlation coefficient shows that the statistical risk of making an error is zero (table 4.4d, g, j):

- Combined with Transbond XT resin there was a correlation of -0,929.
- Combined with Enlight resin the there was a correlation of -0,979.
- Combined with Sure Ortho Light Bond resin there was a correlation of -0,981.

This negative correlation is echoed by the 3M /Transbond XT, GAC bracket/Transbond XT and 3M bracket/Enlight resin combinations (table 4.4l) these correlations are however not of statistically significant but display a low chance of error (table 4.4c, e, f and l).

Three of the bracket/resin combinations showed a small positive correlation these were neither statistically significant nor definite. This correlation showed the potential for a margin of error of between 4% and 20%. These combinations were with the 3M Unitek bracket/Sure Ortho Light Bond resin combination (table 4.4i) and GAC bracket/Sure Ortho Light Bond resin combination (table 4.4k) as well as the GAC bracket/Enlight resin (table 4.4h) combination.

5.6 The bracket adhesive surface, the effects of size and design.

The fourth objective was to assess if the size and design of the bracket base design and size play a significant role in the shear bond strength of the adhesives.

Table 5.6a
Average shear bond strengths displayed per bracket/adhesive resin combination.

	3M	GAC	Ormco
Transbond XT	11.8 MPa	10.4 MPa	7 MPa
Sure Ortho Light Bond	10.9 MPa	11.7 MPa	7.6 MPa
Enlight	9.8 MPa	9.2 MPa	5.8 MPa

This decreased shear bond strength of all three Ormco bracket/adhesive resin combinations is so substantial that it is statistically significant. Using the Kruskal-Wallis multiple-comparison z-value test all three of the Ormco bracket/adhesive resin combinations were shown to be significantly different from any combination of adhesive with either of the other 2 brackets in this study, in almost all cases (tables 4.2.1c and 4.3.1c). Two different tests were used in association with the Kruskal-Wallis multiple-comparisons:

- The Regular Test: This test shows the medians to be significantly different in all cases where z-value is greater than 1.9600.
- The Bonferroni Test: This test shows the medians to be significantly different in all cases where z-value is greater than 3.1970. This test highlights stronger differences.

The statistical analysis of the units of force using the Kruskal-Wallis multiple-comparison z-value test showed that all shear bond strength values of the adhesives associated with the Ormco brackets differed significantly from all the combinations tested with the 3M and GAC brackets. In all cases the z-values were greater than 1.9600 to such a degree that the results of the Regular test were confirmed in almost all of these instances by the results of the Bonferoni test (table 4.2.1c). However there were only two exceptions in the case of stress units (table 4.3.1c);

- The GAC bracket/Enlight resin combination when compared to the Ormco bracket/Sure Ortho Light Bond combination had a z-value of 1,5617 indicating that there was no statistically significant difference between the means of these two combinations, when the units of stress were evaluated statistically.
- The GAC bracket/Enlight resin combination when compared to the Ormco Optimesh bracket/Transbond XT resin combination displayed a z-value of 1,9198 which was less than required (1,9600) by the regular test to register significantly different means values (stress units).

These differences were highlighted and confirmed by the Kruskal-Wallis one-way analysis of variance on ranks (tables 4.2.1a and 4.3.1a). This test showed that all the Ormco bracket/adhesive resin combinations were significantly different in terms of the average rank, the z-value, the median, the mean and the effect, in both cases of force applied (Newtons) and stress units calculated (MPa).

The MPa values in the Tukey-Kramer multiple comparison test (figure 4.3.1a) showed that all the Ormco bracket/adhesive resin combinations displayed shear bond strengths that fell within a group. There were some of these combinations that occurred in more than one group:

- The Ormco bracket/Enlight resin combination with a mean shear bond strength of 5.8 MPa was different from every combination of adhesive used with either the the 3M or the GAC brackets.
- The Ormco bracket/Transbond XT resin combination with a mean shear bond strength of 7.0 MPa was different from the 3M and the GAC brackets combined with only either Transbond XT or with Sure Ortho Light Bond resins.
- The Ormco bracket/Sure Ortho Light Bond resin combination with a mean shear bond strength of 7,6 MPa was different only from the combinations of the GAC bracket/Sure Ortho Light Bond, the 3M bracket/Sure Ortho Light Bond and the 3M bracket/Transbond XT adhesive resin combinations.

The Tukey-Kramer multiple comparison test confirmed that all three mean values of the

Ormco bracket/adhesive resin combinations were significantly different from the other groups, using the force (Newton) values (figure 4.2.1a).

Table 4.5a:

The average bracket base contact surface area size measured three dimensionally and two dimensionally.

Bracket make	*3 dimensional surface area*	*2 dimensional surface area.*
GAC	26.20mm^2	16.1mm^2
3M	25,05mm^2	16mm^2
Ormco	20,90mm^2	14.3mm^2

This table shows that the Ormco brackets have a smaller contact surface area than the other two brackets. Chapter 2 refers to literature that claims that a reduced bracket base contact surface size does not significantly affect the shear bond strength (Cucu *et al* 2002, Matasa 2003a, Banks and Macfarlane 2007). However Sarma-Sayal *et al* (2003) stated that a smaller bracket base size is an important variable that could affect bond strength, other variables are the base design, any treatment applied to the base of the bracket, the adhesive used and intra oral factors like the position in the mouth and the depth of the bite.

The literature claims that the design of the adhesive surface of the base is all important. As far as the mesh design is concerned Matasa (2003a) claims that *mesh number* and *wire diameter* of the mesh are the most important influencing factors.

- *Mesh number* is the number of openings per lineal millimetre measured from the centre of the wire to the centre of the wire.
- The mesh *wire diameter* is almost as important in that if it is to thin it could break, whilst if too thick it could limit sufficient amounts of adhesive particle penetration as well as lowering the surface area.
- The size of the *aperture* in the mesh plays a role in that it can prevent the coarser particles of the adhesive from penetrating the mesh. Currently the trend is for a less dense mesh to be used so as to ensure a larger aperture or open area in the base.

Table 4.5b

Comparison of bracket base mesh dimensions

	Bracket bases		
	3M	**GAC**	**Ormco**
Mesh aperture size (µm)	208.6 x 205	225.1 x 218.9	140.5 x 141
Aperture area (μm^2)	42640	49500	19600
Average thickness of the wire strands of the gauze (µm)	115.5	113.5	126.5

The microscopic inspection of the base revealed that the mesh wire was thicker on the base of the Ormco bracket (126.5 microns) than on the GAC bracket (113.5 microns) and the 3M bracket (115.5 microns). These measurements support the findings of Matasa (2003a) in that the thicker mesh limits the aperture size as well as reducing the contact surface area and the bond strength. He suggested that a smaller aperture prevented the penetration of the larger filler particles in the resin.

The aperture size of the meshes were measured and showed a significant difference. The average aperture size of the Ormco bracket measured 140.5 x 141 microns. The GAC bracket aperture was larger at 225.1 x 218.9 microns, and that of the 3M Unitek bracket measured 208.6 x 205 microns. The area of the aperture of the Ormco Optimesh brackets, when calculated, was less than half the size of the aperture of either of the other two bases (table 4.5b). This significant difference in aperture size supports Matasa's (2003a) claims regarding aperture size being a important consideration for mechanical retention.

The mesh number per lineal millimetre also showed a significant difference. Using figures 3.1.5.1a, b and c the brackets showed:

- The Ormco bracket base showed 4 openings per lineal mm (figure 4.5a).
- The 3M bracket base showed 3 openings per lineal mm (figure 4.5b).
- The GAC bracket base measured 3 openings per lineal mm (figure 4.5c).

The other important difference in the design of the adhesive surfaces of the bases was evident on microscopic investigation:

- The 3M brackets displayed a single mesh design with the mesh crisscrossing the base diagonally from corner to corner. The entire base had an even mat finish as a result of micro-etching (figure 3.1.5.1b).
- The GAC brackets displayed a double mesh structure on the base which they claim will enhance the bond at the adhesive bracket interface as well as serve to reduce the amount of residual adhesive left on the enamel. The bracket construction (GAC US patent 4889485) is such that the mesh material becomes thicker, the apertures wider and the surfaces rougher toward the adhesive bracket interface. The entire base had an even mat finish as a result of sandblasting (figure 3.1.5.1c). The intention of this design is to reduce the amount adhesive left on the enamel after debonding, this was confirmed by the ARI values associated with this bracket, in this study.
- The Ormco bracket surface displayed a single mesh layer. The main feature of this adhesive pad was the size of the apertures which were smaller than the mesh of the other two brackets. The surface of the mesh appeared to be shiny and smooth whilst the 'ceiling' of the aperture had a rough and irregular mat surface (figure 3.1.5.1a). The base is coated with a special Ormco treatment the so-called 'Optimesh XRT' coating.

The GAC bracket was associated with 18 of the 23 incidents of enamel damage. It was the only bracket to remove all the adhesive resin from the enamel surface (ARI 0) in 4 instances. On the contrary the Ormco brackets had no incidence of enamel fracture and most debonding occurred at the bracket adhesive interface. These findings could only be interpreted as being the result of the contact surface design.

Chapter 6

Conclusions and clinical relevance.

6.1 The results of this study showed that:

- There was nothing to suggest that same manufacturer 'in house' bracket/adhesive resin combinations offered any shear bond strength advantages over a random mix of brackets and adhesives.
- The same manufacturer 'in-house' bracket/adhesive resin combinations showed the advantage of no enamel damage.
- The Ormco brackets (irrespective of adhesive resin used) were not responsible for any enamel damage with almost all debonding taking place at the bracket/adhesive resin interface.
- The Ormco bracket/Enlight adhesive resin combination was the weakest bracket/adhesive combination in this study.
- The Ormco brackets combined with any of the adhesive resins showed significantly lower bond strengths when compared to the combinations with either of the other two brackets.
- The shear bond strengths of the three adhesives investigated in this study were all within close range of one another, with Enlight consistently displaying the weakest shear bond strength of the three. This was found with each of the three brackets used in this study (figure 4.2a and 4.3a).
- Sure Ortho Light Bond proved itself to be comparable in bond strength to both other adhesives under the various circumstances of this study.
- The 4 – META content of Sure Ortho Light Bond adhesive resin did not prove, in this study, to be instrumental in a large increase in bond strength over the other adhesives.
- The GAC bracket/Sure Ortho Light Bond adhesive resin combination was responsible for significant enamel damage.
- The overall relatively poor performance of the Ormco brackets with all the

adhesives can only be ascribed to the contact surface size and design of these brackets.

- A thicker mesh wire and a smaller mesh aperture lead to a lower shear bond strength confirming the findings of Matasa (2003a).

6.2 <u>Clinical relevance:</u>

- Sure Ortho Light Bond is suitable for clinical use as far as shear bond strength is concerned. There are concerns with regard to the potential for enamel damage. However, it was shown that *in vivo* bond strengths are significantly lower than *in vitro* bond strengths (Pickett *et al* 2001, Banks and Macfarlane 2007).
- The GAC and 3M Unitek brackets combined with any of the adhesive resins tested could be successfully employed in the molar region. With maximum shear bond values being almost equal to the maximum bite force of 362 Newtons in the molar region (Sonneson and Bakke 2005). Careful positioning of the brackets with regard to the bite in the molar region is mandatory, as well as patient dietary counseling in order to achieve this success. Few authors reveal whether molar brackets were protected from the forces of the occlusion or not (Banks and Macfarlane 2007). The high *in vivo* failure rate maybe as a result of the occlusal forces acting directly on the attachment or that the patient made no dietary adjustments with regard to the presence of the brackets. Therefore successful molar bonding depends on a combination of case selection, patient compliance and operator skill.
- The Ormco brackets delivered significantly weaker bond strengths, with all three adhesives which indicate that these brackets may not be a suitable choice for direct bonding in the molar region as it has been shown that *in vivo* bond strengths are lower than *in vitro* bond strengths (Pickett *et al* 2001, Banks and Macfarlane 2007)
- The base design of brackets play a role in the shear bond strength of orthodontic adhesives. In the case of molar bonding this could be considered as important as any other aspect deemed important in the bracket design.
- Excessively large shear bond strength values increase the debonding force needed with the possibility of enamel damage
- Elliades (2006) reported that with the advent of nano-technology etch times may

be reduced thus reducing the potential for enamel damage. Sure Ortho Light Bond contains nano silica and thus the opportunity exists for potentially reducing the etching times in order to protect the enamel integrity. This remains an avenue for further investigation.

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Personal Communications

Attached are copies of e-mails referred to in the script.