Is a primer needed for orthodontic bonding? A Randomised Controlled Trial

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Abstract

Is a primer needed for orthodontic bonding? A Randomised controlled trial

Objective: To evaluate the clinical performance of APC Victory II™ (3M Unitek) brackets in direct orthodontic bonding with and without the use of primer.

Design: A single operator two centre prospective randomised controlled clinical trial.

Setting: The orthodontic departments at the Leeds Dental Institute and St. Luke's hospital, Bradford.

Subjects and methods: 92 patients requiring orthodontic treatment with fixed appliances. 46 Patients randomly allocated to control (with primer) or test (without primer). Patients bonded using a standardised procedure.

Main outcome measures: Number of bracket failures, time to bond-up appliances and the adhesive remnant index (ARI) when bracket failure occurred, over a six month period

Results: Failure rate with primer 8.8%, without primer 13.8%, no statistically significant difference- P value 0.051. Mean difference in bond-up time per bracket was 0.068 minutes which was not statistically significant (P =0.402). Statistically significant difference in the ARI – ARI 0 with primer 55.9%, no primer 81.5%, (P= 8.1622e-008).

Conclusion: There is no statistically significant difference in the bracket failure rate with or without primer when bonding APC Victory II™ (P =0.051). No significant difference in bond-up times. Statistically significant difference in the ARI, bonding without primer providing a lower ARI

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1. Introduction

Orthodontic appliances (braces) may be removable or fixed to the teeth. Fixed orthodontic appliances allow precise movements of teeth in three dimensions, which is not possible with removable appliances alone. Therefore, the majority of orthodontic treatment within the UK involves fixed appliances. Initially fixed orthodontic appliances were applied to the teeth via the use of brackets soldered to metal bands and these bands were placed around each tooth and cemented in position. Metal bands are still in use (especially for posterior teeth), but have fallen out of favour with the advent of composite bonding, which allows brackets to be bonded directly to the tooth. This application of the brackets directly to the tooth provides superior gingival health, improved patient comfort and improved aesthetics.

Composite bonding in orthodontics has evolved significantly since the concept was first introduced by Buonocore (1963). The initial composite materials developed for bonding brackets involved chemically cured ‘single paste’ or ‘two paste systems. Currently, a wide variety of visible light–cured orthodontic adhesives have become commercially available. The advantages of visible light–cured orthodontic adhesives are the high early bond strength, minimal extent of oxygen inhibition, and the extended working time for optimal bracket placement. The acid etch technique provides the basis for the bonding of orthodontic brackets to enamel. Acid etching allows the penetration of low viscosity bonding resins up to a depth of 50 μm, dependent on factors such as acid concentration and etching time. Once polymerized a micro-mechanical bond is established between the bonding resin and enamel. However, for such bonding to take place, the enamel must first be etched for 15– 30 seconds with 37% orthophosphoric acid, and then rinsed with copious amounts of water to remove the etchant and finally air dried until a frosted glass appearance is achieved. A low viscosity resin (also known as a sealant or primer) is then frequently painted onto the etched surface before a more heavily filled resin is used to bond the brackets to the

teeth. This study will be investigating the need for primer when bonding orthodontic brackets to teeth.

This study will explore the literature in regards to bonding orthodontic brackets to teeth. The literature review will explore; pre- preparation of teeth prior to etching, types of etchant and the procedures for etching; orthodontic bonding materials; different primers used for orthodontic bonding, including no primer; the effect of bracket design on orthodontic bonding and the problems that may occur due to bracket failure.

The next section of this thesis will explore the various techniques of preparing the enamel surface for bonding.

2. Review of the literature

2.1 Enamel etching

Etching is carried out to facilitate bonding of composite resins via micro mechanical retention to the enamel surface. Treatments with various etchants alter the structure of the enamel surface by selective demineralization of exposed enamel rods leaving an increased surface area and high energy, facilitating bonding via micro mechanical retention. The depth of penetration varies due to a number of factors but is generally accepted to be between 3.5μm and 50μm (Legler et al., 1990). Scanning electron microscopes have shown this effect (Carstensen, 1995) and its pivotal role in orthodontic bonding.

The pattern of enamel etches can vary considerably and are broadly classified into three different types:

1. Preferential removal of the enamel prism cores, with the peripheries remaining intact
2. Preferential removal of the prism peripheries with the cores left intact.
3. Removal of enamel prism cores and peripheries and some other less distinct areas of etching.(Obrien, 2002, John F McCabe, 2008)

Acid etch is dispensed in the form of a liquid or a gel, with colouring agents often added which aids the clinician to visualise where the acid has been placed with a higher degree of accuracy. Acid etch is normally applied to the tooth tissue via a small sponge or brush if in liquid form. If in gel form the etch is normally applied with a brush, or through a fine needle directly attached to the gel tube. However with heightened cross infection control procedures and risk management, this method of application is on the decline.

The ideal bond strength for brackets is suggested to be 6-8 MPa by Reynolds (1976). An *in vitro* study (Littlewood et al., 2000) suggested that the bond strength required for a clinically acceptable failure rate of 5 % would be at the lower threshold of about 5 MPa.

The current literature has demonstrated that a variety of factors affects the degree of etch achieved to enamel and thereby affect the bond strength. These factors are:

- Pre preparation of the enamel
- Type of etchant
- Concentration of acid
- Duration of etching
- The washing time
- The drying time

These factors are explored in the following sections.

2.2 Pre- preparation of enamel (prior to etching)

Pre-preparation of enamel may be carried out when using self etch and primer (single stage) or the two-stage acid etch and bond technique. Pre-preparation for the single stage technique is discussed in section 2.7.1, therefore this section will only analyse the literature on pre- preparation for the two-stage technique.

There are several techniques used for pre-preparing the enamel for bonding. One of the most commonly used techniques is to prepare the enamel surface with a slurry of pumice and a brush on the slow speed handpiece. An *in vivo/ in vitro study* (Lindauer et al., 1997) demonstrated no significant difference in the bracket failure rate, and the characteristics of the etched enamel and no significant difference in the bond strength between the use of pumice and no pumice. This is supported by another *in vivo* orthodontic study (Barry, 1995). A more recent development in pre- preparation is the use of laser ablation. An *in vitro* study (Lee et al., 2003) compared the use of phosphoric acid as an etchant with and without the use of laser ablation. The study demonstrated statistically significantly higher bond strengths in the phosphoric acid group alone than with a combination of laser ablation and phosphoric acid.

Another recent development in pre-preparation of the enamel surface is the use air abrasion (micro etching). An *in vivo* split mouth designed study (Miles, 2008) showed no significant difference in bracket failure rate over a six month period. This is consistent with the findings of *in vitro*

studies (Noble et al., 2008, Halpern and Rouleau, 2010)Ozone has also been used for pre –preparation with an *in vitro* study demonstrating no increase in SBS (Cehreli et al., 2010).

Fluoride has also been used in pre-preparation of enamel in a variety of forms. Recent prospective split mouths studies have shown an increased bracket failure rate; with fluoride varnish(Grover et al., 2012),and with fluoride paste as a pre preparation. (Talic, 2011)

It is therefore commonly accepted from the available literature that it is not beneficial to pre-prepare the enamel surface prior to acid etching for bonding other than to remove gross debris. The next step in the bonding process is to etch the enamel and this is explored in the following section.

2.3 Type of etchant

A variety of different etchants have been used for orthodontic bonding, their methods of action are generally similar and have been described above.

The types of etchant available are:

- Citric acid
- Maleic acid
- Nitric acid
- Oxalic acid
- Phosphoric acid
- Air abrasion (micro etching)
- Er:YAG laser ablation

2.3.1 Citric acid

Citric acid ($C_6H_8O_7$) is a week organic acid and is found in a variety of fruit and vegetables. Several studies have been carried out on the effectiveness of citric acid as an etchant but as to date no *in vivo* orthodontic studies have been carried out. Two *in vitro* studies have concluded citric acid to be inappropriate for orthodontic bonding (van der Vyver et al., 1997, Retief et al., 1986).

However another *in vitro* study (Reifeis et al., 1995) demonstrated no statistically significant difference between the bond strength of phosphoric acid and citric acid, however within this study different bonding agents were used for each etchant.

Therefore citric acid is currently not recommended for routine use as an orthodontic bonding agent.

2.3.2 Maleic acid

Maleic acid ($C_4H_4O_4$) is an organic acid which is water soluble.. Two *in vitro* studies (Reifeis et al., 1995, Urabe et al., 1999) have demonstrated no significant statistical difference in bond strength when maleic acid was compared to 37% phosphoric acid, however within these studies there was no mention of the etch duration for either acid.

Another *in vitro* study (Triolo et al., 1993) however found a statistically significant difference between maleic acid and phosphoric acid, with phosphoric acid having a superior bond strength.

To date there have been no *in vivo* orthodontic studies carried out, with no data available for bracket failure rates.

2.3.3 Nitric acid

Nitric acid (HNO_3) is a strong acid and is highly corrosive. An *in vitro* study (Gardner and Hobson, 2001) compared etch patterns with Phosphoric acid 37% and Nitric acid 2.5% at various time intervals. The samples were analysed with a scanning electron microscope, which demonstrated that phosphoric acid (37%) was more effective at creating a better quality etch than nitric acid (2.5%).

However, another *in vitro* study (Blight and Lynch, 1995) demonstrated no significant difference in the bond strength achieved by phosphoric acid (37%) and nitric acid (2.5%) with the only difference noted being a reduced amount of composite being left on the tooth with nitric acid when compared with phosphoric acid. This reduced amount of composite on the tooth implies a shifting of the failure site from the bracket/adhesive

interface to the tooth/adhesive interface, which may be interpreted as a slightly decreased bond strength with nitric acid but which is still sufficient for orthodontic bonding, however further research is required.

2.3.4 Oxalic acid

Oxalic acid is a relatively strong acid and has the chemical composition of $C_2H_2O_4$ in its anhydrous form. Only a limited number of studies have been carried out looking at the sheer bond strength of oxalic acid with variable results (Triolo et al., 1993) (Swift and Cloe, 1993, Holtan et al., 1995). These *in vitro* studies found significantly lower bond strengths with oxalic acid when compared to phosphoric acid, however another *in vitro* study (Reifeis et al., 1995) showed no statistically significant difference in the bond strength of oxalic acid compared to phosphoric acid, however the results of this study may not be applicable as bovine incisors were used. To date there have been no *in vivo* orthodontic studies carried out, therefore currently oxalic acid is not recommended for routine use as an orthodontic bonding agent.

2.3.5 Phosphoric acid

Phosphoric acid is also commonly known as orthophosphoric acid, it is an inorganic acid with the chemical composition of H_3PO_4. Orthophosphoric acid is highly soluble in water. It is acidic with a pH which is dependent on the concentration present within the solution, increasing the pH with decreasing concentration of phosphoric acid. Phosphoric acid is an irritant to the biological tissues and can cause chemical burns, therefore phosphoric acid must be handled with care at all times. Several studies have been carried out on the efficacy of phosphoric acid which have demonstrated its effectiveness as an etchant (Noble et al., 2008, Miles, 2008, Berk et al., 2008, Amm et al., 2008, Gray et al., 2006) with bond strengths equal or greater than other etching methods, with an orthodontic bond failure rate of approximately 5%. Therefore, phosphoric acid remains the current gold standard in etchants for orthodontic bonding.

2.3.6 Air abrasion (Micro etching)

Air-abrasion uses a high-speed stream of aluminium oxide particles, propelled by air pressure to abrade the surface of the tooth(Gerbo et al., 1992). Air abrasion is based on the law of kinetic energy, which states the harder the substance, the faster the cutting speed, the softer the substance, the slower the cutting speed(Gerbo et al., 1992). Therefore enamel is cut much faster than dentine or amalgam, with this effect also protecting the soft tissues. An *in vitro* study (Olsen et al., 1997) compared air abrasion using two different particle sizes (1.50 microm, 2. 90 microm) against the control group of etching with 37% phosphoric acid. The study concluded that enamel surface preparation using air-abrasion results in a significantly lower bond strength, and should not be advocated for routine clinical use as an enamel conditioner at this time(Olsen et al., 1997) with the particle size have little to no effect on bond strength. These findings are consistent with those of other authors(Berk et al., 2008, Gray et al., 2006)

2.3.7 Er:YAG laser ablation

Laser ablation removes the smear layer. After laser etching, some physical changes occur, such as melting and re-crystallization. Numerous pores and bubble-like inclusions appear(Takeda et al., 1999) creating an irregular surface available for bonding, thereby facilitating micromechanical retention.

An *in vitro* study(Berk et al., 2008) was performed where enamel surfaces were laser ablated with different power outputs (0.5, 0.75, 1, 1.5, and 2 W) and compared against the control (37% phosphoric acid) etching. The study demonstrated that 0.5, 0.75, and 1 W gave insufficient bond strength for orthodontic bonding; however 1.5 and 2 W may be a viable alternative to acid etching for orthodontic bonding.

However at this time lasers are still comparatively expensive, delicate and require high maintenance, along with the difficulty of access to the

posterior dentition with the apparatus means it has not as of yet been adopted by the orthodontic community.

2.3.8 Summary

In summary, a wide variety of materials have been used to accomplish etching of enamel to facilitate bonding. The majority of the current literature are *in vitro* studies, with few *in vivo* studies carried out to date. It is accepted within the current literature that the established etchant of choice is phosphoric acid, due to the greater bond strengths achieved (Berk et al., 2008, Amm et al., 2008, Gray et al., 2006), and low bracket failure rates (Noble et al., 2008, Miles, 2008, Berk et al., 2008, Amm et al., 2008, Gray et al., 2006). Therefore phosphoric acid is the product that all other etchants are measured against and remains the gold standard in enamel etching. Another variable in the etching process is the concentration of acid, which will be reviewed in the next section.

2.4 Concentration of acid

As phosphoric acid is the current gold standard in acid etching, this review will only consider variations in concentration of phosphoric acid. An *in vivo* randomised split mouth study (Carstensen, 1993) compared bond failure rates of 2% and 37% phosphoric acid using direct bonding on anterior teeth, finding no statistically significant difference in bond failure rates between the two groups. However, this study was performed on anterior teeth only (canine to canine), which have lower bracket failure rates. The same author (Carstensen, 1995) carried out an *in vitro* study comparing bond strength of phosphoric acid at 2%, 5% and 37% to enamel. The author reported bond strengths of 18.30MPa (37%), 16.49MPa (5%), 15.28MPa (2%), with the author concluding “2% phosphoric acid solution is appropriate for bonding of brackets”.

Other *in vitro* studies (Legler et al., 1990, Oliver, 1988) demonstrated statistically significant increased depth of etch when comparing 37% phosphoric acid to 5% phosphoric acid. However, another *in vitro* study (Legler et al., 1989) found no statistically significant difference between the bond strength of 37%, 15%, and 5% phosphoric acid.

Despite the evidence from these studies the current “gold standard” remains 37% phosphoric acid and this remains what is currently recommended by the manufacturers. The quality of etch is also dependent on the duration of etching and this will be explored in the next section.

2.5 Duration of etching

As in all dental specialities, time is important as good time management is directly related to increased productivity. Orthodontists are always searching for ways to use time more efficiently without compromising the quality of care delivered. As the bond strengths required for orthodontics are less than those of restorative dentistry, one of the ways proposed of being more productive is to reduce etching times. *In vitro* studies have demonstrated increased quality of etch with increased time of etch (Oliver, 1988, Oliver, 1987).

Other *In vitro* studies have demonstrated varied results with some studies reporting no difference in the Shear Bond Strength (SBS) at etching for 30-60 seconds but lower bond strengths at less than 30 seconds (Gardner and Hobson, 2001) (Osorio, Toledano *et al*. 1999). Other studies have demonstrated no significant difference in bond strengths between 10 to 30 seconds of etching, but significantly lower bond strengths when etched for less than 10 seconds (Olsen et al., 1996, Sheen et al., 1993, Wang and Lu, 1991). An *in vitro* study (Bin Abdullah and Rock, 1996) demonstrated statistically significant lower bond strengths at 5 minutes after bonding comparing 15 and 30 seconds of etching, whereas similar bond strengths were achieved with 30 and 60 seconds. However, the author noted surface defragmentation of the enamel after bracket removal when etched for 60 seconds, therefore the author does not recommend an etch time of 60 seconds under “any circumstances”.

A prospective randomised *in vivo* study (Carstensen, 1986) compared bond failure rates in anterior teeth (canine to canine) using 37% phosphoric acid at 15-20 seconds and 30-35 seconds using a split mouth design, with the participants followed up for 9 months. The author

reported no statistically significant difference in bond failure rates between the two groups. These findings are consistent with other authors(Barry, 1995, Kinch et al., 1988)

Currently manufacturers still recommend a time of 30 seconds for etching, although the literature appears to support bonding times of 15 seconds. However, it has been well established that higher bond failure rates occur on premolars and molars than on anterior teeth. To date, no *in vivo* prospective randomised study has been carried out looking at bracket failure rate on all teeth. Another factor to consider is that dentists are not adept at estimating elapsed time, it has been well established that the "dental" 30 seconds is much shorter in duration than 30 seconds as timed by a watch. Therefore, the current gold standard of etching time within orthodontics is still currently 30 seconds. However, this may change in the future. Once etching has been completed, the etchant has to be removed; this is normally achieved by washing with water.

2.6 Washing time

Washing time can affect the bond strength achieved by either being too short so that all the etchant is not removed, or by being too great a period of time with the minerals within the water re-mineralising the etched enamel. Few studies have been carried out into this field to date. An *in vitro* study (Beech and Jalaly, 1980) demonstrated superior bond strengths with increased volume of water used to remove etchant, with 20ml producing a bond strength of greater than 25MPa compared to a bond strength of less than 10MPa with 0.2ml of water. However, the results are not applicable clinically as washing was measured by volume in a syringe which would not take place routinely amongst orthodontic practice. Another *in vitro* study (Williams and von Fraunhofer, 1977) concluded that variations in etch and washing time may increase or decrease bond strength. However, the results are not clinically applicable as etch times of 10, 20 and 60 seconds were used, which differs from the "gold standard" of etch time at 30 seconds.

Therefore the washing time is best determined as by the manufacturers' instructions, which is currently 30 seconds, however more research is required in this field to provide any definitive answers. Once the etchant has been removed, the tooth is than dried until a frosted glass appearance is achieved to facilitate bonding.

2.7 Drying time

This is another critical phase which involves the removal of moisture from the etched surface. This is most commonly achieved with air drying but may also be achieved via the use of acetones. The lack of moisture is critical to achieving effective bond strengths as the majority of bonding agents are hydrophobic.

An *in vitro* study (Galan et al., 1991) investigated the effect of heated drying (with a hair dryer) compared to drying with a conventional dental 3 in 1 (compressed air). The study showed no statistically significant difference in shear bond strengths of the two techniques. Another *in vitro* study (Ichiki et al., 1990) assessed the effect of drying time with a 3 in 1 syringe with regard to bond strengths. The study found no statistically significant difference in shear bond strengths on variation of drying time from 5 seconds up to 80 seconds. Another *in vitro* study (Iwami et al., 1998) compared bond strengths with drying with blotting paper, 3 seconds of pressurised air, and 15 seconds of pressurised air; no statistically significant differences in bond strength were found between the three groups.

To date no published *in vivo* studies have taken place looking at bond failure rates in regard to drying time/ method and no orthodontic studies have been carried out in this field. Therefore, the current accepted standard remains as per the manufacturers' instructions of 30 seconds of air drying (compressed air) to obtain a "frosted glass" appearance of the enamel.

2.8 Summary of etching process

To summarise the literature to date with regards to the process of etching, the current gold standard regime for orthodontic bonding is to etch with 37% orthophosphoric acid for 30 seconds; the acid is than rinsed away using 30 seconds of water from the 3 in 1 syringe; followed by air drying for 30 seconds using the 3 in 1 syringe. Once this etching process has been completed primer is normally applied to the tooth followed by the bracket with the adhesive material already placed on the bracket. In the next section, materials that have been used as adhesives will be considered.

2.9 Materials used for bonding brackets

Various materials have been used for bonding orthodontic brackets, with the search for the ideal bonding agent still ongoing. Materials that have been used to bond brackets are:

Composite

-chemical cure

-light cure Ultra Violet (UV) / blue light

Glass ionomer cement (GIC)

Compomer / GIC hybrids

The literature on these materials is reviewed in the following section.

2.9.1 Composite

The first commercially available composites were introduced in the early 1960's. Composite consists of two main components; which are a resin phase and reinforcing inorganic filler. The resin phase essentially contains a modified methacrylate or acrylate. The most commonly used resin is *bisphenol A diglycidyl ether methacrylate* (BIS-GMA), which is combined with *triethylene glycol dimethacrylate* (TEGDMA), and this allows control of the viscosity of the inactivated material. Fillers have a major role in determining the properties of composite. Commonly used fillers include several types of glass, quartz and fused silica. Thereare three broad types of filler irrespective of their components.

1. Macro filled (filler particles 1-50μm) main disadvantage- gradual roughening of the surface due to preferential removal of the resin matrix.
2. Micro filled (filler particles 0.01-0.1μm) main disadvantage- increased attrition rate due to decreased filler content.
3. Hybrid (filler combination of particles 1-50μm and submicron particles- typically 0.04μm). By use of a combination of the other two filler types overcomes the disadvantages of the other two types.

Hybrid composite has therefore become the composite of choice when bonding orthodontic brackets.

Composite with higher filler contents display improved dimensional stability, tensile strength and increased viscosity. However, it has been demonstrated that increasing composite thickness underneath a bracket when bonding reduces the shear strength of the bracket. (Evans and Powers, 1985, Mackay, 1992, G Schechter, 1980). However, if no filler is present the bond strength achieved is reduced (Moin and Dogon, 1978). Therefore there is an optimal range of concentration of filler which facilitates accurate placement of the bracket and sufficient bond strength (Artun and Zachrisson, 1982). Composite may be then further sub-divided into chemical cure and light cure depending on how the product is activated.

2.9.1.1 Chemical cure composite

Chemical cure composites were the first type of composite developed. Chemical cure composite normally requires mixing of two materials at the chair side to commence the setting reaction. This typically takes the form of two pastes or a powder and a liquid. Several characteristics of the composite are affected by the ratio of mixing; including working time, setting time, strength, and viscosity.

2.9.1.2 Light cure composite

There are two types of light cure composite, which are categorised by the frequency of light used to activate the material. The first light source used

was ultra violet (UV) light, which activated the initiator a *benzoin methyl ether*. However due to the possible dangers of UV light (retinal damage, melanoma) its usage has greatly decreased. UV activation has largely been superseded by visible blue (440nm) light activation. The initiator for visible light composite is Camphorquinone.

For the purposes of this literature review both types of light cure composite will be included but no differentiation will be made between the two types as they share similar properties.

Light cure composite typically is dispensed as a single paste which requires no mixing. Light cure composite has the added advantage of command set as various equipment can be used to activate the initiator once the desired position has been achieved. However, care must be taken when storing / applying the product as if exposed to light for a prolonged period of time activation may take place prior to the desired time.

Studies comparing light cure composite and chemical cure composite have shown variable results in bond strength with some stating an increased bond strength with chemical cure composite (King et al., 1987, Greenlaw et al., 1989, Crow, 1995). Others showing no difference in bond strength (Delport and Grobler, 1988, Sargison et al., 1995, Valiathan and Krishnan, 1997, Joseph and Rossouw, 1990) and one study demonstrating higher bond strengths with light cured composites (Wang and Meng, 1992). However it is agreed that the bond strength achieved by both materials is sufficient for bonding orthodontic brackets, and this has been demonstrated as no significant difference between the bracket failure rates between the two materials (O'Brien et al., 1989). It has also been demonstrated that brackets bonded with chemical cure composite have increased enamel fracture rates on debonding, possibly due to a greater bond strength (Greenlaw et al., 1989, Crow, 1995). Light cure composite possesses superior handling characteristics which facilitates easier removal of excess material (Valiathan and Krishnan, 1997), this decrease in excess material has been demonstrated to decrease plaque levels and thereby reduce the probability of decalcification (Gwinnett and Ceen, 1978, Zachrisson, 1977, Artun and Brobakken, 1986). Therefore,

the majority of orthodontic practices within the UK use light cured composite (Banks and Macfarlane, 2007). Another adhesive that has been used to bond brackets is glass ionomer cement and this will be reviewed in the next section.

2.9.2 Glass ionomer cement (GIC)

GIC has been commercially available since the early 1970's. It is normally dispensed as a powder (sodium aluminosilicate glass with 20% Calcium Fluoride + other additives) and a liquid (water or aqueous solution of maleic/ tartaric acid). As with chemical cure composite the handling characteristics are affected by the ratio in which the powder and liquid are mixed.

GIC has the advantage that it directly bonds to enamel and dentine without the need to acid etch, also due to its chemical composition it acts as a reservoir for fluoride which helps to protect against decalcification/ dental caries. This has been demonstrated in the literature as a reduction in the number of white spot lesions compared to composite (Marcusson et al., 1997). However, bracket failure rates with GIC have been shown to be far greater than with chemical cure and light cure composite(Norevall et al., 1996, Oliveira et al., 2004). Therefore, GIC is not recommended for orthodontic bonding (Millett and McCabe, 1996, Mandall, 2009). As neither GIC nor composite fulfils the criteria of an ideal bonding agent other materials have been developed to attempt to combine the advantages of both these products without the disadvantages which has led to the development of compomers.

2.9.3 Compomers and GIC hybrids

These adhesives are (in simple terms) when GIC has been combined with composite, and a range of materials has been formed; which are broadly termed Compomers, Giomer, and Resin Modified GIC. As all these materials share similar characteristics and handling properties, for the purpose of this literature review they will be considered together.

They are generally dual cured, setting via a chemical and a light initiated reaction.

Bracket failure rates and bond strength have been shown to be similar when compared to light cured composite (Coups-Smith et al., 2003, Millett et al., 2000, Fricker, 1994), and chemical cured composite (Fowler, 1998). Compomers have also been shown to reduce the incidence of decalcification during orthodontic treatment (Millett et al., 2000). A systematic review concluded that compomers may be a suitable material for orthodontic bonding but further long term clinical trials need to be carried out before it can be recommended for routine use (Mandall, Hickman *et al,* 2009).

2.9.4 Conclusion

It has been shown that glass ionomer cement (GIC) is an unsuitable material for bonding orthodontic brackets due to its high bracket failure rate (Millett and McCabe, 1996)(Mandall, Hickman *et al* 2009). Chemical cure composite has also been shown to be less suitable than light cure composite due to less than ideal handling characteristics and increased risk of enamel fracture. Compomers and GIC hybrids appear to show promising early results; however there is insufficient long term data currently to recommend them as direct bonding materials. Therefore the gold standard for direct bonding is light cured composite. Prior to the adhesive (composite) being applied to the tooth primer is normally placed. Primer and its role in orthodontic bonding are reviewed in the next section.

2.10 Primer

Primer is usually the unfilled bonding agent and its primary purpose is enamel surface penetration to improve the effectiveness of the final bond. According to previous reports in the literature (Coreil et al., 1990, Ghiz et al., 2009, Lowder et al., 2008, Paschos et al., 2006), the purpose of the use of a resin sealant in the orthodontic bonding system may also be to protect the enamel from consequent demineralization by the acid-etching

procedures; to enhance bond strength; to increase the etched enamel retention and to reduce marginal leakage. Primer is normally an unfilled low viscosity resin containing *triethylene glycol dimethacrylate* (TEGDMA) and *bisphenol A diglycidyl ether methacrylate* (BIS-GMA). As Glass ionomer cement and compomers have previously been discussed this section will be limited to the use of primer with composite. Therefore within the following sections the following types of primer will be reviewed;

- Self-etch and primer
- Hydrophilic primer
- Cyanoacrylate primer
- Fluoride releasing primer
- Antibacterial primer
- Bonding without primer
- Non orthodontic studies
- *In vitro* orthodontic studies
- *In vivo* orthodontic studies

2.10.1 Self-etch and primer

Self etch and primer (SEP) differs from the “conventional” bonding technique; SEP contains an acidic component and primer component. Therefore bonding with SEP is carried out by application of the SEP directly to the enamel and leaving it in situ for a short period of time (determined by manufacturers’ recommendation). The adhesive is then directly applied with the bracket to the tooth (removing the “conventional” rinsing and air drying phase) and cured under an appropriate light source. As SEP removes 2 phases in the bonding process, the time taken to bond brackets is reduced (Banks and Thiruvenkatachari, 2007, Aljubouri et al., 2004). However, it was initially speculated that due to the acid being incorporated with the primer that SEP would have a higher bracket failure rate than the “conventional” technique.

Randomised controlled trials have shown a higher failure rate of SEP when no pre-preparation of the tooth is carried out (Burgess et al., 2006,

Lill et al., 2008). Therefore pumicing is recommended before SEP is used (Burgess et al., 2006, Lill et al., 2008).

However, with the “conventional” technique as discussed previously no pre-preparation of the tooth is required. Several randomised controlled trials have been carried out which have demonstrated no statistically significant difference in bracket failure rates when SEP is used with pumice compared to the “conventional” technique (Cal-Neto et al., 2009, Shah and Chadwick, 2009, Reis et al., 2008, Pandis et al., 2006, Banks and Thiruvenkatachari, 2007, Aljubouri et al., 2004, Pandis et al., 2005, Manning et al., 2006). However, three randomised controlled trials showed a statistically significant higher bond failure rate for SEP compared to the “conventional” technique (House et al., 2006, Elekdag-Turk et al., 2008a, Murfitt et al., 2006). These differences may be attributable to SEP only applied with no prior pumicing of teeth (Elekdag-Turk et al., 2008b), and different manufactures’ SEP used in different studies. Therefore not all SEP’s are equally effective.

Whilst studies have demonstrated reduced time in bracket application with SEP, these studies did not account for the additional time required in pumicing the dentition, also SEP has a greater cost than separate etch and bond. Therefore, SEP is a viable alternative to the “conventional” technique but for the purposes of this study, we will be using a separate etch and primer.

2.10.2 Hydrophilic primer

Moisture contamination is one of the major causes of bond failure, and is discussed later within the bracket failure section (2.12.1). In an attempt to overcome this problem, hydrophilic primers were developed- which attempted to maintain bond strength in wet conditions. In a split mouth clinical trial a bond failure rate was reported at 7.3% over a period of 12 months(Mavropoulos et al., 2003), which compares favourably to previous “conventional” research. However, this study compared it to a compomer adhesive as opposed to the “conventional” technique. A randomised controlled trial showed a statistically significant higher bond

failure rate with hydrophilic primer when compared to “conventional” primer (Littlewood et al., 2001). Therefore, currently hydrophilic primers are not in routine use for orthodontic bonding. Another primer that has attempted to overcome the problem of moisture contamination is cyanoacrylate primer.

2.10.3 Cyanoacrylate primer

Cyanoacrylate primer in theory has the advantage over conventional primers, as they are “moisture resistant” – mildly wet conditions does not affect bond strength (Cacciafesta et al., 2007). However, *in vitro* studies have shown lower bond strengths for cyanoacrylate primer against conventional primer (Oztoprak et al., 2007, Cacciafesta et al., 2007, Bishara et al., 2002, Al-Munajed et al., 2000), with some authors reporting this to be insufficient for orthodontic bonding (Al-Munajed et al., 2000, Oztoprak et al., 2007), and other authors suggesting that the bond strength achieved would be sufficient (Bishara et al., 2002, Cacciafesta et al., 2007).

A prospective clinical trial (Le et al., 2003) using cyanoacrylate primer with composite adhesive, showed a statistically significant higher failure rate than conventional primer. A randomised control trial has also been carried out and compared the use of a cyanoacrylate primer and adhesive against a conventional primer and adhesive, and showed statistically significant higher failure rate with the cyanoacrylate system (Karamouzos et al., 2002). Therefore, currently cyanoacrylate primers cannot be currently recommended for routine clinical use. As moisture resistant primers have been unsuccessful to date, research has also explored adding factors to the primer that may be of benefit in another method.

2.10.4 Fluoride releasing primer

One of the recognised risks of orthodontic treatment is decalcification around brackets (Gorelick et al., 1982). In an attempt to decrease the

incidence of decalcification, fluoride mouthwashes have been advocated (Benson et al., 2005). However, this relies on patient compliance, and the patients who are at highest risk are those with poor oral hygiene and are most unlikely to comply with addition oral hygiene measures. Therefore, this had led to the development of locally acting agents.

Several *in vitro* studies have been carried out comparing shear bond strength of fluoride containing primer compared to "conventional" primer and they have shown similar bond strengths between the groups (Attar et al., 2007, Bishara et al., 2005). An *in vitro* study has also shown no significant difference in bond strength when fluoride is added to SEP (Korbmacher et al., 2006), or when SEP is used than an additional layer of fluoride containing primer added (Tuncer et al., 2009). However when shear bond strengths of different manufacturers fluoride- releasing primer were compared there was a statistically significant difference in the bond strengths between them, with only one compound having a similar bond strength to "conventional " primer (Arhun et al., 2006).

To date one split mouth orthodontic clinical trial has been carried out investigating bond failure rates of fluoride- releasing primer. A statistically significant higher bracket failure rate was observed with fluoride releasing primer when compared to "conventional" primer (Paschos et al., 2009). Therefore, until the bracket failure rate is addressed there is no merit on proceeding with a study to investigate decalcification rates. Currently fluoride releasing primers cannot be recommended for routine clinical use. Therefore other agents have been developed in an attempt to solve the problem of decalcification by other additives.

2.10.5 Antibacterial primer

Antibacterial primers have been developed in recent years in an attempt to decrease the incidence of decalcification (as discussed above). There are four main agents which have been researched to date: *triclosan, glutaraldehyde, methocryloxyododecyl pyriimo bromide* (MDPB), and *benzalkonium chloride*. For the purpose of this literature review they will

considered together. Due to the recent advent of these primers, to date no clinical trials have taken place.

By placing the antibacterial ingredient within the primer *in vitro* studies have demonstrated increased antibacterial activity when compared to conventional primer (Saito et al., 2007, Bulut et al., 2007). *In vitro* studies have also taken place comparing shear bond strength of antibacterial primer and "conventional" primer with conflicting results. Three *in vitro* studies showed no statistically significant differences in shear bond strength (Bulut et al., 2007, Sehgal et al., 2007, Bishara et al., 2005). However, four *in vitro* studies have demonstrated statistically significant lower shear bond strengths (Saito et al., 2007, Minick et al., 2009, Eminkahyagil et al., 2005, Malkoc et al., 2005), but three of the four authors reported that the bond strength may be acceptable for orthodontic bonding. It has been demonstrated that increasing the concentration of the antibacterial agent decreases the shear bond strength (Saito et al., 2007). This is a possible explanation for this wide variation in results, which may be attributable to the variations between different concentrations and types of antibacterial agents. All of the authors concluded that clinical trials need to take place before antibacterial primers can be recommended for routine use. Therefore, as additives to primer to date have been shown to be ineffective, another question that needs to be addressed is if primer without any additive confers any benefits.

2.10.6 Bonding without primer

Orthodontic bonding without primer has been the subject of research, and analysis of the orthodontic literature has demonstrated that primers with additives to reduce the risk decalcification are not suitable for orthodontic bonding. This poses the question is primer required? This is most suitably assessed by appraising if primer reduces bracket failure rates when bonding with composite. Alternatively, does primer introduce an additional step into the bonding process, which may increase time to perform bonding and thereby increase the risk of moisture contamination, as well

as increasing the cost of the bonding procedure. In order to attempt to answer this question the current orthodontic literature will be explored, analysing *in vitro* and *in vivo* studies. However, initially the review shall consider non orthodontic studies when bonding without primer was assessed.

2.10.6.1 Non orthodontic studies

Initial studies to evaluate the need for unfilled resin sealants were initially carried out with regard to restorative dentistry. Several *in vitro* studies have shown a comparable tensile bond strength with or without the use of a primer (Barnes, 1977, Prevost et al., 1984, Low and von Fraunhofer, 1976, Jorgensen and Shimokobe, 1975, Retief and Woods, 1981). These studies suggested that a resin phase devoid of filler particles is present in sufficient amounts on the surface of the composite resins to fill the micropores in the etched enamel surface and the unfilled resin is not necessary. This has been confirmed further within *in vitro* studies that have measured the depth of penetration of resin tags using scanning electron micrographs (Jorgensen and Shimokobe, 1975, Low et al., 1978, Prevost et al., 1984, Barnes, 1977, Retief and Woods, 1981) . However an *in vitro* study (McLundie and Messer, 1975) demonstrated increased penetration of resin tags of a chemically cured composite adhesive when primer was used compared to no primer; however within this study no sample size is mentioned and a lower concentration of etchant (30% phosphoric acid) was used than is currently recommended. These findings indicate that the highly viscous composite filling materials are able to adapt to the topography of etched enamel surfaces to provide the required mechanical retention.

To date only one randomised clinical trial (Roberts et al., 1978) has taken place within the field of restorative dentistry. This study was carried out on 157 teeth which required class II restorations; one of three different types of chemically cured composite were used, two with primer and one without (as per the manufacturer's instructions). The study lasted for two years and looked at failure rate and recurrence of caries as outcome measures. The final number of teeth included in the study was 104 (due

to drop outs) and the results showed that there was no difference in caries rate between the three groups, but there was a higher failure rate in the no primer group (19.6%) compared to the adhesives with primer (7.4%, 8.5%). The authors suggested that this difference may be attributable to the filler particles preventing resin tag formation. However, the results of this study may not be applicable to orthodontic bonding as restorations are a test of tensile strength rather than shear bond strength, which is required for bonding brackets. The study also compared three different types of adhesive; therefore the adhesive itself may have been the determining factor in relation to failure rates. In addition, the study design is unclear in several areas i.e. method of randomisation, inclusion criteria, exclusion criteria, statistical analysis used, operator variation, and split mouth allocation.

In summary, although these studies pose the question whether the use of a low viscosity bonding resin is necessary, they are not directly applicable to clinical situations involving bonding of orthodontic brackets, as these studies compared bond strengths in composite resin restorations. Therefore, the next section will consider orthodontic bonding studies without primer.

2.10.6.2 *In vitro* orthodontic studies with no primer

To date, six *in vitro* orthodontic studies have been published comparing the use of composite with and without the use of an intermediary liquid resin (primer/ unfilled resin). This was identified by systematically searching through pub-med and med-line and orthodontic journals using the search terms of orthodontic adhesive, orthodontic primer, bracket failure, and searching through the references of any relevant articles.

An *in vitro study* (O'Brien et al., 1991) researched the influence of a low viscosity unfilled 'primer' resin upon the shear bond strength of a bracket adhesive combination to etched enamel. Twenty premolar teeth were used in the study and placed in saline for 24 hours prior to bonding, they were than ground and mounted on composite blocks and mandibular

incisor brackets were placed with a hybrid composite (62% filler by weight) . The shear bond strength was calculated with or without use of a sealant on groups of 10 teeth and the results showed no significant difference in the overall bond strength (12.1 N mm2 (SD 7.79) with primer, 13.1(SD 6.2) without primer, $p>0.05$). But, the shear bond strength at the enamel-adhesive interface was greater with the use of primer (19.7 vs 13.1 Nmm2). The failure pattern was also similar for both groups. Although this study did not show any significant differences in bond strength the results may not be applicable clinically for the following reasons – incisor brackets were used on premolars affecting bracket base area, enamel surface was ground *i.e*. aprismatic layer was lost, occlusal forces may affect failure rates, cross over effects of archwires may affect bond strength and bonding step involved precuring the primer on brackets. Similar *in vitro* studies (Wang and Tarng, 1991) (Tang et al., 2000a), also demonstrated sufficient bond strengths for orthodontic bonding without primer, when bonding with chemically cured/ light cured composite.

Another *in vitro* study (Uysal et al., 2004) compared the shear bond strengths (SBS) and ARI values of 3 flowable composites (filler content 47%. 47% and 41% by volume) with a light cured "conventional" composite with primer for bonding brackets. In this study, 80 1st and 2nd premolars were bonded with the above resins, but no primer was used with one of the flowable composites (47% filler by volume). The bond strengths achieved by all of the three flowable composites were deemed just adequate ranging from 6.6 MPa to 8.53 MPa as compared to the "conventional" composite which had a SBS value of 17 MPa. Additionally, all the flowable composites tended to display failure at the bracket-adhesive interface (ARI scores of 1 and 2). The authors suggested that due to their lower viscosity it is expected that they would flow into the etched porosities better as suggested by the ARI values, but conversely the resin did not penetrate the bracket bases adequately. The authors concluded that although the SBS achieved were acceptable, these composites may not be recommended as results in the clinical setting

may vary considerably from an *in vitro* environment. The results of this study suggest that a combination of adequate filler content and viscosity is essential for good resin penetrability and bond strength when a primer is not used. Also, the results are not applicable to this trial as flowable composites will not be used as an adhesive. Similar *in vitro* studies (Tecco et al., 2005) (Ryou et al., 2008) also demonstrated sufficient shear bond strengths for flowable composite without primer (despite greater variability), for orthodontic bonding.

However, as well as laboratory-based studies, it is also essential to consider clinical studies. Whilst these cannot control all variables to the extent of the laboratory-based studies, they may reflect a more realistic situation and will be considered next.

2.10.6.3 *In vivo* orthodontic studies with no primer

To date only three *in vivo* orthodontic studies have been published assessing the use of no primer. With two studies observing bracket failure rates and one study observing bonded retainer failure rates. This was identified by systematically searching through pub-med and med-line and orthodontic journals using the search terms of orthodontic adhesive, orthodontic primer, bracket failure, and searching through the references of any relevant articles.

A recent randomised controlled clinical trial (Bazargani et al.) compared the failure rate of bonded lingual retainers with and without the use of primer. Fifty-two patients who were planned for retention via a lower bonded retainer were randomly allocated to each group and bonded using a standardised regime by one operator. These patients were then followed up for two years, and the incidence of bond failure was recorded by a blinded operator. The study found a higher failure rate in the no primer group (27%) compared to the with primer group (4%). This was statistically significant and deemed clinically significant by the authors, who recommended bonding lingual retainers with primer. However, this is not truly applicable to bonding of orthodontic brackets as low viscosity composite was used for bonding lingual retainers compared to “normal” composite. As low viscosity generally has a lower shear bond strength

then “normal” composite this may have affected the failure rate. Also the surface area used for bonding retainers is generally less than for bonding of brackets. Therefore, previous studies observing bracket failure rates are more appropriate when analysing bonding brackets without primer.

An *in vivo*, prospective, non randomized clinical trial (Banks and Richmond, 1994) analyzed the risk of enamel decalcification as a primary outcome with or without use of sealants (Chemically cured composite & Light cured composite). Eighty patients participated in the study and were allocated to one of the two composites and alternate brackets were bonded using primer or no primer. These patients were followed up until the end of treatment. The secondary outcome was the bracket failure rate which was similar in both groups (4 % when primer is used and 3 % without primer). Although the incidence of enamel decalcification was high in both groups, the chemically cured composite and primer group had a lower incidence than the no primer group. However, primer in the light cured composite group offered no protection against enamel decalcification. This study does offer relatively stronger evidence that the sealant may play no role in preventing enamel decalcification or bracket failure rates especially when light cured composite is used. The drawbacks of this study are its lack of randomization of sample allocation; lack of appropriate statistical analysis of bracket failure rate; failure to consider cross over effects and unclear details about the duration of the study period.

A retrospective controlled study (Tang et al., 2000b) was carried out on 74 patients comparing a chemically cured adhesive with and without the use of primer on bracket failure rates. Patients were selected from the practices of two consultant orthodontists over a period of 20 years with 37 patients in each group. A standardized pre-preparation and etching regime was used. The first bracket failure incidence was retrieved from patient records (with only the first failure counted for each bracket). The overall bracket failure rate was similar in both groups (5.62 % without primer and 6.22 % with primer), and it was concluded that the fixed appliances bonded without primer worked equally well; and did not reveal any clinician or material factors which may influence bracket failure rates.

The conclusions of this study are not applicable and robust due to poor study design:

- 70% alcohol being applied to teeth after teeth etched-washed- and dried (which does not conform to “conventional” methods within the UK)
- Sample selection criteria is unclear
- Upper appliances only being assessed
- Only patients who completed treatment with full records were included- which may induce selection bias.

2.10.6.4 Summary

To summarize, the evidence available from these studies to refute the use of primer prior to bonding brackets in a clinical setting appears to be weak. The main drawbacks of these studies were related to inconsistent study designs and a lack of randomised prospective clinical trials. Many of the conclusions may not be applicable for the following reasons;

- *In vitro* studies – which may not be applicable to the clinical setting
- Use of chemically cured resins rather than light cured systems- as the primer in these materials can perform differently, and light cured composite is currently the gold standard within the UK for orthodontic bonding materials.
- Variation in bonding procedure which may cause the findings to be no longer applicable to current practice
- Use of flowable composites which are not routinely used for orthodontic bonding within the UK
- Observation of bonded retainer failure rates, which may not be applicable to the bonding of orthodontic brackets
- Cross over effects cannot be accounted for when split mouth studies are performed for bonding studies.

But, the studies suggest the need for further research to investigate if clinically acceptable bracket bond strength can be achieved without the use of a primer. To test this hypothesis, a randomised controlled trial is justified to clarify if the use of a primer is essential prior to bonding

brackets. However, the use of primer is not the only factor implicated in bracket failure, therefore the following sections will analyse some of the other factors.

2.11 Bracket type

There are several different bracket types available for orthodontic bonding with the two most commonly used within the UK being "conventional" brackets and self- ligating brackets. A modification of the "conventional" bracket system is pre-coated brackets, which has also obtained common usage within the orthodontic community.

2.11.1 Conventional brackets

"Conventional" brackets tend to operate on the principle of the straight wire appliance system that has the prescription of all three orders of bends incorporated within the bracket. This allows a "straight" wire to be tied into the brackets (typically with modules/ quick ligatures over the four tie wings) reducing the amount of wire bending required.

2.11.2 Self- ligating brackets

Self- ligating brackets (SLB) were pioneered in the 1930's and were thought to improve the speed of treatment due to reduced friction. They are similar to "conventional" brackets and operate on a straight wire system, with the main difference being the wire being held in position by closing windows built into the bracket. Recently several studies have taken place to assess SLB versus conventional brackets, with systematic reviews (Fleming and Johal, 2010, Chen et al., 2011) concluding there was no advantage in using SLB over "conventional" brackets in relation to:

- Bracket failure rate
- Speed of treatment
- Pain experienced during treatment
- Periodontal condition

Therefore, due to their greater cost and as SLB confer no additional advantage over conventional brackets; the vast majority of orthodontic

treatment within the UK is performed using conventional brackets. A variation on the conventional bracket system is pre-coated brackets.

2.11.3 Pre-coated brackets

Pre-coated brackets have the adhesive paste (composite) already placed on the base of the bracket so that adhesive does not need to be applied chair side. Pre-coated brackets therefore give a standardised amount of composite on each bracket which reduces variation when compared to when composite is applied at the chair side (Ash and Hay, 1996). Randomised controlled trials have shown no significant difference in bracket failure between rates of pre-coated brackets and self apply composite brackets (Kula et al., 2002, Verstrynge et al., 2004, Wong and Power, 2003), and no significant difference in time to place brackets (Ash and Hay, 1996, Wong and Power, 2003). One RCT demonstrated a lower failure rate with pre-coated brackets when compared to self apply brackets (Ash and Hay, 1996). This may be due to a higher filler concentration with pre-coated brackets and decreased time spent on composite "flash" removal. These factors demonstrate pre-coated brackets to be useful aids in bonding studies as they reduce the possible effects in variation in composite and the amount of composite applied to the orthodontic bracket. The literature has established a variety of bonding techniques that may be used for orthodontic bonding, but the factors that cause bracket failure also have to be considered and these are reviewed in the next section.

2.12 Bracket failure

The majority of bond failure has been reported to take place within the first year (Hobson et al., 2002(a)) and at its extreme between the initial placement of the bracket and the first review appointment (Wertz, 1980).

Bracket failure may occur for a variety of different reasons. The orthodontic literature has explored bracket failure and found it to be multifactorial, with the following list cited as possible factors involved in bracket failure:

Moisture
The tooth
Deciduous dentition
Bleaching
Bracket placement
Bracket base design
Operator variation
Force applied
These factors shall be reviewed in the following sections

2.12.1 Moisture

Moisture is a frequently cited cause of bracket failure (Egan et al., 1996, Kinch et al., 1988, Endo et al., 2008). Moisture contamination results in saliva forming a plug within the acid etched surface that cannot be simply removed by water, and this in turn leads to decreased penetration of the bonding agent (Hormati et al., 1980), which may lead to 50% reduction in bond strength. It has been reported that contact of saliva for one second may dramatically reduce the quality of etch achieved, therefore if saliva contamination occurs it is recommended that the tooth be etched once again (Silverstone et al., 1985). Hydrophilic priming agents have been developed to decrease the effect of moisture contamination, but to date have not been demonstrated within the orthodontic literature to provide decreased bracket failure rates to date. The risk of moisture contamination may be reduced by decreasing the amount of stages in bonding, thus decreasing bonding time. Therefore, within *in vivo* bonding studies moisture control procedures should be stringent, to prevent the risk of moisture contamination.

2.12.2 Tooth

Bond strength has been demonstrated *in vitro*, to be superior in posterior teeth than in anterior teeth (Linklater and Gordon, 2001, Hobson et al., 2001). However, this is opposed to the normal clinical picture, as more failures occur on posterior teeth than anterior (Trimpeneers and Dermaut,

1996, Linklater and Gordon, 2003, Hobson et al., 2002(a)). With a reported debond rate of 33.7% on 1st molars (Banks and Macfarlane, 2007) compared to premolar to premolar debond rate of 5-8% (Mitchell, 1994). However, one clinical trial showed no difference in debond rates along the arch (Kinch et al., 1988), but the same author did go onto note that the debond characteristics varied dependent on the tooth position within the arch (Kinch et al., 1989). It is therefore recommended that future *in vitro* studies looking at bond strength and failure rate be standardised, recommending that the same tooth type is used, facilitating comparison of different studies.

It is speculated that the cause of higher failure rates in posterior teeth is due to inferior adaptation of the bracket base leading to an increased thickness of adhesive material, which decreases shear bond strength. Another possible factor is the increased presence of aprismatic enamel in posterior teeth which leads to decreased quality of the etch pattern, which in turn leads to decreased bond strength and higher failure rates . Another factor is moisture control, due to decreased access to the posterior dentition and the proximity of the parotid duct, adequate moisture control is harder to maintain, and as discussed previously even brief saliva contact can dramatically reduce the bond strength. Therefore, when orthodontic bonding studies are performed, survival analysis is also used to analyse the failure rate at specific sites.

2.12.2.1 Deciduous dentition

The deciduous dentition has different enamel characteristics compared to the adult dentition which leads to decreased bond strengths, but the strength achieved is still adequate for orthodontic bonding (Endo et al., 2008, Ozoe-Ishida et al., 2010), with no special measure required in terms of bonding. However, other factors may need to be taken into consideration when bonding to deciduous teeth *i.e*. root resorption. In conclusion, it appears reasonable to assume the bracket failure rate for deciduous teeth would be similar to permanent teeth. Therefore, when performing bonding studies deciduous teeth do not need to be excluded.

2.12.2.2 Dental bleaching

Dental bleaching is on the increase, with the populations' higher cosmetic expectations and desires. It was speculated that due to the bleaching of the enamel bond strengths would be decreased. However, it has been demonstrated that there is no difference in the SBS between bleached and non bleached teeth and if bonding carried out three weeks after bleaching a failure rate of 2.3% was observed (Mullins et al., 2009) . This compares favourably against previous bonding studies. In conclusion, bleached teeth do not need to be excluded from orthodontic bonding studies, as the bond failure rate is similar to that previously established for non bleached teeth.

2.12.3 Bracket placement technique

With the advent of pre adjusted edgewise appliances bracket positioning has gained even more importance: with the adage of "good finishing begins with good bracket positioning" becoming a common phrase within orthodontic circles.

There are two well-established techniques when it comes to placing ("bonding") the brackets to patients' teeth:

1. Indirect technique
2. Direct technique

2.12.3.1 Indirect technique

The indirect bonding technique involves obtaining a cast of the patient's dentition and then "determining" the exact bracket position on these models. A jig is than fabricated on the model so that these positions are translated to the patient and secured into the correct position using a composite adhesive, but the accuracy of this placement is highly dependent upon the accuracy of the models obtained.

2.12.3.2 Direct technique

The direct bracket placement of brackets is similar to that of the indirect technique with the exception that no jig is manufactured to aid in the placement of brackets (reduces laboratory costs). The clinician places the bracket free hand in what they judge to be the correct position. This allows the clinician to customise the bracket position for the patients malocclusion e.g. overcorrection of rotations. The bracket is then firmly pressed against the tooth, and the excess material is removed and the adhesive cured in the appropriate manner.

Theoretically, indirect bonding permits more accurate bracket placement because of the ability to see the bracket position from many different angles. However it has the potential disadvantages of increased bond failure rates due to increased adhesive material between the bracket and the tooth (Zachrisson and Brobakken, 1978), increased laboratory time (Aguirre et al., 1982). and increased flash around the brackets (Zachrisson and Brobakken, 1978), thus leading to increased plaque retention and thereby demineralisation.

Several studies have been carried out in this field with conflicting results. An *in vivo* study (Zachrisson and Brobakken, 1978) demonstrated a bracket failure rate of 2.5% with direct bonding compared to 14% of indirect bonding. However, within this study there was considerable technique variation between the two groups. For example, chemical cure composite was used in the indirect group whilst light cure composite was used in the direct bonding group.

In another *in vivo* study (Aguirre et al., 1982) comparing direct and indirect bonding techniques, it was shown there was no significant difference in the bracket failure rate between the two groups after three months and no difference in the accuracy of the two techniques.

Further *in vivo* studies showed a failure rate of 6.5% (Read and O'Brien, 1990) with the indirect technique using light cured composite, and 5.6% (Miles and Weyant, 2003) for chemical cure composite using the indirect technique, which are both comparable with the direct technique.

In other *in vivo* studies comparing the two techniques, no differences in bond failure rates were observed when using light cured composite(Thiyagarajah et al., 2006) and no difference in duration of treatment and number of appointments. (Deahl et al., 2007) Therefore the use indirect bonding remains one of operator preference.

2.12.4 Bracket base

The majority of bracket failures occur at the bracket /adhesive interface . One of the factors that determines bond strength is the bracket base , with the type of base effecting the bond strength . Research has also shown that plaque retention rates differ between bracket base types with perforated bases retaining more plaque than mesh bases .

All bracket bases have been shown to provide sufficient bond strength for orthodontic bonding; however mesh bases have been demonstrated to obtain greater bond strength than other base types . A more recent advent within dentistry is the use of sandblasting; this technology has been used on bracket bases but has been shown not to improve bond strengthto a clinically significant degree (Faltermeier and Behr, 2009, Lugato et al., 2009). *In vitro* studies have also shown no significant differences in bond strength with variations of mesh bases by different manufacturers e.g. double mesh/ single mesh .

The size of the mesh has been demonstrated to be most effective between 80-100 gauges (Maijer and Smith, 1981) (Cucu *et al*., 2002). However, another author recommended a gauge of 50-70 (Reynolds and von Fraunhofer, 1976), but this *in vitro* study did not evaluate any bracket bases in the 80-99 range, only comparing 50-70 with 100-150.

Larger bracket bases should logically provide greater bond strengths than smaller bases due to increased surface area available for bonding. However, as previously discussed (section 2.12.2) , tooth variability has a role to play in bond strength, and with an increased surface area the bracket base will be more likely to be effected by this variability (Cucu *et al*., 2002). In summary, mesh bases have been shown to provide the

highest in vitro bond strengths, and the size of the mesh should be between 50-100 gauge for optimal orthodontic bonding.

2.12.5 Operator variation

It has been demonstrated in the literature (Millett *et al*., 2001) that different operators obtain different bracket failure rates. Therefore, to reduce the size of the sample required and the effect of operator technique, one operator should bond the brackets on all the patients and carry out the treatment on these patients, as treatment mechanics/ methods vary from individual to individual.

2.12.6 Force

The important variable in bracket failure in terms of force is shear bond strength. As previously cited a minimum shear bond strength of 5-8MPa (Reynolds and von Fraunhofer, 1976) is the accepted figure for orthodontic bonding. If excessive force is placed on the bracket, inevitably failure will occur. The factors which effect how much force is excessive have previously been discussed. Therefore, light forces should be used in orthodontic treatment, and attempt to standardise the forces used, and one operator should apply the mechanics as mentioned in section 2.12.5. Once the bracket has failed, there is often adhesive residue left on the tooth which needs to be removed before a new bracket can be bonded. A method of describing the amount of residue remaining is the adhesive remnant index.

2.12.7 Adhesive remnant index (ARI)

The adhesive remnant index was first described by (Artun and Bergland, 1984) and since then has gained common usage within the orthodontic community when assessing bracket failure/ debonding. The index is a point based system ranking from 0 to 3:

0= no composite left on tooth

1= less than half of the composite left on the tooth

2= more than half of the composite left on the tooth

3= all composite left on tooth with a distinct impression of the bracket base

It would be favourable if the bracket failed at the tooth/ adhesive interface; minimising the time required to clean the tooth after failure/ debonding (Fox et al., 1994). However, the majority of failures occur at the adhesive/ bracket interface (Maijer and Smith, 1981). Therefore if the bond strength to the tooth is reduced (but still sufficient for orthodontic bonding), or the bond strength is increased at the bracket/ adhesive interface, this may lead to a reduction in the ARI produced on debonding/ failure.

The literature has been reviewed regarding factors implicated in bracket failure; however, what are the implications of bracket failure on treatment and the patient experience?

2.13 Problems with failure

Bracket failure has been demonstrated to increase total treatment time (Skidmore et al., 2006, Haeger and Colberg, 2007, Beckwith et al., 1999) and the number of appointments required to complete treatment (Haeger and Colberg, 2007). One author in a retrospective analysis of their own practice reported treatment time to be on average 2.8 months longer and require 1.5 appointments more if the patient had a bracket failure. The author also reported that for every bracket failure treatment time was increased by 1.21 months and 0.77 appointments (Haeger and Colberg, 2007). Therefore reducing the bracket failure rate will decrease the cost to the practice of the treatment, as well as ensuring waiting lists are kept to a minimum (Haeger and Colberg, 2007). Another consequence of increased treatment time is for patient cooperation to decrease (Berg, 1979), which may lead to inferior treatment outcomes.

When a bracket fails there is also the risk that the bracket may be ingested or inhaled (Al-Wahadni et al., 2006, Laureano Filho et al., 2008, Wenger et al., 2007). When a bracket is lost within the patient's mouth and cannot be located, the patient should be immediately sent to accident and emergency for radiographic evaluation, to see if it has been ingested

or inhaled. If a bracket is ingested it typically passes through the GI system in 7-10 days, however on rare occasions, the bracket may become lodged within the GI tract, but due to the small cross sectional area and lack of sharp edges- this is unlikely, with no documented cases to date. If inhaled the bracket must be retrieved immediately (normally via radiographic guided endoscopy). As the bracket is contaminated with bacteria from the oral environment, and if left in situ it may cause infection, lung abscess, pneumonia and Atelectasis. Therefore, bracket failure has potentially life threatening consequences, so any research looking at bracket must be ethically approved and scientifically robust.

2.14 Study design

Evidence-based dentistry/ medicine and has become accepted as the way dentistry should move forward. In the hierarchy of evidence-based dentistry (Figure 1,(Evans, 2003)), systematic reviews are the highest level, with the second highest level being prospective randomised controlled clinical trials (RCTs). RCTs hold this high place in the hierarchy of evidence due to well-designed RCTs reducing potential biases and confounders (known and unknown) within the study e.g. prospective – reduces recall bias. (Sibbald and Roland, 1998)

Figure 2.1: Hierarchy of evidence-based dentistry

Level	Description
One	Strong evidence from at least one systematic review of well designed randomised controlled trials (RCTS)
Two	Evidence from at least one properly

	designed RCT of appropriate size
Three	Evidence from well designed trials without randomization: cohort, time series or matched case controlled studies
Four	Evidence from well designed non-experimental studies from more than one centre or research group
Five	Opinions from respected authorities, based on clinical evidence, descriptive studies or reports from committees
Six	Views of colleagues/peers

Lower level evidence is not necessarily false. However lower level studies have a greater risk of false-positives and therefore have a higher chance of misleading results leasing to recommendations that may not be in the best interests of the patient.

Recent RCTs comparing orthodontic bonding systems have used a 'split-mouth' design where one side or contra-lateral quadrants are bonded using a study adhesive, whilst the alternative side/quadrants serves as the control adhesive. The advantage of this method is that 'patient factors', such as poor care of the appliances will be accounted for evenly, as the patient acts as their own control (Miller, 1997). The main purpose of this design is that by making within-patient comparisons rather than between-patient comparisons, the error variance of the experiment can be reduced. However, unfortunately in bonding studies, due to the interlinking of brackets the treatment effects may 'carry-over' across the quadrant and this may affect the bracket failure rates. Therefore, unless prior knowledge indicates that no carry over effects exist, the reported estimates of bracket failures are potentially biased. (Mandall, Hickman, *et al* 2009). Banks and Thiruvenkatachari (2007) argued that a split mouth

design was inappropriate for the above reasons and therefore within their RCT on bracket failures with a self etch and primer randomly allocated individual patients to each intervention. It is likely that such a study design may increase the sample size, but improve the validity of the trial.

A recent Cochrane review (Mandall, Hickman, *et al* 2009) on orthodontic bonding has suggested that future studies on bracket failures should measure decalcification as a secondary outcome where appropriate. The other recommendations from the review were for a prior sample size calculation to take place; clear inclusion and exclusion criteria; accountability for patient withdrawal and drop outs and modifying the statistical analysis if appropriate; assessing for occlusal interferences that may affect bond failure; blinding; treating all patients in the same way apart from the intervention; use of appropriate statistical analyses and accountability for clustering in study designs.

2.14.1 Statistics

Clustering causes the generation of data that fits outside of the normal distribution i.e. one patient breaks several brackets more than the mean. These values may be treated in one of two ways. Firstly, they may be dismissed and regarded as a nuisance value by using generalising estimating equations (GEE) modelling. However, as stated within a recent systematic review (Mandall, Hickman, *et al* 2009) clustering should be accounted for in the statistical analysis. The second approach is to include the clustered data within the model; this is accomplished with the use of multilevel modelling, which uses the clustered data to provide further information and refinement of the model.

A recent statistical trial (Petracci et al., 2009) analysed methods of statistical analysis on a cohort of survival data from a bracket failure study. It was hypothesised that as bracket failures are not an independent variable, but in fact dependent on several variables e.g. position within the arch. Therefore, when performing a survival analysis a simple Cox proportional hazards model is not appropriate. A method for improving this model is to perform a frailty model, where there is an association

between the failure time and a random effect (i.e. frailty). This improves the quality of the research, by allowing heterogeneity of the sample to be considered. Therefore, the author concluded, a Cox proportional hazards with frailty model is a useful model for bracket failure studies and that this should be used in preference to a simple Cox proportional hazards model in future studies.

2.15 Summary

Therefore to summarise the available literature:

- There is evidence that orthodontic bracket bond strengths may be adequate without the use of primer, although further research is required
- No prospective randomised controlled trial has been carried out to date comparing orthodontic bracket bonding with and without primer
- Phosphoric acid is the current gold standard for etchants
- Pre coated brackets have a similar failure rate to orthodontic brackets when composite is applied at the chair side, and have a consistent amount of composite on the bracket.
- A commonly used secondary outcome for bracket failure studies is the ARI, due to its ease of use and ability to indicate the site of bond failure.
- The majority of bracket failures occur within one year of placement

3. Aims and hypothesis

3.1 Aims of the study

The objective of the trial is to compare direct orthodontic bonding of APC Victory II brackets with and without the use of Transbond® primer by investigating:

- If there is a difference in the bracket failure rate.

- If the bonding time per bracket is different between the groups
- The type of bond failure using the ARI index.

3.2 Hypothesis

The null hypotheses to be tested in this study are:

- There is no difference in the bracket failure rate when pre-adjusted edgewise metal brackets (APC Victory II) are bonded with (control group) or without (experimental group) Transbond® primer over a 6 month period
- There is no difference in the bonding time per bracket between the control and experimental group.
- There is no difference in the type of bond failure as assessed by the ARI index between the control and experimental group.

In order to assess orthodontic bracket bonding without primer, a randomised controlled clinical was designed that would assess orthodontic bracket bonding without primer (experimental group) and with primer (control group). Randomisation was achieved via the use randomly generated number tables to reduce selection bias. Patients were bonded using a standardised procedure by one operator to reduce

the effects of operator variation. Outcome measures used were: bracket failure rate, ARI and time to “bond up”. The study duration was 6 months.

4. Method of Investigation

4.1 Ethical approval

Ethical approval was sought by S. Nandhra and S. Littlewood at Leeds (East) Research Ethics Committee via use of IRAS (Integrated Research Application System), and was granted on the 18th of December 2009 after amendments to the children’s consent form and the statistical analysis to be performed (appendix 1).

4.2 Research and development

Research and Development (R&D) approval was sought at two National Health Service (NHS) trusts (Leeds teaching Hospital NHS Trust and Bradford Hospitals NHS Trust). R&D approval was granted on the 5th of February 2010 and the 23rd of February 2010 respectively. Informed consent was obtained from patients and parents as appropriate prior to the commencement of treatment.

4.3 Information and consent forms

4.3.1 Information leaflets

Information leaflets were provided to patients and parents, children under the age of 16 years received an information leaflet for children (appendix 2), with their parents obtaining the information sheet for adults (appendix 3). If the patient was above the age of 16 they received an information leaflet for adults (appendix 3). Patients and parents were given the information leaflets at least 24 hours prior to informed consent being obtained. Patients and parents were also allowed to read the information leaflet at their own leisure and ask any questions as they deemed appropriate before informed consent was sought.

4.3.2 Informed consent for adults

The consent procedure involved provision of an information leaflet as above at least 24 hours before consent was sought. On the day of the appointment, the operator (S. Nandhra) outlined the study once again and enquired if there were any further questions. If the patient was willing to participate they were asked to sign the consent form for adults (appendix 4) and a copy of the signed form was returned to the patient

4.3.3 Informed consent for children

The consent procedure for children was similar to that of adults as described above. In addition to this, informed consent was obtained from

the patient's parents/ guardian (appendix 5) and Assent (appendix 6) sought from the patient.

4.3.4 Informing referring practitioners

Once consent had been obtained, a letter (appendix 7) was sent to the referring practitioner and the patients' general dental practitioner, informing them of the patients' enrolment within the study.

4.4 Sample Size and Sample Size Calculation

The sample size for each group was estimated by the total number of brackets required for each patient in either the test (No primer) or control group (with primer) for both the upper and lower arches.

A difference of 5% would be acceptable to prove the non inferiority of control (with Transbond® primer) to experiments (without primer). Calculation of sample size to demonstrate inferiority of control was based on maximum difference of 5%, between the two groups and a clinically failure rate of 15% in both groups. For a power of 80% and a type I error of 10%, (one sided test), the sample size necessary to detect non inferiority between the interventions is 469 brackets per group. The formulae used to determine sample size is shown below.

$$m = \frac{2(z_{1-\alpha} + z_{1-\beta})^2 p(1-p)}{\varepsilon^2}, \text{ where p1=p2=p}$$

This would result in a sample size of 23 patients per group assuming that each patient would require at least 20 brackets. However, the study has to account for clustering of brackets within each patient. Previous studies on bracket failure rates used either split-mouth designs (which have cross-over effects) or they do not account for clustering or the design effect.

The design effect provides a correction for the loss of sampling efficiency, resulting from the use of cluster sampling as opposed to simple random sampling. Thus, 'Design effect' may be simply interpreted as the factor by which the sample size for a cluster sample would have to be increased in order to produce survey estimates with the same precision as a simple random sample.

Ideally, an estimate of D for the indicators of interest could be obtained from prior surveys in any given setting. However, unfortunately there are no studies in bracket failures which account for this. If no information is available on the magnitude of design effects for the indicators of interest, the use of a default value is recommended. In many cluster surveys, a default value of D = 2.0 is used. Assuming that cluster sample sizes can be kept moderately small in target group survey applications (*e.g.* not more than 25 elements per cluster), the use of a standard value of D = 2.0 should adequately compensate for the use of cluster sampling in most cases.

Design effect = 1+ (k-1) *intra-class coefficient where k is the cluster size.

i.e. 460 x 2(design effect) = 920 brackets per group

This translates into 920/20 = 46 patients per group

4.5 Subjects

Patients were taken from the waiting lists at the orthodontic departments of the Leeds Dental Institute and St. Luke's Hospital Bradford. The inclusion and exclusion criteria were as follows:

4.5.1 Inclusion criteria

- Patients requiring single or two arch fixed appliance therapy (with no history of previous orthodontic treatment)

- Willing to consent to participate in the trial

4.5.2 Exclusion criteria

- Patients with craniofacial anomalies and those requiring orthognathic surgery
- Patients with several buccal restorations or congenital enamel defects
- Severe hypodontia cases (with more than one tooth missing in each quadrant)

4.6 Assignment

The study was a randomised controlled clinical trial with two groups. All consecutive patients who needed fixed appliance therapy were taken off the waiting list and no attempt was made to match them for age, gender or malocclusion to ensure a representative sample, except for the exclusion criteria. After informed consent was obtained, they were randomly allocated to either the control group (with Transbond® primer) or experimental group (without primer). This was carried out by preparing opaque, numbered sealed envelopes in advance by an independent party (GN) using a random number table, allocating even numbers to group two and odd numbers to group one. The operator (SN) enrolled the participants within the study and assigned them to their group using the sealed envelopes which blinded the operator and participants to the assignment before enrolment. Once the envelopes were opened, the blinding of the operator was lost. The operators therefore cannot be blinded in this trial as the intervention administered to the test group cannot be blinded. Treatment was started on all patients within three months of the enrolment within the study.

4.7 Subject withdrawal criteria

Subjects could voluntarily withdraw from the study at any time without any compromise to the agreed and proposed treatment. Such a subject was accounted for during data and statistical analysis. The drop-out was not replaced during the trial. All data pertaining to first time bracket failure was recorded as agreed, until the withdrawal date for an individual sample. The follow up of such a patient was for orthodontic treatment only and data pertaining to the trial was not subsequently recorded after a participant confirmed their withdrawal.

4.8 Trial termination

It was agreed that the trial would be terminated if more than 50% of the brackets failed (greater than 8 brackets per patient) in the experimental group in at least three patients within the first review appointment (6 weeks). This was because such a high failure rate would be to the detriment of the patient and is clinically unacceptable for continuation of routine orthodontic treatment within the experimental group. This was monitored by the principle investigator (SN) and the chief investigator (Simon Littlewood).

4.9 Bonding Procedure

The same clinician (SN) carried out the bonding procedure and subsequent orthodontic treatment for a period of at least 6 months. The bonding procedure was standardised as follows.

Control group

- Moisture control as deemed appropriate (Isolation with cotton wool rolls and cheek retractors and the use of a saliva ejector)
- 30 second wash and 30 second dry using 3 in 1 syringe, if gross debris present
- 30 second etch with 37% phosphoric acid gel
- 30 second wash and 30 second dry using 3 in1 syringe

- Application of Transbond® primer to acid etched enamel and air thinned.
- Adhesive pre-coated bracket (APC Victory II™, 3M Unitek) placed at long axis point on the buccal surface of the tooth
- Light polymerisation; 30 seconds mesially and 30 seconds distally on each tooth
- Insertion of an appropriate sized arch wire, dependent on the severity of patients' malocclusion.

Test group

- Moisture control as deemed appropriate (Isolation with cotton wool rolls and cheek retractors and the use of a saliva ejector)
- 30 second wash and 30 second dry using 3 in 1 syringe, if gross debris present
- 30 second etch with 37% phosphoric acid gel
- 30 second wash and 30 second dry using 3 in1 syringe
- Adhesive pre-coated bracket (APC Victory II™, 3M Unitek) placed at long axis point on the buccal surface of the tooth
- Light polymerisation; 30 seconds mesially and 30 seconds distally on each tooth
- Insertion of an appropriate sized arch wire, dependent on the severity of patients' malocclusion.

All teeth for the appropriate group were bonded using the above procedures, all incisors, canines, pre-molars and 1st molars were included within the study. If 2nd and 3rd molars were to be bonded, the same bonding procedure was followed; however these teeth were not included within this study.

Data recorded on the bonding visit(s) was (appendix 9);

- Patients hospital number
- Patients date of birth
- Patients initials
- Study participant number
- Study group
- Operator

- Teeth bonded
- Start time of bonding procedure (signified by the 1st application of etchant)
- Finish time of bonding procedure (signified by the end of the light curing cycle on the last tooth)

Once the bonding procedure was completed a colour coded sticker was placed on the patients file to signify which study group they belonged to.

4.10 Bracket failure

If bracket failure occurred ideally the patient would be seen by the same operator (SN) to bond a new bracket. However, due to the nature of casual appointments this was not always possible. All clinicians that could potentially see one of these patients as a casual were fully briefed on the details of the study. At the date of the casual appointment all clinicians were asked to fill in a form (appendix 10), recording the bracket(s) that failed; patients initials; patient hospital number; patients' date of birth; the study group patient was within; the adhesive remnant index; and the date of the bracket failure. (If the patient did not remember the date of the failure the date of the casual appointment was recorded as the date of failure.) A new APC Victory™ bracket was bonded using the appropriate technique and the completed form passed onto SN.

4.11 Blinding

Blinding of the clinician to the use of primer was not possible, although every effort was made as described previously to minimise bias. The patients may have been unaware of which group they were within, however as a stage is missed in the bonding procedure with the experimental group it was also not practical to blind the patients.

4.12 Data Collection

The study duration was 6 months from the date of bonding and bracket failures were recorded as described above using appendix 9. Six months was chosen as most failures occur within the first six weeks of treatment. The date of the first bracket failure for each tooth was recorded, with subsequent failures not recorded to minimise clustering effects. The data was then collated and recorded within a spreadsheet in Microsoft Excel (2008). To allow sufficient time for statistical calculations to be carried out a cut off date for recruitment was determined to be 01/10/2011.

4.13 Statistical analysis

The primary aim of this study was to compare the intervention and the study group. The study intervention will be declared non-inferior to the control (with primer) if the confidence interval for the difference between failure rates of intervention and control covers only values that are smaller than the pre-determined error margin of 5%.

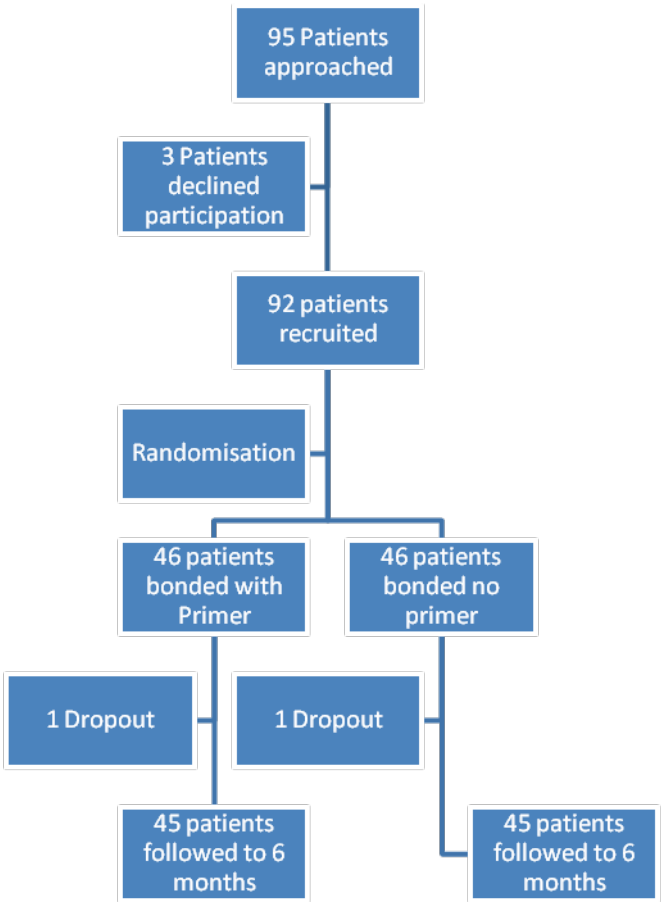
Secondary analysis to investigate the effects of confounders like age, sex etc will be conducted using multilevel logistic regression model as the outcomes are correlated (i.e. clustered within a subject). Survival curves for the test and control group will be compared using the Kaplan Meir estimate of survival function. Further analysis to investigate the effects of covariates was carried out using the Cox regression with frailty model with response time to failure. A p value of 0.05 or less will be considered statistically significant.

Data analysis was carried out with assistance from Mrs T. Munyombwe a lecturer in biostatistics within the University of Leeds.

5 Results

Ninety five patients were approached for inclusion within the study and 92 patients agreed to participate in the study (53 Females and 39 Males) and randomised into each group, as described within the methodology (section 4.6) . Patients were monitored for a period of 6 months and 2 patients withdrew from the study.

Figure 5.1 Consort flow diagram



5. 1 Sample demographics

Below displayed in tabular form are the study sample demographics.

Table 5.1 Study sample demographics

	With Primer	No Primer
Patients	46	46
Male	23	16
Female	23	30
Mean age (years)	15.6	15.6
Minimum age (years)	11.5	9.7
Maximum age (years)	33.7	29.7
LDI	24	24
St Lukes	22	22

The table demonstrates a similar demographic distribution of both study groups.

5.2 Bond failure rates

Bond failure rates for both groups are shown in the table below (table 5.2) for the duration of the study

Table 5.2 bracket failure rate at 6 months

Study Group	Total N	Number of failures	Censored	
			N	Percent
With Primer	794	70	724	91.2%
No Primer	809	112	697	86.2%
Overall	1603	182	1421	88.6%

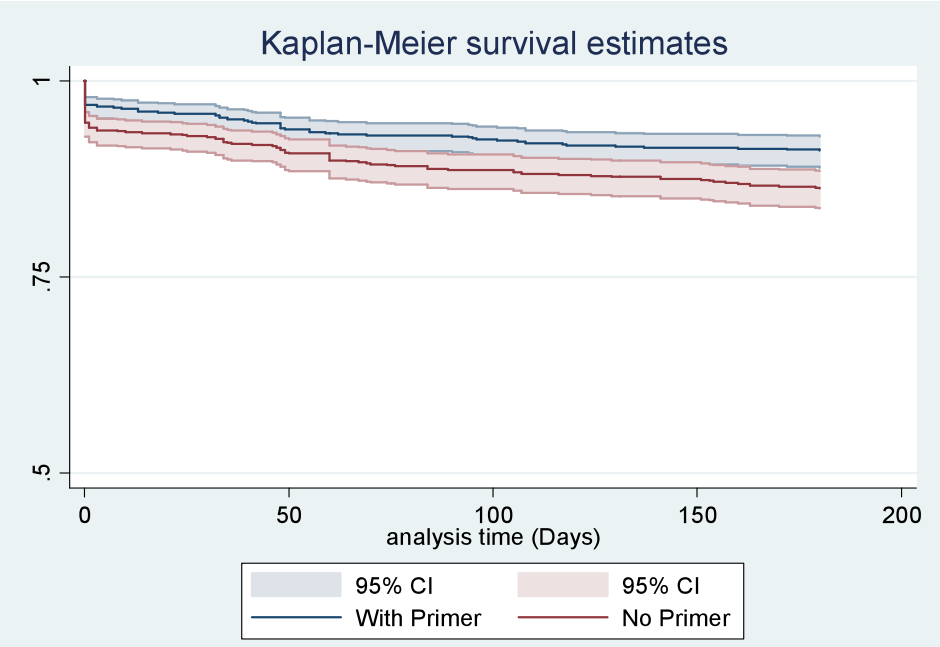
The bracket failure rate at 6 months for bonding with primer is 8.8% and without primer is 13.8%.

The difference in the percentage failure rate between the two groups at six months is 5%.

5.2.1 Survival rates

In order to compare the data with other research life tables were constructed for each group and then analysed.

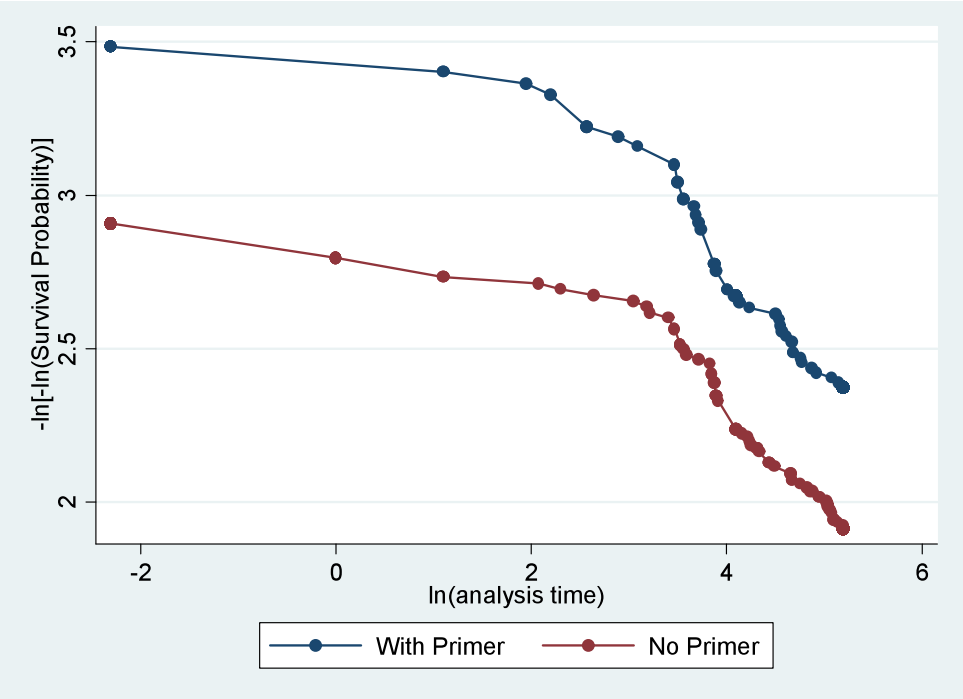
Figure 5.2 Kaplan Meier plot for bracket failure with and without primer.



This graph shows the percentage survival (in days) for brackets bonded with and without primer, with the shaded areas demonstrating the 95% confidence interval for each group.

In order to see which model was appropriate the data was tested to see if it conformed to a proportional hazards model.

Figure 5.3 Graph to test the validity of proportional hazards model



This graph shows that the bond failure rates run parallel to each other therefore the data conforms to the proportional hazards model. Therefore the appropriate test was a Cox proportional hazards model with frailty

Exploration for possible covariates was performed using MLWin with the following equation below generated.

Fig 5.4 MLWin equation for possible covariants

$$\text{Censor (6 months)0= no failure 1=failure}_{ijkl} \sim \text{Binomial}(\text{Cons}_{ijkl}, \pi_{ijkl})$$

$$\text{logit}(\pi_{ijkl}) = -0.057(0.141)\text{No Primer}_{l} + -0.964(0.196)\text{Lateral Incisor}_{ijkl} + -1.694(0.244)\text{Canine}_{ijkl} + -1.810(0.268)\text{1st Premolar}_{ijkl} + -0.928(0.210)\text{2nd Premolar}_{ijkl} + -0.478(0.224)\text{1st Molar}_{ijkl} + -0.519(0.149)\text{St Lukes}_{l} + -0.432(0.139)\text{Upper}_{ijkl} + -0.883(0.192)\text{16 and above}_{ijkl} + -0.662(0.144)\text{Right}_{ijkl}$$

$$\text{var}(\text{Censor (6 months)0= no failure 1=failure}_{ijkl} | \pi_{ijkl}) = \pi_{ijkl}(1 - \pi_{ijkl})/\text{Cons}_{ijkl}$$

$$\textit{Deviance(MCMC)} = 1205.458(1605 \text{ of } 1605 \text{ cases in use})$$

This equation demonstrates a logistic multilevel model with the odds ratio and standard error (in brackets) of the possible covariants within the simplest model that gave the highest explanatory value. These variables were Tooth Number, Hospital, Arch, Age at patient at bonding (Above or below 16), left or right side of the patients mouth. Therefore, a Cox proportional hazards model with frailty was performed to see if these factors were significant within a survival model. The factors which gave the best model were tooth number and study group and can be seen in table 3 (all other factors not statistically significant).

5.2.2 Cox proportional hazards model with frailty including 1st permanent molars

Table 5.3 Bracket failure as analysed by Cox proportional hazards model with frailty.

```
Cox regression --
         Breslow method for ties                 Number of obs      =      1604
         Gamma shared frailty                    Number of groups   =        92
Group variable: idnumber

No. of subjects =         1604                  Obs per group: min =         4
No. of failures =          181                                avg =  17.43478
Time at risk    =     260632.7                                max =        24

                                                Wald chi2(6)       =     33.14
Log likelihood  =   -1287.4463                  Prob > chi2        =    0.0000
```

_t	Haz. Ratio	Std. Err.	z	P>|z|	[95% Conf.	Interval]
studygroup	1.610518	.3935302	1.95	0.051	.9976408	2.5999
_Itoothnum~2	1.203412	.2777385	0.80	0.422	.765532	1.891757
_Itoothnum~3	.6028904	.1645208	-1.85	0.064	.353148	1.029248
_Itoothnum~4	.5436658	.1619667	-2.05	0.041	.3032114	.9748066
_Itoothnum~5	1.163546	.2811103	0.63	0.531	.7246608	1.868237
_Itoothnum~6	2.194031	.5598052	3.08	0.002	1.330636	3.617646
theta	.7849826	.2273011				

```
Likelihood-ratio test of theta=0: chibar2(01) =   39.85 Prob>=chibar2 = 0.000

Note: standard errors of hazard ratios are conditional on theta.
```

The Log likelihood ratio (-1287.4463) and Prob> Chi2 (0.0000) are measures of significance with the closer these numbers are to 0 the higher the explanatory value of the model. The Wald chi2 (33.14) also is a measure of explanatory value with the higher the value the greater explanatory value of the model. All these measures show that the model has a high explanatory value.

This model indicates that brackets bonded without primer are 1.61 times more likely to fail than with primer. However, there is no statistically significant difference in bracket failure rate when bonding with or without primer as the P value is greater than 0.05 (0.051) and the 95% confidence interval for the hazard ratio includes 1 (0.9976 – 2.5999).

5.2.3 Bond failure rates excluding 1st Permanent molars

As most bonding studies are performed from premolar to premolar further analyses were generated which excluded 1st permanent molars

Table 5.4 Bond failure rates with respect to study group excluding 1st permanent molars

Study Group	Total N	Number of failures	Censored	
			N	Percent
With Primer	712	58	654	91.9%
No Primer	747	93	654	87.6%
Overall	1459	151	1308	89.7%

This table shows that the bracket failure rates when excluding 1st permanent molars were excluded were 8.1% with Primer and 12.4% without primer which is a difference of 4.3% over a six month period.

Table 5.5 Bracket failure as analysed by Cox proportional hazards model with frailty excluding 1st permanent molars

```
Fitting final Cox model:

Iteration 0:   log likelihood = -1117.7314
Iteration 1:   log likelihood = -1093.8785
Iteration 2:   log likelihood = -1067.5881
Iteration 3:   log likelihood = -1064.9603
Iteration 4:   log likelihood = -1064.8755
Iteration 5:   log likelihood = -1064.8753
Iteration 6:   log likelihood = -1064.8753
Refining estimates:
Iteration 0:   log likelihood = -1064.8753

Cox regression --
         Breslow method for ties                 Number of obs      =      1458
         Gamma shared frailty                    Number of groups   =        92
Group variable: idnumber

No. of subjects =         1458                  Obs per group: min =         4
No. of failures =          150                                 avg =  15.84783
Time at risk    =       238748                                 max =        20

                                                Wald chi2(1)       =      2.81
Log likelihood  =   -1064.8753                  Prob > chi2        =    0.0939
```

_t	Haz. Ratio	Std. Err.	z	P>|z|	[95% Conf.	Interval]
studygroup~r	1.530871	.3891721	1.68	0.094	.930142	2.519577
theta	.8050861	.2482737				

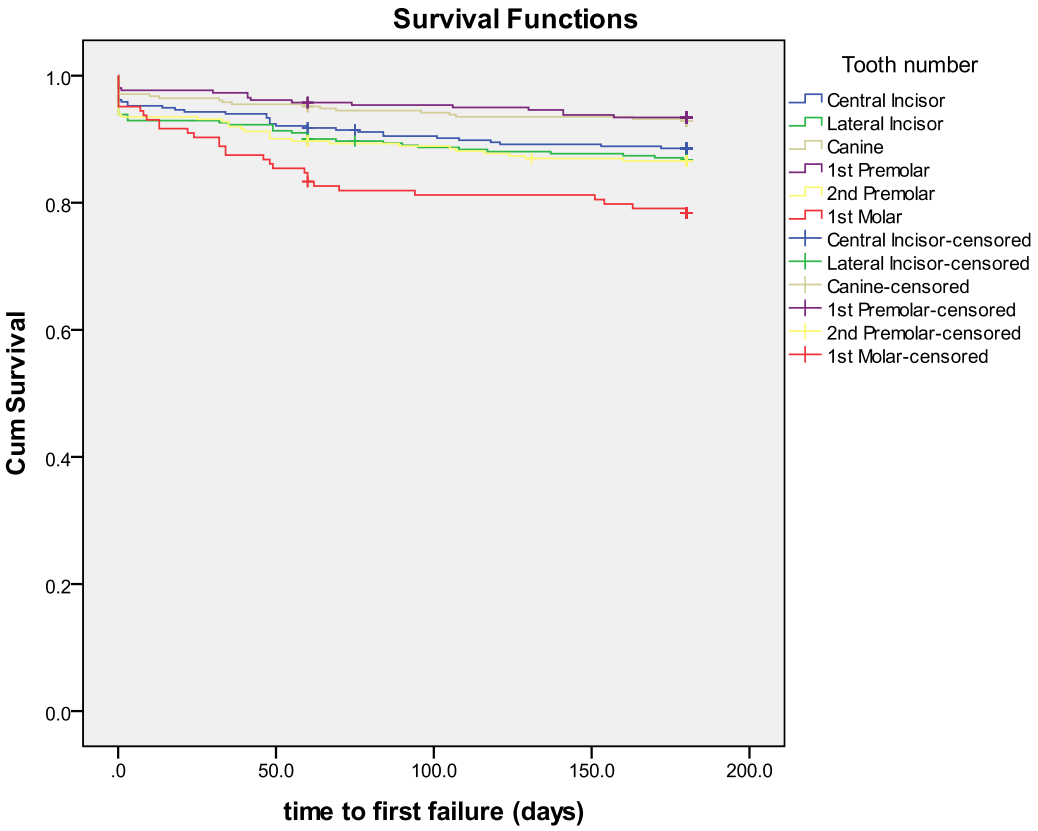
```
Likelihood-ratio test of theta=0: chibar2(01) =   34.19 Prob>=chibar2 = 0.000

Note: standard errors of hazard ratios are conditional on theta.
```

The Log likelihood ratio (-1064.8753) and Prob> Chi2 (0.0939) demonstrate a high the explanatory value of the model. However, the Wald chi2 (2.81) shows a low explanatory value of the model. All these measures show that the model has a high explanatory value. The Cox proportional hazards model with frailty indicates that brackets bonded without primer are 1.53 times more likely to fail than with primer. However, there is no statistically significant difference in bracket failure rate when bonding with or without primer as the P value is greater than 0.05 (0.094) and the 95% confidence interval for the hazard ratio includes 1 (0.93– 2.52).

5.3 Distribution of bond failures

Total bond failures in relation to tooth type. Below in figure 5 shows a graphical demonstration of bracket failures in relation to tooth type.

Figure 5.5 Kaplan Meir graph by tooth number. (Upper and lower arches combined)



The figure demonstates that the highest percentage of bracket failures occured on the 1st molar

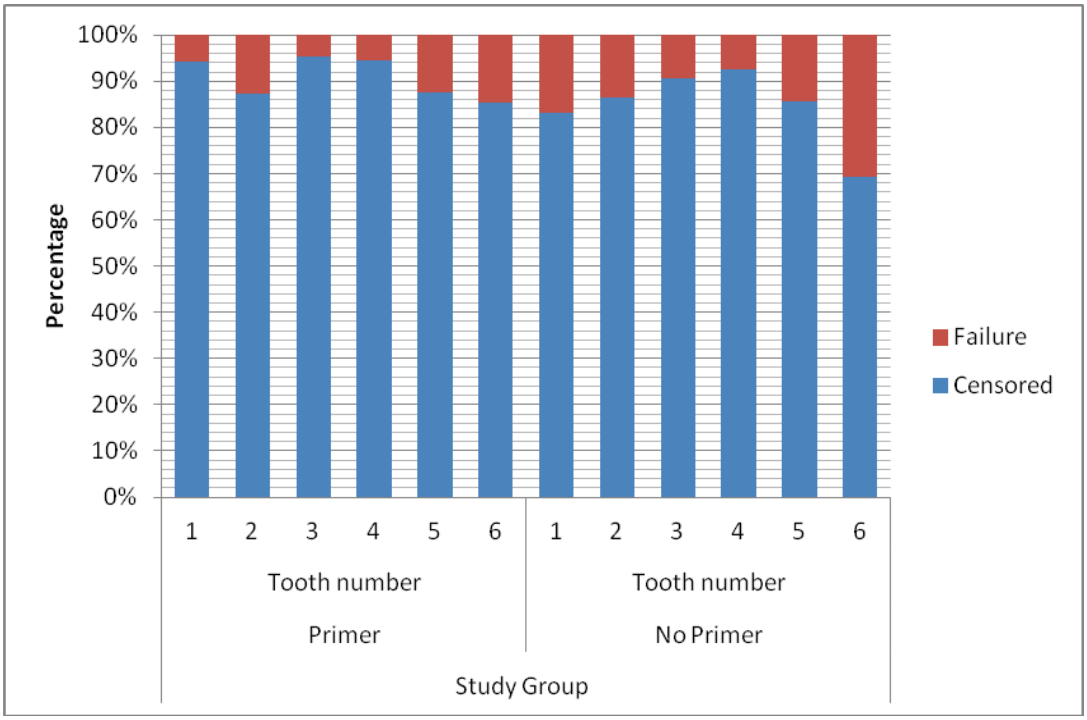
Table 5.6 bracket failure by study group and tooth

		With Primer					
		Tooth number					
		Central Incisor	Lateral Incisor	Canine	1st Premolar	2nd Premolar	1st Molar
		Count	Count	Count	Count	Count	Count
6 months	Censored	146	129	145	120	114	70
	Failure	9	19	7	7	16	12

		No Primer					
		Tooth number					
		Central Incisor	Lateral Incisor	Canine	1st Premolar	2nd Premolar	1st Molar
		Count	Count	Count	Count	Count	Count
6 months	Censored	134	141	143	123	113	43
	Failure	27	22	15	10	19	19

Above is a tabular description of the number failures for both study groups and the tooth position along the arch.

Figure 5.6 Percentage bond failure by tooth and study group



The graph above shows bracket failure rate by tooth number and study group, this was further analysed within the Cox proportional hazards model with frailty with the results in the figure below.

Table 5.7 Cox proportional hazards model with frailty for study group and tooth number

```
Cox regression --
         Breslow method for ties                 Number of obs      =      1604
         Gamma shared frailty                    Number of groups   =        92
Group variable: idnumber

No. of subjects =         1604                  Obs per group: min =         4
No. of failures =          181                                avg =  17.43478
Time at risk    =     260632.7                                max =        24

                                                Wald chi2(6)       =     33.14
Log likelihood  =   -1287.4463                  Prob > chi2        =    0.0000
```

_t	Haz. Ratio	Std. Err.	z	P>|z|	[95% Conf.	Interval]
studygroup	1.610518	.3935302	1.95	0.051	.9976408	2.5999
_Itoothnum~2	1.203412	.2777385	0.80	0.422	.765532	1.891757
_Itoothnum~3	.6028904	.1645208	-1.85	0.064	.353148	1.029248
_Itoothnum~4	.5436658	.1619667	-2.05	0.041	.3032114	.9748066
_Itoothnum~5	1.163546	.2811103	0.63	0.531	.7246608	1.868237
_Itoothnum~6	2.194031	.5598052	3.08	0.002	1.330636	3.617646
theta	.7849826	.2273011				

```
Likelihood-ratio test of theta=0: chibar2(01) =    39.85 Prob>=chibar2 = 0.000

Note: standard errors of hazard ratios are conditional on theta.
```

The results for study group have been described in section 5.1.1. The above figure compares the odds ratio of failure by tooth number with the

reference group being tooth number 1 (Central Incisor). The odds ratio of the tooth numbers were;

- 2 (lateral Incisor) 0.766 to 1.892
- 3 (canine) 0.353 to 1.029
- 4 (1st Premolar) 0.303 to 0.975
- 5 (2nd Premolar) 0.725 to 1.868
- 6 (1st Molar) 1.331 to 3.618

The teeth that were statistically significant from the 1 (central incisor) were the 4 (1st Premolar) and 6 (1st Molar) as the confidence interval does not include 1 and the p value is less than 0.05.

5.3.1 Distribution of bond failure rates between arches

Below is a table showing the number of bracket failures in the maxillary and mandibular arches

Table 5.8 number of bracket failures in the maxillary and mandibular arches

	Arch	
	Upper	Lower
	Count	Count
Censored	711	710
Failure	101	81

This table shows a similar number of bracket failures for between the mandibular and maxillary arches with more failures in the upper arch; however this was not statistically significant (Appendix 10). The next table shows the number of bracket failures in each arch with respect to the study group.

Table 5.9 Distribution of bracket failures maxillary and mandibular arches with respect to study group.

	Arch			
	Upper		Lower	
	Study Group		Study Group	
	Primer	No Primer	Primer	No Primer
	Count	Count	Count	Count
Censored	373	338	351	359
Failure	40	61	30	51

Table 5.9 shows a similar number of bracket failures in each arch with respect to study group with an increased number of bracket failures in the upper arch.

5.3.2 Distribution of bracket failure in transverse plane

Table 5.10 Distribution of bond failure in transverse plane

	Transverse	
	Left	Right
	Count	Count
Censored	706	715
Failure	96	86

Table 5.11 Distribution of bond failure in transverse plane and study group

	Transverse			
	Left		Right	
	Study Group		Study Group	
	Primer	No Primer	Primer	No Primer
	Count	Count	Count	Count
Censored	361	345	363	352
Failure	36	60	34	52

These tables demonstrate a similar number of bracket failures between the left and right sides of the oral cavity with and without primer, and

irrespective of the study group. The difference between bracket failure rates on the left/ right was not statistically significant (Appendix 11).

5.4 Appliance bond-up times

Ninety two patients were bonded-up during the course of the study. The time recorded commenced from the application of the etchant and finished when the final cure cycle was completed. Mean bonding time per a tooth was calculated in minutes. As some patients had different numbers of teeth bonded, dependant on whether it was an extraction or non-extraction case, and if the molars were to be banded or bonded.

The data was then checked for normality of distribution and equality of variance via graphically measures of a Histogram and Box and whisker plots as shown below.

Figure 5.7 Box and Whisker plot of time mean to bond a bracket

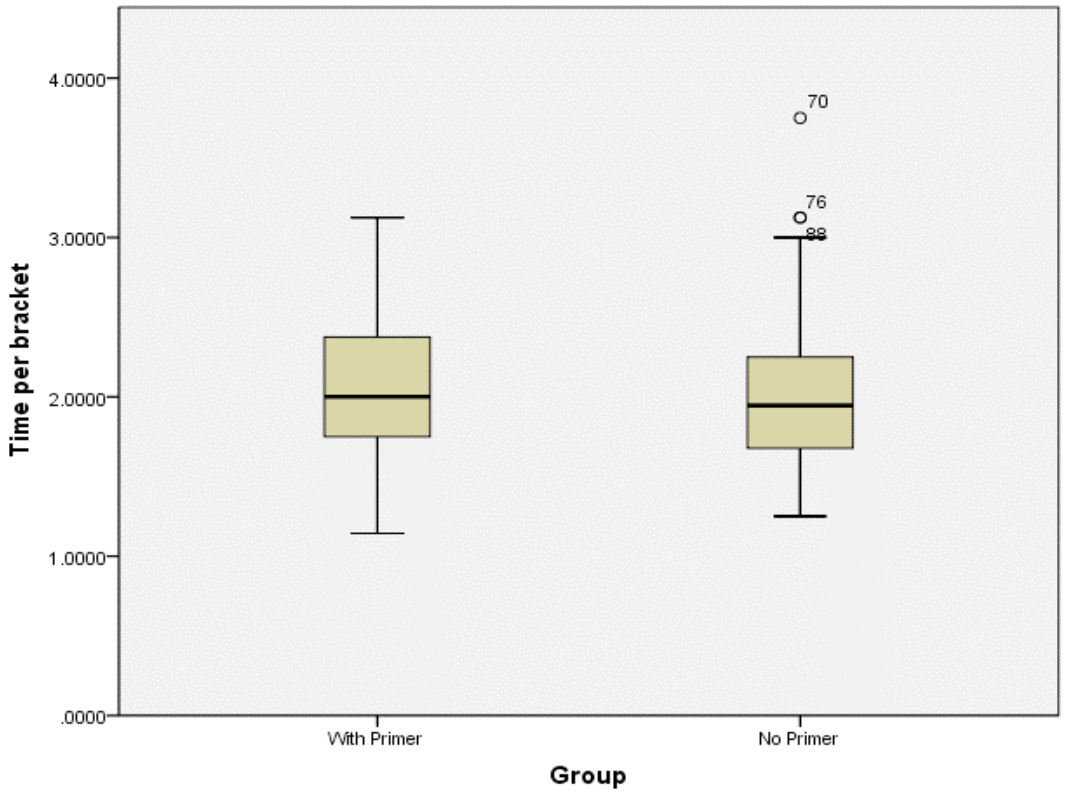
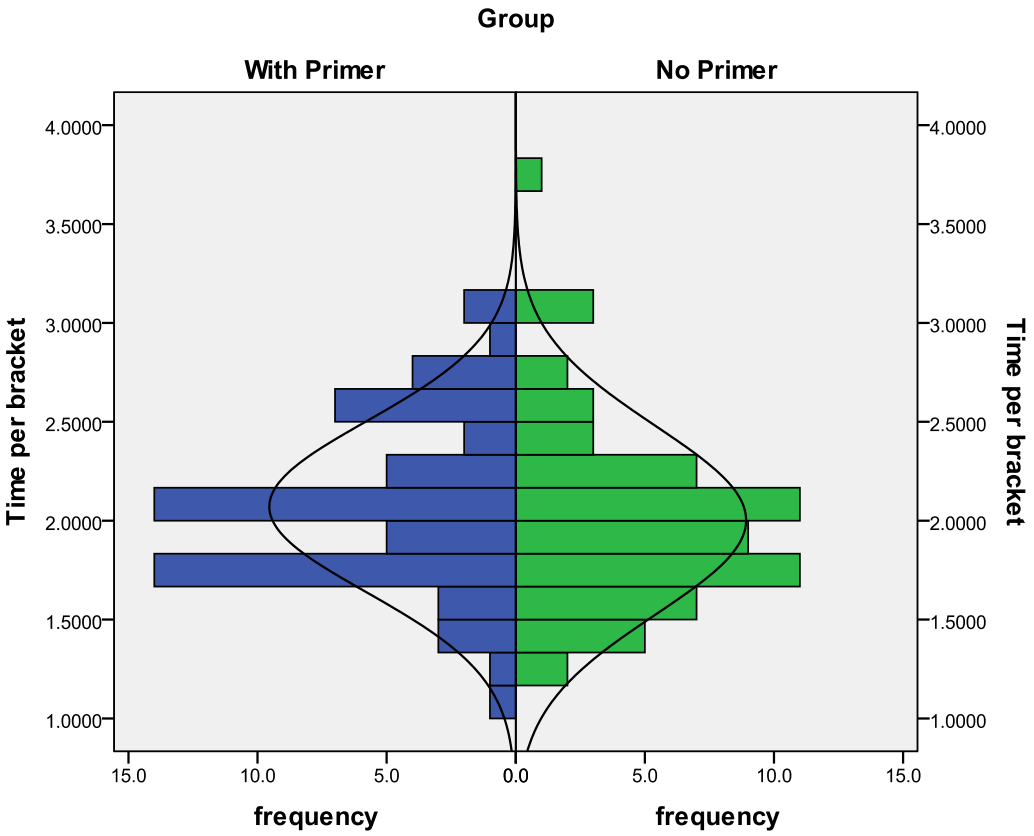


Figure 5.8 Histogram showing distribution of time to bond a bracket



Therefore as the data was normally distributed (figures 5.7 and 5.8), an independent samples t-test was performed to compare the means.

Table 5.12 Independent samples t-test assuming equal variance

	Group	N	Mean	Std. Deviation	Std. Error Mean
Time per bracket	With Primer	62	2.070542	.4319669	.0548599
	No Primer	64	2.002287	.4770836	.0596355

T test

T	Df	Sig	Mean difference	Std error difference	95% Lower CI	95% Higher CI
.841	124	.402	.0682552	.0811593	-.0923818	.2288922

The mean difference of bond- up times per bracket was .0682552 minutes with less time taken to bond without primer. This is not statistically significant as the p value is greater than 0.05 and the 95% confidence interval includes 0.

5.5 Adhesive remnant index (ARI)

The ARI of each bracket failure was assessed prior to replacement with a new bracket as per the study protocol. The table (Table 5.13) below demonstrates the ARI by study group.

Figure 5.9 Distribution of ARI on bracket failure

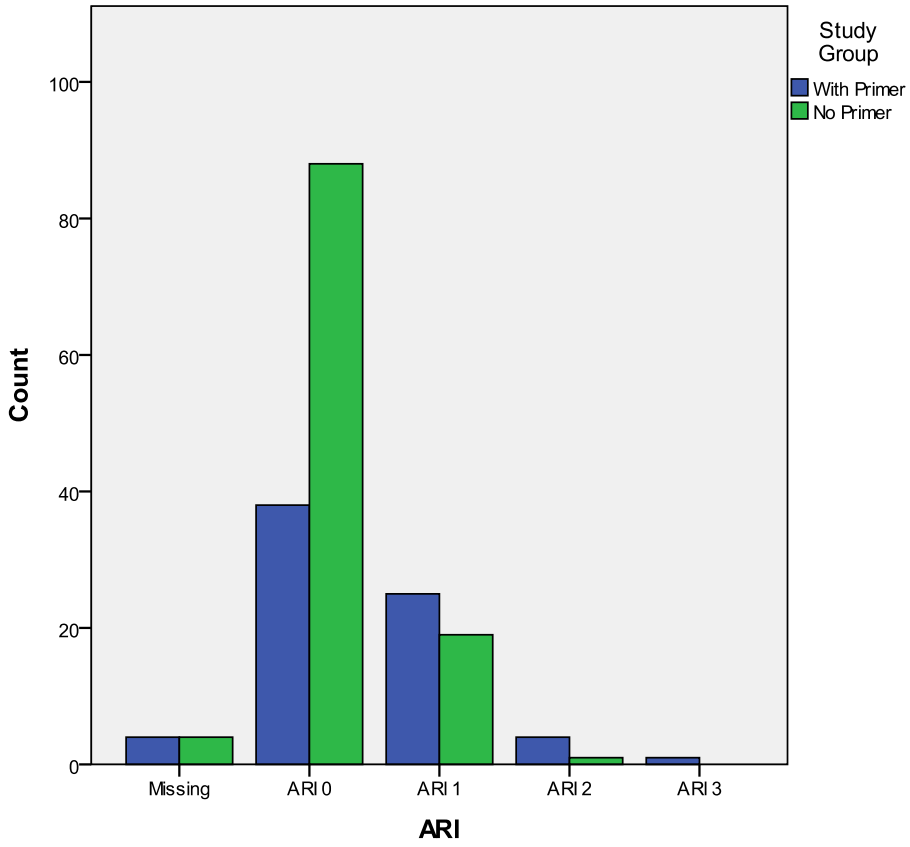


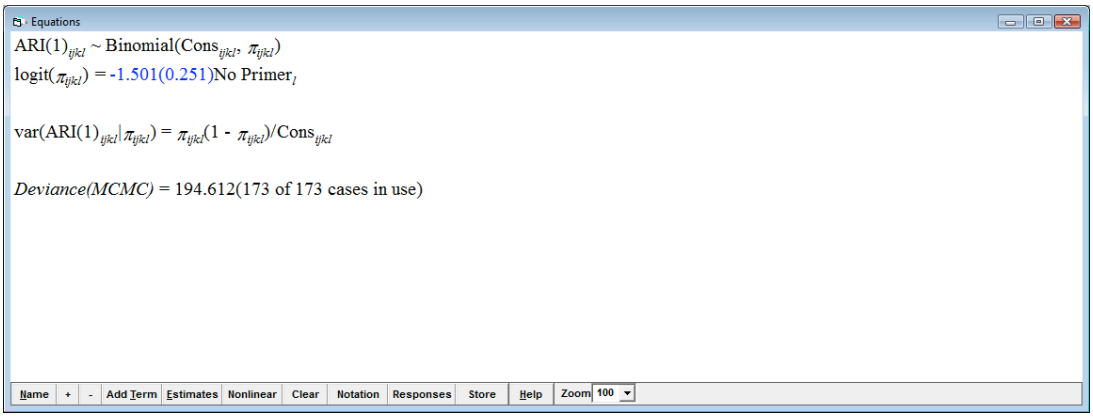
Table 5.13 tabular description of ARI with respect to study group

		ARI				
		Missing	ARI 0	ARI 1	ARI 2	ARI 3
		Count	Count	Count	Count	Count
Study Group	With Primer	4	38	25	4	1
	No Primer	4	88	19	1	0

Figure 9 and table 13 demonstrate that most failures occurred with an ARI of 0 and 1 in both study groups and that an ARI of 3 was only recorded once (with primer group).

Statistical analysis was performed using MLWin to fit a model with the highest explanatory value with the fewest variables. Due to the low occurrence of ARI above 1 a binomial model was fitted rather than multinomial model with the two groups being ARI of 0 or ARI 1 or greater. The equation generated is show below

Figure 5.10 MLWin equation for ARI



The deviance value shows this model has a high explanatory value and brackets failing which are bonded without primer are 5.36 times more likely to have an ARI of 0 on failure compared to a bracket failure with primer the p value of is 8.1622e-008 which is statistically significant.

The separate statistical equations from which this odds ratio is derived demonstrate the following values for bonding without primer -1.501 (95% CI -1.992 to -1.01) with Primer -0.283 (95% CI -0.777 to 0.211)

5.6 Summary of the results

When using APC Victory II™ brackets;

There is no statistically significant difference in the bracket failure rate when bonding with or without primer at 6 months (P value 0.051)

There is no statistically significant difference in the bonding time per bracket with and without primer

There is a statistically significant difference in the ARI on failure when bonding with or without primer, bonding with primer providing higher ARI scores.

6 Discussion

6.1 Principle findings of the study

There were three main aims of this study. The primary objective was to investigate the bracket failure rate of direct orthodontic bonding of APC Victory II™ brackets with and without the use of Transbond® primer over a six month period. The time to bond-up each appliance was also investigated, along with the ARI when bracket failure occurred.

There was no statistically significant difference in the bracket failure rates between the two groups (p value 0.051), but there was a tendency for a higher bracket failure rate for the study group without primer.

There was no statistically significant difference in bonding up times with and without primer.

There was a statistically significant difference in the ARI with the no primer group having greater tendency to fail at the composite/ tooth interface.

6.2 Critique of the methodology

6.2.1 Study design

Randomised controlled clinical trials are the gold standard for intervention studies when feasible. However due to their nature they tend to be expensive and time consuming to perform. When performing a RCT, every effort should be made to ensure sufficient sample size is achieved to create a high level of power. It has been reported that sample size calculation in medical (Pocock, 1983) and dental (Prihoda et al., 1992, Jokstad et al., 2002, Hujoel and DeRouen, 1992, Pandis et al., 2010) journals is suboptimal. It must also be remembered that the likelihood of random error occurring is increased in small sample sizes because of the uncertainty in obtaining a truly representative random sample (Pandis et al., 2011b). However, a balance must be struck between the power, a clinically important difference, trial feasibility and credibility (Pandis et al., 2011b).

The study design was that of a non-inferiority prospective randomised controlled trial where participants were randomly allocated to each group upon in enrolment in the study as described in section 4.6. This design has the effect of preventing any potential cross over effects that occur with split mouth studies. However, this dramatically increases the sample size required for the statistical calculation to have significant power (Pandis et al., 2011b). Within this study the sample size increased from 46 to 92 when the design effect had been included.

Therefore, recruitment took a significantly greater period of time, decreasing the possible length of follow up of the study. This larger number also was more difficult to recruit as on average, a specialist orthodontic registrar will have 100 to 120 patients during their training. This has to also include knowledge of several different bracket systems and several patients not being suitable for the study due to the exclusion criteria (Orthognathic, previous fixed appliance treatment, *etc*). This had the effect of decreasing the population from which the sample size can be achieved.

One method of potentially reducing the sample size would have been to use previous research as a historic control group, however as there is variation from operator to operator, variations in protocols *etc,* historical controls are not ideal and should be avoided if possible. Control groups are important within clinical trials for a variety of reasons; firstly because participants could modify their behaviour just because they are involved within a trial, secondly patients who are more likely to perform well could be preferentially selected (Pandis et al., 2011a). Within any clinical trial there is a risk of participation bias, within this trial three patients declined participation in the study. In an effort to minimise the risk of bias both the recruiter and patient/ patients' parents were blinded from their study group until enrolment was completed. This randomisation ensures treatment allocation cannot be predicted in advance, as predication of allocation is associated with biased treatment effects (Pandis, 2012, Moher et al., 2010).

Unfortunately, due to the nature of the intervention it was not possible to maintain blinding throughout the study, as a stage in the bonding

procedure was removed. In an ideal situation one person would perform the bonding procedure and one person who was blinded to the intervention would perform the orthodontic treatment. This however is not achievable within this study as when the failures occurred, the brackets needed to be rebonded in a standardised fashion as is appropriate for each study group.

As all bracket breakages could not seen by the same operator, a study protocol sheet was placed within the notes (Appendix 9) which contained the details required and bonding procedure for re-bonding brackets.

Also the results achieved are only truly representative of SN's practice, therefore if this was to be extrapolated to the whole of the orthodontic population a multicentre/ multi-operator trial would be required.

Another potential form of bias could have been if the investigator (SN) had a subconscious preconceived notion as to if primer was required, as this may have affected the clinical management of the cases (Pandis, 2011) *e.g.* use of different orthodontic mechanics. Therefore, every effort was made to maintain equipoise throughout the study; methods employed to decrease this included the use of a standardised bonding technique, and not performing any statistical analysis until the minimum amount of time required to write up the study was reached.

6.2.2 Statistical analysis

Within any clinical study attrition bias/ post randomisation bias is often encountered. This is the drop out of participants after they have been recruited to the study for whatever reason. Excluding these patients from the data analysis often creates misleading results as often the most severely affected participants data is excluded from the analysis (Pandis, 2011). To overcome this problem it is recommended that an intention to treat analysis is performed, as has been performed within this study. This includes all the data from all participants and provides a more conservative, closer to real life effects of the intervention; and this has been recommended within the updated CONSORT statement (Schulz et al., 2010).

It has been suggested to overcome the issue of differing clinical failure rates depending on the length of trials, median survival time should be used which calculates the probability of 50% of the specimens failing (Mitchell and Walls, 1991). However, due to the low failure rate of orthodontic brackets this is not possible, as extrapolation beyond the normal point is not accurate. Another approach is to quote the mean survival time (Millett and Gordon, 1994). This approach requires data to the completion of treatment to allow accurate extrapolation. As this was not possible within this study it has been suggested it is better to quote the bracket failure rate at the end of the study period (six months).

In order to compare the data, the use of Kaplan Meier survival plots is recommended which allows descriptive statistical analysis of the bracket failure rate between the two groups. Clinical experience has suggested that some patients are more prone to bracket failure than others, which may be due to a multitude of factors *e.g.* diet, tooth anatomy *etc.* Therefore, the usual assumption of the independence of the bracket failures will be invalid (Petracci et al., 2009). Violation of the assumption of independence the observation often occurs within in the dental literature in a variety of situations *e.g.* periodontal pockets, restorations, *etc.* This is known as clustering and is when multiple measurements belonging to the same person are likely to be correlated (Koletsi et al., 2011).Clustering has the effect of reducing the amount of information gathered from each sample within a cluster compared to a non clustered study (Koletsi et al., 2011). To overcome this non-independence two models have been suggested: the marginal model and frailty model. The marginal model uses robust variance-covariance estimation but does not place any dependent structure within the model. The frailty model specifies the within patient correlation by use of a random variable (frailty), this term is shared by all observations within that cluster. Therefore the appropriate methodology for use of this frailty solution is within the Cox proportional hazards model. This statistical model is often advocated within the medical literature for survival analyses.

Clustered observations often occur in patient orientated dental research, in normal survival analysis the population experiences the same risks.

However, with bracket failures risk may vary from patient to patient because of unknown or unmeasured factors. This use of a frailty allows for this difference in risks and thereby improves the quality of the research. An example of the frailty model in the orthodontic bracket failure setting (Petracci et al., 2009) demonstrated age at the start of treatment being a statistically significant factor in a basic Cox model, however when frailty was used within the model age was no longer statistically significant. Therefore if clustering is ignored it increases the chance of achieving statistically significant results which may not be genuine (Koletsi et al., 2011).

Secondary analyses were performed using multilevel modelling to identify covariates. The use of multilevel modelling has already been described in section 2.14.1. When additional covariates were established these were then run through the Cox model with frailty to confirm/ refute their statistical significance and there effects with time, as multilevel modelling for this study could only be used in a logistic fashion *i.e.* determining if the bracket would fail or not. If these factors were clinically significant statistically or shown to be statistically significant they were included within the model. The only factor that fit the criteria was the tooth number (*i.e*. Central Incisor, Lateral Incisor, *etc*).

In regards to bond time per bracket the data were checked for normality and equality of variance, to compare the two groups an independent samples T test was used. However, it is arguable that a Z test should have been used as the samples were greater than 30, with equal numbers in each group. The T test was chosen as within a large sample it does function as a Z test, whilst also having the advantages of being more adaptable to the data and established within the medical literature.

6.3 Comparison of the results to other published work

6.3.1 Bracket failure rate

The bond failure rates achieved in this study were 8.8% with primer and 13.8% without primer (overall 11.4%) including 1st permanent molars. In comparison to previously published work the control group (with primer)

achieved a bracket failure rate of 8.8% which is similar to the higher range of the established literature when pre coated brackets were used, 2.7 %,7.5%, and 8.06% (Kula et al., 2002, Wong and Power, 2003, Ash and Hay, 1996).

When the experimental group is compared to the previously published work of *in vivo* orthodontic studies the bond failure rate is greater at 13.8% compared to 3% (Banks and Richmond, 1994) and 5.62 % (Tang et al., 2000b). This may be to a number of factors, which include;

- The increased filler content within pre-coated brackets inhibited penetration of the resin into the etched enamel
- The *in vivo* orthodontic study (Tang et al., 2000b) used chemically cured composite, which may provide superior bond strengths
- Cross-over effects of brackets were significant, which was not taken into account within the (Banks and Richmond, 1994) study
- Clinicians performing the bond-ups were more experienced clinicians. This been shown to influence bracket failure rate. (Millett et al., 2001)
- Lack of randomisation within previous study (Banks and Richmond, 1994)
- Retrospective nature of previous study (Tang et al., 2000b) and exclusion of patients without full medical records, which may have decreased the bracket failure rate
- Inclusion of 1st permanent molars within the study, which have been shown to have a higher bracket failure rate. However, this was corrected within the study (12.4%) and the bracket failure remained greater than in the previous literature.

When comparing the two groups within this study there was no statistically significant difference between the two groups. However, there was a tendency for a higher bracket failure rate without primer. This mean difference would be clinically significant (If it was a true difference, as

demonstrated by being statistically significant) with a difference of 5% between the two groups (which equates to 1 more bracket failure) and using the standard deviations a maximal odds ratio of 2.5999 and a minimal ratio of 0.9976. This means brackets bonded without primer are 2.5999 times more likely to fail than brackets bonded with primer at the upper limit and brackets bonded with primer are 1.0024 times likely to fail than brackets bonded without primer at the lower limit.

This difference between the two groups may be attributable to:

- There is no true difference between the two groups as the confidence interval of the odds ratio includes 1.
- Bonding without primer may be more technique sensitive, as if brackets did not fail at the initial bond up the failure rate between the two groups was similar as demonstrated by the Kaplan Meir graph figure 2
- Pre-coated brackets may be less suitable for bonding without primer due to their increased filler content compared to non pre-coated brackets.
- Orthodontic brackets bonded without primer may require more time to reach sufficient bond strength for tying in of the archwire

Bonding without primer may induce a cost saving by eliminating the need of primer for bonding orthodontic brackets. However, this is only valid if bonding without primer is demonstrated to produce a similar bracket failure rate to bonding with primer across multiple operators.

6.3.2 Distribution of bracket failures

Previous literature has shown that higher bracket failure rates occur in the posterior region (Trimpeneers and Dermaut, 1996, Linklater and Gordon, 2003, Hobson et al., 2002(a)). With a reported debond rate of 33.7% on 1st molars (Banks and Macfarlane, 2007) compared to premolar to premolar debond rate of 5-8% (Mitchell, 1994). Within this study the highest bond failure rate was achieved on first permanent molars (21.5%) with the second highest failure rate on the 2nd Premolars (13.4%). Higher

failure rate in posterior regions may be caused by access problems, increased difficulty in moisture control and an increased presence of aprismatic enamel as discussed in section 2.12.2.

Within this study, a higher bracket failure rate was achieved in the maxilla (12.4%) compared to the mandible (10.2 %). However, this was not statistically significant. Previous work has reported higher bracket failure rates in the mandibular arch (Zachrisson, 1977, De Saeytijd et al., 1994, Trimpeneers and Dermaut, 1996, Chung and Piatti, 2000). The authors speculated this might be due to occlusal forces and increased risk of moisture contamination. However, other work has shown a higher failure rate in the maxillary arch (Manzo et al., 2004, Carstensen, 1986). There is also other research which demonstrates a similar failure rate in both arches (Petracci et al., 2009, Cacciafesta et al., 1999, Armas Galindo et al., 1998), and suggest that occlusal forces are of little importance and any differences may be more attributable to known and unknown factors such as operator technique and dietary habits.

6.3.3 Bonding times

Bracket bonding time was reported per tooth, as if the case was non extraction or extraction this would cause variation in number of teeth bonded for the patient. Also if a tooth/ teeth were excluded from the initial bond up, these teeth would also need to be included. This study demonstrated a tendency for decreased bond up time per bracket without primer, but this was not statistically significant. This was as expected, as without the use of primer one stage is removed from the bonding process. However, this step only takes a matter of seconds, therefore in order to be statistically significant a much larger sample size would be required. A more important question would be, is this tendency for a decreased bonding up time “clinically significant”. The mean bond up time per bracket was 2.070542 minutes with primer and 2.002287 minutes without primer and the mean difference was .0682552 minutes (4.1 seconds). Therefore in terms of time saving it is clinically insignificant. If however,

missing the primer stage had led to better moisture control and thereby a lower bracket failure this time difference would be clinically significant.

The bonding time per bracket was greater in this study than in previous research (Russell et al., 2008, Ash and Hay, 1996, Wong and Power, 2003). This may be due to a number of factors including differences in etching time/ curing time compared/bonding technique to previous research and operator variation as SN may have spent more time positioning brackets than other operators.

6.3.4 Adhesive remnant index

Another secondary outcome measure was the adhesive remnant index (ARI). This relates to the interface at which the bracket failure occurs and has been described within section 2.12.7. Within this study, there was a statistically significant difference between the two groups, with those failures occurring within the no primer (experimental) group displaying an increased tendency to fail at the tooth / composite interface than the primer (control) group.

This implies that orthodontic bonding with no primer has lower bond strengths than orthodontic bonding with primer.

Failure with a low ARI has the potential advantage of saving time by reducing the amount of time required for removal of residual composite. Other factors that may also be affected by bonding brackets without primer includes the use of debond burs / handpieces.

However these outcomes were not included within the scope of this study as it is of greater importance to enquire whether treatment with no primer is feasible in respect to bracket failure rates as described in section 5.2 , and as there was no significant statistical difference between the two groups these measures should be included in further work. Another outcome measure for future research is measuring any difference in decalcification between the two groups.

In comparison to previously published work previous authors have also noted that orthodontic bracket failures with primer mostly occur with an ARI of 0 or 1, which is similar to the findings of this study. In regards to

bonding with no primer, no *in vivo* study has analysed the ARI as an outcome measure. *In vitro* orthodontic studies have suggested that the interface of failure is similar for bonding with and without primer (O'Brien et al., 1991, Wang and Tarng, 1991) (Tang et al., 2000b). However, ARI was a secondary outcome measure in these studies and therefore may not have had a sufficient sample size to achieve a statistically significant result, it also has to be considered that these studies were performed in "ideal" conditions and therefore does not reflect the situation *in vivo*.

6.5 Clinical Implications of the research

1. This study demonstrates no statistically significant difference in bracket failure rates between the use of primer and no primer to bond APC Victory™ brackets (P value 0.051). There is an increased tendency for higher bracket failure rates without primer. Therefore further work needs to be carried out before bonding with or without primer can be recommended
2. The time required to bond-up the appliance was slightly reduced in the no primer group, but was not statistically significant and any time saving would not be clinically significant. Therefore, there is no advantage in terms of time saving by not using primer.
3. The ARI of brackets failing in the no primer group was lower by a statistically significant degree. Therefore, no change to current practice but further work should be carried out to see if this lower ARI confers any advantages/ disadvantages

6.6 Future research

Bonding without primer for APC victory II™ brackets has been shown to have no statistically significant difference (P value 0.051) in the bracket failure rate compared to bonding with primer over a six month period. The next logical step is to follow these patients to the completion of treatment and to observe if there is any significant difference at the end of

treatment, and if there is any difference in treatment time and the quality of the result.

If there is no difference in the bracket failure rate after these patients at the completion of treatment; future research could focus on bonding orthodontic brackets without primer in multicentre multi-operator (operators at varying levels of clinical experience) randomised controlled trials, which account for clustering and avoid cross-over effects. Other factors that could also be assessed are bonding with different brackets/ adhesives; also patient comfort at removal of the fixed appliance and the time required to remove the fixed appliance(s) and any residual adhesive.

7 Conclusions

This study has confirmed two hypotheses proposed in section 3.2 and has disproved one hypothesis

- There is no difference in bracket failure rate when APC Victory II™ brackets are bonded without Transbond® primer compared to with brackets bonded with Transbond® primer over a six month period (P = 0.051)
- There is no significant difference in the bonding time per bracket when bonding with or without primer.
- There is significantly lower Adhesive Remnant Index on failure of APC Victory II™ brackets bonded without primer compared to those bonded with primer.

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9. List of abbreviations

Adhesive remnant index (ARI)

Bisphenol A diglycidyl ether methacrylate (BIS-GMA)

Consolidated Standards of Reporting Trials (CONSORT)

Glass ionomer cement (GIC)

S. Nandhra (SN)

G. Nandhra (GN)

methocryloxyododecyl pyriimo bromide (MDPB)

Millilitres (ml)

Newtons (N)

Pascals (Pa)

Research and Development (R&D)

Scanning electron microscope (SEM)

Shear bond strength (SBS)

Standard deviation (SD)

Triethylene glycol dimethacrylate (TEGDMA)

Versus (vs)

Ultra Violet (UV)

Appendix 1

Leeds (East) Research Ethics Committee
Room 5.2, Clinical Sciences Building
St James's University Hospital
Beckett Street
Leeds
LS9 7TF

Telephone: 0113 3926788
Facsimile: 0113 3926788

18 December 2009

Mr Simon Littlewood
Consultant Orthodontist
Bradford Teaching Hospitals NHS Trust
Department of Orthodontics
St.Luke's Hospital
Little Horton Lane, Bradford
BD5 0NA

Dear Mr Littlewood

Study Title:	**Is a primer needed for orthodontic bonding? A Randomised Controlled Trial**
REC reference number:	**09/H1306/102**
Protocol number:	**1**

Thank you for your letter of 08 December 2009, responding to the Committee's request for further information on the above research and submitting revised documentation.

The further information was considered by the Alternate Vice Chair of the REC.

Confirmation of ethical opinion

On behalf of the Committee, I am pleased to confirm a favourable ethical opinion for the above research on the basis described in the application form, protocol and supporting documentation as revised, subject to the conditions specified below.

Ethical review of research sites

The favourable opinion applies to all NHS sites taking part in the study, subject to management permission being obtained from the NHS/HSC R&D office prior to the start of the study (see "Conditions of the favourable opinion" below).

The Committee has not yet been notified of the outcome of any site-specific assessment (SSA) for the non-NHS research site(s) taking part in this study. The favourable opinion does not therefore apply to any non-NHS site at present. I will write to you again as soon as one Research Ethics Committee has notified the outcome of a SSA. In the meantime no study procedures should be initiated at non-NHS sites.

Conditions of the favourable opinion

The favourable opinion is subject to the following conditions being met prior to the start of the study.

Management permission or approval must be obtained from each host organisation prior to the start of the study at the site concerned.

For NHS research sites only, management permission for research ("R&D approval") should be obtained from the relevant care organisation(s) in accordance with NHS research governance arrangements. Guidance on applying for NHS permission for research is available in the Integrated Research Application System or at http://www.rdforum.nhs.uk. *Where the only involvement of the NHS organisation is as a Participant Identification Centre, management permission for research is not required but the R&D office should be notified of the study. Guidance should be sought from the R&D office where necessary.*

Sponsors are not required to notify the Committee of approvals from host organisations.

It is the responsibility of the sponsor to ensure that all the conditions are complied with before the start of the study or its initiation at a particular site (as applicable).

Approved documents

The final list of documents reviewed and approved by the Committee is as follows:

Document	*Version*	*Date*	
Covering Letter		06 September 2009	
REC application		07 September 2009	
Protocol	1	06 September 2009	
Investigator CV		06 September 2009	
Participant Information Sheet: Adult	1	06 September 2009	
Participant Information Sheet: Child	1	06 September 2009	
Participant Consent Form: Adult	1	06 September 2009	
GP/Consultant Information Sheets	1	06 September 2009	
Evidence of insurance or indemnity		02 October 2008	
Letter from Statistician		06 September 2009	
Summary/Synopsis	1	06 September 2009	
CV for Dr Sarabhjit Nahndra			
Participant Consent Form: For Children	2	08 December 2009	
Statistical Information		08 December 2009	
Response to Request for Further Information		08 December 2009	

Statement of compliance

The Committee is constituted in accordance with the Governance Arrangements for Research Ethics Committees (July 2001) and complies fully with the Standard Operating Procedures for Research Ethics Committees in the UK.

After ethical review

Now that you have completed the application process please visit the National Research Ethics Service website > After Review

You are invited to give your view of the service that you have received from the National Research Ethics Service and the application procedure. If you wish to make your views known please use the feedback form available on the website.

The attached document *"After ethical review – guidance for researchers"* gives detailed guidance on reporting requirements for studies with a favourable opinion, including:

- Notifying substantial amendments
- Adding new sites and investigators
- Progress and safety reports
- Notifying the end of the study

The NRES website also provides guidance on these topics, which is updated in the light of changes in reporting requirements or procedures.

We would also like to inform you that we consult regularly with stakeholders to improve our service. If you would like to join our Reference Group please email referencegroup@nres.npsa.nhs.uk.

09/H1306/102	**Please quote this number on all correspondence**

Yours sincerely

Dr Carol Chu
Chair

Appendix 2

Information Sheet for Children

Is a primer needed for orthodontic bonding? A Randomised Controlled Trial

I would like to invite you to take part in a study.

You will be wearing fixed braces as part of your orthodontic treatment. Brace treatment is carried out by placing small metal components or brackets on teeth. These metal brackets are bonded or glued onto the tooth surface by a three step process. Sometimes when we stick them on we use a glue layer called a primer. It is possible that this layer is not needed, and this is what we are testing in the study.

If you decide to take part in the study your brace will be glued on your teeth by either using the primer or without. The method used will be randomly decided; you will not be able to choose. We will record how long it takes to attach the brace to your teeth. Occasionally braces can break and new brackets need to be placed, if this happens to you we would record how many breakages you have during your treatment.

The study will finish when your brace treatment is completed.

You do not need to do anything differently from any other patient wearing a fixed brace, and your treatment will be no different from any other patient.

The only people who will know you are in the study are your dentist, orthodontist and some of the staff on the clinic. No one else will know unless you tell them.

You do not have to take part in this study if you do not want to. If you decide to take part and then change your mind; that is fine too.

If you decide to take part in this study you will be given a copy of this information sheet to keep and asked to sign a consent form. Thank you for taking part in this study.

Mr Sarabjit Nandhra
Specialist Registrar in Orthodontics
Leeds Dental Institute, Clarendon Way, Leeds. LS2 9LU ☎ 0113 3436232

Appendix 3

Information Sheet for Adult Patients

Is a primer needed for orthodontic bonding?
A Randomised Controlled Trial

You will be wearing fixed braces as part of your orthodontic treatment. We would like to invite you to take part in a research study. Before you decide it is important for you to understand why the research is being done and what it will involve. Please take time to read the information carefully and feel free to ask if there is anything that is not clear or if you would like further information.

What is the purpose of this study?
Brace treatment is carried out by placing small metal components or brackets on teeth and a wire runs through them which help move teeth. These metal brackets are bonded or glued onto the tooth surface by a three step process. Firstly, a mild acid is used to roughen the tooth surface, secondly a free flowing glue (composite primer) is used to fill in the roughened pores and thirdly, the bracket is glued on to the tooth surface with a 'composite' material which sets hard by exposure to a high intensity light. The success of this procedure is measured by the number of brackets which become loose and is also known as the bracket failure rate. This is not presently good evidence that the primer stage is needed or not.
We would like to investigate if rate/ number of brackets lost is different when the brackets are glued onto the tooth surface without the use of a primer (second step) as compared to brackets glued with the a primer over a 12 month study period.

Why have I been chosen?
You have been chosen because you/your child are about to begin fixed braces. There will be approximately 110 patients in total participating in this study.

Do I have to take part?
No, this study is voluntary; it is up to you to decide. If you decline to take part it will not affect your standard of care or treatment. If you agree to take part you will
be given this information sheet to keep and asked to sign a consent form. If you decide to take part you are still free to withdraw at any time and without giving a reason. A decision to withdraw at any time, or a decision not to take part, will not affect the standard of care you receive. We will also inform your dentist that you are taking part in the study.

What will happen to me if I take part?

Your treatment will not be changed or altered in any way because you are in this study. The study is a randomised controlled clinical trial. If you take part in the study you will be randomly allocated to either one of two groups. One group will have their braces glued on to the teeth using a primer and the other without the primer. The time taken to glue the brackets on to teeth, any brackets which may become loose and the pattern of the breakage will be recorded in each group during the study. You will be followed up until your treatment is completed. If a bracket is lost from one of your teeth (unfortunately this does occasionally happen) this too will be recorded and replaced at an emergency visit or during your next routine visit.

What do I have to do?
Your treatment will be no different to anyone else wearing fixed braces and you will have to follow routine brace care as expected from all patients.

What is the treatment or procedure that is being tested?
We are comparing two different bonding (gluing) methods for fixed braces -one using a primer and other without the use of a primer. We wish to study whether there is a difference between the two bonding methods in the time it takes to put the braces on, and see if there is a difference in the number of brackets lost from the teeth or if so, how.

What are the side effects of taking part?
We believe it is unlikely that there will be any side effects. However, occasionally a bracket may become loose in both groups. But, all fixed braces can be replaced soon after and this will not affect your overall result in any way. All braces cause some discomfort when they are placed on the teeth and also when your orthodontist adjusts them.

What are the possible disadvantages and risks of taking part?
The risks involved are no different from those of standard fixed orthodontic brace treatment. You may have to attend extra appointments to replace the bracket if it becomes loose, which can happen in either of the groups during brace treatment.

What are the possible benefits of taking part?
None, but your contribution to the research project will help us improve our understanding about different bonding methods.

What if new information becomes available?
Sometimes during the course of a research project, new information becomes available about the treatment being studied. If this happens your orthodontist will tell you about it and discuss with you whether you want to continue in the study.
If you decide to withdraw your orthodontist will still continue your treatment.
Also, on receiving new information your orthodontist might consider it to be in your best interest to withdraw you from the study. He/she will explain the reasons and arrange for you care to continue.

What if something goes wrong?
No special indemnity arrangements are provided in the unlikely event that you are harmed during this study. If you are harmed due to someone's negligence then you may have grounds for a legal action but you may have to pay for it. Regardless of this, if you wish to complain, or have any concerns about any aspect of the way you have been approached or treated during the course of the study, the normal National Health Service complaints mechanism should be available to you.

Will my taking part in this study be kept confidential?
The people who will know that you are taking part in this study are your dentist, orthodontist and some of the clinical staff. All information that is collected during the course of the research will be kept strictly confidential. Any information about you that leaves the orthodontic department will have your name and address removed so that you cannot be recognized from it. This research is registered according to the Data Protection Act. This research is carried out under the relevant laws and regulations. To ensure these are adhered to the regulatory authorities will have legal access to your records when you agree to take part.

What will happen to the results of the research study?
At the end of the study all the information will be put together and the results will be presented as a DDS research project and published in an orthodontic journal so that other orthodontists can read about what we have found. We will also write to you regarding the results of the study and inform your dentist.

Who is organising and funding the research?
This research has been organised through the Leeds Dental Institute. Your orthodontist will not be paid for including you in the study.

Please feel free to ask questions if anything is unclear. If you are happy to take part in the study you will be given a copy of this information sheet and the consent form. Thank you very much for your attention and co-operation.

Mr. Sarabjit Nandhra
Specialist Registrar in Orthodontics
St Luke's Hospital
Little Horton Lane, Bradford,
BD5 0NA
☎ 01274365646

Leeds Dental Institute,
Clarendon Way,
Leeds. LS2 9LU
☎ **0113 3436232**

Appendix 4

Consent Form Adult

Centre Number:
Study Number:
Patient Identification Number for this trial:

Title of Project: **Is a primer needed for orthodontic bonding?**
A Randomised Controlled Trial

Name of Researcher: Mr Sarabjit Nandhra
Specialist Registrar in Orthodontics
Leeds Dental Institute
Clarendon Way
Leeds. LS2 9LU
☎ 0113 3436232

Please initial box

1. I confirm that I have read and understand the information sheet dated 17/08/09 for the above study and have had the opportunity to ask questions. ☐
2. I understand that my participation is voluntary and that I am free to withdraw at any time, without giving any reason, without my medical care or legal rights being affected. ☐
3. I understand that sections of any of my medical notes may be looked at by responsible individuals from Leeds Dental Institute or from regulatory authorities where it is relevant to my taking part in research. I give permission for these individuals to have access to my records and for my dentist to be informed regarding my participation in the study ☐
4. I agree to take part in the above study ☐

_____	_____	_____
Name of Patient	Date	Signature
_____	_____	_____
Name of Person taking consent (if different from researcher)	Date	Signature
_____	_____	_____
Researcher	Date	Signature

1 for patient; 1 for researcher; 1 to be kept with hospital notes

Appendix 5

Consent Form for children

Centre Number:
Study Number:
Patient Identification Number for this trial:

Title of Project: **Is a primer needed for orthodontic bonding?**
A Randomised Controlled Trial

Name of Researcher: Mr Sarabjit Nandhra
Specialist Registrar in Orthodontics
Leeds Dental Institute
Clarendon Way
Leeds. LS2 9LU
☎ 0113 3436232

Please initial box

1. I confirm that I have read and understand the information sheet dated 17/08/09 for the above study and have had the opportunity to ask questions. ☐

2. I understand that the participation of my child is voluntary and that they/me are free to withdraw at any time, without giving any reason, without my medical care or legal rights being affected. ☐

3. I understand that sections of any of my Child's medical notes may be looked at by responsible individuals from Leeds Dental Institute or from regulatory authorities where it is relevant to my taking part in research. I give permission for these individuals to have access to my Child's records and for my dentist to be informed regarding my participation in the study ☐

4. I agree for my child to take part in the above study ☐

_____	_____	_____
Name of Parent/Guardian	Date	Signature
_____	_____	_____
Name of Person taking consent (if different from researcher)	Date	Signature
_____	_____	_____
Researcher	Date	Signature

1 for patient; 1 for researcher; 1 to be kept with hospital notes

Appendix 6

Assent form for children
(To be completed by the child and guardian)

Project title: Is primer needed for orthodontic bonding? A randomised controlled trial
Child (or if unable, guardian on their behalf)/ young person to circle all they agree with:

Has someone explained this project to you? Yes/ No
Do you understand what this project is about? Yes/ No
Have you asked all the questions that you want? Yes/ No
Have you had your questions answered in a way you understand? Yes/ No
Do you understand it is OK to stop taking part at any time? Yes/ No
Are you happy to take part? Yes/ No

If any of the answers are "no" or you do not want to take part, don't sign your name!

If you want to take part, you can write your name below.

Your name:

Date:

The doctor who explained this project to you need to sign too.

Print name: Sarabjit Nandhra

Sign:

Date:

Thank you for your help.

Appendix 7

LETTER TO DENTIST INFORMING PARTICIPATION OF PATIENT IN THE STUDY

To, Dated:

Dear Dentist,

Patient details:

I am writing to you to inform you that the above patient who is under your care has consented to be a part of a study which we intend to undertake in our department during their orthodontic treatment.

The study is randomised controlled single blinded trial to investigate if clinically acceptable bracket failure rates can be achieved when APC Victory metal brackets are bonded **without** the use of a primer as compared to brackets bonded **with** a conventional Transbond primer in orthodontic patients over a 12 month study period. The other objectives are to determine if the bonding time per bracket is different between the groups and the type of bond failure using Adhesive Remnant Index.

The study will be undertaken at the Leeds Dental institute and Bradford teaching Hospitals NHS Trust.

I request your ongoing support in the routine dental management of this patient during the course of study and throughout his/her orthodontic treatment.

Many thanks for your help in this regard and please do not hesitate to contact me if you have any queries.

Yours sincerely

Dr. Sarabjit Nandhra
Specialist Registrar in Orthodontics
Department of Orthodontics
Leeds Dental Institute
Clarendon Way
Leeds LS2 9LU

Appendix 8

Data Collection Sheet 1 (Do we need Primer)

Group 1 no primer ☐ Group 2 with primer ☐
(please tick correct box)

Date _____

Patient DOB _____

Hospital Number _____

Patient initials _____

Patient Identifying number _____

Clinician _____

Teeth to be bonded (please ring) 87654321/12345678
87654321/12345678

Upper arch

Start time (upper arch) _____

Finish time (Upper Arch) _____

Time taken to Bond upper arch _____

Lower arch

Date (if different from above) _____

Start time (lower arch) _____

Finish time (lower Arch) _____

Time Taken to Bond Lower arch _____

Total time (if applicable) _____

Total Brackets _____

Appendix 9

Data Collection Sheet 2 (Do we need Primer?) Bracket failure

Please complete details of the bracket(s) that have failed, when they failed and how much composite was left on the tooth or bracket.

Patient DOB

_____

Hospital Number

_____

Patient initials

_____

Group 1 no primer ☐ Group 2 with primer ☐
(please tick correct box)

Date(s) of Bracket failure(s)

_____
(If patient unaware please place casual attendance date)

Tooth notation of failed Bracket e.g. UR5

_____

ARI (adhesive remnant index) of failed Bracket(s) _____

ARI
0= no composite left on tooth
1= less than half of the composite left on the tooth
2= more than half of the composite left on the tooth
3= all composite left on tooth with a distinct impression of the bracket mesh.

Please follow instructions below in bonding technique below to replace bracket

Group 1 (no Primer)

1. 30 second wash and 30 second dry using 3 in 1 syringe
2. 30 second treatment with 37% phosphoric acid gel
3. 30 second wash and 30 second dry using 3 in 1 syringe
4. Metal bracket placed at long axis point on the outer surface of the tooth
5. Light polymerisation; 30 seconds each on either side of each tooth

Group 2(Primer)

1. 30 second wash and 30 second dry using 3 in 1 syringe
2. 30 second treatment with 37% phosphoric acid gel
3. 30 second wash and 30 second dry using 3 in 1 syringe
4. Application of primer to acid treated enamel and air thinned.
5. Metal bracket placed at long axis point on the outer surface of the tooth
6. Light polymerisation; 30 seconds each on either side of each tooth

Appendix 10

Table 10.1 Cox proportional hazards model for bracket failure dependent arch

Cox regression --
Breslow method for ties
Gamma shared frailty
Group variable: idnumber

Number of obs = 1604
Number of groups = 92

No. of subjects = 1604
No. of failures = 181
Time at risk = 260632.7

Obs per group: min = 4
avg = 17.43478
max = 24

Log likelihood = -1303.523

Wald chi2(1) = 1.43
Prob > chi2 = 0.2311

_t	Haz. Ratio	Std. Err.	z	P>|z|	[95% Conf.	Interval]
arch	.8329322	.1271578	-1.20	0.231	.6175368	1.123457
theta	.8038959	.2279514				

Likelihood-ratio test of theta=0: chibar2(01) = 42.72 Prob>=chibar2 = 0.000

Note: standard errors of hazard ratios are conditional on theta.

Appendix 11

Table 10.2 Cox proportional hazards model for bracket failure dependent on the side of the mouth

```
Cox regression --
         Breslow method for ties                 Number of obs      =      1604
         Gamma shared frailty                    Number of groups   =        92
Group variable: idnumber

No. of subjects =         1604                  Obs per group: min =         4
No. of failures =          181                                avg =  17.43478
Time at risk    =     260632.7                                max =        24

                                                Wald chi2(1)       =      0.66
Log likelihood  =   -1303.9144                  Prob > chi2        =    0.4182
```

_t	Haz. Ratio	Std. Err.	z	P>|z|	[95% Conf.	Interval]
left0right1	.8861945	.1322464	-0.81	0.418	.6614615	1.187281
theta	.8077951	.2286413				

Likelihood-ratio test of theta=0: chibar2(01) = 43.00 Prob>=chibar2 = 0.000

Note: standard errors of hazard ratios are conditional on theta.