CHAPTER 1

INTRODUCTION

THE INFLUENCE OF ORTHODONTIC BRACKET BASE DIAMETER AND MESH SIZE ON BOND STRENGTH

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INTRODUCTION

" Work like you don't need the money.
Love like you've never been hurt.
Dance like nobody's watching. "

- Veruska de Vita

1.1 FOREWORD

In contemporary orthodontics, directly bonded brackets are widely used. If a directly bonded attachment fails, the treatment process is interrupted, and the bracket itself may present a health hazard if it obstructs the airway. In order to minimize these problems, it is in the best interests of both the orthodontist and the patient to use an attachment with adequate bond strength (Zachrisson, 1994).

In 1965, with the advent of epoxy resin bonding, George Newman began to apply his findings to the direct bonding of orthodontic attachments. This resulted in most dramatic changes in the practice of clinical orthodontics (Gerbo *et al.*, 1992; Wang and Meng, 1992). Bonding of attachments is extensively used in orthodontics today, both in full fixed techniques (Figure 1) and in combination with removable appliances (Betteridge, 1979). In the 1970s, numerous articles were published on different commercially available direct and indirect bonding systems (Silverman and Cohen, 1974; Moin and Dogon, 1977; Zachrisson, 1977; Zachrisson and Brobakken, 1978; Tavas and Watts, 1979). In the nineties, the acid-etch bonding technique has become an universally used procedure in orthodontics (Fox, McCabe and Buckley, 1994) and it has become routine to bond metal, plastic and ceramic attachments to enamel (Zachrisson, 1977; Brännström, Nordenvall & Malmgren, 1978; Hirce, Sather & Chao, 1980; Aguirre, King & Waldron, 1982; Mizrahi, 1983; Carstensen, 1986; Kinch *et al.*, 1988; Ødegaard and Segner, 1988; Forsberg and Hagberg, 1992; Newman, 1992; Surmont *et al.*, 1992; Fox, McCabe & Buckley, 1994; Mizrahi, 1995; Olsen *et al.*, 1997a; 1997b; Bishara *et al.*, 1998a; Galindo *et al.*, 1998; MacColl *et al.*, 1998).

Figure 1: Bonding of orthodontic attachments has become contemporary practice in clinical orthodontics.

The advantages of bonding orthodontic attachments to teeth have been well documented (Newman, 1965; Retief, Dreyer & Gavron, 1970; Retief and Sadowsky, 1975; Newman, 1978; Hirce, Sather & Chao, 1980; Wertz, 1980; Bryant *et al.*, 1987; Alexander, 1991; Boyd and Baumrind, 1992; Zachrisson, 1994; Bishara *et al.*, 1998a) and are as follows:

1. It is aesthetically superior.
2. It is faster and simpler.
3. There is less discomfort for the patient (no band seating and separation).
4. Arch length is not increased by band material.
5. It allows more precise bracket placement (aberrant tooth shape does not result in difficult banding and poor attachment position).
6. Bonds are more hygienic than bands, thus an improved gingival and periodontal condition is possible and there is better access for cleaning.
7. Partially erupted (or fractured) teeth can be controlled.
8. Mesiodistal enamel reduction is possible during treatment.
9. Interproximal areas are accessible for composite buildups.
10. Caries risk under loose bands is eliminated. Interproximal caries can be detected and treated.
11. Dental invaginations on incisors can be controlled.
12. Fluoride mouthwashes can be continued because almost the whole tooth surface is accessible to the fluoride.
13. There are no band spaces to close at the end of treatment.
14. No large inventory of bands is needed.
15. Brackets may be recycled, further reducing the cost.
16. Lingual brackets, invisible braces, can be used when the patient rejects visible orthodontic appliances.
17. Attachments may be bonded to fixed bridgework, particularly when the facial surfaces of the abutment teeth are not in metal.
18. There is a decreased incidence of gingival irritation with bonding.
19. If a bond fails the loose bracket is immediately apparent to the patient.
20. Debonding is easier.

Probably the most important of these advantages are the *improved appearance*, *the hygiene*, the *decreased discomfort* of the patient, and the *ease of application* for the clinician.

The bond strength of orthodontic attachments must be able to withstand the forces applied during orthodontic treatment. On the other hand, an easy debonding and clean-up procedure at the end of treatment is desirable to avoid iatrogenic damages such as cracks, scratches and enamel fractures (Carstensen, 1986).

In the direct bonding of orthodontic attachments to the teeth, several factors may influence the strength of the bond. These factors include the nature of the enamel surface, the conditioning procedure, the type of adhesive and the design of the bracket base itself (Ferguson, Read and Watts, 1984).

A wide variety of bracket designs are available for clinical use. A considerable amount of development has improved their clinical properties. Three basic types of orthodontic attachments are available for bonding (Maijer and Smith, 1981):
* metal brackets (stainless steel),
* ceramic brackets; and
* plastic brackets (for example, polycarbonate brackets and plastic brackets with metal-reinforcing endoskeleton).

The most popular material currently in use is stainless steel. However, stainless steel brackets do not form a chemical bond with any of the available bonding adhesives. Therefore mechanical interlocking must be obtained for an adequate bond. Several bracket base designs have been devised for this purpose. Extensive research has been carried out to determine the *in vitro* bond strengths for each type of base design. Reynolds and Von Fraunhofer (1976), and Lopez (1980) reported on solid metal bases with perforations; these designs performed poorly, compared to the foil-mesh combinations at that time in clinical use.

Reynolds and Von Fraunhofer (1976) also suggested that wire mesh sizes in the range of 60 to 70 provide the optimum bond strength. Maijer and Smith (1981) found that brackets with a mesh size of 100 gauge have a higher shear bond strength than brackets with 40 gauge.

Foil-mesh bracket bases have since replaced the perforated bracket bases, because the foil-mesh bracket bases retain less plaque and allow stronger bonds (Zachrisson and Brobakken, 1978). The foil provides a smooth hygienic oral surface with a more aesthetic appearance than that provided by perforated bases.

To improve the aesthetic properties of metal attachments, the trend is to reduce both the sizes of the bracket as well as the bracket base. As adhesive systems improve, the bases become smaller and smaller. As the retentive surface area reduces in size, other variables such as mesh wire size, bracket base contour and bonding technique become more important to the overall bond strength of bracket bases (Zachrisson and Brobakken, 1978).

1.2   PURPOSE OF THE STUDY

The purpose of this research project was to compare, *in vitro*, the shear bond strengths of orthodontic brackets with 80 gauge vs. 100 gauge mesh bases and standard size vs. mini size bases, utilizing a conventional macro-filled orthodontic bonding agent.

1.3 MOTIVATION FOR THE STUDY

Because foil mesh bases with different size gauges are used for retention, an investigation of the two most popular foil mesh gauge sizes was found necessary.

1.4 RESEARCH HYPOTHESIS

Null Hypothesis: There is no difference in the shear bond strengths of 80 and 100 gauge mesh bases and standard and mini size bases when bonded with Concise orthodontic bonding agent to human enamel.

CHAPTER 2

LITERATURE REVIEW

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2.1 ORTHODONTIC BONDING

2.1.1 Enamel pretreatment

Several important developments have made the routine bonding of orthodontic attachments feasible. The direct bonding of attachments to enamel has become a clinical reality by the application of an acid-etch technique using a weak acid such as phosphoric acid (H_3PO_4). Buonocore first introduced this procedure in 1955. He showed that a 30-second application of 85% phosphoric acid improved the retention of acrylic resins to enamel.

The purpose of etching the tooth is to obtain a microscopically irregular surface of the enamel into which the bonding resin can flow to form a good mechanical resin tag which interlocks between the enamel and the adhesive (Buonocore, Matsui & Gwinnett, 1968). This procedure results in an increased surface area for the mechanical attachment of orthodontic brackets (Buzzitta, Hallgren & Powers, 1982).

The acid-etch technique and composite bonding resins are currently an integral part of contemporary orthodontic treatment (Zachrisson, 1977; Brännström, Nordenvall & Malmgren, 1978; Betteridge, 1979; Maijer and Smith, 1981; Mizrahi, 1983; Carstensen, 1986; Kinch et al., 1988;

Ødegaard and Segner, 1988; Forsberg and Hagberg, 1992 Bishara, Olsen & Von Wald, 1997; Bishara *et al.*, 1998b; MacColl *et al.*, 1998).

A routine etching removes from 3 to 10µm of surface enamel (Silverstone, 1975; Zachrisson and Årtun, 1979; Ceen and Gwinnett, 1980b; Pus and Way, 1980; Thompson and Way, 1981). Another 25µm reveals subtle histologic alterations, creating the necessary mechanical interlocks (Buonocore, 1973; Gwinnett, 1973; Silverstone, 1974; Fritzpatrick and Way, 1977; Brown and Way, 1978). Deeper localized dissolutions will generally cause penetration to a depth of about 100µm or more (Buonocore, 1973; Silverstone, 1975).

The mean loss of enamel in depth after application of phosphoric acid solutions in concentrations of 30% to 50% were found to be approximately 3-l0µm after 1-minute exposure and up to 15µm after 2 minutes (Silverstone, 1974; Retief, 1975; Fritzpatrick and Way, 1977; Brown and Way, 1978; Pus and Way, 1980).

The depth of the etch, or amount of surface enamel removed during the etching procedure, is dependent upon the type of acid used, the concentration of acid, the duration of etching, and the chemical composition of the enamel (Retief *et al.*, 1985; Bryant *et al.*, 1987; Legner *et al.*, 1989; Wang and Lu, 1991; Surmont *et al.*, 1992; Sheen, Wang & Tarng, 1993; MacColl *et al.*, 1998). If this process is hindered in any way, the possibility of bond failure is greatly increased (Brännström, Nordenvall & Malmgren, 1978).

Although laboratory studies indicate that the enamel alterations are largely (though not completely) reversible (Silverstone, 1982; Ten Cate and Arends, 1977), it can be stated that the overall effect of applying etchant to healthy enamel is not detrimental. This is augmented by the fact that normal enamel is from 1000 to 2000µm thick (Zachrisson and Mjør, 1975) except as it tapers towards the cervical margin, abrasive wear of facial enamel is normal and proceeds a rate of up to 2µm per

year, and facial surfaces are self-cleaning and not prone to caries (Mannerberg, 1960). On the other hand, caution should be exercised when etching damaged teeth with exposed dentin, deep enamel cracks, external or internal demineralization (Ceen and Gwinnett, 1980b). The clean, dried enamel surface obtained after etching, is a high-energy surface, which assists in the spreading of polar organic fluids. The curing dental resin flows into the porous zones, polymerizes, and establishes a micro-mechanical bond/interlocking to etched enamel (Buonocore, 1955; Retief, 1978; Arakawa, Takahashi & Sebata, 1979; Knoll, Gwinnett & Wolff, 1986).

The presence of tags indicates that the surface area available for bonding has been increased (Retief, 1978; Soetopo, Beech & Hardwick, 1978). Considerable attention has been focused on the tags of polymers, which are found to penetrate the etched enamel surface (Gwinnett and Buonocore, 1965; Gwinnett and Matsui, 1967; Buonocore, Matsui & Gwinnett, 1968; Silverstone, 1974). Gwinnett and Buonocore (1965) were among the first to describe this phenomenon. Gwinnett and Matsui (1967) and Buonocore, Matsui & Gwinnett (1968) observed that tag lengths varied from one material to another and ranged from 10μm to 25μm. Retief (1973) reported tags up to 50μm. The penetration of the adhesive into etched enamel has been reported to achieve a depth of up to 80μm, and in some cases more than 100μm (Arakawa; Takahashi & Sebata, 1979; Diedrich, 1981).

Despite the extensive application of the acid etch technique in clinical dentistry, the optimal concentration of phosphoric acid as an etching agent (Buonocore, 1955; Gwinnett and Buonocore, 1965; Newman, 1965; Miura, Nakagawa & Ishizati, 1973; Retief, 1973; Retief, 1974a; Retief, 1974b; Retief, 1974c; Silverstone, 1974; Moser et al., 1976; Gorelick, 1977; Williams and Von Fraunhofer, 1977; Soetopo, Beech & Hardwick, 1978; Gottlieb, Retief & Jamison, 1982; Zidan and Hill, 1986; Barkmeier, Gwinnett & Shaffer, 1987; Legner et al., 1989; Carstensen, 1992; Carstensen, 1993; Sheen, Wang & Tarng, 1993; Wang et al.,

1994; Carstensen, 1995; Olsen *et al.*, 1996; 1997a; Bishara *et al.*, 1998a; MacColl *et al.*, 1998) and the optimal etching time (Buonocore, 1955; Miura Nakagawa & Ishizati, 1973; Retief, 1974b; Retief, 1974c; Silverstone, 1974; Gorelick, 1977; Williams and Von Fraunhofer, 1977; Nordenvall, Brännström & Malmgren, 1980; Carstensen, 1986; Barkmeier, Gwinnett & Shaffer, 1987; Kinch et al, 1988; Viljoen *et al.*, 1988; Kinch *et al.*, 1989; Surmont *et al.*, 1992; Sheen, Wang & Tarng, 1993; Wang *et al.*, 1994; Olsen *et al.*, 1997a) remains highly controversial.

Moin and Dogon (1977) recommended 37% phosphoric acid applied for 60 seconds. The use of 37% orthophosphoric acid is generally used as the conditioning agent for enamel before bonding, with etching times ranging from 15 to 120 seconds (Wang and Lu, 1991). Surmont and coworkers (1992) compared the shear bond strength of orthodontic brackets between five bonding systems related to different etching times. They found that there was no significant difference in shear bond strength between 15 and 60 seconds enamel etching before bond application.

The optimum etching time for young enamel to achieve high bond strengths has been shown to be 15 seconds (Wang and Lu, 1991; Sheen, Wang and Tarng, 1993). It has also been shown that the thickness of the adhesive cement should not exceed 0.2mm to ensure maximum bond strength (Schiffer, Jost-Brinkmann and Miethke, 1992). However, a comparison of 10% maleic acid and 35% phosphoric acid showed that maleic acid etching resulted in less enamel loss while producing a similar enamel surface structure to phosphoric acid, with etching times also ranging from 15 to 120 seconds (Hermsen and Vrijhoef, 1993).

Bishara and coworkers' (1998a) *in vitro* findings indicated, that the use of acidic primers to bond orthodontic brackets to the enamel surface could provide clinically acceptable shear bond forces when used with a highly

(77%) filled adhesive. These debonding forces were comparable to those obtained when the enamel was conditioned with either phosphoric or maleic acids. With the use of a lightly (10%) filled adhesive, the shear bond strength was significantly lower. There was a tendency to have less residual adhesive remaining on the tooth when an acid primer was used than when phosphoric and maleic acids were used. This might be of advantage to the clinician because it will require less time to clean the teeth after debonding.

MacColl and coworkers in 1998 found that 10% aqueous maleic acid etching of the enamel was associated with the highest shear bond strength, compared to 37% phosphoric acid gel, 37% phosphoric acid aqueous solution and 10% maleic acid gel. There was no statistically significant difference between the three acids.

The most widely used concentrations of phosphoric acid in clinical practice range from 30% to 60% with an application of 30 to 60 seconds (Newman, 1965; Retief, 1974a; Retief, 1974b; Retief, 1974c; Soetopo, Beech & Hardwick, 1978; Bryant et al, 1987; Surmont et al., 1992; MacColl et al., 1998). Maximum bond strengths of resin to enamel have been recorded for acid concentrations in the range of 30 to 50% (Retief, 1974c).

Crystal growth after use of polyacrylic acid with residual sulfate is reported (Maijer and Smith, 1979) to provide retention areas in enamel similar to those after phosphoric acid etching with less risk of enamel damage at debonding. This is advantageous when using ceramic brackets (Årtun and Bergland, 1984).

Garcia-Godoy, Hubbard & Storey (1991) showed that, fluoridated phosphoric acid solutions and gels provide an overall morphologic etching effect similar to nonfluoridated ones. They found these to give adequate bond strength in direct bonding procedures.

Retief (1974a) conferring the fundamental requirements for good bonding, stated that one key requirement was intimate interfacial contact between the adhesive and the substrate.

Miura, Nakagawa & Ishizati (1973) maintained that the bonding surface must be pretreated with pumice in order to remove the organic pellicle that normally covers the crown. This initial step must be done correctly in order for the acid-etching procedure to succeed. On the other hand, in a study by Lindauer and coworkers in 1997, they could not provide any clear support for pumice prophylaxis as a prerequisite for achieving adequate enamel etching during orthodontic bonding procedures. *In vitro* bond strengths were similar in pumiced and non-pumiced samples as were the etching patterns observed under SEM. Pumiced surfaces showed scratches under SEM, whereas non-pumiced surfaces showed retained plaque and debris in some areas after etching. Clinically, bracket failure rates were similar whether or not a pumice prophylaxis was performed as part of the bonding procedure. According to the above-mentioned authors, some mechanism to clean the teeth before orthodontic bonding is still recommended, however, to remove gross plaque accumulations before brackets are placed.

In a study by Hirce, Sather and Chao (1980), it was stated that, although the application of acidulated phosphate fluoride to a tooth, can prevent dental decay or decalcification, the bond strength decreases and enamel detachment is found after debonding. Their result showed that the application of acidulated phosphate fluoride after acid etching enamel has an adverse effect on orthodontic bond strength of human enamel.

Brännström, Nordenvall & Malmgren (1978) and Brännström, Malmgren & Nordenvall (1982), showed that extra etching time is not necessary when teeth have been pretreated with fluoride. This is in contrary to the opinion of Lehman and Davidson (1981). They have shown that enamel treated with fluoride has an acid-resistant layer two to four microns thick, and that such enamel requires longer etching to obtain a similar surface

topography compared to that obtained with non-fluoridated etched enamel.

Meng, Li and Wang in 1998, supports the use of topical fluoride after acid etching, a procedure that achieves the benefits of increased fluoride uptake without changing the bond strength of the resin adhesive.

2.1.2 Historical background of orthodontic bonding

Several workers were researching adhesive systems at the same time (Newman, 1992). Although Sadler (1958) was the first to report a trial to cement orthodontic attachments directly to the enamel surface, the first detailed article on the concept of using the acid-etch technique for bonding orthodontic attachments, and the article most referred to in the literature, was published by Newman in 1965.

Bowen (1962) patented a bisphenol A glycidyl dimethacrylate (bis-GMA) resin. This bis-GMA proved to be stronger and more stable than the acrylic and epoxy resins in use at that time, especially when an inorganic filler material was added.

Retief (cited in Reynolds, 1975) also described an epoxy resin system designed to withstand orthodontic forces. In 1968, Smith introduced zinc polyacrylate (carboxylate) cement, and bracket bonding with this cement was subsequently reported (Mizrahi and Smith, 1971).

Newman (1969) was the first to bond metal brackets to teeth by means of the acid-etch technique and an epoxy-derived resin (present day no-mix adhesives). The technique of directly bonding orthodontic attachments to acid-etched teeth via resin-based cements was first cited in the United Kingdom by Mizrahi and Smith in 1971.

Buonocore (1970) combined the acid-etch technique with a bis-GMA resin as a means of sealing pits and fissures against caries.

Around 1970 several articles appeared on bonding attachments with different adhesives (Reynolds, 1975). Miura, Nakagawa & Masuhara (1971) described an acrylic resin (Orthomite), using a modified trialkyl borane catalyst, that proved to be particularly successful for bonding plastic brackets and for enhanced adhesion in the presence of moisture.

Also diacrylate resins, both as sealants and adhesives, were introduced in orthodontics (Reynolds, 1975).

Thus, in the early 1970s, a considerable number of preliminary reports were published on different commercially available direct or indirect bonding systems. Weisser (1973) and Silverman and coworkers (1972) applied directly bonded orthodontic brackets using the acid-etch and bis-GMA resin systems. Use of the acid-etch technique for orthodontic bonding became generally accepted in the late 1970s (Zachrisson, 1977; Mizrahi, 1983; Carstensen, 1986; Kinch *et al.*, 1988; Newman, 1992; Fox, McCabe & Buckley, 1994; Zachrisson, 1994; Mizrahi, 1995; MacColl *et al.*, 1998).

It was not until 1977, however, that the first detailed post-treatment evaluation of direct bonding, over a full period of orthodontic treatment, in a large sample of patients was published (Zachrisson, 1977). The clinical implication of this study, that acid etching and bonding had come to stay in orthodontics, has indeed been verified by clinicians worldwide. Today it is an exception to find an orthodontist who does not directly or indirectly bond some type of attachment to the teeth (Gorelick, 1979).

2.1.3 Types of adhesives

Selection of adhesives for direct bonding among the myriad alternatives available depends largely on factors like handling characteristics, bond strength, and cost (Reynolds, 1975). The choice of bonding resin used is mainly dictated by the orthodontists' personal preference. As most clinicians activate appliances in the mouth 10 to 15 minutes after bonding, the initial bond strength of attachments is very important (Millet and Gordon, 1994).

The early epoxy resins had a 15-minute setting time, which limited their acceptance in clinical practice (Retief and Sadowsky, 1975). There are two basic types of dental resins currently in use for orthodontic bracket bonding. Both are polymers and are classified as *acrylic* or *diacrylate* resins (Reynolds, 1975). The acrylic resins (Orthomite, Genie, etc.) are based on self-curing acrylics and consist of a methylmethacrylate monomer and ultrafine powder. Most diacrylate resins are based on the acrylic modified epoxy resin mentioned earlier: bis-GMA or Bowen's resin (Bowen, 1962; Bowen and Rodriguez, 1962; Bowen, 1963; Bowen, 1964), modified for optimal penetration into etched enamel surfaces. The Bis-GMA resin is favored by many manufacturers of composites and is used to bond both metal and ceramic attachments (Brown, 1988; Joseph and Rossouw, 1990a; Gerbo *et al.*, 1992; Wang and Meng, 1992; Mitchell, 1994; Lloyd and Scrimgeour, 1995). Bis-GMA resins polymerize rapidly under oral conditions by free radical chain reactions and has reduced the setting time to 3-8 minutes (Bowen and Marjenhoff, 1992; Gerbo *et al.*, 1992; Wang and Meng, 1992; Mitchell, 1994; Lloyd and Scrimgeour, 1995; Mizrahi, 1995). A fundamental difference is that resins of the first type (acrylic-) form linear polymers only whereas those of the second type may be polymerized also by cross-linking into a three-dimensional network. This cross-linking contributes to greater strength, lower water absorption, and less polymerization shrinkage (Reynolds, 1975).

Both types of adhesive exist in either filled or unfilled forms. A number of independent investigations indicate that the filled diacrylate resins of the bis-GMA type have the best physical properties and are the strongest adhesives for metal brackets (Buzzitta, Hallgren & Powers, 1982; Jost-Brinkman, Schiffer & Miethke, 1992). Reported failure rates for steel mesh-backed brackets direct-bonded with highly filled diacrylate resin may be as low as 1-4% (Zachrisson and Brobakken, 1978). The clinical implication is that adhesives with large-particle fillers are recommended for extra bond strength but careful removal of the excess is mandatory since such adhesives accumulate plaque more easily than do others (Zachrisson and Brobakken, 1978).

Acrylic or combination resins have been most successful with plastic brackets. Some composite resins (i.e. Concise) contain large coarse quartz or silica glass particles of highly variable size averaging 3 to 20 μm that increases abrasion resistance properties, reduce the setting shrinkage and decrease the coefficient of thermal expansion to values closer to those of enamel to prevent long-term microleakage (Brobakken and Zachrisson, 1981; Brown, 1988; Eversoll and Moore, 1988; Bryan and Sherriff, 1995).

Others (Endur, Dynabond, etc.) contain minute filler particles of uniform size (0.2 and 0.3 μm) which, consequently, yield a smoother surface that retains less plaque (Zachrisson and Brobakken, 1978) and are more prone to abrasion (Brobakken and Zachrisson, 1981).

Faust and coworkers (1978) examined the penetration coefficients of thirteen direct bonding orthodontic adhesives. They concluded that the use of primers produce the highest penetration coefficient values. The primers tested were diacrylates, derived from bis-GMA, modified to produce good wetting properties. Low viscosity resin can penetrate deeper into the etched enamel and form tag-like projections 20 to 50 microns long (Newman, 1973; Faust et al., 1978).

According to Gorelick (1979), 93% of orthodontists in the USA used chemically cured resins for orthodontic bonding procedures.

The resin based materials used in bonding systems are cytotoxic to a certain degree, but not to the level which is considered potentially harmful (Mitchell, 1994).

There are several alternatives to chemically autopolymerizing paste-paste systems:

1. *No-mix adhesives.*

   These materials set when one paste under light pressure is brought together with a primer fluid on the etched enamel and bracket backing or when there is another paste on the tooth to be bonded. Thus one adhesive component is applied to the bracket base while another is applied to the dried etched tooth. As soon as it is precisely positioned, the bracket is pressed firmly into place and curing occurs usually within 30 to 60 seconds (Bryant *et al.*, 1987).

   Ødegaard and Segner (1988) point out that a "no-mix" adhesive is really not an adhesive in which no mixing takes place; therefore it is a misnomer. Thus, the no-mix adhesives are also known as "contact adhesives". A "no-mix" adhesive depends on the mixing of a primer and the adhesive for polymerization to take place during the placement of the bracket on the tooth. The mesh will help in the mixing process as the bracket is pressed into position. Reports on laboratory evaluation (Evans and Powers, 1985) and clinical application of some of these systems have been published (Weiss, 1985; Millett and Gordon, 1994; Bryan and Sheriff, 1995). According to Newman and coworkers (1994), no-mix, chemically cured systems are currently the most popular for bonding metal and ceramic brackets.

Although the clinical bonding procedure may be simplified with the no-mix adhesives, little long-term information is available on their bond strengths when compared with those of the conventionally mixed paste-paste systems. Delport and Grobler (1988) concluded that both two paste and no-mix adhesives maintain adequate bond strength to keep orthodontic brackets bonded in any clinical situation. Alexandre and coworkers (1981) indicated that if either system is to be used, a minimal uniform thickness of adhesive must be recommended for maximum bond strength. Theoretically, bond strength decreases as the thickness of the adhesive increases because of a greater amount of thermal expansion, polymerization shrinkage, trapped volatiles and imperfections (such as voids and cracks) (Buonocore, 1975). When one-step or no-mix adhesives are used, the depth of cure at the primer-paste interface also becomes an important factor as thickness increases (Garn, 1976).

Furthermore, little is known about how much unpolymerized residual monomer remains in the cured adhesive and its eventual toxicity (Thompson, Miller & Bowles, 1982). *In vitro* tests have shown that liquid activators of the no-mix systems are definitely toxic (Fredericks, 1981; Thompson, Miller & Bowles, 1982) and allergic reactions have been reported in patients, dental assistants, and dentists when such adhesives were used (Malmgren and Medin, 1981).

2. *Visible-light polymerized adhesives.*

These materials may be cured by transmitting light through tooth structure and ceramic brackets. They have become increasingly fashionable as working time can be manipulated (Greenlaw, Way & Galil, 1989; Wang and Meng, 1992; Smith and Shivapuja, 1993; Mitchell, 1994; Chamda and Stein, 1996; Cacciafesta *et al.*, 1998; Galindo *et al.*, 1998). Ultraviolet light-polymerized resins were popular with plastic and perforated metal brackets, but the inaccessibility of

the light to the resin under mesh-backed brackets turned most clinicians toward the autopolymerizing resins.

Maximum curing depth of light-activated resins is dependent on the composition of the composite, the light source, and the exposure time (Ruyter and Øysaed, 1982).

Cohl, Green and Eick in 1972 were the first to introduce ultraviolet light-cured materials. These materials had the disadvantages of radiation hazards and limited depth of cure. Therefore, visible light-activated adhesives were developed (Bassiouny and Grant, 1978; Tavas and Watts, 1979; Ruyter and Øysaed, 1982; Smith and Shivapuja, 1993; Chamda and Stein, 1996; Cacciafesta et al., 1998; Galindo et al., 1998). The visible light-cured resin is a single paste system that consists of a ketone and an amine as initiators. The ketone, camphoroquinone, is sensitive to white light at 470nm wavelength, which catalyzes the polymerization reaction (Bassiouny and Grant, 1978, Zachrisson, 1994).

Studies comparing the bond strengths of light-activated and self polymerizing composites for orthodontic bonding have indicated that materials are comparable, provided the light-cured adhesive is adequately polymerized (O'Brien et al., 1989; Wang and Meng, 1992; Chamda and Stein, 1996; Cacciafesta et al., 1998; Galindo et al., 1998). While this technique allows the operator the opportunity to ensure the bracket is positioned entirely to satisfaction before command setting thereof, a full mouth bonding can take a considerable amount of time and complete polymerization cannot be assured (Mitchell, 1994). In visible light-cured systems the time required to cure an entire maxillary and mandibular arch is (20 brackets x 40 seconds) approximately 13.5 minutes (Smith and Shivapuja, 1993).

This led to the development of dual-cure resins in the 1980's. This class of composite can be either polymerized entirely by light; partially polymerized by light with chemical polymerization completing the setting reaction, or left to auto-polymerize. A study by Smith and Shivapuja (1993), indicated that dual-cure composites are capable of producing clinically adequate bond strengths and that the curing time required for a dual cure cement is (20 brackets x 10 seconds + 3 minutes for final set at the end of curing) approximately 6.5 minutes, which is about half of the time required to cure with a visible light-cured resin to bond the maxillary and mandibular arch.

By 1990, about 20% of orthodontists in the United States were using light curing routinely (Gottlieb, Nelson & Vogels, 1991). With the introduction of new techniques and adhesives, this number is likely to rise in years to come (Wang and Meng, 1992).

Interesting in this development are improved types of fluoride-releasing, visible light-curing adhesives, which are now becoming available (McCourt, Cooley & Barnwell, 1991; Rezk-Lega & Øgaard, 1991; Øgaard *et al.*, 1992, Lloyd and Scrimgeour, 1995; Trimpeneers and Dermaut, 1996; Bishara *et al.*, 1998b). Disappointingly, the results of initial research into the efficacy of the "fluoride releasing" composites is uncertain (Mitchell, 1994). Some studies report evidence of an inhibition of decalcification, whilst others have found no advantage to their use (Mitchell, 1993; Trimpeneers and Dermaut, 1996). *In vitro* research has shown that some "fluoride releasing" composites release their fluoride early after placement with the concentration dropping rapidly following this initial phase (Bishara, Swift & Chan, 1991; Wiltshire and Janse van Rensburg, 1995), or that the amount of fluoride released is very small (Fox, 1990).

3. *Glass ionomer cements.*

The glass ionomer cements were introduced in 1972 by Wilson and Kent, primarily as luting agents and direct restorative materials, with unique properties for bonding chemically to enamel and dentine, as well as to stainless steel, being able to release fluoride ions for caries protection. Several recent studies have evaluated the use of glass ionomer cements in orthodontics (Kvam, Broch & Nissen-Meyer, 1983; Mizrahi, 1988; McCourt, Cooley & Barnwell, 1991; Rezk-Lega, Øgaard & Arends 1991; Rezk-Lega and Øgaard, 1991; Ashcraft, Staley & Jakobsen, 1997; Jobalia *et al.*, 1997; Bishara *et al.*, 1998a, Cacciafesta *et al.*, 1998).

Such cements are now used routinely by orthodontists for cementing bands, because they are stronger than zinc phosphate and polycarboxylate cements, with less demineralization at the end of treatment (Kvam, Broch & Nissen-Meyer, 1983; Mizrahi, 1988; Rezk-Lega, Øgaard & Arends 1991). But the present chemically- or light-cured glass ionomers seem to have significantly lower *in vitro* bond strength than composite resins for bonding brackets (Klockowski *et al.*, 1989; Fajen *et al.*, 1990; McCourt, Cooley & Barnwell, 1991; Rezk-Lega and Øgaard, 1991; Compton *et al.*, 1992; Fricker, 1992). However, improved glass ionomer cements may become an interesting alternative for bonding of metal and ceramic brackets in the future, mainly because of the caries prevention properties.

Glass ionomer cements consist of two components, namely, a calcium-aluminium fluorosilicate glass powder and a carboxylic acid copolymer, such as polyacrylic acid (McLean, Wilson & Prosser, 1984). Unlike resin-filled materials, glass ionomer cements can adhere to unetched enamel and dentine by physicochemical means (Kent, Lewis & Wilson, 1973), and to non-precious metals and plastic (Hotz *et al.*, 1977).

The bond strength of glass ionomer to enamel may be enhanced by "conditioning" the tooth surface with a weak acid, such as 10 to 40% polyacrylic acid to remove contaminants and debris (Compton et al., 1992). The high fluoride content of glass ionomers makes tooth structure more resistant to the caries process (Forsten, 1977; Swartz, Phillips & Clark, 1984; Forss and Seppa, 1990). It has also been shown that a less cariogenic flora is found in plaque deposits adjacent to glass ionomer cements (Hallgren, Oliveby & Twetman, 1992).

According to Cook and Youngston (1988), glass ionomers for direct bonding are cheaper than comparable amounts of composite resin. The shear bond strengths of glass ionomer have been reported to be significantly less than the shear bond strengths of composite resins (Klockowski et al., 1989; Fajen et al., 1990; Mitchell, 1994; Wiltshire, 1994; Ashcraft, Staley & Jakobsen, 1997). Using glass ionomers as bracket adhesives has been dissapointing as the failure rate is reported to be high (Brown, 1988; Oen, Gjerdet & Wisth, 1991; Fricker, 1992). According to Compton and coworkers (1992), however, glass ionomers have sufficient mean shear bond strengths to enable them to be successfully used as orthodontic bonding agents. This has been confirmed by several other investigations (Jobalia et al., 1997; Bishara et al., 1998b; Cacciafesta et al., 1998).

The most recent addition to the glass ionomer family has been the introduction of the resin containing glass ionomers or resin-glass ionomers. Whilst, bond strengths achieved, in vitro, are greater than for conventional glass ionomers, they do not approach those attained with composite based adhesives (McCourt, Cooley & Barnwell, 1991; Rezk-Lega and Øgaard, 1991; Ashcraft, Staley & Jakobsen, 1997). Silverman and coworkers (1995) reported a 96.8% success rate with 150 fully banded cases over an 8 month period when using a new light-cured bonding system with a hybrid adhesive containing a resin reinforced glass ionomer, namely Fuji Ortho LC.

Little is known about the release of fluoride from light-cured glass ionomer cements when used as orthodontic bonding agents. Ashcraft, Staley and Jakobsen (1997) measured the fluoride release from three "hybrid" light-cured glass ionomer cements. The light-cured glass ionomer cements in their study released fluoride after initial curing and after exposure to a topical fluoride gel. This property may help reduce or possibly even prevent enamel decalcifications seen around bracket bases, which is recognized as a possible side effect of bonding orthodontic brackets with composite resins. Vorhies and coworkers (1998) did a study to evaluate two fluoride-releasing hybrid glass ionomer bonding agents, Advance and Fuji Ortho LC, for inhibition of enamel demineralization surrounding orthodontic brackets. They found that when compared to a composite resin Transbond XT, the hybrid glass ionomer adhesives showed less demineralized areas.

Cook in 1990 proposed that glass ionomer cements could be used in moist conditions and that acid etching was not necessarily required for successful bonding. Bishara and coworkers recent study (1998b) compared Fuji Ortho LC with a more traditional light-cured bonding system, namely, Transbond. They found that etching of enamel is still necessary for both materials for achieving clinically acceptable bond strength. Lippitz, Staley and Jakobsen (1998) confirmed that Fuji Ortho LC had significantly lower bond strength than the composite resin when it was bonded to unetched, water-moistened enamel. Conversely, the other resin-glass ionomers Advance and Fuji Duet had similar bond strength as the composite resin, and were found suitable for routine use as orthodontic bracket-bonding adhesives.

In an attempt to save chairside time during bonding, orthodontists are using ceramic and metal brackets that have been precoated with the adhesive material. The adhesive used on the precoated brackets is similar in composition to that used for bonding uncoated brackets; the difference is essentially in the percentages of the various ingredients

incorporated in the material. Bishara, Olsen and Von Waldt recently (1997) concluded in their study on precoated and uncoated brackets, that all bracket/adhesive combinations tested provided clinically acceptable shear bond forces.

2.1.4 Brackets

Three types of attachments are presently available for orthodontic bracket bonding: plastic based, ceramic based, and metal (stainless steel) based (Maijer and Smith, 1981). Of these, most clinicians prefer the metal attachments for routine applications, at least in children (Sheykholeslam and Brandt, 1977; Gorelick, 1979; Gottlieb, Nelson and Vogels, 1991).

Although the metal brackets are not as aesthetically pleasing as ceramic and plastic brackets, small metal attachments are an improvement over bands. Metal brackets rely on mechanical retention for bonding, and mesh gauze is the conventional method of providing this retention (Reynolds and Von Frauenhofer, 1976, Lopez, 1980; Maijer and Smith, 1981; Regan and Van Noort, 1989; Zachrisson, 1994; MacColl et al., 1998). Photo etched recessions or machined undercuts are also available (Zachrisson, 1994).

When it comes to bond strength with mesh-backed brackets, the area of the base itself is probably not a critical factor. The use of small, less noticeable, metal bases helps avoid gingival irritation. For the same reason the base should be designed to follow the tissue contour along the gingival margin. The base must not be smaller than the bracket wings, however, because of the danger of demineralization around the periphery (Zachrisson, 1994; MacColl et al., 1998).

Corrosion of metal brackets is a problem, and black and green stains have appeared with bonded stainless steel attachments (Ceen and Gwinnett, 1980a; Maijer and Smith, 1982). Crevice corrosion of the metal arising in areas of poor bonding may be due primarily to the type of stainless steel alloy (Type SS304) used (Maijer and Smith, 1982). However, other factors such as galvanic action, bracket base design and construction, particular oral environment, and thermal recycling of

brackets may be contributing factors (Hixson *et al.*, 1982; Mascia and Chen, 1982). Thus careful attention should be paid to any signs of corrosion in bonded brackets to avoid the possibility of enamel staining. The use of more corrosion-resistant stainless steel alloys would seem to be preferable in minimizing this problem (Maijer and Smith, 1982).

Foil-mesh bases are superior to perforated metal bases (Zachrisson and Brobakken, 1978), and wire mesh sizes in the range of 60 to 70 provide the optimum bond (Reynolds and Von Fraunhofer, 1976; Thanos, Munholland & Caputo, 1979).

Maijer and Smith (1981) tested various bracket bases as a variable to bond strength. They found that for the lightly filled diacrylate resin system, brackets with a larger mesh size (80 to 100) generally resulted in higher bond strengths.

Recently, MacColl and coworkers (1998) found that the shear bond strength is independent of surface area between 6.82 and 12.35 mm². A reduction in bond strength was associated with the reduction of base surface area from 6.82 to 2.38 mm². Their findings indicate that there appears to be no need to increase base surface area beyond 6.82 mm².

The reduction of bracket size improves aesthetics and produces a more easily cleansed appliance (Maijer and Smith, 1981). This reduction, however, does result in less base surface area available for bonding with the concomitant clinical reality of increased debond rates. High debond rates in the past has guided studies to improve the bond to enamel (Cavina, 1977).

Brazing the base to the bracket rather than welding it, produces superior bond strengths (Maijer and Smith, 1981; Regan and Van Noort, 1989). Deleterious effects of welding include weld spots that reduce the base retentive area and weld spurs that prevent complete seating of the base against tooth structure. Dickinson and Powers (1980) found that spot

welds act as areas of stress concentration which can initiate the fracture of the adhesive at the adhesive/bracket interface. Sharp edges on a metal bracket can also lead to stress concentration at the junction of the adhesive with the bracket.

Sandblasting (Mizrahi and Smith, 1971; Diedrich and Dickmeiss, 1983; Millet, McCabe and Gordon, 1993, MacColl *et al.*, 1998), photoetching (Siomka and Powers, 1985), silicoating (Siomka and Powers, 1985; Norris, Norling and McCourt, 1990; Akin *et al.*, 1991), and sputter coating with silicon dioxide (Norris, Norling and McCourt, 1990) also improve retention of the bracket bases. Sandblasting for less than 9 seconds enhances the bond, but when performed in excess of this time, damages and distorts the wire mesh. Olsen and coworkers (1997b) compared shear bond strength and surface structure between conventional acid etching and air-abrasion of human enamel. Their findings indicated that, enamel surface preparation using air-abrasion results in significant lower bond strength and should not be advocated for routine clinical use as an enamel conditioner at this time. MacColl and coworkers (1998) found that the retention of foil-meshed brackets is significantly enhanced if they are either microetched or sandblasted before bonding to the teeth.

The two techniques for bracket placement include the direct and indirect methods. The literature has thoroughly described both techniques and analyzed the advantages and disadvantages of each (Brandt, Servoss and Wolfson 1975; Moin and Dogon 1977; Aguirre, King and Waldron 1982). Some of the advantages of direct bonding over the indirect procedure included:

- the closeness of the fit of the bracket base to the tooth surface;
- the ease of removal of excess flush from around the bracket base; and
- the consistent covering of the entire contact surface by the bonding adhesive.

Silverman and Cohen (1974) reported that the advantages of the indirect technique were:

- decreased chair time;
- reduced stress for the operator; and
- more accurate positioning of the bracket.

2.1.5 Bond strength in orthodontics

An essential requirement of the directly bonded attachments is that they should remain attached to the teeth during treatment (Millet and Gordon, 1994). The bonding of orthodontic brackets may be described as a temporary procedure and needs only to withstand orthodontic and occlusal forces during treatment. After completion, the brackets must be removed with minimal or no damage to the enamel (Heringer, Almeida & Miguel, 1993).

Newman and coworkers (1994) stated that maximum bond strength is needed in orthodontic bonding to compensate for the unfavorable moist environment in which the polymer adhesive system operates, as well as thermal changes, variations in pH, impact of forces from sticky, chewy, or hard foods, and sport accidents. Maijer and Smith (1981) pointed out that bonded attachments are exposed to tensile, shear, torque and peel functional stresses in the oral cavity.

Successful clinical bonding is achieved by means of an adhesive that produces a shear bond strength of 5.9-7.9MPa (60-80kg/cm^2) (Reynolds and Von Fraunhofer, 1976). Newman (1965) reported that orthodontic forces should not exceed 14.5kg/cm^2, due to the risk of deleterious effects on the enamel surface. Proffit, Fields and Nixon (1983) showed values of 35.6kg and 15.5kg for occlusal force during chewing and swallowing in normal and long-faced adult groups, respectively. It was suggested that in children these mean values would be even lower. Incisal biting forces have been reported in the 13 to I5kg range (Garner and Kotwal, 1973). Despite all the variables noted, a bracket must resist a displacement force of at least 5 to 15kg for clinical success (Garner and Kotwal, 1973; Proffit, Field and Nixon, 1983). The limit to which the bracket base area can be reduced and still maintain an adequate bond to resist orthodontically and orally generated displacement forces can not

realistically be established due to the many variables involved (Maijer and Smith, 1981).

The observations of Retief in his study in 1974(b) should always be borne in mind when accessing bond strengths *in vitro*, since he demonstrated enamel fractures on specimens with bond strengths as low as 9.7MPa.

Bond strengths of orthodontic attachments to etched enamel vary from study to study and are dependent on various factors of the *in vitro* study design. True shear bond strength is tested *in vitro*, by applying the debonding force directly to the junction of the bracket and composite (Fox, McCabe & Buckley, 1994). As *in vitro* studies cannot replicate the clinical situation, caution is advised in the direct interpretation and extrapolation of *in vitro* data to the clinical situation. Nevertheless, the *in vitro* data from the numerous reported studies serve as a useful guide for clinical bonding applications.

Finally, stronger bond strength is not necessarily better since iatrogenic damage to teeth during debonding must be taken into account. Until such time as a clinical optimization study is accomplished under controlled conditions, the full ramifications of laboratory studies cannot be presented (Kusy, 1994).

2.1.6 Bond failure in orthodontics

The occurrence of a bracket bond failure is one of the most frustrating aspects within any orthodontic practice, resulting in either increased treatment time, additional costs in materials and personnel, or additional visits by the patient. Knowing where the bond failure has occurred can assist the orthodontist in modifying the bonding technique and in counseling the patient on care of their appliances (Powers, Kim & Turner, 1997).

Hence, an increasing number of *in vitro* studies have been done on the bond strengths of different brackets and adhesives. The characteristics evaluated included the area of bonding, mesh size and type of bracket base. Actual clinical failure rates vary from an unacceptably high 34% to figures as low as 1% (Regan and Van Noort, 1989).

There is much controversy regarding the characteristics of the optimal bond failure site (O'Brien; Watts & Read, 1988). Årtun and Bergland (1984) proposed that the "Adhesive Remnant Index" (ARI) system should be used when evaluating fracture sites. This system evaluates the amount of adhesive left on the tooth after debonding and the criteria are as follows:

Score 0 = No adhesive left on the tooth.
Score 1 = Less than half of the adhesive left on the tooth.
Score 2 = More than half of the adhesive left on the tooth.
Score 3 = All adhesive left on the tooth, with distinct impression of the bracket mesh.

According to Brown (1988) and Fox, McCabe and Buckley (1994), the ideal bond should fail during debonding at the enamel/composite interface, in other words, by the clean separation of the resin from the etched enamel, as this would make the subsequent polishing much easier. This situation rarely occurs in practice, and it is often the resin

that fractures, leaving behind material that has to be removed. However, this is preferable to bonds adhering in such a way that the enamel becomes the weakest link in the chain and fractures during debonding.

O'Brien, Watts and Read (1988) stated that most *in vitro* investigations of bond failure of metal brackets have shown that there are two main failure sites. These are the bracket base/adhesive interface (Reynolds and Von Fraunhofer, 1976; Dickinson and Powers, 1980; Alexandre *et al.*, 1981; Maijer and Smith, 1981; Buzzita, Hallgren & Powers, 1982; Wright and Powers, 1985; Ødegaard and Segner, 1988; Ng'ang'a *et al.*, 1992; Carstensen, 1993; Heringer, Almeida & Miguel, 1993; Sheen, Wang & Tarng, 1993; Wang, Meng & Tarng, 1997) and the enamel/adhesive interface (Knoll, Gwinnett & Wolff, 1986; Miller, 1995; Egan, Alexander & Cartwright, 1996; Bishara, Olsen & Von Wald, 1997; Bishara *et al.*, 1998b; MacColl *et al.*, 1998). Cohesive failure within the main bulk of the adhesive material can be largely discounted. Several studies have however reported that composite failure is usually a combination of adhesive and cohesive, in other words, a mixed fracture (Retief, 1974b; Low, Von Fraunhofer & Winter, 1975; Keizer, ten Cate & Arends, 1976; Reynolds and Von Fraunhofer, 1976; Gorelick, 1977; Faust *et al.*, 1978; Rasmussen, 1978; Zachrisson and Brobakken, 1978; Alexandre *et al.*, 1981; Evans and Powers, 1985; Schultz *et al.*, 1985; Cook and Youngston, 1988; Wang and Meng, 1992; Wiltshire, 1994; Zachrisson, Zachrisson & Büyükyilmaz, 1996; Bishara *et al.*, 1998b; MacColl *et al.*, 1998).

CHAPTER 3

MATERIALS AND METHODS

CHAPTER 3

MATERIALS AND METHODS

3.1   MATERIALS USED IN THIS STUDY

3.1.1 Concise orthodontic bonding system

Table 1: Bonding material

BONDING MATERIAL	MANUFACTURER	REMARKS	BATCH NR
Concise	3M Corp., St. Paul, Minn., USA	Self-cured resin, two-paste system	34-70396045-9

Figure 2: The Concise orthodontic bonding system consists of an acid etching liquid, a resin A and B, and a paste A and B.

The orthodontic Concise bonding system was used in this research project. The manufacturer is shown in Table 1.The bonding kit contains a bottle of an etching solution (37% phosphoric acid), two jars of composite resin pastes (pastes A and B) and two bottles of liquid unfilled resins (liquid resins A and B) (Figure 2). Paste A is simply made up of liquid resin A reinforced with inorganic filler particles, and paste B is made up of liquid resin B reinforced with the same filler particles. These four components are fully compatible and may therefore be mixed in different proportions to change viscosity and setting time. In both the composite and liquid resins the A (red) components contain an initiator and the B (yellow) components contain an inhibitor. Therefore, a higher proportion of A than B components in a mix will give faster setting (less working time) and a higher proportion of B than of A will provide a slower setting (more working time) (Årtun and Zachrisson, 1982). Thus the proportions may vary from 2:1 and 1:2 up to 5:1 and 1:5 without significantly influencing clinical bond strength (Hocevar, 1977).The working and setting times are also affected by temperature and humidity (Hocevar, 1977; Årtun and Zachrisson, 1982; Årtun and Urbye, 1988).

The Concise bonding system is a bis-GMA composite resin, which has a quartz filler (77%). The sealant resin and pastes are catalyzed by equivalence mixing (Mimura at al., 1995). A decrease in bond strength of paste-primer adhesives has been reported as the thickness of the resin composite adhesive increased (Evans and Powers, 1985). The cause of the decreased strength was attributed to incomplete polymerization of the composite. This effect was not observed for chemically and light-cured resin composites (Zachrisson, 1994), and therefore it is assumed that equal mixing of Concise according to the manufacturers instructions should not cause inadequate polymerizations of the material.

The working time with any diacrylate resin is very temperature-sensitive i.e. cold room temperature, a cold slab and refrigeration of the components will slow the set and give the operator additional working time (Zachrisson and Brobakken, 1978). Concise has the further

advantage of a short snap time, which allows for almost immediate ligation (Zachrisson, 1977). It is known to be the strongest adhesive for metal brackets (Zachrisson and Brobakken, 1978; Buzzitta, Hallgren & Powers, 1982), and no allergic reactions have been reported with it (Flores *et al.*, 1990). With this background and until more long-term information becomes available on the alternatives, it seems safe to recommend an adhesive, both *in vitro* and *in vivo*, that has been working efficiently in direct bonding for the past 22 years.

3.1.2 Premolar brackets

Table 2: Orthodontic brackets used

Group	Manufacturer	Size	Surface area (mm²)	Gauge mesh size	Batch number
1 M80	A Company, Amersfort, The Netherlands	Mini	8.92	80	7052701000
2 S80	A Company, Amersfort, The Netherlands	Standard	13.56	80	6052000000
3 M100	Ormco Corp., Glendora, Calif., USA	Mini	10.99	100	351-0514
4 S100	Ormco Corp., Glendora, Calif., USA	Standard	14.00	100	342-1524

Bondable, standard, twin premolar brackets were used (Figures 3 and 4). The different manufacturers, bracket sizes, mesh area sizes, gauge mesh sizes and batch numbers can be obtained from Table 2.
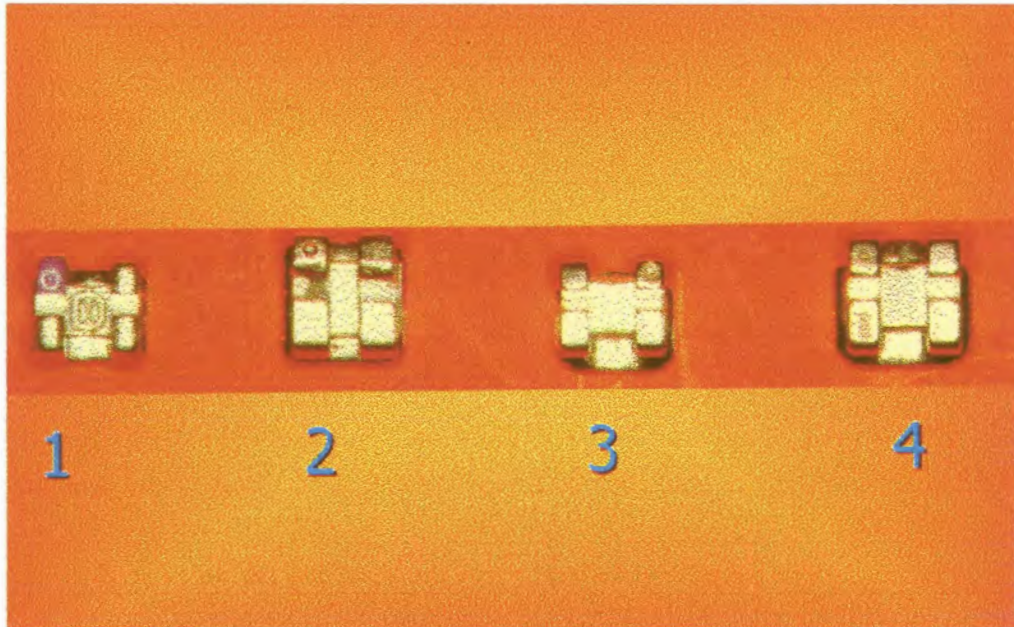

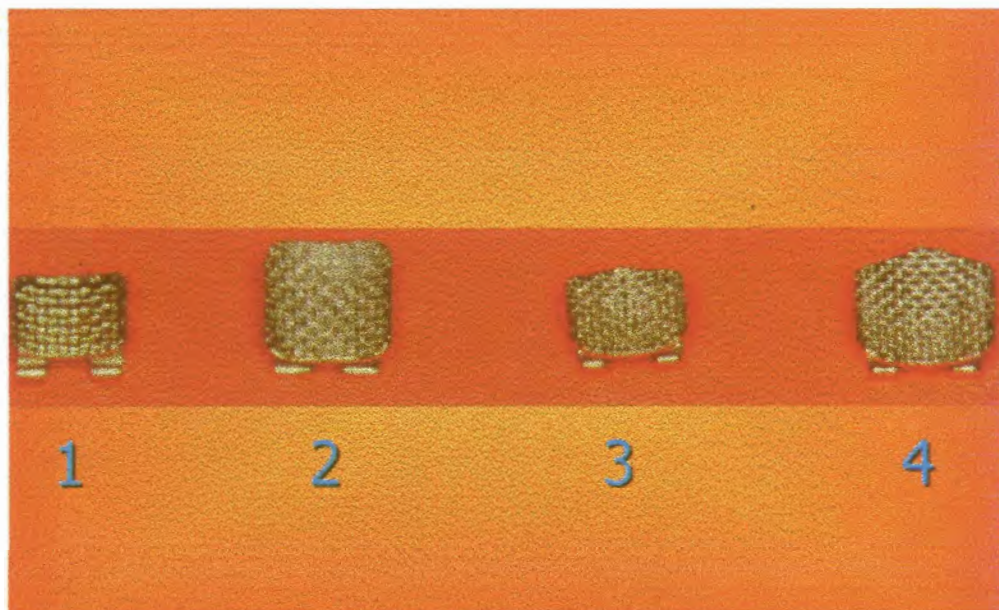*Figure 3*: Brackets (viewed from slot side) depicting Group 1 to 4

Figure 4: Brackets (viewed from mesh side) depicting Group 1 to 4

3.1 EXPERIMENTAL PROCEDURE

3.2.1 Specimen collection and storage

Eighty (80) sound, surgically removed human bicuspid teeth were used. The teeth were extracted for orthodontic purposes from patients 10 to 16 years of age. After extraction, the teeth were washed, pumiced and stored at 4°C, immersed in a solution of saline with 0.001% sodium-azide. The maximum storage time was 3 months.

The criteria of tooth selection were as follows:
- The crowns were visually normal, i.e., and no cracks as result of the extraction forceps.
- There were no caries; and
- None had pretreatment with chemical agents, such as: hydrogen peroxide, formalin, or alcohol.

3.2.2 Specimen preparation for bonding

The teeth had their roots removed using a water-cooled circular diamond cutter (*Beuhler Isomet™ Low Speed Saw, Beuhler, Lake Bluff, Illinois, USA*), to separate the crowns from the roots. The pulps of the crowns were then removed, using endodontic instruments and rinsing. The teeth were then stored another week in the aforementioned solution of saline and sodium-azide.

Before bonding, the teeth were cleaned and then pumiced with a slow-speed dental handpiece and a rubber-polishing cup, and then thoroughly rinsed, and dried with oil-free compressed air.

The 80 teeth were then randomly divided into four groups of 20 each (Table 2).

3.2.3 Bonding procedure

Instructions of the manufacturer were carefully followed for the bonding of the brackets, using Concise orthodontic bonding system. The phosphoric acid solution of Concise was used to etch the buccal surface of the teeth for 60 seconds. The etching time of 60 seconds was chosen because it is universally proposed in most manuals and supported by research results (Moin and Dogon, 1977; Wang and Lu, 1991; Surmont *et al.*, 1992; Sheen, Wang & Tarng, 1993).

The teeth were rinsed with abundant water spray for 30 seconds to remove all traces of calcium phosphate deposition formed during the etching procedure, in order to obtain optimal bonding (Soetopo, Beech & Hardwick, 1978). The specimens were then dried with oil-free air spray. In all cases a frosty white appearance of etched enamel was evident.

According to the manufacturer's directions, the etched enamel and bracket base was coated with the bonding agent (an equal amount of resin A and B mixed).

The composite resin components were mixed by hand (an equal amount of paste A and B) and were immediately applied to the bracket. The bracket was seated and pressed on the demarcated etched buccal tooth surface. The bracket was centered mesio-distally with a placement scaler and then adjusted so that the bracket slots were 4mm from the cusp tip. Once the bracket was in the correct position, the scaler was removed. Pressure was then applied with a jig, which placed a constant downward force of 500 grams for 5 minutes onto the tooth surface. The excess

composite resin was removed carefully from the bracket margin with a dental probe to avoid disturbing the setting of the adhesive and at the same time eliminate any increase in nominal base area. The bonded teeth were allowed to bench-cure at 22°C at 50% humidity for 10 minutes.

3.2.4 Specimen embedding

Directly after the bench-curing, the teeth were embedded in cold-cure acrylic (*Super-cryl, Premier CC, Johannesburg, South Africa*) in the specimen holder rings (SHR) of the Bencor Multi-T (BM-T) system (*Danville Engineering Inc., San Ramon, California, USA*), using the BM-T facilities for the procedure (Driessen *et al.*, 1989) (Figures 5 and 6).

A mounting jig was used to align the buccal surface of the tooth to be perpendicular with the bottom of the mold.

The samples were then placed in a bath containing deionized water in an incubator at 37°C and 100% relative humidity. The debonding procedures commenced 24 hours later.
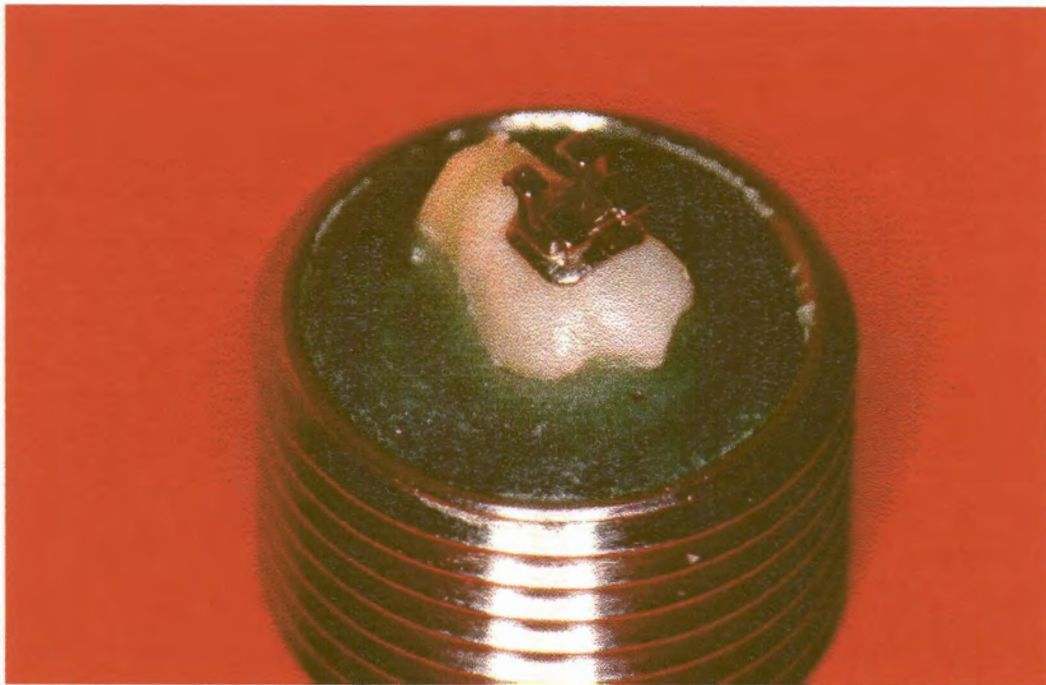
Figure 5: The tooth crowns with their bonded brackets were embedded in the specimen holder rings (SHR) of the Bencor Multi-T (BM-T) system (Danville Engineering Inc., San Ramon, California, USA)
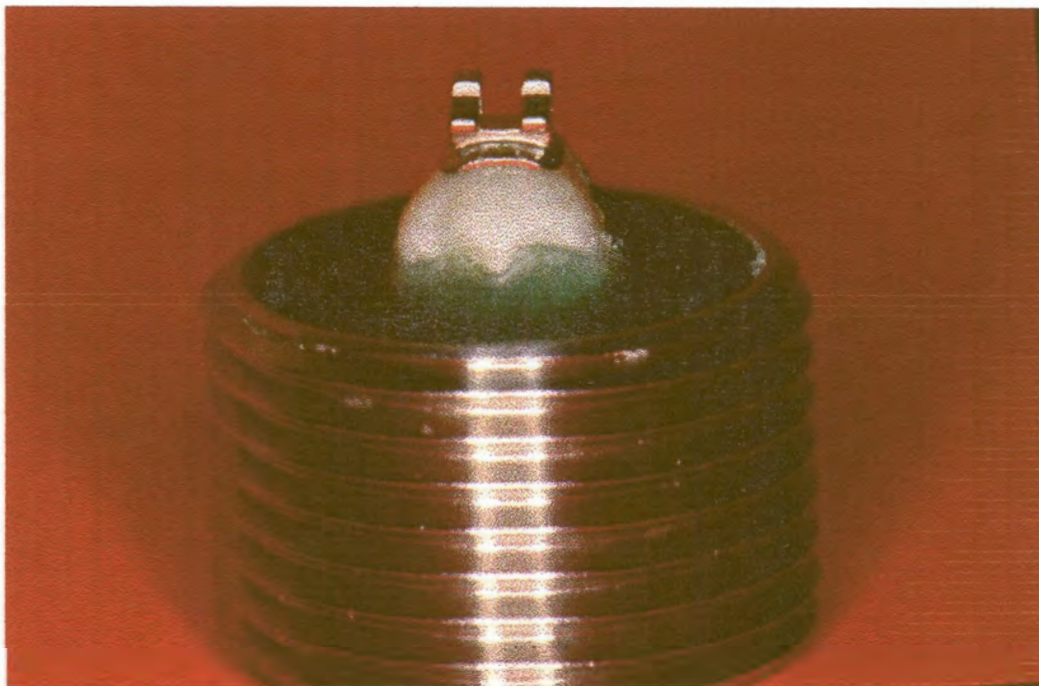

Figure 6: The tooth crowns with their bonded brackets were embedded in the specimen holder rings (SHR) of the Bencor Multi-T (BM-T) system (Danville Engineering Inc., San Ramon, California, USA) (perpendicular view)

3.2.5 Preparation of teeth for SBS

The BM-T system was assembled for SBS testing of the orthodontic brackets, utilizing a Zwick Universal Testing Machine (*Model Z010/TND, Zwick GmbH & Co., Ulm, Germany*) connected to a computer that recorded the results of each test and expressed the SBS-values in MPa.

An occluso-gingival load of 10kN was applied to the bracket by a knife-edged guillotine producing a shear force at the bracket-tooth interface (Figures 7 and 8). Shear bond strengths were measured at a crosshead speed of 0.5mm/min.
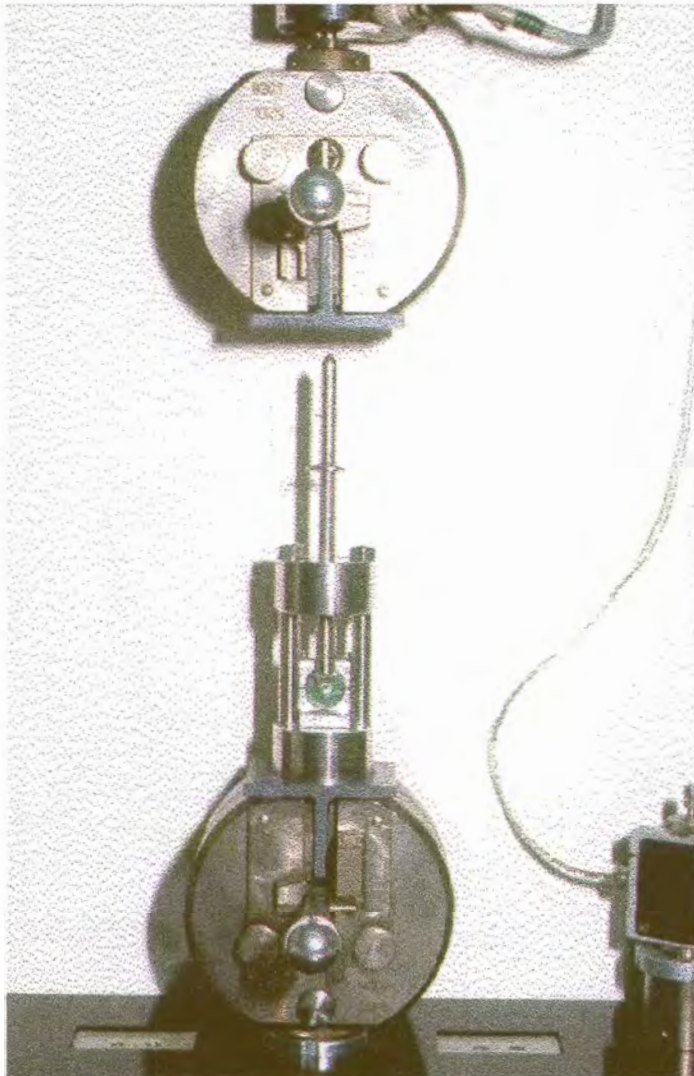

***Figure 7**: The Bencor Multi-T testing device with a mounted specimen for SBS testing in the Zwick Universal Testing Machine (Model Z010/TND, Zwick GmbH & Co., Ulm, Germany)*

Figure 8: *The SBS components of the Bencor Multi-T system contains a knife-edge guillotine for standardised positioning during force application on the bracket*

3.2.6 Evaluation of fracture sites

After shear mode testing, the bracket bases and the enamel surfaces were inspected independently by one evaluator, to determine the predominant bond failure site. All identification markings were covered, and the samples were chosen at random for examination. The teeth and debonded attachments were examined under a light-optical stereomicroscope (*Nikon SM2-10, Tokyo, Japan*) at X20 magnification to determine fracture sites, to establish the character of the debonded surface. The sites were classified as Type 0, 1, 2 or 3, according to the Adhesive Remnant Index (ARI), described by Årtun and Bergland in 1984. This index determines the amount of bonding material remaining on the enamel surface after bond failure.

3.2.7 Preparation of SEM specimens

Samples were selected randomly from each group to be examined by scanning electron microscopy (SEM), in order to further analyze the fracture sites and confirm the character. Specimens consisted of the tooth surface as well as the matching debonded bracket.

The buccal surface-area of the tooth specimens was separated from the rest of the crown, using the Beuhler water-cooled circular diamond cutter. The selected specimens were stored for 2 days in absolute alcohol, allowed to air dry for 2 hours, mounted on SEM stubs so that the relevant area of interest could be seen, sputter-coated with Gold/ Argon in a Polaron SEM Autocoating Unit (*Model E5200, Polaron Equipment Ltd., Watford, England*). These were then viewed in a JEOL (*Model JSM 840, JEOL, Tokyo, Japan*) scanning electron microscope (SEM), operated at 10 kV, at various magnifications. Samples representing the mean of the ARI scores were chosen and photomicrographs were taken.

3.2.7 Statistical analysis of the data

The descriptive statistics for the debonding strengths of the four groups were calculated and recorded in MPa.

Descriptive statistics included the mean, minimum and maximum values, standard deviation and coefficient of variation for the SBS tests.

The Adhesive Remnant Index (ARI) scores were noted and their percentages were calculated for each of the four groups of teeth tested.

The analysis of variance (ANOVA) was used to determine if significant differences were present in the SBS-values, followed by an unpaired t-test to identify which of the groups were different. For the purpose of the statistical analysis groups 1 and 2 were combined, as were groups 3 and 4 when appropriate. Significance for all statistical tests was predetermined at $p < 0.05$.

The Kruskal-Wallis statistical test was used to determine if there were any significant differences present in the Adhesive Remnant Index (ARI) scores between the four group ($p < 1.00$).

CHAPTER 4

RESULTS

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CHAPTER 4

RESULTS

4.1   SHEAR BOND STRENGTH (SBS)

The mean shear bond strengths, standard deviations, maximum and minimum values and coefficient of variation are presented in Table 3. The mean shear bond strengths, standard deviations and maximum and minimum values are presented graphically as bar diagrams in Figure 9.

The mean shear bond strengths were 9.97 ± 2.94MPa and 10.72 ± 2.54MPa for 80 gauge mini and standard size respectively, and 10.45 ± 3.27MPa and 11.39 ± 3.32MPa for 100 gauge mini and standard size. The lowest SBS (2.95MPa) was recorded in the M80 (mini size/80 gauge) group. The highest SBS (19.77MPa) was recorded in the S100 (standard size/100 gauge) group.

The highest coefficient of variation (31.3%) was recorded in the M100 group.

Table 3: Mean SBS (MPa), standard deviation (MPa), minimum values (MPa), maximum values (MPa) and coefficient of variation (CV) for the four groups

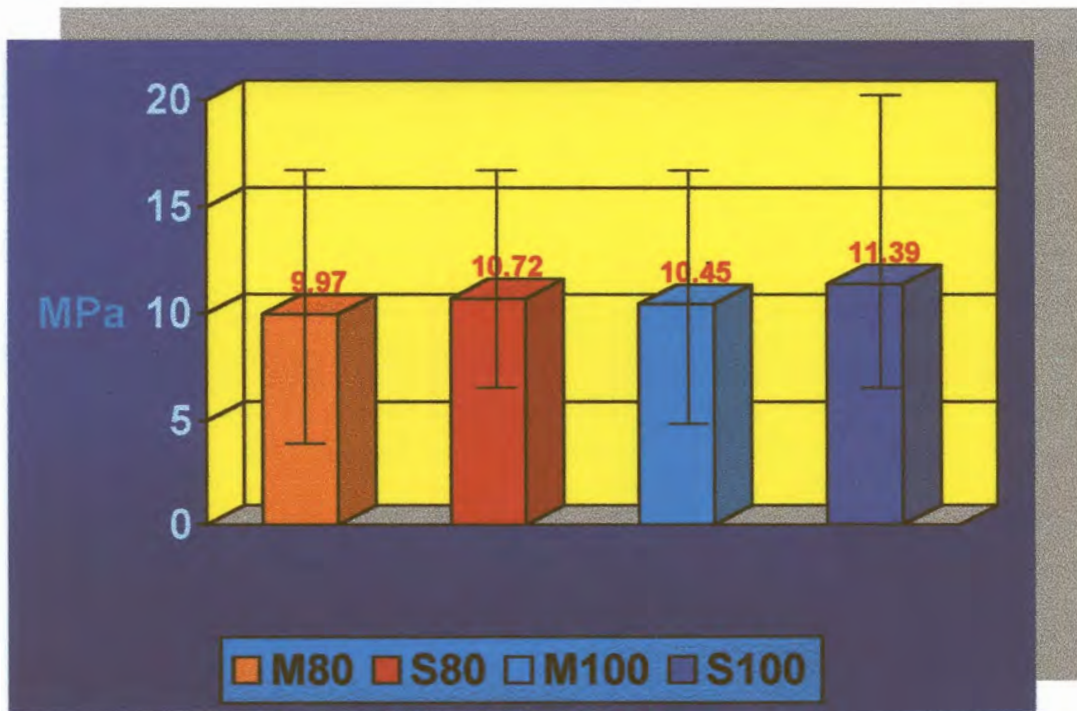| Group	Number of teeth	Mean (MPa)	Standard Dev. (MPa)	Min. values (MPa)	Max. Values (MPa)	CV (%)
1 M80	20	9.97	2.94	2.95	15.84	29.5
2 S80	20	10.72	2.52	6.31	15.94	23.5
3 M100	20	10.45	3.27	3.82	16.09	31.3
4 S100	20	11.39	3.32	6.39	19.77	29.2

Figure 9: *Mean SBS (MPa), minimum values (MPa) and maximum values (MPa) for the four groups of brackets*

Table 4 shows that there was no statistically significant differences (p<0.05) between the mean shear bond strengths of the 80 gauge mini and standard size brackets than for the 100 gauge mini and standard size brackets (9.97±2.94MPa and 10.72±2.52MPa vs. 10.45±3.27MPa and 11.39±3.32MPa). There was also no significant difference (p<0.05) between brackets with the same gauge mesh, but of a different surface area size.

Table 4: *Comparison of SBS values between the different groups by means of the ANOVA test.*

Group	Number of teeth	Mean (MPa)	Standard Deviation
1 M80	20	9.97	2.94
2 S80	20	10.72	2.52
3 M100	20	10.45	3.27
4 S100	20	11.39	3.32

P=0.517

4.2   ADHESIVE REMNANT INDEX (ARI) SCORES

Three specimens showed partial detachment of enamel and were therefore discarded. Three other specimens were used in their place.

The Adhesive Remnant Index (Årtun and Bergland, 1984) scores for each individual bonded surface as was observed under the light stereomicroscope at a x20 magnification, are presented in Table 5. The percentages of each score are shown diagrammically in Figure 10 for the 80 gauge mini and standard size brackets enamel surfaces, and in Figure 11 for the 100 gauge mini and standard size brackets enamel surfaces, respectively.

Table 5: Adhesive Remnant Index (ARI) scores presented after debonding the different bracket types.

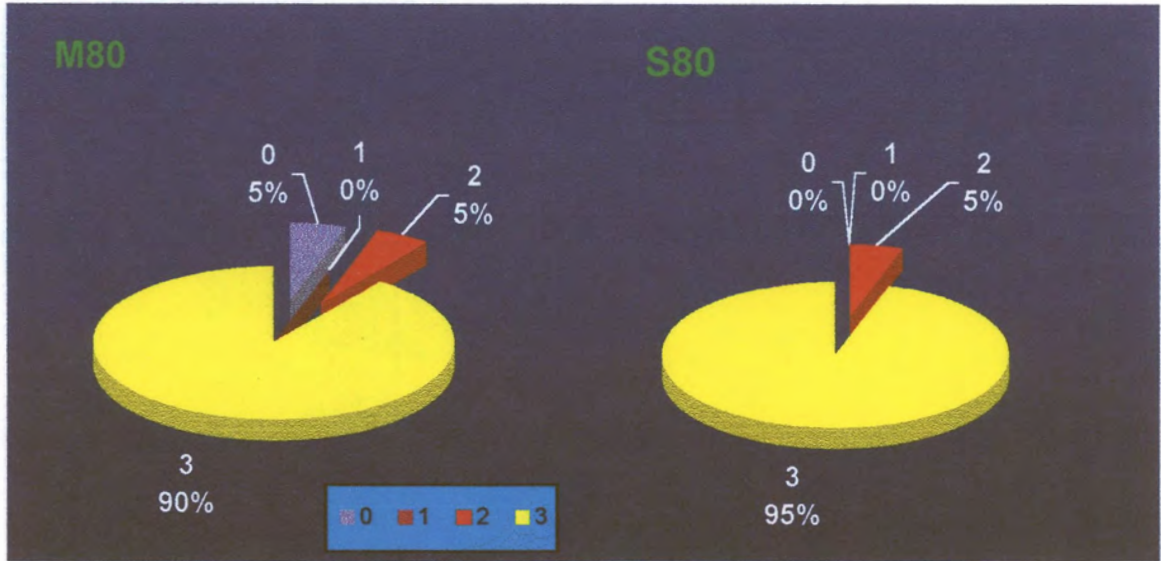| Group	Number of teeth	Score 0	Score 1	Score 2	Score 3
1 M80	20	1	0	1	18
2 S80	20	0	0	1	19
3 M100	20	1	1	1	17
4 S100	20	1	0	1	18

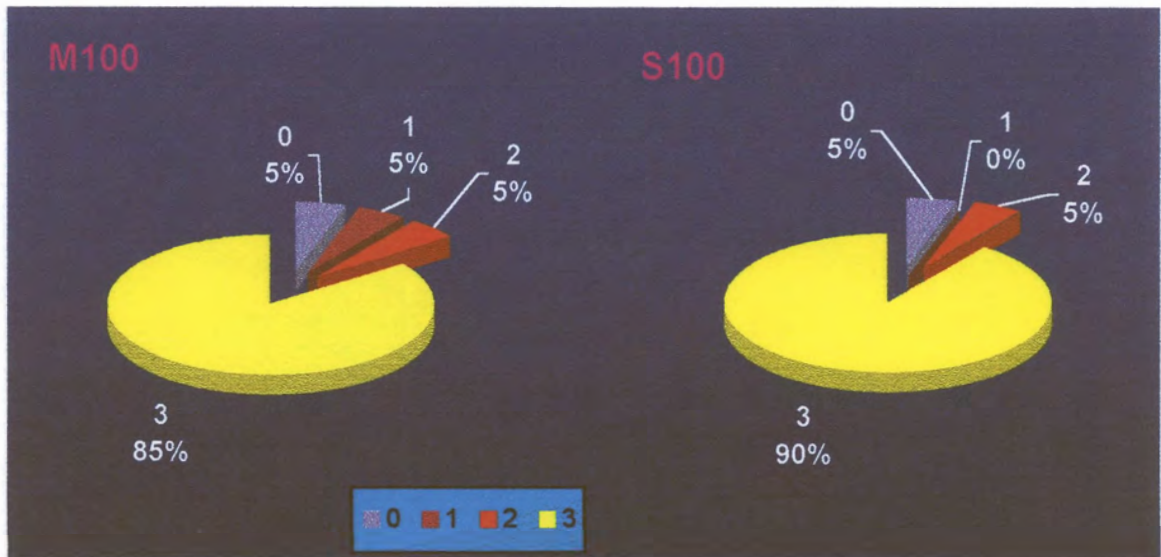*Figure 10*: Adhesive Remnant Index (ARI) scores for 80 gauge brackets

Figure 11: Adhesive Remnant Index (ARI) scores for 100 gauge brackets

The Kruskal-Wallis statistical test for the scores of the Adhesive Remnant Index (ARI) (r=0.140 with 3 degrees of freedom), showed no statistically significant differences (p<1.00) between the failure sites of 80 and 100 gauge, mini and standard size brackets.

Bond failure occurred almost solely at the bracket/resin interface (85-95%) for all groups.

4.3 SCANNING ELECTRON MICROSCOPY EVALUATION

Scanning electron microscopy analysis on representative debonded samples of teeth and brackets (Figures 12, 13, 14 & 15) verified the findings that bond failure predominantly took place at the bracket/resin interface. Figure 12 and 13 show that a small amount of resin remained on the bracket and the majority on the enamel surface.
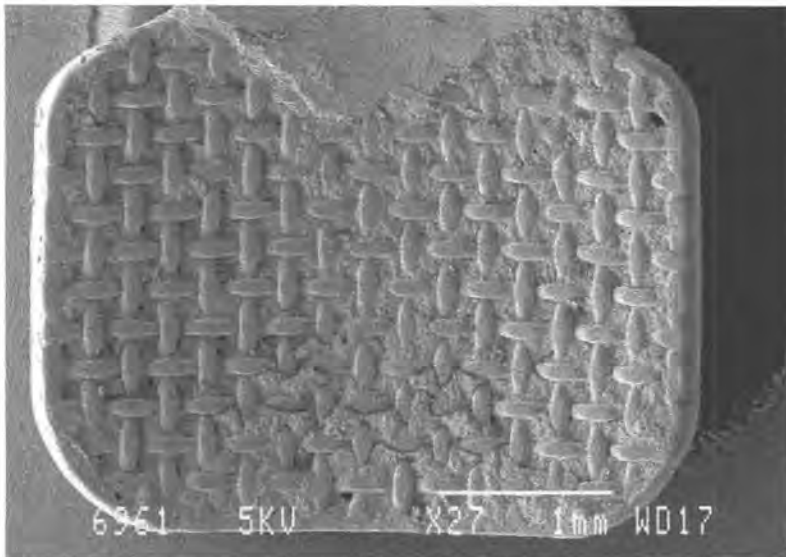

Figure 12: After debonding, the bracket base remained relatively clean, although a small amount of resin can be seen on the top of the bracket (original magnification x27)
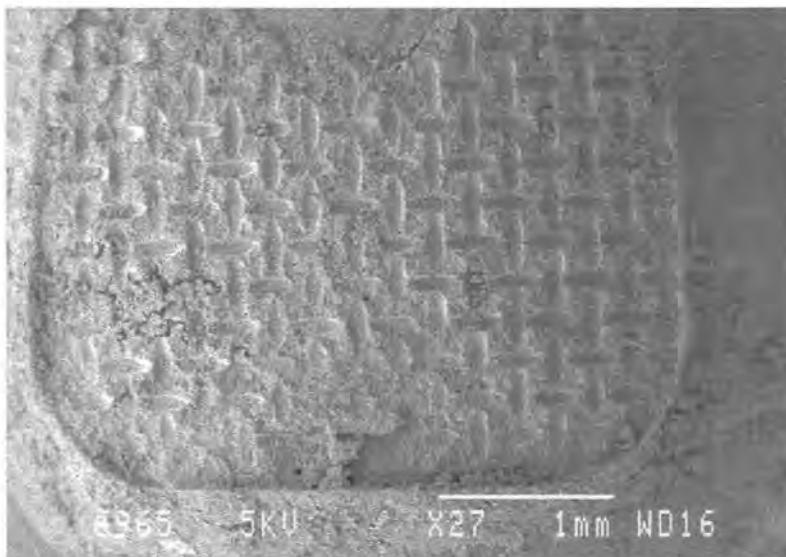

Figure 13: After debonding, the enamel surface shows that most of the resin remained on the tooth. The mesh markings can be clearly seen (original magnification x27)
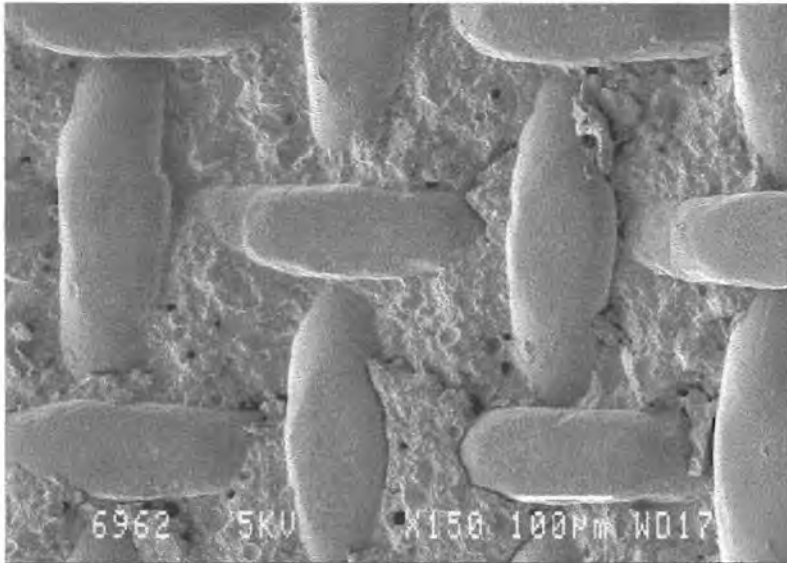
Figure 14: Even though most of the resin remained on the tooth, a substantial amount can be seen remaining in the mesh (original magnification x150)
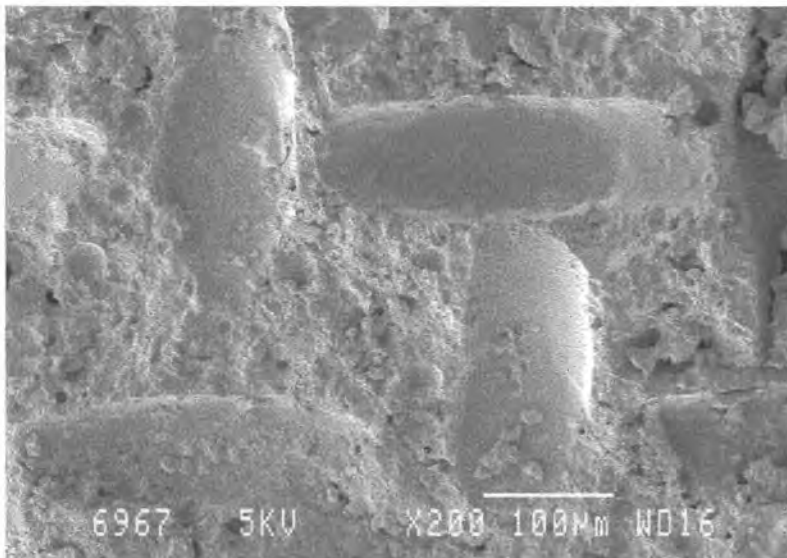

Figure 15: The mesh markings on the enamel surface shown under higher magnification (original magnification x 200)

CHAPTER 5

DISCUSSION

CHAPTER 5

DISCUSSION

5.1 SHEAR BOND STRENGTH (SBS)

Reducing the size of the bracket will lead to improvements in aesthetics and will also ease the ability for a good oral hygiene (Maijer and Smith, 1981). This reduction, however, does result in less base surface area available for bonding with the concurrent clinical reality of increased debond rates (MacColl, 1998).

Fixed orthodontic appliances are plaque-retentive devices and may subsequently lead to an increased incidence of enamel demineralization and caries (Shannon, 1981). Continuing efforts to produce a more aesthetic orthodontic appliance has influenced manufacturers to produce smaller brackets and base surface areas (Glatz and Featherstone, 1985). However, there are possible limitations when reducing bracket base surfaces, such as less enamel protection under the actual bracket and tie-wing areas, which are the plaque-retentive parts of the attachments.

Figure 10 clearly shows that when comparing the mean shear bond strength values, they are in the same order of magnitude for all four groups compared. Also the maximum and minimum values are in a comparable range. Each group in this study, yielded relatively high mean SBS-values of 10-11.4MPa, which confirms similar with results that were recently reported by MacColl and coworkers in 1998.

Consequently, at present it seems more important to improve and simplify the clinical operating procedures rather than to increase the adhesive strength of the currently available adhesives or brackets (Zachrisson, 1977). Moreover, an increased bond strength to enamel could provoke more damage of the enamel because of the difficulties in debonding (Betteridge, 1979; Carstensen, 1986). However, higher bond strengths could reduce the surface area needed for a strong bond, which would ultimately result in the use of smaller brackets. It should be pointed out that the MegaPascals (N/mm²) provide an indication of the force per unit area required to dislodge the bracket. This would mean that a bracket with twice the surface area of the one tested would require twice the force to dislodge it. In each case the bond strength would be the same when quoted in MegaPascals. If the same bond strength were to be quoted in Newtons or kilograms, the larger bracket would appear to have twice the bond strength. This should be remembered when interpreting these results.

The minimum bond strength required for clinical success is related to the forces of occlusion and not to the forces generated by an orthodontic arch wire. The force generated by an orthodontic arch wire ranges from 15 to 150 gm (Proffit, 1993), except in situations where torquing moments are introduced, which induce much higher forces. In this study, all the base surface areas and base treatments produced shear bond strengths that clearly exceeded these values.

The use of a thin transducer to measure the maximum biting force during chewing by a patient on command has been reported (Proffit, Fields & Nixon, 1983). Their study showed that, in children with normal lower face heights between the ages of 6 and 11 years, this force is 5.0 kg and in adults 13.5 kg. These results are similar to the values reported by other investigators, where thick strain gauges were used (Garner and Kotwal, 1973; Graf, Grassl & Aeberhard, 1974; Finn, 1978; Haraldson, Carlsson & Ingervall, 1979). It would thus be reasonable to presume from these studies that bracket displacement forces may range from 5 to 13 kg.

The results of the current study shows that bracket bases ranging in surface area from 8.92 to 14.00 mm² exhibited no statistically significant differences in SBS. This is in agreement with MacColl and coworkers (1998), who found no significant differences in SBS between 6.82 and 12.35 mm² bracket bases. However, they found that reduction of the surface area to 2.38 mm² resulted in a statistically significant drop in SBS, and it can only be speculated that this drop would also be of clinical significance. This study did not address the critical surface area below which clinical performance would be unacceptable. Nonetheless, the results indicated that brackets with base areas in excess of 8.92 mm² perform equally well.

The work of Retief (1974b) on bond failure at the enamel-adhesive interface indicated that fractures in the enamel could occur with bond strengths as low as 13.5 MPa. This is almost comparable with the mean linear tensile bond strength of 14.5 MPa for enamel previously reported by Bowen and Rodriguez (1962). Although enamel can often withstand much greater forces during debonding, the prudent clinician should avoid using any bracket-conditioner-adhesive combination that can result in bond strengths significantly greater than 13.5 MPa (Retief, 1974b). The current findings indicated that all combinations tested produced mean bond strengths of less than 11.4 MPa, which would appear to be relatively safe mean debonding force values.

Clinical perception is that the larger the bracket base diameter and mesh size, the better bond can be obtained. As proven in this study, that is untrue. A smaller bracket independent of mesh size does not lead to inferior bond strength. Therefore a mini bracket which is more advantageous to patient comfort and aesthetics can be chosen by the clinician.

Also, the smaller brackets are more hygienic and due to that, it is assumed, that there would be a decreased risk of decalcifications of the enamel surface (O'Reilly and Featherstone, 1987).

According to the results of this study, there is no difference between 80 and 100 gauge meshes, and therefore the use of either of these mesh sizes can be recommended. This is not in accordance with Maijer and Smith (1981), who found brackets with finer mesh size (100 gauge) to have higher SBS than brackets with coarser mesh size (40 gauge). Reynolds and Von Fraunhofer (1976) found mesh sizes between 60 and 70 gauge to perform the best.

However, the SBS-values obtained in this study are not fully comparable to Reynolds and Von Fraunhofer's (1976) results, due to the fact that they used tensile bond strength. Also, Dickinson and Powers (1980) found no correlation between mesh sizes (40 to 100 gauge) when measuring tensile bond strength.

The use of t-tests and ANOVA may be criticized in the context of bond strength testing (Fox, McCabe & Buckley, 1994). The reason is that they assume that the bond strength data are drawn from a normally distributed population and this is not always the case. A mean and standard deviation may not be the best indicator of the performance of a bonding material (Fox and McCabe, 1992). Reynolds and Von Fraunhofer (1976) also stated that quoting the mean bond strength is of limited usefulness to the clinician. When considering bond failure, the weaker values (the tail of the distribution) may be of more importance. The use of a survival analysis such as the Weibull analysis may be appropriate in this case and has been used in orthodontic bond strength testing (Britton et al., 1990; Fox and McCabe, 1992) although its use is not currently widespread (Fox, McCabe & Buckley, 1994). In vitro bond strength tests are notable for producing results that have a wide variation. Maijer and Smith (1981) suggest that from a mechanical point of view, acceptable clinical direct bonding techniques require not only a high mean bond strength, but also a narrow distribution about the mean, because the lowest value governs the possibility of clinical failure.

Retief (1974a) found that the coefficients of variation in bonding studies range from 16 to 27%. In the present study, the coefficient of variation ranged from 23.5 to 31.3%, the higher value being found in the M100 group. One of the most dramatic changes in the orthodontic specialty in the 1970s was the use of composite resin as a bonding material (Newman, 1965). The use of self-cured composite resin for direct bonding of orthodontic brackets to the tooth surface was then well documented (Reynolds, 1975; Johnson, Hembree & Weber, 1976; Keizer, Ten Cate & Arends, 1976). The polymerization of self-cured resin with the two-paste system starts immediately on mixing; thus the operator is unable to perfectly manipulate the setting time, which affects bracketing accuracy and positioning on the tooth surface (Wilson, 1988). The air bubbles that arise during mixing or the uneven consistencies in resins that are mixed by hand result in the weakening of the bond strength in the two-paste system. Variability in SBS-values could be explained by the fact that perhaps in some instances brackets were applied after the initial polymerization reaction had been started (Legner et al., 1989). This factor can be disregarded in this study since all the bonding procedures were performed by one operator.

The variations in layer thickness might be an additional and reasonable explanation for a higher variation between minimum and maximum values. Every product has its own critical thickness at which the SBS is highest (Evans and Powers, 1985; Britton et al., 1990; Surmont et al., 1992; Bishara et al., 1998a). An increased layer thickness will result in a lower bond strength (Silverman, Cohen & Gwinnett, 1979; Evans and Powers, 1985). The critical layer thickness is closely related to the adhesive consistency and the need to mix the adhesive in a standardized manner (Silverman, Cohen & Gwinnett, 1979). This variable was controlled in the present study by placing all specimens in a jig with a 500 gram force perpendicular to the bracket base, while polymerization took place.

The bond strengths recorded in this study ranged from 10.0 to 11.4 MPa compared with 16 to 25 MPa reported in other studies (Surmont *et al.*, 1992; Powers, Kim & Turner, 1997; MacColl, 1998). These differences may be attributed to variations in types of tested samples (human or animal teeth, plastic cylinder, or a combination of these), types of teeth (incisor, canine, premolar, or molar; young or old permanent teeth, deciduous teeth, or a combination of these) (Lopez, 1980; Knoll, Gwinnett & Wolff, 1986; Kinch *et al.*, 1988; Sheen, Wang & Tarng, 1993, Fox, McCabe & Buckley, 1994; Bishara *et al.*, 1998a; 1998b). Other possible factors are the type and size of bracket base, contour of tooth surface, etching times, concentrations of etchant, pretreated condition (humidity, temperature, and duration of water bathing), rebonding of tooth surface, recycling of bracket, types of resin or testing speed of the debonding machine (Silverman and Cohen, 1974; Brännström, Nordenvall & Malmgren; 1978; Zachrisson and Brobakken, 1978; Kinch *et al.*, 1988; Smith and Shivapuja, 1993; Wang, Hsiang & Chen, 1993; Zachrisson, 1994; MacColl *et al.*, 1998). All the above variables were the same for all the specimens in this study.

It should be mentioned that bond failures, which are failures in the enamel-adhesive interface, are likely to be due to inadequate technique (e.g., moisture contamination or disturbed setting).
Failures in the adhesive-bracket interface are more likely caused by a weak adhesive.

Clinically, bond failures usually occur at the adhesive-enamel interface and not at the gauze (mesh backing)— adhesive interface. This indicates that an *in vivo* moisture contamination is a major factor contributing to adhesion failure in clinical orthodontics. Moisture contamination probably occurs from saliva or from within the enamel itself (Reynolds and Von Frauenhofer, 1976).

The SBS-values in the four groups compared favorably to Reynolds (1975) values for minimal bond strength that are clinically acceptable (5.9

to 7.8MPa). Again, it needs to be emphasized that this is an *in vitro* study and the test conditions have not been subjected to the rigors of the oral environment. The retention of the bonded orthodontic attachments *in vivo* is governed partly by factors related to the operator, but also by factors related to the patient. A careful clinical technique, moisture control, choice of appliance fitted, and instructions to the patient are all controlled by the operator. The age and sex of the patient, malocclusion type and appliance care are not controlled by the operator, but also influence clinical success (Millett and Gordon, 1994). A composite-enamel bond must resist the stresses induced by polymerization shrinkage and regular differential thermal changes between the composite resin and enamel. In a clinical environment the theoretical bond strength of a composite material is never achieved due to the presence of internal stress concentrations (such as air voids, cracks or defects) and increases in external stress which are due to the geometry of the occlusal loading (Bryan and Sheriff, 1995).

According to Joseph and Rossouw (1990a), the true cohesive bond strengths of the composites are masked by bracket deformation during test procedures. Another problem that has always existed when comparing *in vitro* bond strengths is the method of testing. Differences exists in the type of the method of evaluation bond strengths (shear, peel, tensile, brittleness, hardness, or compressive), machine used in testing, and the type of mounting apparatus (Smith and Shivapuja, 1993). Nevertheless, *in vitro* studies can serve as useful guides for clinical bonding applications.

5.2 ADHESIVE REMNANT INDEX (ARI) SCORES

There have been many studies on the bond strength of directly bonded orthodontic brackets to etched enamel. Most of these studies have shown values that are adequate for clinical use.

The site of failure provides information about the quality of the bond between the composite and the bracket base. Ideally in orthodontics, one would like an adequate bond, which fails at the enamel/composite interface as this would make debonding and subsequent polishing much easier.

When the bond is tested for failure, there are two main failure sites (O'Brien, Watts & Read, 1988). These are the bracket base/adhesive interface and the enamel/adhesive interface. Cohesive failure within the main bulk of the adhesive material can be largely discounted.

Most investigators reported that in many cases the breakage of bonding was within the resin itself or the bracket-resin interface (Keizer, Ten Cate & Arends, 1976; Lee, Orlowski & Rogers, 1976; Reynolds and Von Fraunhofer, 1976; Gorelick, 1977; Faust *et al.*, 1978; Zachrisson and Brobakken, 1978; Richard and Gwinnett, 1980; Wheeler and Ackerman, 1983; Schulz *et al.*, 1985; Evans and Powers, 1985; Wiltshire, 1994; Wang, Meng & Tarng, 1997; Bishara *et al.*, 1998b; MacColl *et al.*, 1998).

However, limited information regarding resin-tooth interface and tooth surface detachment was reported, probably because of the difficulty in identifying resin or enamel under SEM observation. In this study, three different fractured interfaces were found, metal-bracket, within the resin itself, and resin-enamel interface. As mentioned earlier, on three specimens, one in the M80 and two in the S100 group, enamel detachment was noted. They were therefore discarded from this study,

due to the fact that their respective debonding values did not represent true shear values.

It has been stated that the most common failure site when stainless steel brackets are used is the adhesive/bracket base interface and consequently the bond strength at the etched enamel/adhesive interface is greater than that at the bracket base/adhesive interface (Dickinson and Powers, 1980; Maijer and Smith, 1981).

According to O'Brien, Watts and Read (1988), when an adhesive material is used in very thin sections, as in orthodontic bonding systems, the site of failure becomes influenced by the design of the bracket base and by the type of adhesive material used. It is not a case of differing bond strengths at the separate interfaces that governs failure site. It is probably caused by stress concentration and consequent crack formation that progresses to bond failure.

Gerbo and coworkers in 1992 found that there does not appear to be a correlation between the tensile bond strength and the Adhesive Remnant Index (ARI).

One cannot under the conditions of an *in vitro* study, predict the site of failure of a bonded bracket for a given force applied. Guzman, Faust and Powers in 1980, stated that the method of bond testing (shear, peel or tensile) influences the quantity of residual adhesive left on the surface. Kusy (1994) stated that bond failure with stainless steel brackets may be influenced by bracket "flex", or distortion on loading, decreasing SBS forces exerted on tooth enamel during debonding. The mechanism of adhesive failure is not fully understood (Jassem, Retief & Jamison, 1981).

Failure at the base/adhesive interface results in adhesive remnants being firmly attached to the enamel. Removal of large amounts of debris can

be time-consuming and may cause enamel surface damage (Zachrisson, 1994).

Most failures occurred in the adhesive/bracket interface, and these values may therefore not reflect the real adhesive strength to enamel. The debonding strengths will represent the true adhesive force only if the failure is of an adhesive nature, i.e., is located in the adhesive interface, and not if they are cohesive fractures, i.e., failure in one of the materials to the side of the interface (Zachrisson, Zachrisson & Büyükyilmaz, 1996).

As mentioned, the debonding strength values may represent the true adhesive force of composite to enamel only if cohesive fractures can be avoided. A failure in one of the materials to the side of the interface indicates that the physical properties of that material limits the bond strength of the assembly. In orthodontic bond strength testing, cohesive fractures in the composite resin (ARI score 3) reflect the internal strength of the composite rather than the actual adhesion to the surface under study (Zachrisson, 1994).

Årtun and Bergland (1984) have attempted to quantify the amount of residual debris by means of the adhesive remnant index (ARI). However, this approach may suffer from being a subjective one. To avoid any subjectivity during this study, the samples were chosen at random and examined blind, by one operator. The teeth and the debonded brackets were examined under a light stereomicroscope at X20 magnification to determine failure sites and selected representative samples were further analyzed by scanning electron microscopy (SEM).

Orthodontists use the acid-etch bonding technique as a primary means of attaching brackets to the enamel surface. Maintaining a sound unblemished enamel surface after debonding orthodontic brackets is a primary concern to the clinician. As a result, bond failure at the bracket-adhesive interface or within the adhesive is more desirable (safer) than

at the adhesive-enamel interface, because enamel fracture and crazing have been reported at the time of bracket debonding (Britton *et al.*, 1990).

CHAPTER 6

CONCLUSIONS

CHAPTER 6

CONCLUSIONS

6.1 CONCLUSIONS

The following conclusions can be made from this study:

- There was no significant difference ($p < 0.05$) in the shear bond strength between 80 and 100 gauge mesh mini and standard size brackets.

- There was no significant difference ($p < 0.05$) in the mean shear bond strength between mini and standard size brackets with 80 and 100 gauge mesh.

- There is no statistical difference ($p < 1.00$) in the Adhesive Remnant Index (ARI) scores between the four groups.

- The failure site was predominantly at the adhesive/bracket interface.

- The null hypothesis stated, that there is no difference in the shear bond strengths of 80 and 100 gauge mesh bases and standard and mini size bases when bonded with Concise orthodontic bonding agent to human enamel, is therefore accepted.