COMPARING TWO ORTHODONTIC BRACKETS' BOND TO FLUOROSED AND NON-FLUOROSED ENAMEL- AN IN VITRO STUDY

By

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Declaration

STATEMENT BY CANDIDATE

I, Serufe Emily Monehi, hereby declare that the work on which this thesis is based is original (except where acknowledgements indicate otherwise) and that neither the whole work nor any part of it has been, or shall be submitted for another degree at this or any other university.

The work reported in this thesis was performed in the Department of Orthodontics, University of Pretoria, School of Dentistry, Republic of South Africa.

All opinions or statements expressed in this thesis do not necessarily reflect that of the University of Pretoria, the supervisors of the thesis or the external examiners.

Signature:

Date: 30-06-2014

SE Monehi

Dedication

This dissertation is dedicated to my mother Kukuna, for being my rock, brothers-Solly,Osar and Matseba for always being by my side and to my lovely husband and son Marcus and Bophelo. Thank you for your constant love and support.

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Our Creator and God, thank you for giving me a clear mind and a healthy body.

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Shear bond Strength

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Summary

Orthodontic attachments must be able to bond to a wide range of tooth and prosthetic surfaces. Despite the high prevalence of fluorosis in many parts of South Africa (Louw A, Chikte U 1997), only limited information is available on the integrity of the bond between orthodontic brackets and fluorosed teeth.

The objective of this study was to measure and compare Shear Bond Strengths (SBSs) of metal and ceramic orthodontic brackets on fluorosed and non-fluorosed teeth.

One hundred and twenty (60 fluorosed and 60 non-fluorosed) extracted premolar teeth were divided into four groups A to D, consisting of 30 teeth in each group. BluGloo® was used as an orthodontic adhesive to bond brackets on the buccal surface of each tooth. The experimental groups consisted of Group A, in which Nu-Edge® metal brackets were used and Group B, in which InspireIce® ceramic brackets were bonded to fluorosed teeth. Group C and D consisted of Nu-Edge® metal brackets and InspireIce® ceramic respectively, bonded to non-fluorosed teeth.

Bonding techniques were kept the same and standardised for all four groups. An Instron testing device was used to debond and measure the SBSs. SBSs were compared using ANOVA with posthoc analysis done using Dunnett's C test for pairwise comparisons. Significance was set at $P<0.05$.

The results showed that SBS of Group B>Group C>Group D>Group A. Ceramic brackets bonded to fluorosed teeth had the highest SBS with a mean of 15.78 (SD=9.07) Megapascals (MPa), while metal brackets bonded to fluorosed teeth produced the lowest SBS of 8.41 (SD=4.68) MPa. The SBSs of ceramic brackets bonded to fluorosed teeth was significantly higher than that of SBS of metal brackets bonded to fluorosed teeth, but not significantly different from SBSs obtained from either brackets bonded to non-flurosed teeth.

The BluGloo adhesive if used to bond ceramic brackets to fluorosed teeth can produce adequate SBS for clinical use. The recommendation from this study is that ceramic brackets can be used efficiently to bond to fluorosed teeth. A follow up study should be carried out to assess the nature of enamel damage caused during debonding of flourosed teeth. This is a laboratory study and thus the clinical application should be interpreted with caution.

Chapter 1

Introduction

Background

Successful orthodontic treatment greatly depends on patient compliance and the ability of orthodontic attachments to withstand orthodontic and occlusal forces over the duration of treatment. Orthodontic attachments must be able to bond to a wide range of tooth and prosthetic surfaces. Successful bonding of orthodontic brackets depends on the nature of the enamel surface, enamel conditioning procedure, type of adhesive used and the shape and design of the bracket base (Sunna S 1998) (Adanir, Turkkahraman & Gungor 2007).

Orthodontic bonding is based on the mechanical locking of an adhesive to irregularities in the enamel surface of the tooth and mechanical locks formed in the base of the orthodontic attachment. The recommended amount of shear bond strength (SBS) the orthodontic attachment should withstand has been estimated to be between 5.9 MPa and 7.8 Mpa during clinical use (Reynolds 1975). Enamel damage has been reported during debonding in cases where the tensile bond strength was above 14.5Mpa (Bowen RL 1962).

Ceramic brackets are made of high-purity aluminum oxide, and the brackets are available in both polycrystalline and monocrystalline forms. It is important to note that the SBS of polycrystalline ceramic brackets has been reported to be higher than that of stainless steel metal brackets (Viazis A.D, Cavanaugh G & Bevis R.R. 1990). Monocrystalline brackets have been reported to have higher bond strength than polycrystalline brackets. The occurrence of the enamel fractures previously reported during debonding is due to the high bond strength of ceramic brackets. Though aesthetic ceramic brackets have an advantage of being more cosmetic and have increased bond strength, they also come with some clinical shortfalls. They may result in increased enamel wear and enamel fracture during the debonding process. The brackets are structurally harder and stronger than enamel.

Dental fluorosis, prevalent in many parts of South Africa, (Louw A, Chikte U 1997) is a condition caused by excessive ingestion of fluoride of more than 1-2 ppm during tooth development (Fejerskov O, Larsen MJ, Richards A,Baelum V, 1994) (Adanir, Türkkahraman & Güngör 2009). There are marked differences in the enamel structure between non-fluorosed and different degrees of fluorosed teeth. Fluorosed enamel may pose a huge challenge for orthodontists working in endemic fluorosed regions (Miller 1995) (Adanir, Türkkahraman & Güngör 2009) (Adanir, Türkkahraman & Güngör 2009). A number of studies have carried out SBS tests on both fluorosed and non-fluorosed enamel surfaces (Adanir, Türkkahraman & Güngör 2009) (Isci *et* *al*. 2011). These studies tested SBS on fluorosed teeth using metal bracket and the literature indicated that no study has tested for SBS using ceramic brackets.

Motivation of Study

Despite the high prevalence of fluorosis in many parts of South Africa (Louw A, Chikte U 1997), only limited information is available on the integrity of the bond between orthodontic brackets and fluorosed teeth.

Aim of this Study

The aim of this in vitro study was therefore to evaluate and to compare the effects of fluorosis on the SBS achieved by directly bonding orthodontic ceramic and metal brackets to fluorosed teeth.

The Objective of this Study

1. To measure and compare the SBS of metal and ceramic orthodontic brackets on fluorosed and non-fluorosed teeth.

Hypothesis

Null Hypothesis

SBSs of metal and ceramic brackets bonded to fluorsed and non fluorosed teeth will not differ from each other

Chapter 2

Literature review

The orthodontic profession has gone through an evolving process to reach the current bracket systems used in clinical practice. Materials used in orthodontics have gone through continuous refinement over the years. The first orthodontic attachments used in orthodontics were bands, and these are used less frequently today. The orthodontic brackets have evolved from metal brackets to more aesthetic brackets (i.e. plastic and ceramic brackets). Orthodontic bands were replaced by brackets directly bonded onto the enamel surface. The rule in contemporary orthodontics is that bonded attachments are almost always preferred for anterior teeth and premolars (Profit RW 2013).

Listed below are a couple of draw backs of orthodontic banding which may have led to the introduction of directly bonded attachments:

- Unattractive
- Tooth separation can be painful
- Extensive chair time
- Decalcification of the tooth structure under the bands
- Mechanical and chemical irritation of gingiva
- Difficulty in maintaining periodontal health

- Bands encroached additional spaces in the arch length hence pose difficulty in critical anchorage and borderline cases
- Residual spaces after removal of bands have to be closed by removable appliance

Orthodontic Bonding

Direct bonded orthodontic appliances should remain secure for the duration of treatment but should also be easily removed at the termination of active therapy without any damage to tooth structure. The adhesion to the enamel surface is therefore a critical factor. Poor adhesion can cause bond failure during treatment, and too strong adhesion to enamel surfaces is more likely to cause enamel damage on removal of the bracket.

Orthodontic bonding is based on the mechanical locking of an adhesive to irregularities in the enamel surface of the tooth and mechanical locks formed in the base of the orthodontic attachment. The amount of shear bond strength (SBS) the orthodontic attachment should withstand has been estimated to be between 5.9 MPa and 7.8 MPa during clinical use (Reynolds 1975). Enamel damage has been reported during debonding in cases where the tensile bond strength was above 14.5Mpa (Bowen RL 1962).

Bonding Process

Orthodontic bonding procedure generally involves pumicing, conditioning/etching enamel, primer application and placement of attachment. There are two main ways in which orthodontic attachments are secured onto the enamel surface, namely indirectly or directly. The direct bonding occurs in a single appointment whereas the indirect bonding requires two appointments.

Pumice

The effect of pumicing the tooth surface is controversial. Cleaning the enamel with pumice removes plaque and organic pellicle that is found to cover all teeth (Aboush, Tareen & Elderton 1991). The need for pumice polishing before acid etching has been questioned (Lew, Chew & Lee 1991) (Swartz 1994). It appears that prophylaxis does not affect bonding procedure negatively (Barry 1995). Cleaning teeth before bonding is advocated to remove plaque (Aboush, Tareen & Elderton 1991) (Adanir, Turkkahraman & Gungor 2007) or debris that might remain trapped at the enamel resin interface after bonding (Graber, Vanarsdal & Vig 2005).

Enamel Conditioning

Enamel conditioning procedure may include the use of phosphoric acid, crystal growth and laser etching.

Acid etching

Phosphoric acid with thirty seven percent concentrations is the most commonly used method for enamel conditioning today. Clinically, the etching of enamel creates microporosity within the enamel (Figure. 1) and reduces surface tension that allows the resin to penetrate and polymerize within the etched enamel rods. Standard thirty seven percent phosphoric acid typically dissolves about 5 - 10 µm of enamel surface and creates a zone of etched enamel rods for about 15 - 25 µm. Tooth surface water rinse removes calcium monophosphate and calcium sulphate by-products created by the enamel conditioning stage. Lightly dabbing the enamel surface with the acid etchant avoids polishing or fracturing the exposed enamel rods. Etched enamel is porous, making it susceptible to retention of stains, although precipitates from saliva fill the porosities over time.

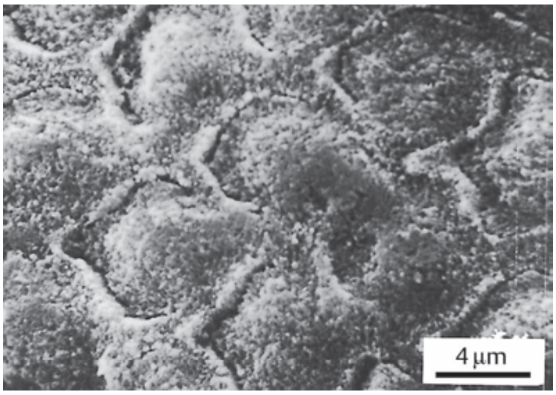

Figure 1 Typical etching pattern of human enamel

Showing enamel rods with micro-porosities. (Faust et al. 1978)

Shortfalls of the enamel conditioning procedure are listed below.

Table 1 Possible iatrogenic effects of acid etching of enamel (Brantly, Eliades 2001a)

- Fracture and cracking of enamel upon debonding
- Increased surface porosity - possible staining
- Loss of acquired fluoride in outer 10 µ.m of enamel surface
- Loss of enamel during etching
- Resin tags retained in enamel - possible discoloration of resin
- Rougher surface if over-etched

Crystal growth

Orthodontic bonding in the past included the use of crystal growth as an alternative for enamel preparation. Polyacrylic acid containing residual sulphate ions reacts with the enamel surface to produce a deposit of white spherulitic crystalline calcium sulphate to which the adhesive resin bonds. The crystals were identified as calcium sulphate dihydrate, $CaS0_4 \cdot H_20$ (gypsum) (Smith, Cartz 1973). The crystal growth bonding technique has several advantages over the phosphoric acid etch technique namely:

(1) The enamel surface is not significantly damaged,
(2) Debonding and enamel clean-up are easier,
(3) There is minimal loss of the outer fluoride-rich enamel layer, and
(4) Few if any resin tags are left in the enamel after debonding (157 Smith,D.C. 1973).

Maijer and Smith (Smith, Cartz 1973) compared the conditioning of enamel by the acid-etch technique with the crystal growth method. They concluded that conditioning with polyacrylic acid had a bond strength comparable to that of acid-etching with phosphoric acid, both in the laboratory (Smith, Cartz 1973) (Smith DC, Bennett G, Pcltoniemi R 1980) (Smith DC, Lux, Maijer R. 1981) and clinically.

However, other researchers found that bond strength when using crystal growth conditioning was much weaker than that of the conventional acid etching techniques (Artun, Bergland 1984).

In a study by Bishara et al 1997,the use of polyacrylic enamel conditioner in the crystal growth technique resulted in a reduced debonding strength when compared with the use of phosphoric acid in the conventional acid etch technique (Bishara *et al*. 1994). However, the "reduced" strength was still above the minimum bond strength of 60 kg/ cm2 (5.88 MPa) recommended by Reynolds (Reynolds 1975) as being adequate for clinical usage. This relative reduction in bond strength might be advantageous when debonding ceramic brackets, because it reduces the stress on the enamel surface.

Laser etching

The application of laser energy to an enamel surface causes localized melting and ablation (removal of material from the surface of an object by vaporization, chipping, or other erosive processes). Removal of enamel (etching) results primarily from the micro-explosion of entrapped water in the enamel. In addition, there may be some melting of the hydroxyapatite crystals. Laser etching of enamel by a neodymiumyt-trium-aluminum garnet (Nd:YAG) laser typically produces lower bond strengths than does acid etching (Brantly, Eliades 2001a).

Sealant/ Primer/ Bonding agent

A sealant contains unfilled resin (methyl methacrylate) (Millett DT 1996). A thin layer of the sealant is applied to the dry tooth surface after etching. Bracket placement should be done immediately after all teeth have been coated with the sealant. Primers contain monomers and hydrophilic molecules (HEMA, a coupling agent) (Dutta, Singh 2007). Primers are used in dentine bonding to expand the collapsed collagen fibres after etching.

It has been suggested that sealants increase bond strength and decrease micro-leakage (Graber, Vanarsdal & Vig 2005). The autopolymerizing sealants have been shown to have weaker bond strength due to oxygen inhibition of the curing process. Self-curing primers show low bond strength. This is less of a problem in the light cured sealants (Graber, Vanarsdal & Vig 2005).

There are many disagreements regarding the use of sealant/primers in orthodontic bonding. Some authors see no use of a sealant (Joseph, Rossouw 1992). Light polymerized sealants protect enamel adjacent to brackets from dissolutions and subsurface lesions (Ceen, Gwinnett 1980) (Ceen, Gwinnett 1981) whereas chemical curing sealants may polymerize poorly, exhibit drift and have low resistance to abrasion (Ceen, Gwinnett 1980).

Unfilled resins have been used as bonding agents in resin composite systems. The basic difference between these fluid bonding resins and the resin composites is the absence of filler particles in the fluid bonding resins (Brantly, Eliades 2001a). The compositions of these systems differ from those of their composite counterparts in the increased proportion of the comonomer relative to the monomer (Brantly, Eliades 2001a). The use of unfilled resins is based on their lower viscosity and thus superior diffusion into enamel rods (Brantly, Eliades 2001a). Both the sealant and primer are unfilled and can be said to be bonding agents.

Moisture-insensitive primers

Moisture sensitive primers were introduced to combat the bond strength short fall of the sealants. Hydrophilic primers (Transbond MIP, 3M/Unitek; Assure, Reliance Orthodontics) that can bond to wet tooth surfaces have been introduced (Graber, Vanarsdal & Vig 2005). For optimal results, moisture sensitive primers should be used with their respective adhesives. These primers show low bond strengths in wet conditions than in dry conditions.

Moisture sensitive primers are mostly indicated for tooth surfaces with increased risk of saliva/blood contamination. Partially erupted teeth and second molars are examples.

Self-etching primers

This combines the etchant/conditioner and the sealant in a one-step application. It has the advantage of reduced cost and chair time. The overall time saved during bonding has been estimated to be about 65 % (White 2001). The active ingredient of the Self etching primer (SEP) is a methacrylated phosphoric acid ester that dissolves calcium from hydroxyapatite. The etching process involved in SEP is stopped by:

- The acid group attached to the monomer are neutralized by forming a complex with calcium from hydroxyapatite
- The solvent from the primer stops the flow of the acid deep into the enamel
- Light curing the primer stops the acid from flowing into the enamel interface

The bond strength of SEPs has been found to be lower than the conventional etching and priming and differs between SEPs (Fritz 2001) (Aljubouri 2003).

Adhesives

There are two types of dental resins which may be used in orthodontic bracket bonding. Both are polymers and are classified as acrylic or diacrylate resins. Both types of adhesives are available in filled and unfilled forms.

The filler content of resin composites affects the in vitro bond strength to brackets that depends on mechanical retention. Highly filled resin composites bond to metal brackets with mechanical retention better than do slightly filled composites. Hybrid glass-ionomer cements used with metal brackets have bond strengths much lower than resin composites and similar to conventional glass-ionomer cements, and require careful patient selection for direct bonding.

Orthodontic adhesives may be classified according to the mechanism of polymerization initiation as follows (Brantly, Eliades 2001b):

- Chemically activated /chemically cured or self-cure
- Light cure/photo-cured
- Dual-cured (chemically activated and light activated)
- Thermo-cured

The light cured adhesives are now the most popular adhesives used in orthodontics (Keim, Gottlieb 2002). These have an added advantage of increased working time. Light cured adhesives used for metal brackets are usually dual cure resins incorporating light initiators and a chemical catalyst. Maximum curing depth depends on the composition of composite, the light source and the exposure time (Tirtha, Fan 1982).

Bond strength

The orthodontic literature reports bond strength as the force of debonding divided by the area of the bonded interface. Publications have reported the bond strength in units of megapascals (MPa), kilo- grams per square centimeter (kg/cm2), and pounds per square inch (lb/in2 or psi). If a typical bracket has a nominal bonding area of 16 mm^2 and the force of debonding is 120 N, then the bond strength will be 7.5 N/mm^2 or 7.5 MPa.

An adhesive-bracket system should be able to withstand a stress of at least 6 - 8 MPa. To improve retention through a larger bonding area, a larger bracket base or bracket base micro-etch is carried out before placement.

There is a significant increase in the bond strength at the bracket adhesive interface in ceramic brackets. A number of studies have shown that chemically retained ceramic brackets produce stronger bond strength when compared to conventional metal brackets (Ødegaard, Segner 1988) (John Gwinnett 1988) (Joseph, Rossouw 1990). Increased bond strength with ceramic brackets resulted in bond failure at enamel-adhesive interface, rather than the safer bracket adhesion interface, which is common with metal brackets (Bishara, Olsen 1997). Miller reported that orthodontic bond failure to fluorosed teeth to occur almost universally at the enamel-resin interface, which increases the risk of enamel fracture (Miller 1995).

Some manufactures developed ceramic brackets designed to reduce bond strength. These brackets have mechanical retention only, or silane found only in the mechanical recesses. The use of these two methods together produced increased bond strength (Iwamoto H, Kawamoto T, Kinoshita Z 1987). Some studies found that the use of both chemical and mechanical retention methods does not change tensile strength (Ripley KT. 1988) but significantly reduce the shear bond strength when compared to that of the chemically backed ceramic brackets (Iwamoto H, Kawamoto T, Kinoshita Z 1987) (Ripley KT. 1988) (Hyer KE. 1989).

Light Source

Light source is important in initiating polymerization of light cured and dual cured adhesives. The orthodontist has the following options for light sources:

1.0 Conventional and fast halogen lights: In light-initiated bonding resins the curing process begins when a photo initiator is activated. Halogen bulbs produce light when electric energy heats a small tungsten filament to high temperatures. Despite their common use, halogen bulbs have several disadvantages. The light power output is less than 1 % of the consumed electric power, and halogen bulbs have a limited lifetime of about 100 hours because of degradation of the components of the bulb by the high heat generated.The halogen lights can cure orthodontic composite resins in 20 seconds and light-cured resin-modified glass ionomers in 40 seconds per bracket.

2. *Argon lasers:* In the late 1980s, argon lasers promised to reduce the curing times dramatically. Argon lasers produce a highly concentrated beam of light centred on the 480-nm wavelength. Their use in orthodontics at present is not extensive, probably because high cost and poor portability (Keim, Gottlieb 2002).

3. *Plasma arc lights:* In the mid-1990s, the xenon plasma arc lamp was introduced for high-intensity curing of composite materials in restorative dentistry*.*The heat generated might course pulpal damage.

4. *Light emitting diodes (LEDs):* The most recent light category is the LED sources. They have a lifetime of more than 10,000 hours and of little degradation of output over this time.

The following are important to note when bonding orthodontic attachments; (Graber, Vanarsdal & Vig 2005)

- The light source and adhesive must be compatible
- All new light sources cure resin faster than conventional halogen light
- Fast halogen sources are more brand specific but generate low heat and are less expensive than plasma lights and LEDs
- Plasma arc lights offer the shortest curing times but are expensive and generate heat.

Dental Fluorosis

Successful bonding of orthodontic brackets depends on the integrity of the enamel surface. Dental fluorosis results from excessive deposit of fluoride in enamel and dentine, producing unsightly permanent stains and weakening of the enamel. Different concentrations of fluoride in drinking water cause varying degrees of fluorosis.

The severity of fluorosis depends on the amount of fluoride ingestion. Clinically, the enamel surfaces may have different degrees of un-aesthetic appearance depending on the severity of fluorosis. Categorizing the severity of fluorosis uses specific classification systems. The most commonly used systems include the Dean's Index and the Thylostruf Ferjeskov Index (TFI). The TFI is illustrated in addendum A. These indices use clinical appearance of the enamel for the diagnosis of the severity of fluorosis (Dean HT. 1934) (Thylstrup, Fejerskov 1978). The table below briefly explains some of the studies carried out in South Africa and the levels of fluoride found in drinking water.

Table 2 Research on fluoride levels in South Africa (153 Louw A,J 1997)

Prominent Research Findings						
References	**Age**	**Country/ Region**	**Fluoride (mg/L)**	**Index**	**Fluoros. (%)**	**Moderate Severe,%**
Ockerse& Meyer	6-15	Pilanesberg	0.33-35	Dean	49	57
	6-17	Upington	0.38	Dean	16	3
Ockerse	6-16	Kenhardt	6.8	Dean	100	70
	6-16	Pofadder	2.5 (av)	Dean	94	53
Bischoff *et al*	14-23	Saulspoort	0.4-6	Dean	83	60
Van d. Merwe*et al*		Saulspoort (H)	0.4-6	Dean	83	60
		Mabeskraal (L)	0.02-0.2	Dean	11.4	22
Retief *et al*	14-17	Kenhardt	3.2	Dean	94	58
Zietsman	5-20	Northwest Province (5 villages)	0.5 - 1.6	Dean and TF	53	20
Lewis *et al*		KwaNdebele (H)	8 - 9	Dean	88	54
Lewis &Chikte	6-18	KwaNdebele (L)	0.6 - 1.6		90	3

Fluorosed enamel surfaces may present as white opaque areas with zones of yellow to dark-brown discolouration and deep irregular brown pits (Neville 2009). Even though fluorosed teeth are un-aesthetic, they have the advantage of being resistant to caries development.

Dental fluorosis is a condition caused by excessive ingestion of fluoride of more than 1-2 ppm during tooth development (Fejerskov O, Larsen MJ, Richards A,Baelum V, 1994) (Adanir, Türkkahraman & Güngör 2009). Fluoride appears to create significant enamel defect through retention of the amelogenin proteins in the enamel structure, leading to formation of hypo-mineralized enamel (Neville 2009). Fluorosed enamel is characterized by an outer hyper-mineralized layer that is acid resistant and a hypo-mineralized subsurface that has enamel that is more porous. Hydroxyl-apatite and fluororidated-hydroxyapatite, or both can be found in the highly mineralized surface layer.

These fluoridated crystals are acid resistant (Robinson *et al.* 2004). The larger apatite crystals, better crystallinity, and the buffering action of fluoride released from enamel crystals during the early stages of acid attack contribute to reduction in enamel acid solubility (Clarkson J, Hardwick K & Barmes D. 2000). It is believed that fluorosed enamel may be more resistant to acid etching, resulting in decreased bond strengths of orthodontic attachments to enamel (Miller 1995, Miller 1995).

The World Health Organization Guidelines record that an increased fluoride concentration of up to 10 mg/L can be found in groundwater, which in South Africa, contributes between 13% and 15% of total water use, mainly in rural communities. Hence, as the demand for treatment increases, orthodontists in South Africa will be confronted by numerous patients presenting with various degrees of fluorosis. It will be helpful to acquire further data on how effective bonding is to the affected enamel and on how the enamel surface is altered by the debonding process.

A number of studies have carried out SBS tests on both fluorosed and non-fluorosed enamel surfaces (Adanir, Turkkahraman & Gungor 2007) (Adanir, Türkkahraman & Güngör 2009) (Isci *et al*. 2011). Interventions in increasing Shear Bond Strength (SBS) include altering etching time, use of adhesion promoters, adjusting concentration of etchant and increasing surface area (micro-abrasion).

In the study by Isci (2011), etching fluorosed and non-fluorosed enamel surfaces with 37 percent phosphoric acid for 30 seconds did not show any significant difference (Isci *et al*. 2011). Studies have recommended etching with 37 percent phosphoric acid of 120 and 180 seconds to fluorosed teeth as they found that the etching pattern resembled that of normal teeth etched for 60 seconds (Opinya GN, Pamier CH. 1986). The etch depth and etch pattern on non-fluorotic and fluorotic teeth showed insignificant difference when etching with 40 percent phosphoric acid for 60 seconds (Ng'ang'a *et al*. 1992).

When SBS, was assessed on non-fluorosed enamel, the concentration of the etchant and etching time showed some significant difference in SBS (Carstensen 1986) (Mitić Vladimir 2008). It was concluded that etching for longer periods (45 seconds) reduced bond strength and that the ideal periods are between 15 and 30 seconds in non-fluorosed teeth (Miller 1995) (Noble, Karaiskos & Wiltshire 2008).

A few previous studies have assessed these requirements as observed on fluorosed teeth, these studies showed that SBS can be affected negatively by fluorosis of the enamel surface (Pietersen K 2005) (Noble, Karaiskos & Wiltshire 2008) (Mitić Vladimir 2008). One option to overcome this problem was to increase the enamel surface area of fluorosed teeth by first micro-etching followed by acid etching (Miller 1995).

More recently, a chemical enhancement in the form of adhesion promoters has been found to provide clinically successful bonding of orthodontic brackets to severely fluorosed human teeth (Olsen ME, Bishara SE,Boyer D *et al.* 1994). Adhesion promoters used in orthodontic bonding to fluorosed teeth may have an effect of increasing SBS and reducing chair time. A study by Adanir *et al*. (2009) found that fluorosis significantly reduced bond strength and that the adhesion promoter increased the SBS on fluorosed enamel (Adanir, Türkkahraman & Güngör 2009). Measures of improving bonding to fluorosed enamel include adjusting the conditioning solution's concentration.

Micro abrasion of fluorosed teeth Improves bond strength of these teeth (Opinya GN, Pamier CH. 1986) (Miller 1995) (Duan Y, Chen X & Wu J. 2006). After mechanical grinding of 100 µm of enamel surface, no significant difference in tensile bond strength (TBS) was noted between normal and ground fluorosed teeth (Opinya GN, Pamier CH. 1986).

In a study evaluating failure rate of brackets bonded to fluorosed teeth, Nobel *et al* (2008) reported that additional micro mechanical abrasion with 50 µm of aluminium silicate was not necessary to increase micro-mechanical bracket retention when an adhesion promoter is applied (Noble, Karaiskos & Wiltshire 2008). Elimination of micro abrasion results in the preservation of enamel, prevents a roughened enamel surface adjacent to the bracket, and allows for a bonding appointment that is more time efficient, less complicated, and more comfortable for the patient and the orthodontist (Noble, Karaiskos & Wiltshire 2008).

Metal and Ceramic Brackets

The morphology of the metal bracket base comprises of a metal mesh, yields adequate adhesive bond strength values to enamel. The enormously increased active surface area of the base resulted in much greater mechanical interlocking (Droese V, Diedrich P. 1992).

Manufacturers have incorporated a variety of mesh designs in their currently marketed products. Recent investigations, however, were not able to identify any differences in bond strength between conventional bracket bases and bases with more condensed mesh configurations (Brantly, Eliades 2001a).

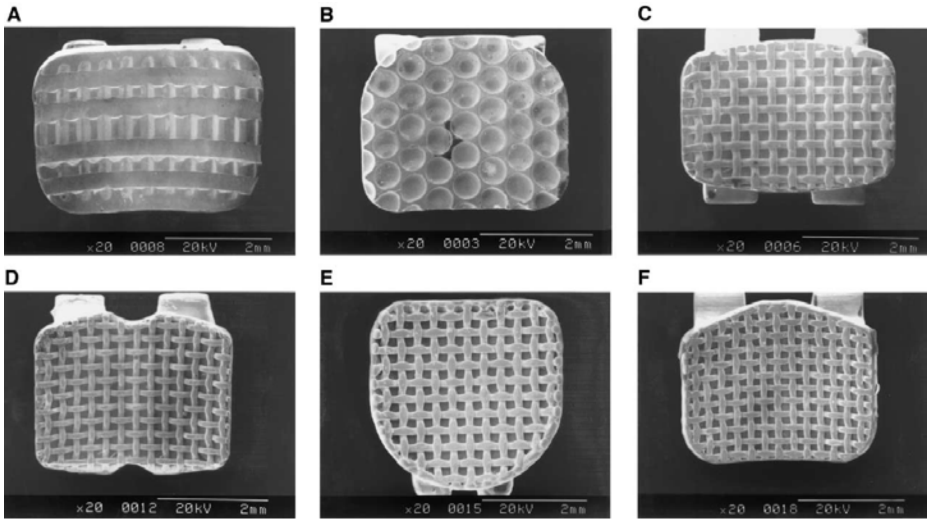

Figure 2 Different bracket base designs (Wang *et al*. 2004)

Figure 2 illustrates different bracket base designs used in a study by Wang *et al* 2004. Picture A shows a Unitek (Dynalock) bracket base bracket with horizontal retention groove; B, Tomy bracket base, with regular circular concave form; C, Dentaurum bracket, with relatively large mesh spacing; D, Leone bracket, with relatively small mesh spacing; E, TP Orthodontics bracket, with relatively small mesh spacing; F, Ormco bracket, with relatively small mesh spacing. This particular study had the following conclusions: (Wang *et al*. 2004)

1. The size and design of a bracket base can affect bond strength.

2. The Tomy bracket, with a circular concave base design, produced greater bond strength than the Dentaurum, Leone, TP Orthodontics, and Ormco brackets, with their mesh bases.

3. Bracket bases with larger mesh spacing have larger SBS.

4. The Unitek 1-piece cast bracket with a horizontal retention groove base produced moderate bond strength.

5. Most debonding interfaces are between bracket and resin and between enamel and resin.

Attempts made to improve bond strength of orthodontic attachments using the bracket base include varying mash design (as mentioned above), plasma-coating bracket base, micro etching, as well as ceramic bracket base.

One of the disadvantages of using metal brackets includes corrosion products diffusing from the metal bracket into the adhesive and around the enamel surface (Maijer, Smith 1982) resulting in tooth discoloration. The chief concern is the release of nickel ions during corrosion of stainless steel brackets (Brantly, Eliades 2001a).

Nickel can cause a hypersensitive reaction. The prevalence of nickel hypersensitivity is higher in the patients with pierced ears fitted with braces after ear piercing. Children who start orthodontic treatment before ear-piercing have significantly lower prevalence of nickel hypersensitivity as compared to patients starting orthodontic treatment after ear piercing (Brantly, Eliades 2001a).

Most ceramic brackets are made of high-purity aluminum oxide (alumina), and the brackets are available in both polycrystalline and single-crystal (sapphire) forms. Polycrystalline alumina brackets are manufactured by first combining a suitable binder with aluminium oxide particles (average of 0.3 µm size) which is molded into a shape of a bracket.

Single-crystal brackets also have excellent optical clarity owing to the absence of internal boundaries of grains. Single-crystal alumina has lower resistance to crack propagation than polycrystalline alumina, where the advancing cracks follow irregular paths along grain boundaries. The strength of both single-crystal and polycrystalline alumina can be increased by eliminating surface flaws that can serve as sites of stress concentration and fracture initiation. Decreasing the grain size will also increase the strength of polycrystalline alumina.

The ceramic bonding mechanisms are classified into three major categories according to bracket base morphology: (Brantly, Eliades 2001a)

- Mechanical retention employing large recesses
- Chemical adhesion facilitated by the use of silane layer
- Micromechanical retention through the utilization of a number of configurations, including protruding crystals, grooves, a porous surface and spherical particles

Retention of adhesives to ceramic brackets can be mechanical, chemical, or both. Mechanical bonding requires indentations or undercuts in the bracket base, a roughened surface created by micro-abrasion (sandblasting or micro etching) or roughness caused by chemical etching with a 9.6 % hydrofluoric acid (HF) gel. One bracket (Transcend 2000, 3MUnitek) uses fused aluminum oxide particles to provide increased surface area and greater retention of the adhesive. Chemical bonding requires treatment of the ceramic bracket base with silane. One end of the silane molecule bonds to the ceramic, while the other end bonds to the carbon-carbon double bonds available from the resin composite adhesive (Brantly, Eliades 2001a).

The table below (Table 3) illustrates some of the commercially available polycrystalline and monocrystalline brackets and the type of retention mechanism they employ.

Table 3 List of Polycrystalline and monocrystalline brackets (Ghafari 1992)

Polycrystalline and monocrystalline commercial ceramic brackets and modes or retention	
Polycrystalline brackets	**Retention**
Transcend 2000 (Unitel)	M2
Allure IV (GAG)	M2/C
Quasar (Rocky Mountain)*	M2/C
Intrigue (Lancer)	M2/C
Illusion (Ortho Organizers)	M2/C
20/20 (American Orthodontics)	C
Fascination (Dentaurum)	C
Lumina (Ormco)	M2
Eclipse (Masel)	M2/C
Polycrystal (OIS)*	M1/C
Contour	M1/C
Monocrystalline brackets	
Starfire (A Company)	C
GEM (Ormco)	M1/C

Legend *: M= Mechanical retention*

1- Recesses or grooves

2- Fibrous, crusty or dimpled

C= Chemical retention

**indicates discontinued brackets*

Metal brackets rely on mechanical retention for bonding and a mesh base is the conventional method of providing this retention unlike ceramic brackets which may rely on chemical or mechanical factors or a combination of the two (Bishara, Fehr & Jakobsen 1993). Debonding techniques are also mechanical and ideally create a fracture within the resin bonding material or between the bracket and resin with little or no damage to the enamel surface. Increasing the strength of bonding adhesives becomes a potential problem in debonding when the enamel surface may tear as the bracket base is pulled away from it. Ceramic brackets are more likely than metal brackets to be associated with enamel damage during debonding (Profit RW, Fields HW 1999).

The biggest drawback of ceramic brackets is the possibility of enamel damage during the debonding process. The following can reduce the debonding strength responsible for enamel fracture:

- An increase in the size and a decrease in the number of protruding crystals of projected complexes, thus reducing the mechanical retention of the interfacial layer.

- Elimination of silane coating to reduce the adherence between the adhesive and bracket.

- Combination of the relatively rigid ceramic brackets with flexible base consisting of a low elastic modulus polycarbonate or other polymeric material.

A review of ceramic brackets by Bishara and Fehr in 1997 and an article by Ghafail (1992) summarizes the disadvantages of ceramic brackets as follows: (Bishara, Fehr 1997) (Ghafari 1992)

1. Ceramic brackets have a higher incidence of fracture during debonding, particularly with the conventional debonding technique
2. Increased pain or discomfort can be experienced when debonding ceramic brackets
3. Ceramic brackets are unable to withstand strong torsional forces
4. The use of ceramic brackets should be avoided on compromised teeth
5. Enamel wear occurs if ceramic brackets contact opposing tooth surface (deep bite cases)
6. Ceramic brackets can cause nicks in the arch wire, resulting in in more friction between the bracket and the arch wire
7. Some ceramic (i.e. polycrystalline) brackets do stain

Chapter 3

Materials and methods

Sample Size

One hundred and twenty extracted human teeth were equally divided into four groups and stored in distilled water. Teeth used in this study were classified according to the Thylstrup-Fejerskov Index (TFI) and not the Dean's index. TFI has been shown to be more sensitive with regards to the lower degrees of fluorosis than the Dean's index (Thylstrup, Fejerskov 1978) (Burger P, Cleaton-Jones P, du-Pleasis J, De Vries J. 1987). The TFI index is included as Addendum A.

The fluorosed teeth were mainly collected from dental clinics in Rustenburg and Hammanskraal areas. Groups A and B together comprised of 60 fluorosed teeth selected according to the TFI (Thylstrup, Fejerskov 1978) and only fluorosed teeth classified as TF4-6 were used. Groups C and D constituted the control samples of 30 non-fluorosed teeth each. The teeth used in the control sample were collected from the Pretoria Oral and Dental Hospital. Permission to collect the teeth from the different facilities was obtained from the Tshwane Research Council and the Dean of Pretoria Oral and Dental Hospital. The research protocol was presented to and approved by the Research Committee of the School of Dentistry (RESCOM). Ethical clearance was granted by the Ethics Committee of the University of Pretoria.

The teeth were embedded in orthodontic acrylic in metal rings with only the crowns exposed (Figure 3). Each tooth was oriented with the Instron Material Testing Device shearing blade as a guide, so that it’s labial surface is parallel to the force during the shear strength testing (Figure 4).

Figure 3 Mounted premolar tooth with metal bracket bonded on buccal surface

Figure 4 Illustration of Instron testing device shearing blade used to debond brackets

Bonding Procedure

In Groups A and C, metal orthodontic brackets having a mesh base, and in Groups B and D, ceramic monocrystalline brackets, were bonded to the teeth using the conventional bonding protocol (polish, etch, prime and bond).

Teeth were cleaned using fluoride free pumice followed by pre-treatment etching with thirty seven percent phosphoric acid (Etching Solution, Ormco®) for 30 seconds, then rinsed thoroughly and air dried. Primer (Ortho Solo, SDS Ormoco®) was applied to the etched enamel surface followed by application of the BluGloo® adhesive (SDS Ormco®) (Figure 5 and Figure 6) on the fitting surface of the bracket, which was then positioned with firm pressure on the primed enamel surface. Excess resin material was removed with a fine tip probe from the tooth surfaces before curing. All instruments used for bonding are illustrated in Figure 7.

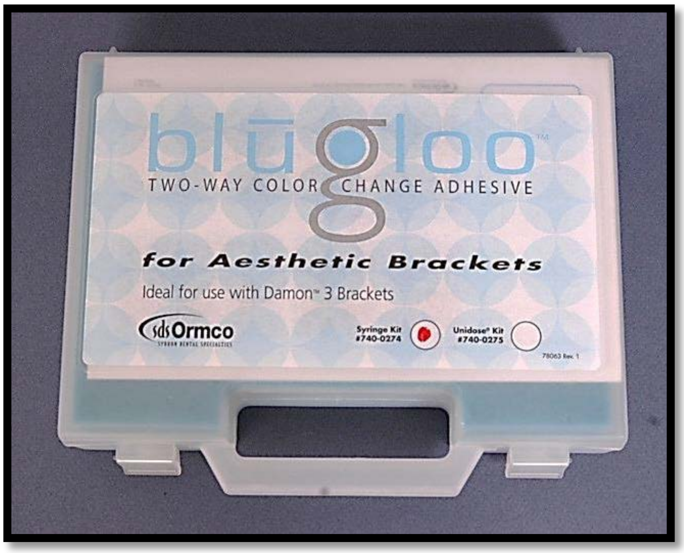

Figure 5 Blu gloo Adhesive used to bond brackets on to teeth

Figure 6 BluGloo two-way color change kit

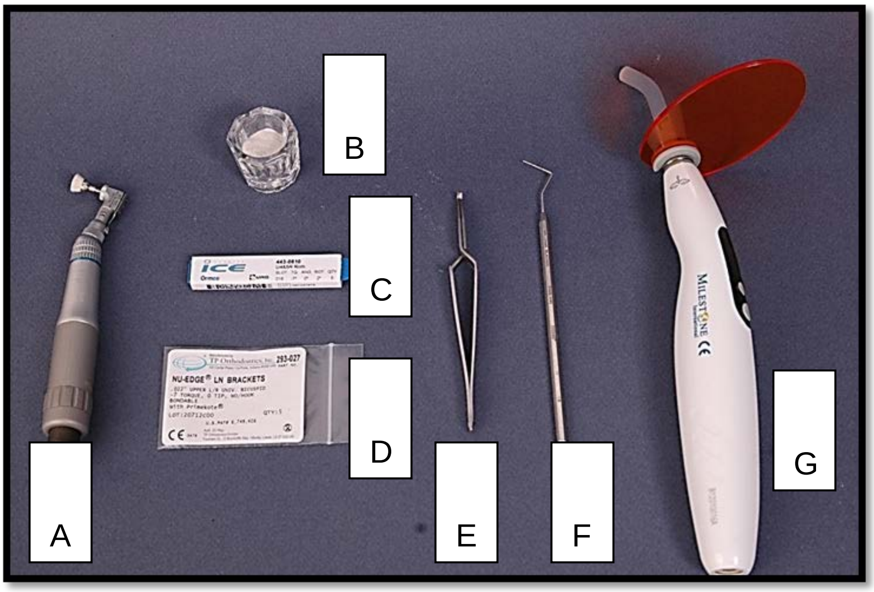

Figure 7 Materials used in bonding process

The BluGloo® (SDS Ormco®) adhesive was polymerized with a conventional LED curing light for 15 seconds for ceramic brackets and 20 seconds for metal brackets. Bonded teeth were stored in distilled water for 24 hours before determination of the SBS and subsequent debonding as recommended (Fox, McCabe & Buckley 1994).

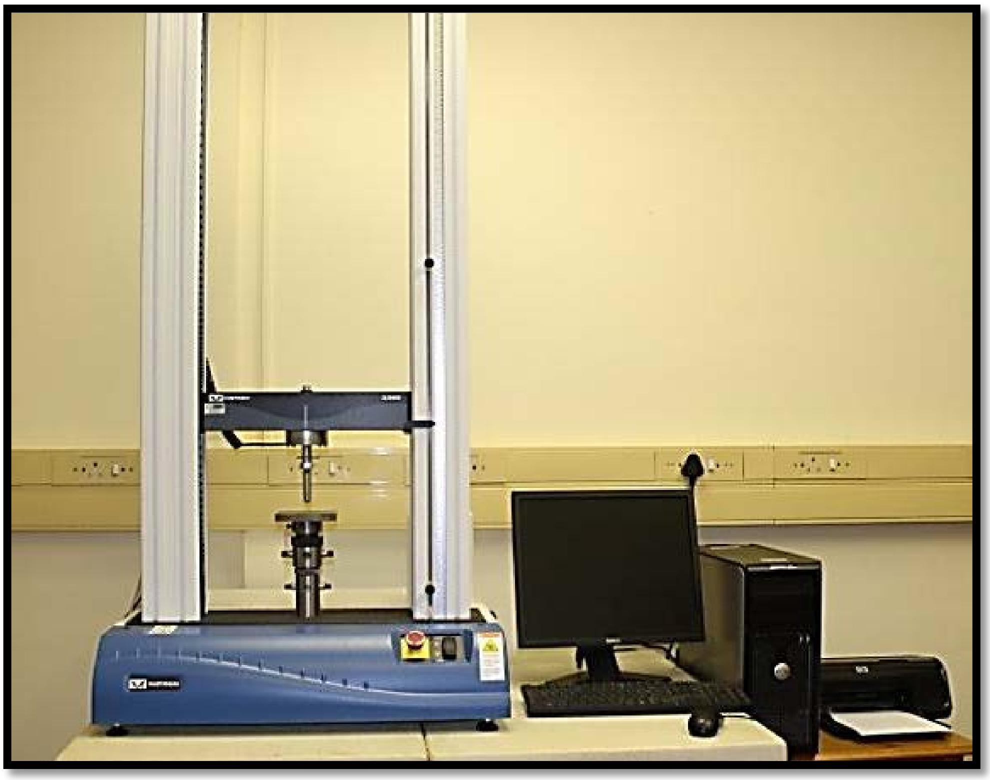

Figure 8 Instron universal testing device (Model 3366)

Debonding Procedure

An Instron Material Testing Device (Figure 8) was used for the debonding of brackets and for measuring the SBS. The shearing blade was set to move at a speed of 1mm/min during debonding. The shearing debonding force was directed occluso-gingivally and recorded initially in Newtons and these values were converted into Megapascals (MPa) using the formula:-

Bond strength (MPa) = Force (Newtons) / surface area of brackets (mm^2)

Surface Area: Nu Edge Bracket (metal): 11.29mm^2

: Inspire Ice Bracket (Ceramic): 12.19mm^2

Data Management and Analysis

Recordings on SBS of both fluorosed and non-fluorosed teeth were collected. Bond strengths were compared by an analysis of variance (ANOVA), which allowed for posthoc pairwise (Dunnett's C test for unequal variances) comparison of the data associated with the metal and ceramic brackets together with that associated with the fluorosed and non-fluorosed teeth.

Chapter 4

Results

The results as seen in Table 4 and Figure 10 show SBS in order of increasing strength as: fluorosed teeth to metal (8.406 MPa) < non fluorosed teeth to ceramic brackets (11.13 MPa) < Non Fluorosed teeth to metal (13.55 MPa) <fluorosed teeth to ceramic brackets (15.78 MPa).

Table 4 Shear Bond strengths by group assignments

Group*	N	Minimum	Maximum	Mean (MPa)	Std. Deviation
Group A	30	1.87	24.73	8.41	4.68
Group B	30	1.08	35.97	15.78	9.07
Group C	30	2.36	22.02	13.56	5.50
Group D	30	3.59	32.48	11.14	5.91

Group A= Metal bonded to fluorosed teeth; Group B=Ceramics bonded to Fluorosed teeth; Group C=Metal bonded to non-fluorosed teeth; Group D=Ceramics bonded to non-fluorosed teeth.

Table 5 Multiple pairwise comparisons of SBS between groups

(I) Grpexp	**(J) Grpexp**	**Mean Difference (I- J)**	**95% Confidence Interval**	
			Lower Bound	**Upper Bound**
Group A	Group B	-7.38*	-12.26	-2.50
	Group C	-5.15*	-8.56	-1.75
	Group D	-2.73	-6.33	.87
Group B	Group A	7.38*	2.50	12.26
	Group C	2.23	-2.84	7.29
	Group D	4.65	-.55	9.84
Group C	Group A	5.15*	1.75	8.56
	Group B	-2.23	-7.29	2.84
	Group D	2.42	-1.43	6.27
Group D	Group A	2.73	-.87	6.33
	Group B	-4.65	-9.84	.55
	Group C	-2.42	-6.27	1.43

The mean difference is significant at the 0.05 level (Dunnett's C test)

The multiple pairwise comparisons analysis found statistically significant group differences in mean SBSs at a significant level of 0.05 Table 5 and Figure 9.

1. Group A displayed significantly lower shear bond strength when compared with the group B

2. Group C displayed a significantly higher bond strength when compared with group A

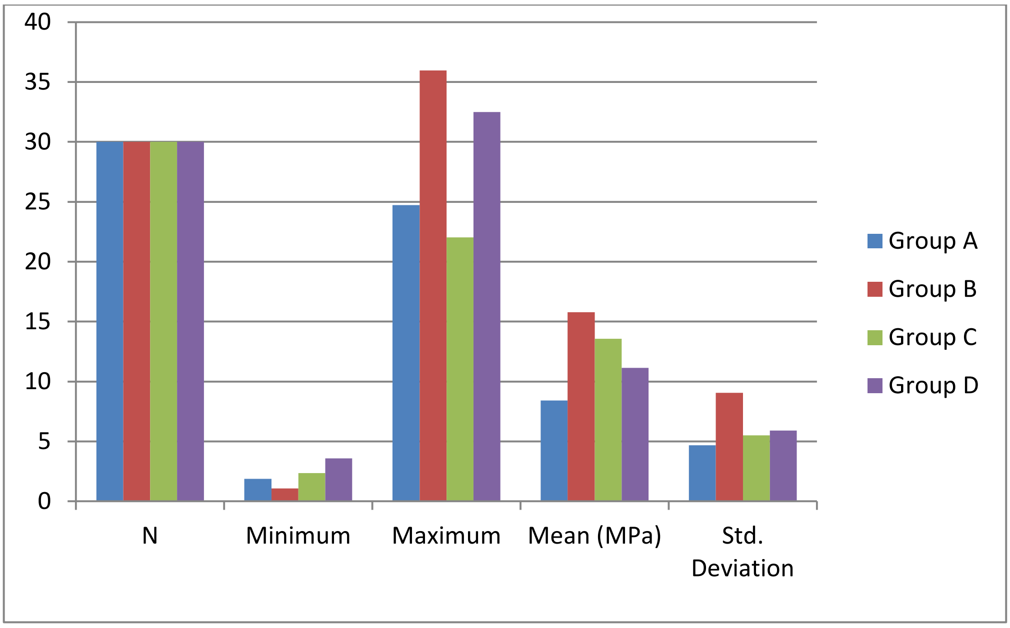

Figure 9 Overall results of SBS of all four groups

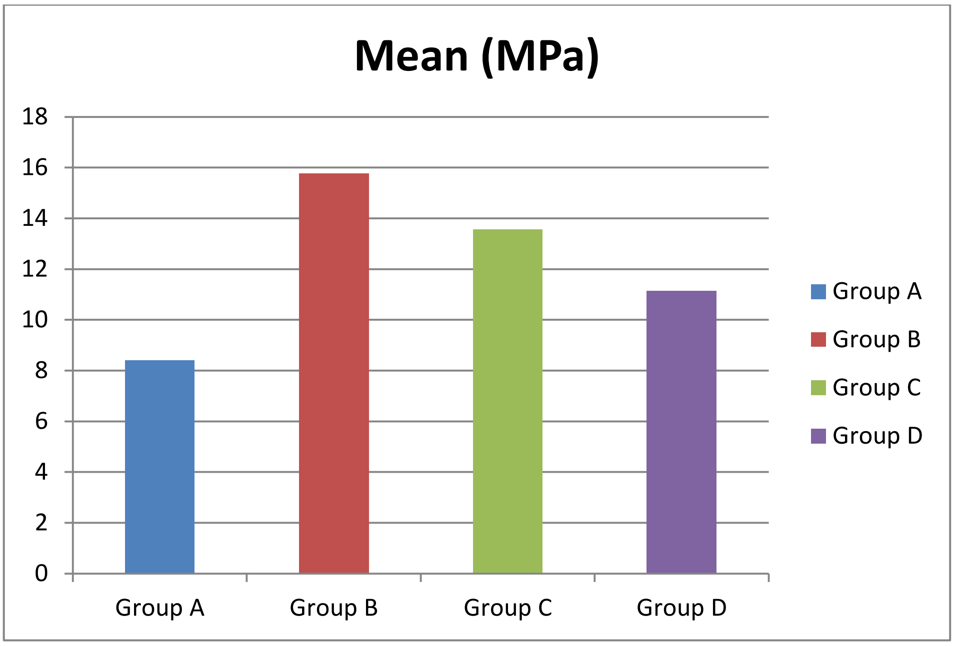

Figure 10 Mean SBS of all four groups

Chapter 5

Discussion

In this study, the mean SBS value ranges between 8.4 MPa and 15.7 MPa. These SBS were consistent with the ranges previously reported in a study by Bishara *et al.* (1993) (Bishara SE 1993). In the later study, the SBS value ranges were found to be between 3.9 MPa and 18.6 MPa (Fox, McCabe & Buckley 1994) (Bishara SE 1993). Most of the adhesives available in the literature found bond strength between 5.9 MPa to 11.3 MPa (Bishara SE 1993) (Olsen ME, Bishara SE,Boyer D *et al*. 1994) and few studies have reported SBS as high as 29.4 MPa (Ødegaard, Segner 1988) (Hyer KE. 1989). The minimum bond strength of between 5.9 MPa and 7.8 MPa has been established to be adequate for most clinical orthodontic needs (Reynolds 1975). The SBS obtained in this study for the two types of brackets irrespective of the tooth surface structure are therefore adequate for use in orthodontics.

However, in the present study, when the teeth bonded to metal brackets were compared, it was found that the shear bond strength to fluorosed teeth was significantly lower (8.406 MPa) than that to non-fluorosed teeth (13.55 MPa). These observations were in agreement with the findings of studies by Adanir *et al*. (2009) and Opinya and Pamier (1986) (Adanir, Türkkahraman & Güngör 2009) (Opinya GN, Pamier CH. 1986). However, in contrast to our findings, Ng'ang'a *et al.* (1992) and Isce *et al* (2011) observed that there was no significant difference between the fluorosed and non fluorosed groups with regard to SBS (Ng'ang'a et al. 1992) (Isci *et al*. 2011).

Table 6 Summary of studies on SBS on fluorosed teeth

Author	**Journal & year of Pub**	**Title**	**Classification**	**summary**	**Brackets used**
Noble J, karaiskos, Wiltshire	Angle Orthod 2008	In Vivo bonding of orthodontic brackets to fluorosed enamel using adhesion promoter		Severe flourosedteeth , split mouth design , micro abrasion,,Scotchbond + adhesion promoter	metal brackets (3M Unitek, Victory brackets)
Opinya GN, Pameijer CH.	Int Dent J. 1986 Dec; 36(4):225-9.	Tensile bond strength of fluorosed Kenyan teeth using the acid etch technique.	Abstract		
Adanir N, Türkkahraman H, YalçinGüngör A.	Eur J Orthod. 2009 Jun;31(3):276-80.	Effects of adhesion promoters on the shear bond strengths of orthodontic brackets to fluorosed enamel.	TFI	Enhence LC adhesion promoter	Metal brackets (Ormco Mini 2000)
AhmetYalcinGungor, HakanTurkkahraman, NecdetAdanir, and HuseyinAlkisa	Eur J Dent. Jul 2009; 3(3): 173–177.	Effects of Fluorosis and Self Etching Primers on Shear Bond Strengths of Orthodontic Brackets	TFI	Transbond XT	Metal brackets (Ormco Mini 2000)

Adanir N, Türkkahraman H, Güngör AY.	Eur J Dent. 2007 Oct;1(4):230-5.	Effects of fluorosis and bleaching on shear bond strengths of orthodontic brackets.	TFI	35% H_2O_2	Metal brackets (Ormco Mini 2000)
Isci D1, SahinSaglam AM, Alkis H, Elekdag-Turk S, Turk T.	Eur J Orthod. 2011 Apr;33(2):161-6	Effects of fluorosis on the shear bond strength of orthodontic brackets bonded with a self-etching primer.	TFI	SEP(Transbond Plus), Phosphoric acid 37%,	Metal brackets (Gemini bracket; 3M Unitek, Monrovia, California, USA)
Suma S1, Anita G, Chandra Shekar BR, Kallury A.	Indian J Dent Res. 2012 Mar-Apr;23(2):230-5	The effect of air abrasion on the retention of metallic brackets bonded to fluorosed enamel surface.		Enlight LC , Transbond XT	0.022-inch PEA Roth brackets, Gemini series, 3M Unitek
Ng'ang'a PM1, Ogaard B, Cruz R, Chindia ML, Aasrum E.	Am J OrthodDentofacialOrthop. 1992 Sep;102(3):244-50.	Tensile strength of orthodontic brackets bonded directly to fluorotic and nonfluorotic teeth: an in vitro comparative study.	TFI	Concise composite	Metal brackets (GAC International, Inc New York)

A review of the literature showed no previous studies comparing the SBS of ceramic orthodontic brackets between fluorosed and non-fluorosed teeth (Table 6). In this study the orthodontic bonding of ceramic brackets to fluorosed teeth showed higher shear bond strength when compared to non-fluorosed teeth. However, the difference noted in these two groups was statistically insignificant. This observation therefore suggests that ceramic brackets would be adequate for clinical use on fluorosed teeth.

The SBS of ceramic brackets have been found in previous studies to be higher than that of stainless steel brackets (Bowen RL 1962) (Ødegaard, Segner 1988) (Viazis A.D, Cavanaugh G & Bevis R.R. 1990) (Franklin S 1993). It was therefore no surprise that our study also demonstrated (Pietersen K 2005) a significantly higher SBS when comparing fluorosed teeth bonded with ceramic brackets (15.7MPa) with those bonded to metal brackets (8.4 MPa). However, with regards to non-fluorosed teeth, this study found a statistically significant difference in SBSs between ceramic brackets (11.13MPa) and metal brackets (13.56 MPa); even though the SBS of ceramic brackets tended to be lower that of metal brackets.

It is clear from studies reported in the literature that the bond strengths of orthodontic attachments to enamel vary greatly depending on the material used, the conditioning agent, the adhesive, enamel morphology, preparation of enamel surface, and the test conditions (Wiltshire, Noble 2010). Differences in testing equipment, crosshead speed, load cell application, storage media, thermocycling, test method (tensile, shear), and variations in the site of force application, make comparisons between different studies difficult or even impossible (Wiltshire, Noble 2010).

This study was not without limitations. First, this was an in vitro study, therefore the performance of these materials under clinical conditions in vivo still needs to be established. Furthermore, considering the relatively high SBS obtained for ceramic brackets bonded into fluorosed teeth, there is a need for further examination of the nature of debonding to eliminate possibility for enamel fractures that may preclude the clinical use of these brackets, especially given that the metal brackets, which are alternatives for fluorosed teeth, also produced acceptable levels of SBS. Despite these limitations, this study has produced valuable information establishing the clinical utility of ceramic brackets on fluorosed teeth.

Chapter 6

Conclusions

The following conclusion can be drawn from this study:

1. The BluGloo® adhesive can produce adequate SBS for clinical orthodontic use.
2. Metal Brackets bonded to fluorosed teeth have the lowest SBS and ceramic brackets bonded to fluorosed teeth have the highest SBS
3. Metal brackets bonded to fluorosed teeth showed a significantly lower SBS when compared with the metal brackets bonded to non fluorosed teeth.
4. Ceramic brackets bonded to fluorosed teeth showed higher, but no significantly different SBS when compared to ceramic brackets bonded to non-fluorosed teeth.

This study thus concludes that both metal and ceramic brackets bonded to fluorosed teeth can be efficiently used in orthodontics.

References

Aboush, Y., Tareen, A. & Elderton, R. 1991, "Resin-to -enamel bonds:effect of cleaning the enamel surface with prophylaxis pastes containing fluoride or oil", *Br Dent J,* vol. 171, pp. 207.

Adanir, N., Turkkahraman, H. & Gungor, A.Y. 2007, "Effects of fluorosis and bleaching on shear bond strengths of orthodontic brackets", *European journal of dentistry,* vol. 1, no. 4, pp. 230-235.

Adanir, N., Türkkahraman, H. & Güngör, A.Y. 2009, "Effects of adhesion promoters on the shear bond strengths of orthodontic brackets to fluorosed enamel", *European journal of orthodontics,* vol. 31, no. 3, pp. 276-280.

Aljubouri , Y. 2003, "Six and 12 month evaluation of an SEP versus two stage etch and prime for ortodontic bonding: a randomized clinical trial", *Eur J Orthod,* vol. 26, pp. 565.

Artun, J. & Bergland, S. 1984, "Clinical trials with crystal growth conditioning as an alternative to acid-etch enamel pretreatment", *American Journal of Orthodontics,* vol. 85, no. 4, pp. 333-340.

Barry, G. 1995, "A clinical investigation of the effects of omission of pumice prophylaxis on band and bond failure", *Br Dent J,* vol. 22, pp. 245.

Bishara SE, F.D. 1993, "Comparisons of the effectiveness of pliers with narrow and wide blades in debonding ceramic brackets", *Am J Orthod Dentofac Orthop,* vol. 103, pp. 253-257.

Bishara, S.E., Fehr, D.E. & Jakobsen, J.R. 1993, "A comparative study of the debonding strengths of different ceramic brackets, enamel conditioners, and adhesives", *American Journal of Orthodontics and Dentofacial Orthopedics : Official Publication of the American Association of Orthodontists, its Constituent Societies, and the American Board of Orthodontics,* vol. 104, no. 2, pp. 170-179.

Bishara, S.E., Forrseca, J.M., Fehr, D.E. & Boyer, D.B. 1994, "Debonding forces applied to ceramic brackets simulating clinical conditions.", *Angle Orthodontist,* vol. 64, no. 4, pp. 277-282.

Bishara, S.E. & Olsen, M. 1997, "Comparison of shear stength of precoated and uncoated brackets", *Am J Orthod,* vol. 112, pp. 617.

Bishara, S.E. & Fehr, D.E. 1997, "Ceramic brackets: Something old, something new, a review", *Seminars in orthodontics,* vol. 3, no. 3, pp. 178-188.

Bowen RL, R.M. 1962, "Tensile strength and modulus of elasticity of tooth structure and several restorative material.", *J. Am Dent Ass,* vol. 64, pp. 378-387.

Brantly, W. & Eliades, T. 2001a, "Enamel etching and bond strength" in *Orthodontic materials: Scientific and clinical aspect* Thieme, Germany, pp. 105.

Brantly, W. & Eliades, T. 2001b, "Orthodontic adhesive resins" in *Orthodontic materials: Scientific and clinical aspect* Thieme, Germany, pp. 201.

Burger P, Cleaton-Jones P, du-Pleasis J, De Vries J. 1987, "Comparison of two fluorosis indeces in the primary dentition of Tshwana children.", *Community Dent Oral Epidemiol,* vol. 15, pp. 95-97.

Carstensen, W. 1986, "Clinical results after direct bonding of brackets using shorter etching times", *American Journal of Orthodontics,* vol. 89, no. 1, pp. 70-72.

Ceen, R. & Gwinnett , A. 1981, "White spot formation associated with sealant used in orthodontics", *Pediatr Dent,* vol. 3, pp. 174.

Ceen, R. & Gwinnett, A. 1980, "Indelible iatrogenic staining of enamel following debonding", *J Clin Orthod,* vol. 14, pp. 713.

Clarkson J, Hardwick K & Barmes D. 2000, "International collaborative research on fluoride", *Journal of dental research,* vol. 79, no. 4, pp. 893-904.

Dean HT. 1934, "Classification of mottled enamel diagnosis", *J Am Dent Assoc,* vol. 21, pp. 1421.

Droese V & Diedrich P. 1992, "The tensile bonding strength of metal plasma-coated bracket bases. [In German].", *Fortschr Kiefer-,* vol. 53, pp. 142.

Duan Y, Chen X & Wu J. 2006, "Clinical comparison of bond failuires using different enamel preparations of severly fluorotic teeth", *JCO,* vol. 40, pp. 152.

Dutta, P. & Singh, G. 2007, "Luting materials " in *Textbook of Orthodontics.*, 2nd edn, Jaypee Brothers Medical Publishers, New Delhi, pp. 355.

Faust, J.B., Grego, G.N., Fan, P.L. & Powers, J.M. 1978, "Penetration coefficient, tensile strength, and bond strength of thirteen direct bonding orthodontic cements", *American Journal of Orthodontics,* vol. 73, no. 5, pp. 512-525.

Fejerskov O, Larsen MJ, Richards A,Baelum V, 1994, "Dental tissue effects of fluoride.", *Advances in Dental Research,* vol. 8, no. 1, pp. 15-31.

Fox, N.A., McCabe, J.F. & Buckley, J.G. 1994, "A critique of bond strength testing in orthodontics", *British journal of orthodontics,* vol. 21, no. 1, pp. 33-43.

Franklin S, G.F. 1993, "Shear bond strengths and effects on enamel of two ceramic brackets.", *J Clin Orthod,* vol. 27, pp. 83-88.

Fritz, U. 2001, "Self etching primers - an alternative to the conventional acid etch technique?", *J Orofac Orthop,* vol. 62, pp. 238.

Ghafari , J. 1992, "Problems associated with ceramic brackets suggest limiting use to selected teeth.", *Angle Orthod.,* vol. 62, pp. 145-152.

Graber, T., Vanarsdal , R. & Vig, K. 2005, "Bonding in orthodontics" in *Orthodontics:current principles and techniques*, 4th edn, Elsevier Mosby, St lous, pp. 557.

Hyer KE. 1989, *An in vitro study of shear and tensile bond strengths comparing mechanically and chemically bonded ceramic brackets with three bonding agents.* , University of Iowa.

Isci, D., Sahin Saglam, A.M., Alkis, H., Elekdag-Turk, S. & Turk, T. 2011, "Effects of fluorosis on the shear bond strength of orthodontic brackets bonded with a self-etching primer", *European journal of orthodontics,* vol. 33, no. 2, pp. 161-166.

Iwamoto H, Kawamoto T, Kinoshita Z 1987, "Bond strength of new ceramic brackets as studied in vitro 66:928", *J Dent Res,* vol. 66, pp. 928.

John Gwinnett, A. 1988, "A comparison of shear bond strengths of metal and ceramic brackets", *American Journal of Orthodontics and Dentofacial Orthopedics,* vol. 93, no. 4, pp. 346-348.

Joseph , V. & Rossouw , P. 1992, "Do sealants seal: an SEM investigation", *J Clin Orthod,* vol. 26, pp. 141.

Joseph, V.P. & Rossouw, E. 1990, "The shear bond strengths of stainless steel and ceramic brackets used with chemically and light-activated composite resins", *American Journal of Orthodontics and Dentofacial Orthopedics,* vol. 97, no. 2, pp. 121-125.

Keim, R. & Gottlieb, L. 2002, "Study of orthodontic diagnosis and treatment procedures.1 Results and trends", *J Clin Orthod,* vol. 36, pp. 553.

Lew , K., Chew , C. & Lee, K. 1991, "A comparison of shear bond strengths between new recycled ceramic brackets", *Eur J Orthod,* vol. 13, pp. 306.

Louw A, J. & Chikte U, M.,E. 1997, "2nd International workshop on fluorosis and defluoridation of water", *Fluoride and fluorosis : The Status of reseach in South Africa*, 19-22 November.

Maijer, R. & Smith, D. 1982, "Corrosion of orthodontic bracket bases .", *Am J Orthod,* vol. 81, pp. 43.

Miller, R.A. 1995, "Bonding fluorosed teeth: new materials for old problems", *Journal of clinical orthodontics : JCO,* vol. 29, no. 7, pp. 424-427.

Millett DT, M.J. 1996, "Orthodontic bonding with glass ionomer cement- a review", *Eur J Orthod,* vol. 18, pp. 385.

Mitić Vladimir, J.M. 2008, "The effect of phosphoric acid application time on the bond strength of orthodontic brackets", *Serbian Dental Journal,* vol. 55, no. 1, pp. 23.

Neville, B.W., 2009, *Oral and maxillofacial pathology,* Saunders/Elsevier, St. Louis, Mo.

Ng'ang'a, P.M., Øgaard, B., Cruz, R., Chindia, M.L. & Aasrum, E. 1992, "Tensile strength of orthodontic brackets bonded directly to fluorotic and nonfluorotic teeth: An in vitro comparative study", *American Journal of Orthodontics and Dentofacial Orthopedics,* vol. 102, no. 3, pp. 244-250.

Noble, J., Karaiskos, N.E. & Wiltshire, W.A. 2008, "In vivo bonding of orthodontic brackets to fluorosed enamel using an adhesion promotor", *The Angle Orthodontist,* vol. 78, no. 2, pp. 357-360.

Ødegaard, J. & Segner, D. 1988, "Shear bond strength of metal brackets compared with a new ceramic bracket", *American Journal of Orthodontics and Dentofacial Orthopedics,* vol. 94, no. 3, pp. 201-206.

Olsen ME, Bishara SE,Boyer D et al. 1994, "Effect of varying etching time on the bond strength of ceramic brackets.", *J Dent Res,* vol. 73, pp. 197.

Opinya GN , Pamier CH. 1986, "Tensile bond strength of fluorosed Kenyan teeth using etching technique.", *Int Dent J,* vol. 36, pp. 225.

Pietersen K 2005, *Groundwater crutial to rural development.*.

Profit RW, F.H. 2013, "Contemporary orthodontics appliances" in *Contemporary orthodontics*, 5th edn, Elsevier Mosby, St Louis, pp. 347.

Reynolds, R. 1975, "A review of direct orthodontic bonding", *Br Dent J,* vol. 2, pp. 171-178.

Ripley KT. 1988, *In vitro comparative study of shear and tensile bond strengths for stainless steel and ceramic orthodontic brackets.* , University of Iowa.

Robinson, C., Connell, S., Kirkham, J., Brookes, S.J., Shore, R.C. & Smith, A.M. 2004, "The effect of fluoride on the developing tooth", *Caries research,* vol. 38, no. 3, pp. 268-276.

Smith DC, Bennett G, Pcltoniemi R 1980, "Further studies of bonding to enamel through crystal growth", *Dent Res,* , no. Special Issue B, pp. 995.

Smith DC, Lux, Maijer R. 1981, "Crystal bonding to enamel", *Dent Res,* vol. 60, no. Special issue A, pp. 178.

Smith, D.C. & Cartz, L. 1973, "Crystalline interface formed by polyacrylic acid and tooth enamel.", *Journal of dental research,* vol. 52, no. 5, pp. 1155.

Sunna S, R.W., 1998, "Clinical performance of orthodontic brackets and adhesive systems: a randomized clinical trial", *British journal of orthodontics,* vol. 25, no. 4, pp. 283-287.

Swartz, M. 1994, "Why prophy prior bracket bonding?", *Clinical Impressions,* vol. 3, pp. 11.

Thylstrup, A. & Fejerskov, O. 1978, "Clinical appearance of dental fluorosis in permanent teeth in relation to histologic changes", *Community dentistry and oral epidemiology,* vol. 6, no. 6, pp. 315-328.

Tirtha, R. & Fan, P. 1982, "In vitro depth of cure of photo-activated composites", *J Dent Res,* vol. 61, pp. 1184.

Viazis A.D, , Cavanaugh G, & Bevis R.R. 1990, "Bond strength of ceramic brackets under shear stress: An in vitro report", *American Journal of Orthodontics and Dentofacial Orthopedics,* vol. 98, no. 3, pp. 214-221.

Wang, W.N., Li, C.H., Chou, T.H., Wang, D.D.H., Lin, L.H. & Lin, C.T. 2004, "Bond strength of various bracket base designs", *American Journal of Orthodontics and Dentofacial Orthopedics,* vol. 125, no. 1, pp. 65-70.

White , L. 2001, "An expedited bonding technique", *J Clin Orthod,* vol. 35, pp. 36.

Wiltshire, W.A. & Noble, J. 2010, "Clinical and Laboratory Perspectives of Improved Orthodontic Bonding to Normal, Hypoplastic, and Fluorosed Enamel", *Seminars in orthodontics,* vol. 16, no. 1, pp. 55-65.

Addendum A

Thylstrup Ferjeskov Index (1978)

Score	Characteristics
0	Normal translucency of enamel remains after prolonged air-drying
1	Narrow white lines located corresponding to the perikymata
2	Smooth surface: More pronounced lines of opacity which follow the perikymata. Occasionally confluence of adjacent lines. Occlusal surfaces: Scattered areas of opacity< 2mm in diameter and pronounced opacity of cuspal ridges
3	Smooth surfaces: Merging and irregular cloudy areas of opacity. Accentuated drawing of perikyma often visible Occlusal surfaces: Confluent areas of marked opacity. Worn areas appear almost normal but usually circumscribed by a rim of opaque enamel
4	Smooth surface: The entire surface exhibits marked opacity or appear chalky white. Parts of the surface exposed to attrition appear less affected Occlusal surfaces: Entire surface exhibits marked opacity. Attrition is often pronounced shortly after eruption
5	Smooth and occlusal surface: Entire surface displays marked opacity with focal loss of outmost enamel (pits) < 2mm in diameter
6	Smooth surface: Pits are regularly arranged in a horizontal bands < 2mm in vertical extension Occlusal surface Confluent areas < 3 mm in a diameter exhibit loss of enamel. Marked attrition
7	Smooth surface: Loss of outer most enamel in irregular areas involving < ½ of entire surface Occlusal surface: Changes in the morphology caused by merging pits and marked attrition
8	Smooth and occlusal surfaces: Loss of outermost enamel involving >1/2 of surface
9	Smooth and occlusal surfaces: Loss of main part of enamel with change in anatomic appearance of surface. Cervical rim of almost unaffected enamel is often noted.

Addendum B

Informed consent form

(Must be signed by each research subject, and must be kept on record by the researcher)

1 TITTLE OF RESEARCH PROJECT

An *in vitro* study comparing the bond strengths of two types of orthodontic

brackets to fluorosed and non-fluorosed enamel

2 EXPLANATION OF PROCEDURES TO BE FOLLOWED

Extracted teeth will be used to carry out the experiment on which orthodontic attachments (braces) are to be cemented. The orthodontic attachments will be removed and the tooth surface assessed for damage coursed by the removal of attachments.

Teeth to be used in the experiment will have to be extracted on patients request and only teeth extracted due to periodontal problems will be collected. No extra precautionary measures are required for the extraction of teeth and the normal extraction procedure will be followed.

Your participation in this study is entirely voluntary. You can refuse to participate by refusing to donate extracted teeth without giving any reason. Your withdrawal will not affect you or your treatment.

3 INFORMATION AND CONTACT PERSON

The contact person for the study is Dr Serufe Monehi if you have any questions about the study please contact her on telephone number: 012 319 2150. Alternatively you may contact my supervisor on telephone number: 012 319 2448 (Prof. SM Dawjee).

4 CONSENT TO PARTICIPATE IN THIS STUDY

I confirm that the person asking my consent to take part in this study has told me about nature, process, risks, discomforts and benefits of the study. I have also received, read and understood the above written information (Information Leaflet and Informed Consent) regarding the study. I am aware that the results of the study, including personal details, will be anonymously processed into research reports. I am participating willingly. I have had time to ask questions and have no objection to participate in the study. I understand that there is no penalty should I wish to discontinue with the study and my withdrawal will not affect any treatment / access to treatment in any way.

I have received a signed copy of this informed consent agreement.

Participant's name …..(Please print)

Participant's signature: ....………………… Date............................

Investigator's name ....…………………………..(Please print)

Investigator's signature ....………………… Date……......................

Witness's Name ....……………….............. (Please print)

Witness's signature ....…………………... Date……......................

VERBAL INFORMED CONSENT

I, the undersigned, have read and have fully explained the participant information leaflet, which explains the nature, process, risks, discomforts and benefits of the s research project to the participant whom I have asked to participate in the research project.

The participant indicates that s/he understands that the results of the research project, including personal details regarding the interview will be anonymously processed into a research report. The participant indicates that s/he has had time to ask questions and has no objection to participate in the interview. S/he understands that there is no penalty should s/he wish to discontinue with the research project and his/her withdrawal will not affect treatment in any way. I hereby certify that the client has agreed to participate in this research project by donating extracted teeth.

Participant's Name ....…..(Please print)

Person seeking consent ....…….......(Please print)

Signature ....…………………...........Date.................................

Witness's name ....…………….…...........(Please print)

Signature ....……………………………Date.…........................

Addendum C

Ethics Approval

The Research Ethics Committee, Faculty Health Sciences, University of Pretoria complies with ICH-GCP guidelines and has US Federal wide Assurance.

* **FWA** 00002567, Approved dd 22 May 2002 and Expires 20 Oct 2016.
* **IRB** 0000 2235 IORG0001762 Approved dd 13/04/2011 and Expires 13/04/2014.

UNIVERSITEIT VAN PRETORIA
UNIVERSITY OF PRETORIA
YUNIBESITHI YA PRETORIA

Faculty of Health Sciences Research Ethics Committee
Fakulteit Gesondheidswetenskappe Navorsingsetiekkomitee

DATE: 1/03/2012

NUMBER	32/2012
TITLE	An *'in vitro'* study comparing the bond strengths of two types of orthodontic brackets to fluorosed and non fluorosed enamel
PRINCIPAL INVESTIGATOR	**Student Name & Surname:** Dr SE Monehi **Dept:** Othodontics; Oral and Dental Hospital ;University of Pretoria **Cell:** 0725577350 **E-Mail:** serufem@gmail.com
SUB INVESTIGATOR	Not Applicable
STUDY COORDINATOR	None
SUPERVISOR (ONLY STUDENTS)	Prof SM Dawjee **E-Mail:** S.Dawjee@up.ac.za
STUDY DEGREE	MChD (orthodontics)
SPONSOR COMPANY	University of Limpopo
CONTACT DEATAILS OF SPONSOR	Prof IC du Preez **E-Mail:** ProfIc.DuPreez@ul.ac.za
VAT NO.	Not Applicable
SPONSORS POSTAL ADDRESS	P O Box D18, Medunsa, 0204
ORDER / CONTRACT NUMBER	Not Applicable
MEETING DATE	29/02/2012

The Protocol and Informed Consent Document were approved on 29/02/2012 by a properly constituted meeting of the Ethics Committee subject to the following conditions:

1. The approval is valid for 3 years period [till the end of December 2014] , and
2. The approval is conditional on the receipt of 6 monthly written Progress Reports, and
3. The approval is conditional on the research being conducted as stipulated by the details of the documents submitted to and approved by the Committee. In the event that a need arises to change who the investigators are, the methods or any other aspect, such changes must be submitted as an Amendment for approval by the Committee.

Members of the Research Ethics Committee:

Prof M J Bester	(female)BSc (Chemistry and Biochemistry); BSc (Hons)(Biochemistry); MSc(Biochemistry); PhD (Medical Biochemistry)
Prof R Delport	(female)BA et Scien, B Curationis (Hons) (Intensive care Nursing), M Sc (Physiology), PhD (Medicine), M Ed Computer Assisted Education
Prof JA Ker	MBChB; MMed(Int); MD – Vice-Dean (ex officio)
Dr NK Likibi	MBB HM – Representing Gauteng Department of Health) MPH
Dr MP Mathebula	(female)Deputy CEO: Steve Biko Academic Hospital; MBCHB, PDM, HM
Prof A Nienaber	(female) BA(Hons)(Wits); LLB; LLM; LLD(UP); PhD; Dipl.Datametrics(UNISA) – Legal advisor
Mrs MC Nzeku	(female) BSc(NUL); MSc(Biochem)(UCL, UK) – Community representative

2012/03/08MS: dd 2012/03/08: C:\Documents and Settings\user\My Documents\Protokolle\Grade briewe\Letters 2012\32.2012.doc

Addendum D

RESCOM Approval

UNIVERSITEIT VAN PRETORIA
UNIVERSITY OF PRETORIA
YUNIBESITHI YA PRETORIA

Faculty of Health Sciences
School of Dentistry

2011/10/26

Prof AJ Ligthelm
Dean
School of Dentistry

Dear Professor

PROTOCOL APPROVAL: DENT 11/2011

Name: Dr E Monehi

Title: An in vitro study comparing the bond strengths of two types of orthodontic brackets to fluorosed and non-fluorosed enamel

The protocol attached hereto was evaluated by the Research Committee of the School of Dentistry. The Research Committee recommends the approval of the title and the protocol.

Your sincerely

PROF PJ VAN WYK
CHAIRPERSON: RESEARCH COMMITTEE

Protocol approved/not ~~approved~~

PROF AJ LIGTHELM
DEAN: SCHOOL OF DENTISTRY

University of Pretoria
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Addendum E

Raw data for Metal brackets bonded to non fluorosed teeth

	Tooth Structure	Maximum Compressive load (N)	Compressive stress at Maximum Compressive load (MPa)	Compressive load at Break (Standard) (N)	Compressive stress at Break (Standard) (MPa)
1	Group A	166.27177	2.46435	166.27177	2.46435
2	Group A	180.50291	2.67527	180.50291	2.67527
3	Group A	247.47554	3.66789	247.15215	3.66310
4	Group A	74.74027	1.10774	72.07090	1.06818
5	Group A	156.35703	2.31740	155.46640	2.30420
6	Group A	191.39738	2.83674	191.39738	2.83674
7	Group A	230.17207	3.41143	229.36922	3.39953
8	Group A	201.36562	2.98448	179.50732	2.66052
9	Group A	211.07744	3.12842	211.07744	3.12842
10	Group A	194.16634	2.87778	191.28606	2.83509
11	Group A	148.26660	2.19749	144.72917	2.14506
12	Group A	38.85697	0.57591	36.47776	0.54064
13	Group A	123.70438	1.83345	122.97221	1.82260
14	Group A	89.76035	1.33036	89.76035	1.33036
X 15	Group A	59.20318	0.87746	51.63828	0.76534
16	Group A	169.38744	2.51053	154.66893	2.29238
17	Group A	135.96013	2.01509	135.96013	2.01509
18	Group A	80.66601	1.19557	52.20612	0.77376
X 19	Group A	39.85266	0.59066	21.67695	0.32128
20	Group A	149.44540	2.21496	142.66142	2.11442
21	Group A	173.10481	2.56562	170.70782	2.53010
22	Group A	236.28072	3.50197	220.33255	3.26560
23	Group A	161.03833	2.38678	159.30835	2.36114
24	Group A	122.96047	1.82242	122.61686	1.81733
25	Group A	216.93094	3.21518	216.56096	3.20970
26	Group A	84.18490	1.24772	84.18490	1.24772

	Tooth Structure	Maximum Compressive load (N)	Compressive stress at Maximum Compressive load (MPa)	Compressive load at Break (Standard) (N)	Compressive stress at Break (Standard) (MPa)
X 27	Group A	210.42621	3.11877	201.36041	2.98441
28	Group A	160.74179	2.38239	160.74179	2.38239
29	Group A	26.58863	0.39408	26.58863	0.39408
X 30	Group A	174.63336	2.58828	165.61861	2.45467
31	Group A	248.57304	3.68416	248.57304	3.68416
32	Group A	185.91919	2.75555	185.91919	2.75555
33	Group A	64.30528	0.95308	58.70043	0.87001
34	Group A	11.85662	0.17573	0.00560	0.00008
Coefficient of Variation		44.00200	44.00200	46.03070	46.03070
Maximum		248.57304	3.68416	248.57304	3.68416
Mean		149.40195	2.21432	145.25926	2.15292
Median		160.89006	2.38459	157.38737	2.33267
Minimum		11.85662	0.17573	0.00560	0.00008
Range		236.71643	3.50843	248.56744	3.68407
Standard Deviation		65.73985	0.97434	66.86386	0.99100

Raw data for Ceramic brackets bonded to non fluorosed teeth

	Tooth Structure	Maximum Compressive load (N)	Compressive stress at Maximum Compressive load (MPa)	Compressive load at Break (Standard) (N)	Compressive stress at Break (Standard) (MPa)
1	Group B	207.26300	29.20112	207.26300	29.20112
2	Group B	167.38896	23.58330	164.50500	23.17698
3	Group B	144.23747	20.32150	143.95399	20.28156
4	Group B	58.35643	8.22179	58.35643	8.22179
5	Group B	66.88699	9.42365	58.39816	8.22767
X 6	Group B	174.93961	24.64710	174.93961	24.64710
7	Group B	106.31483	14.97861	105.43124	14.85412
8	Group B	136.13663	19.18018	136.13663	19.18018
9	Group B	99.68082	14.04395	99.68082	14.04395
10	Group B	129.43715	18.23630	129.43715	18.23630
11	Group B	136.29477	19.20246	81.80475	11.52540
X 12	Group B	261.52454	36.84598	110.93847	15.63003
13	Group B	125.77209	17.71993	125.77209	17.71993
14	Group B	117.87795	16.60773	117.87795	16.60773
15	Group B	198.88507	28.02076	198.88507	28.02076
16	Group B	168.89362	23.79529	168.89362	23.79529
17	Group B	88.27168	12.43653	88.27168	12.43653
18	Group B	134.72978	18.98197	133.97314	18.87537
19	Group B	99.27542	13.98683	99.06709	13.95748
20	Group B	43.78036	6.16818	43.13309	6.07699
21	Group B	135.55455	19.09817	135.27220	19.05839
22	Group B	133.76147	18.84555	133.76147	18.84555
23	Group B	0.00617	0.00087	-0.00572	-0.00081
24	Group B	68.51852	9.65352	63.35583	8.92615
25	Group B	106.60189	15.01906	106.13039	14.95263
26	Group B	396.00662	55.79306	396.00662	55.79306
27	Group B	136.23001	19.19334	134.95087	19.01312
28	Group B	46.49048	6.55001	43.51765	6.13117

	Tooth Structure	Maximum Compressive load (N)	Compressive stress at Maximum Compressive load (MPa)	Compressive load at Break (Standard) (N)	Compressive stress at Break (Standard) (MPa)
X 29	Group B	143.75255	20.25318	136.37401	19.21362
30	Group B	81.46839	11.47802	81.30967	11.45565
31	Group B	119.88380	16.89033	119.88380	16.89033
32	Group B	50.25289	7.08009	50.25289	7.08009
33	Group B	81.42794	11.47232	58.26623	8.20908
Coefficient of Variation		58.49086	58.49086	61.22963	61.22963
Maximum		396.00662	55.79306	396.00662	55.79306
Mean		119.52286	16.83948	116.11809	16.35979
Median		118.88088	16.74903	112.00417	15.78018
Minimum		0.00617	0.00087	-0.00572	-0.00081
Range		396.00045	55.79219	396.01234	55.79386
Standard Deviation		69.90995	9.84956	71.09868	10.01704

Raw data for Ceramic brackets bonded to fluorosed teeth

	Tooth Structure	Maximum Compressive load (N)	Compressive stress at Maximum Compressive load (MPa)	Compressive load at Break (Standard) (N)	Compressive stress at Break (Standard) (MPa)
1	Group C	194.35303	29.03593	194.35303	29.03593
2	Group C	163.05426	24.35996	160.90257	24.03851
3	Group C	309.42725	46.22778	309.42725	46.22778
4	Group C	260.58679	38.93112	260.58679	38.93112
5	Group C	273.07538	40.79688	273.07538	40.79688
6	Group C	161.12318	24.07146	161.12318	24.07146
7	Group C	160.09575	23.91797	160.09477	23.91782
8	Group C	387.82211	57.93981	317.50552	47.43466
9	Group C	155.23357	23.19157	155.23357	23.19157
10	Group C	277.44687	41.44998	277.44687	41.44998
11	Group C	215.03941	32.12643	215.03941	32.12643
12	Group C	85.51069	12.77512	83.64940	12.49704
13	Group C	144.01721	21.51587	144.01721	21.51587
14	Group C	338.91626	50.63338	338.91626	50.63338
15	Group C	210.19725	31.40303	209.72600	31.33262
16	Group C	260.09601	38.85780	259.99704	38.84301
17	Group C	206.70810	30.88175	204.20259	30.50744
18	Group C	318.78949	47.62648	318.78949	47.62648
X 19	Group C	13.15234	1.96493	13.15234	1.96493
X 20	Group C	52.72517	7.87703	52.38681	7.82648
X 21	Group C	56.02734	8.37037	51.63520	7.71419
22	Group C	83.92130	12.53766	82.48973	12.32379
23	Group C	158.67427	23.70560	158.67427	23.70560
24	Group C	298.40189	44.58061	298.40189	44.58061
25	Group C	327.23651	48.88844	327.23651	48.88844
26	Group C	439.06561	65.59547	381.35071	56.97299
27	Group C	235.01105	35.11015	183.45737	27.40814
28	Group C	113.07470	16.89312	113.07470	16.89312

	Tooth Structure	Maximum Compressive load (N)	Compressive stress at Maximum Compressive load (MPa)	Compressive load at Break (Standard) (N)	Compressive stress at Break (Standard) (MPa)
X 29	Group C	46.57940	6.95886	37.40213	5.58780
30	Group C	28.24625	4.21993	25.54129	3.81582
31	Group C	82.11428	12.26770	82.06214	12.25991
32	Group C	110.12232	16.45204	90.21843	13.47844
Coefficient of Variation		47.13684	47.13684	45.50020	45.50020
Maximum		439.06561	65.59547	381.35071	56.97299
Mean		214.19146	31.99975	206.66405	30.87517
Median		208.45267	31.14239	199.27781	29.77168
Minimum		28.24625	4.21993	25.54129	3.81582
Range		410.81936	61.37554	355.80942	53.15717
Standard Deviation		100.96309	15.08367	94.03256	14.04827

Raw data for Metal brackets bonded to fluorosed teeth

	Tooth Structure	Maximum Compressive load (N)	Compressive stress at Maximum Compressive load (MPa)	Compressive load at Break (Standard) (N)	Compressive stress at Break (Standard) (MPa)
1	Group D	29.69217	4.43595	11.86506	1.77262
2	Group D	189.23340	28.27107	186.39970	27.84772
3	Group D	97.15192	14.51429	47.85239	7.14905
4	Group D	72.35316	10.80941	65.77664	9.82689
5	Group D	99.33710	14.84075	96.68082	14.44391
6	Group D	126.04913	18.83147	104.42770	15.60128
7	Group D	279.24219	41.71819	274.19443	40.96407
8	Group D	106.73289	15.94567	100.73334	15.04935
9	Group D	90.44079	13.51166	88.80219	13.26686
10	Group D	65.55740	9.79414	48.19918	7.20086
11	Group D	55.28719	8.25979	0.00157	0.00024
12	Group D	67.89348	10.14314	67.73159	10.11896
13	Group D	120.37189	17.98331	120.37189	17.98331
14	Group D	118.41705	17.69126	116.72614	17.43864
15	Group D	88.51897	13.22455	87.72660	13.10617
16	Group D	58.62950	8.75912	58.59578	8.75409
17	Group D	48.92621	7.30947	31.48507	4.70380
18	Group D	44.20702	6.60443	22.65013	3.38388
19	Group D	74.22868	11.08961	39.59383	5.91523
20	Group D	57.53346	8.59538	48.73133	7.28036
21	Group D	124.10289	18.54071	25.73940	3.84541
22	Group D	90.21456	13.47786	90.10815	13.46197
23	Group D	150.82217	22.53251	139.84114	20.89197
24	Group D	21.50281	3.21247	21.32101	3.18531
25	Group D	67.35907	10.06330	21.37707	3.19369
Coefficient of Variation		58.07058	58.07058	79.34513	79.34513
Maximum		279.24219	41.71819	274.19443	40.96407

	Tooth Structure	Maximum Compressive load (N)	Compressive stress at Maximum Compressive load (MPa)	Compressive load at Break (Standard) (N)	Compressive stress at Break (Standard) (MPa)
Mean		93.75220	14.00638	76.67729	11.45542
Median		88.51897	13.22455	65.77664	9.82689
Minimum		21.50281	3.21247	0.00157	0.00024
Range		257.73937	38.50572	274.19285	40.96383
Standard Deviation		54.44245	8.13359	60.83969	9.08932