THE RETENTIVE STRENGTH OF BONDED AMALGAM RESTORATIONS

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A minithesis submitted in partial fulfillment of the requirements for the degree of Master of Science in Dental Sciences in Restorative Dentistry at the Faculty of Dentistry University of the Western Cape

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September 2005

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KEYWORDS

Retentive strength,

Amalgam restorations.

ABSTRACT

Amalgam bonding agents have been shown to enhance retention of amalgam restorations by mechanical means. However, recent studies showed that the use of glass ionomer cements and resin cements as lining and bonding materials to amalgam restorations will increase the retentive strength of the amalgam restorations, hence reducing the microleakage and secondary caries.

Purpose:

The purpose of this *in vitro* study is to compare the relative retentive strength of conventional amalgam restorations and bonded amalgam restorations using resin adhesive, glass ionomer cements and resin cements.

Materials & methods:

Eighty non-carious extracted human premolar teeth were randomly divided into 4 groups, 3 test groups and 1 control group of 20 teeth each. The preparations were 2.5 mm deep and 3 mm wide at the pulpal floor on the buccal surfaces. A plastic pipe used for domestic electrical works was cut into 20 mm pieces and the selected groups of teeth were embedded in different colours of orthodontic acrylic material (Orthocryl, Dentaurum-Germany) in the pipe that had a 20 mm diameter. A 26 mm, 18 gauge flat-headed wire nail was placed in the cavity with its head on the pulpal floor. The tail of the nail was bent to grip the hook that was attached to the upper grid of the Zwick testing machine. All the nail heads were coated with cavity varnish prior to their placement to avoid any bonding between the tooth and the nail head. For this study Adper ScotchBond Multi-Purpose -

Adhesive Resin (dual cure, 3M ESPE, USA), Fuji Plus- Glass-ionomer cement (luting cement-chemical cure, GC Corporation, Japan) and Panavia-F- Resin cement (dual cure, Kuraray Medical Inc. Japan) were used as the bonding agents to bond the amalgam restorations to the tooth. Amalgam (Dispersalloy, regular set, dispersed phase alloy, Dentsply Caulk, USA) was mixed in an amalgamator for 8 seconds trituration time and then immediately condensed into the preparations around the nail before the setting of the bonding materials. Except for the resin cement all the margins were cured after condensation of the amalgam. All the restorations were stored for 24 hours in distilled water at $37^{o}C$ and then subjected to 500 cycles at temperatures of $5^{o}C$ and $55^{o}C$. After one week all the samples were tested to failure in tension using the Zwick/material testing machine (Zwick GmbH & Co, D-7900 Ulm, Germany) and the peak loads in Kg was recorded.

Results:

The results of the 4 groups were analyzed using a one-way ANOVA $(p<0.05)$ test and Tukey's test for specific comparison with a SAS computer software package (SAS Institute Inc., Cary, NC, USA).

DECLARATION

I hereby declare that "An *in vitro* Comparative Study of the Retentive Strength of Bonded Amalgam Restorations" is my own work, that it has not been submitted before for any degree or examination in any university, and that all the sources I have used or quoted have been indicated and acknowledged by complete references.

Banna T Rao

September 2005

Signed:………………………………………

DEDICATION

To my Parents for their constant support and sacrifice.

To my wife and daughter for their encouragement to pursue higher studies at the University of the Western Cape, far away from my home country.

To my supervisor whose guidance, encouragement, kind help and support made this project successful.

ACKNOWLEDGEMENTS

I owe my teacher Prof. YI Osman, professor and deputy dean of the dental faculty, UWC, deep gratitude. He has always inspired and encouraged me to think. I was never deprived of his valuable views and suggestions which helped me not only in this thesis work but also during my entire course of post graduation. He is great.

I am grateful to my dean Prof MH Moola for always encouraging me to strive hard for success.

I would like to express my gratitude to Prof. Wilson, Prof Parker, Prof. Ratilal, Dr. Ricky, Dr. Shabbir, and Dr. Dudu for their kind hearted co-operation during my thesis work and during my entire study of post graduation.

My heartfelt thanks to Prof. SR Grobler and Dr. Rossouw, Department of Oral and Dental health research, UWC for their constant help without which this study would not have been possible at all.

I would like to thank Prof. R Madsen, professor in Statistics, University of Missouri, USA for his excellent statistical analysis for giving my thesis its final shape.

Words are all I have to say a big thank you to my friends Dr. AL-Omari, Dr. Majid, Dr. Kalanzi, the assistant in A clinic Ms. Felicia Claasen and all the lab technicians especially Mr. D Valentine who were a pillar of support during my entire post graduate course.

Many other people have been responsible for helping me during my thesis work and in my study period. I deeply appreciate all of them for their whole hearted support.

I thank god almighty for showing his blessings on me and showing me the right path.

Banna T. Rao

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CHAPTER

1

INTRODUCTION

1. INTRODUCTION

Amalgam is dentistry's main therapeutic agent for restoring decayed teeth. The oldest written record of the use of amalgam in dentistry is a publication in 1528. Approximately three out of four restorations of individual teeth are of amalgam. This preeminence has been attained during the last hundred years and reflects the many developments that have made dental amalgam a remarkable metallurgical achievement (ADA guide.1976).

An amalgam restoration is initially plastic and within a few minutes after mixing becomes hard. During hardening little or no change in volume occurs. Properly condensed amalgam restorations exhibit compressive strength values as high as that attained with some cast iron. The amalgam restorations can withstand the corrosive oral environment and blend into the host. The combination of all these properties makes amalgam the most universally used restorative material (ADA guide. 1976).

Dental amalgam is composed of a silver-tin-mercury alloy that was introduced in 1855 by Elisha Towesend, followed by another formulation by J.F.Flagg in 1860. Continued progress was made in the work on amalgam alloys throughout the latter part of the nineteenth century. G.V.Black published the results of his studies in 1895 and that marked the beginning of precision measurements on amalgam alloys. Black had previously published in 1891 his theories on cavity design and preparations, that although only remotely related to dental materials included certain principles of mechanics that involved properties of the materials that were used for the restorations (Peyton and Craig. 1971).

Amalgam is used most commonly for direct, permanent, posterior restorations and for large foundation restorations for cores that are precursors prior to placing crowns. Dental amalgam restorations are reasonably easy to insert, are not overly technique sensitive, maintain anatomical form, have reasonably adequate resistance to fracture, prevent marginal leakage after a period of time in the mouth, can be used in stress bearing areas, and have a relatively long service life (Craig and Powers. 2002).

Dental amalgam has been used successfully for more than 170 years as a restorative material. This is still the material of choice for posterior restorations where masticatory loads are high (Cenci *et al.* 2004). It has several advantages, such as easy manipulation and placement; good wear resistance, low technique sensitivity, acceptable life expectancy, and low cost. However, the material lacks adhesive properties, making undercuts essential for mechanical retention. Where as bonded amalgam restorations using different bonding agents can eliminate the unnecessary removal of sound tooth structure due to extensive cavity preparation that is necessary to accommodate undercuts. Bonded amalgam restorations have been found to increase retentive strength and reduce microleakage commonly associated with the conventional amalgam restorations (Cenci *et al.* 2004; Winkler, Rhodes and Moore. 2000).

The developments in adhesive dental materials have resulted in some advantages including aesthetics and good chemical bonding to tooth structure (Mertz-Fairhurst *et al.* 1998). However, they are still lacking in colour stability and strength in the oral environment over a long period of time. Due to these disadvantages of adhesive dental materials amalgam restorations are still

preferable as the restorations of choice for the posterior region of the mouth. However, amalgam restorations require the removal of additional intact tooth structure in order to provide long-term retention. The remaining tooth structure is weakened rather than strengthened. Bonded amalgam restorations, on the other hand, have excellent retention abilities, do not require pins for additional retention , strengthen the remaining tooth structure, eliminate the likelihood of cuspal fracture, and eliminate post-operative sensitivity if optimally done (Balanko. 1992).

The conventional amalgam restoration lacks adhesive properties and is prone to microleakage and secondary caries (Staninec *et al*. 1998). Considering the advantage of chemical bonding of the adhesive materials to tooth structure and the mechanical interlocking due to the formation of tags that the amalgam restoration makes in the bonding agent can result in an increase in the retentive strength and a reduction in the microleakage (Cenci *et al*. 2004). For a long time adhesive bonding agents (Bis-GMA and HEMA) have been used to bond amalgam restorations in the clinical environment (Winkler, Rhodes and Moore. 2000).

Now that there are newer adhesives and resin cement materials available to bond amalgam restorations (3M ESPE info. 2004) the technique of bonding amalgam restorations should gain popularity. However, there is little information available on resin cements such as Panavia F and Calibra that are currently being used as bonding materials to bond amalgam restorations.

In this *in vitro* study amalgam restorations will be bonded using an adhesive bonding agent (Adper Scotchbond MultiPurpose-dual cure), a glass ionomer

cement (Fuji Plus luting cement-chemical cure) and a resin cement (Panavia-F-dual cure). The retentive strength of the bonded amalgam restorations will be evaluated and a comparison will be done between the retentive strength of these materials to determine the bonding agent with the highest retentive strength.

CHAPTER

2

LITERATURE REVIEW

2. LITERATURE REVIEW

2.1. Amalgam – Restorations.

In dentistry, the term amalgam denotes a type of restorative material that is prepared by mixing a powdered alloy, basically composed of silver and tin, with mercury. The resultant plastic mass can then be placed directly into the prepared cavity in the tooth where it rapidly hardens. Amalgam restorations constitute the large majority of all permanent fillings placed by dentists to repair the ravages of dental caries. Dental amalgams have the advantage over most other metallic restorations of being able to be placed and finished in the same visit except for the final polishing that should be delayed for at least 24 hours (Greener, Harcourt and Lautenschlager. 1972).

Recent metallurgical improvements and additional information concerning preparation design have further increased the likelihood of clinical success when using this incredible alloy. Well designed, properly condensed, carved and smoothly polished amalgam restorations can provide the patient with lasting functional restorations, and the clinician with a great pride of accomplishment (Reisbick. 1982).

Amalgams are cost effective, easy to manipulate, have a long survival life and a high strength against masticatory forces (McCabe. 1990). Recently, some concerns have arisen with reference to free mercury being released by amalgam restorations from both a biological and an environmental viewpoint (Kingman, Albertine and Brown. 1998); however, it is presently believed that dental amalgam restorations present an acceptable risk-to-benefit ratio when properly

executed. The primary application of amalgam in dentistry is for the restoration of posterior teeth and, to some degree, as cores for building teeth up when doing crown and bridge work (O'Brien. 1997).

2.2. Glass ionomer cements

It was some 30 years ago that Dr Alan Wilson and Dr John McLean began the development of a very special material that we now know as glass ionomer cements. Glass ionomer cements are quite unique, providing chemical adhesion to the tooth and the added benefits of fluoride release (Davidson and Mjor. 1999).

However, glass ionomer cements for restorative dentistry were already developed by the end of the 1960s and were first described in 1971 by Wilson and Kent (Karlzen-Reuterving and van Dijken. 1995). In spite of the remarkable characteristics of the material, amongst which is the adhesion to tooth structure and the release of fluoride that must be mentioned, glass ionomer cements have made only limited headway into general dental practice especially in the United States of America. This is primarily due to technical problems with the application of glass ionomer cements that include concerns regarding their long-term mechanical and aesthetic properties. The major advance in the glass-ionomer cement is its ability to adsorb permanently to the hydrophilic surfaces of the oral hard tissues. The bond strength of these cements to dentin is higher than that to enamel due to the enamel being more highly mineralized, more rigid, and less porous than the dentin that has a higher percentage of hydroxyapatite that is involved in the chemical bond with the glass ionomer cement (Davidson and Mjor. 1999).

Bond strength with glass ionomer cements may be enhanced by cleaning the organic debri off the dentin surfaces with polyacrylic acid prior to bonding. The advantage of glass ionomers that is, the constant fluoride release that inhibits secondary caries has been extensively reported on in the literature (Zimehl and Hannig. 2000).

The setting reaction of conventional glass-ionomer cements is initiated when the glass powder and the aqueous solution of polyacrylic acid are combined and undergo an acid-base reaction. The setting reaction of the resin-modified glass ionomer cements is the same acid base reaction between the glass powder and the polyacrylic acid that is initiated by mixing the powder and the liquid. However at the same time, the polymerization of HEMA and the cross-linking of the material is started by an oxidation-reduction or a photo polymerizing catalyst. This forms a hardened mixture in which the HEMA polymer and the polycarboxylic acid are supposed to be linked by hydrogen bonding (Davidson and Mjor. 1999).

The material sets as a result of the metallic salt bridges between the $Al + + +$ and $Ca + + +$ ions that had leached out from the glass and the acid groups on the polymers. The reaction proceeds to completion at a slow pace, with the formation of a cross-linked gel matrix in the initial set and an aluminum ion exchange strengthening the cross-linking in the final set. A chelating effect also takes place with the calcium on the exposed tooth surface, creating an adhesive bond. Glass ionomer cements bond chemically to enamel and dentin during the setting process. The mechanism of bonding appears to involve an ionic

interaction with calcium and /or phosphate ions from the surface of the enamel or dentin. Treating dentin with an acidic conditioner followed by a dilute solution of ferric chloride improves the bonding process.

The cleaning agent removes the smear layer from the dentin while the Fe^{3+} ions are deposited on exposed tooth surface and increase the ionic interaction between the cement and the dentin (Craig and Powers. 2002)

2.3. Resin cements

Composite resins are clinically well proven dental restorative materials that were developed at the beginning of the 1960's. Typically, the organic component of the composite resin contains Bisphenol-A-glycidylmethacrylate (Bis-GMA) and/or urethane dimethacrylate (UDMA). Often triethylene glycol dimethacrylate is added to dilute the viscous resin and to control the viscosity of the composite resin (Zimehl and Hannig. 2000).

The advent of adhesive luting cements has considerably expanded the scope of fixed prosthodontics (Terry and Jeffrey. 2001). Bonding of all-ceramic, metal or indirect composite restorations, including fiber posts to root canals are now routine procedures in clinical practice. Improving the adhesion of the resin cements to tooth substrates is paramount for increasing the fracture resistance of these brittle indirect restorations. Panavia F contains sodium benzene sulphinate in the Primer B component, and a proprietary sodium aromatic sulphinate in the Universal paste of the resin cement to ensure that optimal polymerization of the cement occurs under an acidic environment. It also contains patented polysiloxane-coated sodium fluoride fillers for sustained

fluoride release that are represented by the coated filler particles in Panavia F (Carvalho *et al.* 2004).

Composition of the resin luting agents and their polymerization mechanism may also influence their properties. Different viscosities of the luting agents and of monomer compositions have resulted in differences in adhesive properties of these resin luting agents. The polymerization method of the composite influences the bonding obtained to the dental substrate. Bond strengths are directly related to the degree of conversion of monomer to polymer during polymerization. The bond strength between the resin luting agent and the dental structures is an important feature that must be investigated. Resin luting agents should provide bond strengths sufficient to resist stresses generated by the polymerization shrinkage that accompanies the setting of the resin materials. However, adhesive ability can be influenced by the variation in the dental substrates to which the adhesive materials are bonded to. Bond strengths to enamel and dentin higher than 20 MPa may be adequate to resist stresses generated by the polymerization shrinkage process. However, there is a large range of variation between 7 and 40 MPa in relation to bonding of different dentin bonding agents or resin luting agents to the different dental substrates (Cristiane *et al.* 2003).

The bonding of resin luting cements to base metal alloys has been successful, and there have been numerous studies regarding the strength of resin composite bonds to etched and non-etched base metal alloys (Yoshida and Atsuta. 1997). Resin cements account for a growing proportion of cement use, the reasons for that include their better physical characteristics compared to the conventional luting cements, the reduction in potential for pulp damage

and the reduction in postoperative sensitivity. The most common use of resin cements is for salvaging old crown and bridge prostheses that make the adhesive luting cements an attractive alternative to conventional luting cements (Yoshida *et al.* 1996)

The reports form the studies on luting cements concur with those reported for restorative cements, i.e. that the fracture toughness of the conventional glass ionomer cements is significantly less than that of the resin-modified glass ionomer cements , which in turn is less than that of the resin composite cements (Mitchella, Douglasa and Cheng. 1999).

Twenty years ago, the use of adhesive resin agents to cement dental restorations was not common. Moreover, adhesive resin luting cements are much less water-soluble and show much better marginal closure compared to the conventional luting agents such as zinc phosphate, polycarboxylate and glass ionomer cements. These properties make adhesive luting cements an attractive alternative to conventional luting agents (Yoshida and Atsuta. 1997).

Currently these resin cements are being recommended for use in bonding to conventional amalgam restorations, because of their good adhesive (micro mechanical) nature to the tooth structure thus increasing the strength and reducing the microleakage associated with conventional amalgam restorations (3M ESPE info. 2004).

2.4. Bonded amalgam restorations.

Bonding of amalgam restorations has proved to enhance the strength and reduce the microleakage of the bonded amalgam restorations compared to the non-bonded or conventional amalgam restorations (Abraham, Sudeep and Bhat. 1999).

A cavity varnish has previously been advocated during the insertion of a silver amalgam restoration to prevent microleakage. However, the application of dentinal bonding agents used with silver amalgam restorations has shown a marked reduction in the microleakage associated with these restorations (Marigo *et al*. 2000).

The bonding agent's viscosity also plays an important role in the increased retention by means of an interlocking mechanism. The amalgam mix produces interlocking projections into the bonding agents for improved mechanical retention (Zidan and Abdel-Kariem. 2003).

Amalgam bonding agents have clinically proven that they are capable of reducing microleakage associated with conventional restorations (Ziskind *et al*. 2003).

A study conducted on the comparison of pin retained complex amalgam fillings and bonded amalgam fillings showed that there was no difference in the bond strength of the different amalgam fillings in that study (Summitt *et al*. 2004).

Bonded amalgam restorations appear to be as effective as bonded composite restorations in supporting undermined enamel in terms of resistance to fracture of the enamel (Franchi, Breschi and Ruggeri. 1999).

Another study showed that cavity preparations reduce stiffness and weaken the tooth; however by using bonded amalgam restorations it partially restores the strength and rigidity of the lost tooth structure compared to teeth that have non-bonded amalgam restorations (Winkler, Rhodes and Moore. 2000).

A number of laboratory and clinical studies over the past 15 years have explored the potential advantages of bonding amalgam restorations to tooth surfaces. Bond strengths have been reported to range from 2 to 20 MPa, with higher bond strengths been reported when filled adhesives were used with bonded restorations (Ruzickova *et al.* 1997).

The study also showed that the use of bonding agents resulted in a considerable reduction in microleakage, when compared to copal varnish or no lining being used at all with the restoration. The use of bonding agents provides retention values that are equivalent to, or better than, those obtained with the use of mechanical undercuts only (Cenci *et al.* 2004).

The study evaluating the strength of restored teeth reported on an improvement in resistance to fracture or cuspal flexing as measured by strain gauges (Franchi, Breschi and Ruggeri. 1999). It also showed the penetration of secondary caries along the interface to be inhibited by the bonding agent (Dias de Souza *et al.* 2002).

The mode of failure of the bonded amalgam restorations has generally been reported to be at the interface between the adhesive resin and the amalgam retsoration (Grobler *et al.* 2000).

Another study confirmed that the fracture resistance of the restored tooth was greatly enhanced by the bonded amalgam restorations as compared to when conventional amalgam restorations were placed in the tooth (Eakle, Staninec and Lacy. 1992).

The study of bonded amalgam restorations placed in the posterior permanent teeth of 190 adult patients and examined at intervals over periods of up to five years showed only five restoration failures (1.4%), from tooth fractures, involving Class II preparations in molar teeth. No instances of persistent pulpal sensitivity or recurrent caries were reported in that study (Summitt *et al.* 2004).
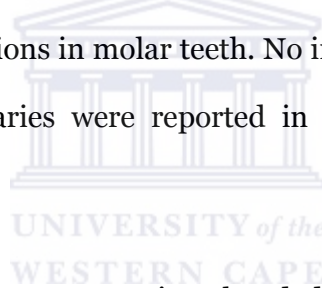
In another study on amalgam restorations bonded with different agents found that these restorations had significant advantages over pinned restorations, particularly where the pulp might be compromised. It was concluded that amalgam will be retained in preparations without undercuts, and in pits and fissures without any tooth preparation by bonding the amalgam restorations to the tooth structure (Ruzickova *et al.* 1997).

The study conducted on using bonding and pins simultaneously showed an increase in the strength of the amalgam core material. The use of a glass ionomer cement liner with the amalgam restorations made the most significant reduction in microleakage when compared to bonding adhesives used with the

amalgam restorations (Nobilo, Consani and de Goes. 1997; Arcoria, Fisher and Wagner. 1991).

Glass ionomer cements, when used as an adhesive liner for amalgam restorations, may effectively reinforce the remaining tooth structure and therefore, enhance the fracture resistance compared to using adhesive bonding resins on their own (Sen, Nayir and Cetiner. 2002).

The glass ionomer cements showed the highest bond strength when compared to that achieved with the adhesive resins and the resin cements (Davidson and Mjor. 1999). Glass ionomer cements (type 1) can also be effectively used as bonding agents between the amalgam restoration and the tooth when the glass ionomer is painted onto the cavity walls and the amalgam is condensed against it immediately prior to the setting of the glass ionomer cement as compared to when conventional bonding resins are used (Abraham, Sudeep and Bhat. 1999).

In a comparative study a glass ionomer cement used as a liner reduced the amount of microleakage compared to that of a cavity varnish, a topical fluoride gel and an adhesive system (Davidson and Mjor. 1999). The glass ionomer cements possess the ability to bind to both the tooth structure as well as to the components of the dental amalgam. When compared to 4- META the shear bond strength of the glass ionomer cement mediated bond is significantly higher and may be adequate for clinical applications (Smales and Wetherell 2000).

In a comparative study related to sensitivity the glass ionomer cement bonded teeth were significantly less sensitive when compared to teeth restored with

only a zinc phosphate lining under the amalgam restorations (Scherer *et al.* 1990).

Bonding amalgam restorations seems to have more advantages compared to the placement of conventional amalgam restorations. Different materials as bonding agents for conventional amalgam restorations are now available. When comparing the use of adhesives and resin cements as bonding agents for amalgam restorations the use of adhesives may not be as effective as regards the bond strength to the amalgam and in reducing the miroleakage (Toledano *et al.* 2000).

The use of adhesives as bonding agents for conventional amalgam restorations has contributed to the strengthening of the cusps weakened by the cavity preparations, but the extent of the strengthening is material specific when compared to non-bonded amalgam restorations (Piloas, Brosha and Chweidana. 1998).

Using resin modified glass ionomer cements, as bonding materials for amalgam restorations will increase the shear bond strength of the amalgam restorations. The bonding mechanism of amalgam to enamel with the use of either an adhesive resin or a resin modified glass ionomer cement is mainly micro-mechanical (Mitchella, Douglasa and Cheng. 1999). When evaluating the remaining tooth structure after a cavity preparation, practitioners should consider any enamel that has an insufficient amount of sound dentin supporting it to be unsupported. This unsupported enamel is susceptible to fracture if it is not reinforced (Franchi, Breschi and Ruggeri. 1999). However, if the amalgam restorations were bonded to the remaining tooth structure,

structural reinforcement would be provided and the unsupported enamel could be preserved, leading to a more conservative tooth preparation (Cenci *et al.* 2004). Moreover, if the margin of the amalgam restoration could adhere to the cavo surface margin of the prepared cavity, that is placed mainly in enamel, the occurrence of marginal fracture of the restoration or the tooth and marginal leakage through the interface could be eliminated or at least reduced (Supoj *et al.* 2001)

When the amalgam restorations are bonded with either adhesives, resin cements or glass ionomer cements they showed reduced microleakage, increased retention, inhibition of secondary caries, reinforcement of tooth structure, and reduced cuspal deflection when compared to non-bonded amalgam restorations (Staninec and Setcos. 2003; Chen *et al.* 2000).

The caries susceptibility of enamel surfaces adjacent to amalgam restorations bonded with fluoride-releasing bonding agents was shown to decrease considerably (Abraham, Sudeep and Bhat. 1999; Davidson and Mjor. 1999). It seems likely that the incorporation of the amalgam-bonding resin with fluoride-releasing capabilities provided greater protection against a constant cariogenic attack in the interfacial area over that achieved with conventional amalgam restoration (Hicks *et al.* 2002).

Resin adhesive bonded amalgam restorations reduce microleakage when compared to copal varnish lined amalgam restorations and non-bonded amalgam restorations (Saiku, Germain and Meiers. 1993; Al-Jazairy and Louka. 1999).

Bonded amalgam restorations in service have been found to be more retentive when compared to non-bonded amalgam restorations over longer periods of time (Setcos, Staninec and Wilson. 1999).

Bonded amalgam restorations in primary teeth using Scotchbond MultiPurpose Plus showed a significant decrease in microleakage when compared to copal varnish lined amalgam restorations and one-step adhesive system bonded amalgam restorations and conventional amalgam restorations (Myaki *et al.* 2001).

Conventional amalgam restorations are retained in a cavity by mechanical undercuts (Cenci *et al.* 2004). This may lead to removal of unnecessary sound tooth structure to accommodate the undercuts. However bonded amalgam restorations using adhesives as the bonding agents could be used that the adhesive takes the place of the traditional undercuts to retain the restorations of amalgam and gallium alloys, thus saving a considerable amount of tooth structure (Eakle *et al.* 1994).

It has been demonstrated that bonded amalgam restorations have retentive strength in the cavities that are similar to that of using pins to retain conventional amalgam restorations. Thus by avoiding the use of pins, the removal of unnecessary tooth structure is avoided and the likelihood of damaging the pulp and or the periodontal ligament is decreased (Temple-Smithson, Causton and Marshall. 1992).

Bonding dental amalgams to tooth structure reduces the occurrence of marginal leakage, marginal fracture and sensitivity (Scherer *et al.* 1990).

However, most studies on amalgam bonding have supported the use of resin cements and the conventional three-bottle bonding agents for bonding the restorations (Orosa. 2003; Scherer *et al.* 1990; Tarim, Suzuki and Cox. 1996).

Microleakage studies of adhesively bonded cervically placed amalgam restorations showed lower levels of microleakage in enamel and dentin with bonded amalgam restorations as opposed to the non-bonded amalgam restorations. In addition the dual adhesives were found to be more effective than the "one bottle" adhesives in the bonded amalgam groups (Briso *et al.* 2002).

Several materials are now available that bond amalgam to tooth surfaces with bonding strengths exceeding 10 MPa (Dias de Souza *et al.* 2002). Amalgam restorations can be satisfactorily retained in preparations without undercuts, and in pits and fissures without any tooth preparation (Staninec *et al.* 1997).

Bonded amalgam restorations can be used as pit and fissure sealants without any mechanical preparation (Mertz-Fairhurst *et al.* 1998).When comparing the two-year retention rate of the bonded amalgams to that of the resin-based pit and fissure sealants, clinical examinations at six months, one year and two years revealed no statistically significant differences in the retention rates of the two sealants (Setcos, Staninec and Wilson. 1999). This technique opens up the possibility of using bonded amalgams in pits and fissures surrounding very conservative preparations when using preventive amalgam restoration (Setcos, Staninec and Wilson. 2000).

The results of a study to compare the coronal microleakage of conventional and bonded amalgam coronal-radicular restorations on endodontically treated molar teeth showed that it may be preferable for a coronal seal to prevent the reinfection of the endodontically treated molar, by restoring the tooth immediately after obturation with the bonded amalgam coronal-radicular technique (Howdle, Fox and Youngson. 2002).

A clinical study based on a 3-year follow-up evaluated the efficacy of adhesive amalgam restorations in pediatric dental practice. The results showed that the bonded amalgam restorations are preferable in pediatric dentistry due to their retentive periods that are significantly greater than the conventional amalgam restorations (Cannon, Tylka and Sandrik. 1999).

A study was conducted to measure and compare the reduction in dentin permeability in Class II preparations, after restoration with resin composite or bonded amalgam, using either a multi-step or a one-bottle dental adhesive system. The results showed that after 1 week, the resin composite using a one-bottle dental adhesive system provided the highest reduction in dentine permeability, whereas after 3 months the bonded amalgams demonstrated the highest reduction. The results of this study indicated that on the basis of reducing dentine permeability *in vitro*, resin composite restorations using the one-bottle adhesive system were superior to the multi-step equivalent in the period immediately following placement. However, bonded amalgams due to their favorable performance over 3 months could also be used in Class II restorations (Ozok *et al.* 2001).

Applying a bonding agent and a resinous adhesive layer before condensing the amalgam has become common clinical procedure. However, interactions between the different interfaces formed, and the extent of the sealing obtained are the important factors in their success (Marigo *et al.* 2000). Results from the Meiers and Turner study (1998) indicate that placing a bonding material under the amalgam restoration is essential in preventing microleakage. When this amalgam is condensed against an uncured or a cured adhesive material; the adhesive resinous layer creates a thick interface with protrusions and inclusions of the amalgam, in the bonding agent. However, microleakage studies (Marchiori *et al.* 1998) seems to indicate that condensation over an uncured adhesive layer results in a better seal when compared to that obtained when the amalgam is condensed over a cured adhesive material. A SEM study combined with an elemental analysis evaluation indicated that the adhesion between the amalgam restoration and the adhesive material is mainly of a mechanical character and is formed by interdigitations of the amalgam protruding into the adhesive material (Geiger *et al.* 2001).

The mean bond strength values of amalgam adhesives are lower than those achieved with composite resins. However, dentino-enamel adhesive systems specific for amalgam restorations have to be taken into consideration particularly in the case of conservative restorations that need additional chemical retention to retain the restorations, due to the mechanical retention not being enough (Marigo *et al.* 2000).

A study was done to determine the effect of restoration size on the fracture strength of conventional amalgam restorations and amalgam restorations

bonded with adhesives (Lindemuth, Hagge and Broome. 2000). The research had shown that the adhesive was dispersed throughout the unset amalgam during the condensation procedure and that a decrease in diametral tensile strength, proportional to the amount of adhesive incorporated into the unset amalgam was noted. There was however no difference in the bulk fracture strength between the large amalgam restorations restored with and without adhesives (al-Moayad, Aboush and Elderton. 1993). However, in the case of the small amalgam restorations restored with adhesives there was a significantly greater (p < 0.025) bulk fracture strength than in the small amalgam restorations restored without the use of the adhesive systems (Lindemuth, Hagge and Broome. 2000).

Despite a lack of data based on clinical research, many positive characteristics have been attributed to the placement of amalgam restorations with an adhesive resin liner (al-Moayad, Aboush and Elderton. 1993). In a clinical study evaluate at 42 months, the results showed that all restorations bonded with adhesive resins were still retained, free of secondary caries and were rated clinically acceptable (Baghdadi. 2003). Practitioners wary of using new methods that have not undergone thorough clinical testing can feel comfortable placing adhesive liners under amalgam restorations based on the available evidence in the literature (Browning, Johnson and Gregory. 2000).

A study done to evaluate the marginal integrity of amalgam restorations using SEM and profilometry data demonstrated that the marginal integrity of amalgam alloy restorations was significantly improved by the use of bonding

systems when compared to the marginal integrity of traditional amalgam restorations (Tarim, Suzuki and Cox. 1996).

Another study done to investigate the 1-year results of the dentin bond (DBS)/viscous resin liner combination found that the DBS/ liner combinations could provide significant protection against microleakage under high-copper amalgam alloys for up to 1 year when compared to a copalite lining under the amalgam alloys when compared to amalgam restorations without any liner (Meiers and Turner. 1998).

Based upon the results of an *in vitro* investigation the adhesive resin luting agents significantly improve the fracture resistance of teeth restored with MOD amalgam restorations, when compared to non-bonded MOD amalgam restorations in the controlled teeth (Rasheed. 2005).

CHAPTER

3
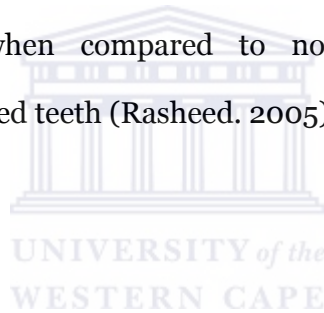
AIMS AND OBJECTIVES

3. AIMS AND OBJECTIVES

The aim of the study is to compare the retentive strength of amalgam restorations bonded with different materials; an adhesive resin (Adper ScotchBond Multi-Purpose-dual cure), a glass ionomer cement (Fuji Plus luting cement-chemical cure) and a resin cement (Panavia F-dual cure) with conventional amalgam restorations.

3.1. NULL HYPOTHESIS

There is no significant difference of retentive strength of the bonded amalgam restorations with different bonding materials when compared to the conventional amalgam restorations.

CHAPTER

4

MATERIALS AND METHODS

4. MATERIALS AND METHODS

4.1. Brief history of bonded amalgam restorations

Dental amalgam has been used successfully for more than 170 years as a restorative material. This is still the material of choice for posterior restorations where the masticatory loads are high (Varga, Matsumara and Masuhara. 1986). It has several advantages, such as easy manipulation and placement, good wear resistance, low technique sensitivity, acceptable life expectancy, and low cost. However, the material lacks adhesive properties, making undercuts necessary for mechanical retention (Cenci *et al*. 2004).

The developments in adhesive dental materials have certain advantages including aesthetics and good chemical bonding to tooth structure. However, they lack in color stability and strength in the oral environment over long periods of time (Mitchella, Douglasa and Cheng. 1999; Terry and Jeffrey. 2001). Due to these disadvantages of the adhesive dental materials amalgam is preferably indicated as the material of choice for posterior restorations. However, amalgam restorations require the removal of additional, intact tooth structure in order to provide long term retention resulting in the remaining tooth structure being weakened rather than strengthened. Bonded amalgam restorations, on the other hand, have excellent retention, do not require pins, strengthen the remaining tooth structure, eliminate the likelihood of cuspal fracture, and eliminate post-operative sensitivity (Cenci *et al*. 2004; Zidan and Abdel-Kariem. 2003; Supoj *et al*. 2001; Balanko. 1992).

However, amalgam restorations lack adhesive properties and are prone to microleakage and secondary caries. Considering the properties of chemical

bonding to the tooth structure due to the adhesive material and the mechanical interlocking due to the tags formed by the amalgam restoration there can be a resultant increase in the retentive strength of the amalgam restoration and an accompanying reduction in the microleakage (Davidson and Mjor. 1999). For a long time the adhesive bonding agents (Bis-GMA and HEMA) were used to bond the amalgam restorations (Frederick *et al.* 1996). Now there are new adhesive and resin cement materials available that can be used to improve the bond of the amalgam restorations (3M ESPE info 2004). However, little information is available about the resin cements- Panavia F and Calibra; that are also used as bonding materials to bond the amalgam restorations.

In this *in vitro* study the amalgam restorations will be bonded by using an adhesive bonding agent (Adper ScotchBond Multi-Purpose-dual cure, 3M ESPE, USA) a glass ionomer cement Fuji Plus, luting cement-dual cure, GC Corp. Japan) and a resin cement (Panavia F-dual cure, Kuraray Medical Inc. Japan) and the retentive strength of the amalgam restorations will be evaluated and compared for the three materials being tested.

4.2 Study sample

Eighty extracted human premolar teeth without any fractures and or caries were selected from teeth extracted in the service rendering clinics at the Oral Health Centers at Mitchells Plain and Tygerberg.

All the teeth were cleaned under running water and all the surfaces were thoroughly examined.

The teeth were preserved in 0.2% thymol to prevent any bacterial activity during the storage period.

4.3 Sample design

Fig.1: Study sample

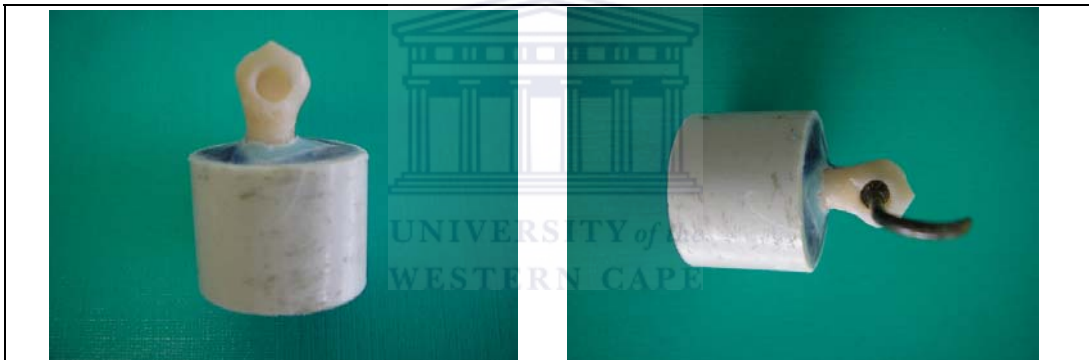*Fig.2: Cavity preparation*   *Fig.3: Nail in position*

4.4 MATERIALS

4.4. a Amalgam-alloy

Dispersalloy (Dentsply Caulk, USA), regular set, dispersed phase alloy.

The capsule contains Silver, Copper, Tin and Zinc   and Mercury.

4.4. b Brief history

The first scientific appraisals of dental amalgam were carried out by G.V.Black in 1896, who developed instruments to study the properties of this material, and who subsequently developed a formulation for amalgam alloys to be mixed with mercury that he called 'a balanced alloy'. Black's formulation is still the basis for the composition of dental amalgam alloys today, almost more than a century later (Von Fraunhofer. 1975).

4.4. c Adhesive bonding agent

Adper ScotchBond Multi-Purpose, dual cure (3M ESPE, USA).

Etchant: 10% maleic acid pH 1.2

Activator: ethanol based solution of a sulfinic acid salt and a photo-initiator component.

Primer: aqueous solution of HEMA and polyalkenoic acid co-polymer

Adhesive: Bis-GMA and HEMA resin combined with a novel initiation system.

4.4. d Brief history

The use of adhesives as bonding agents for amalgam restorations has been recent as compared to conventional amalgam restorations and have contributed to the strengthening of the cusps weakened by the cavity preparations, but the extent of re-inforcement is material specific when compared to the non-bonded amalgam restorations (Piloas, Brosha and Chweidana. 1998).

4.4. e Glass ionomer cement.

Fuji plus luting cement, chemical cure (GC Corporation. Japan).

Powder contains Fluoroalumino-silicate glass and liquid contains aqueous solution of a modified polyalkenoic acid.

4.4. f Brief history

It was some 30 years ago that Dr Alan Wilson and Dr John McLean began the development of that very special material that we now know as glass ionomer cement. Glass ionomer cements are quite unique, providing chemical adhesion to the tooth and the benefits of fluoride release (Davidson and Mjor. 1999).

4.4. g Resin cements

Panavia F - dual cure (Kuraray Medical Inc. Japan).

Contains primer A and B. and paste A and B.

4.4. h Brief history

Composite resins are clinically well proven dental restorative materials that were developed at the beginning of the 1960s. Typically, the organic component of the composite resin contains Bisphenol-A-glycidylmethacrylate (Bis-GMA) and/or urethane dimetharylate (UDMA). Often triethylene glycol dimethacrylate is added to dilute the viscous resin and to control the viscosity of the composite resin (Zimehl and Hannig. 2000).

Panavia F contains sodium benzene sulphinate in the Primer B component, and a proprietary sodium aromatic sulphinate in the Universal paste of the resin

cement to ensure that optimal polymerization of the cement occurs under an acidic environment. It also contains patented polysiloxane-coated sodium fluoride fillers for sustained fluoride release that are probably represented by the coated filler particles (Carvalho *et al.* 2004).

Fig.4: Materials used for the study

Table 1: *List of Restorative materials their composition, trade names, and manufacturer's information*

Material	Trade name	Composition	Manufacturer's information
Amalgam alloy	Dispersalloy, regular set, dispersed phase alloy	Alloy powder per 1 spill contains; Silver – 277.2 mg Copper – 47.2 mg Tin – 71.6 mg Zinc – 4.0 mg (Total – 400 mg) Mercury – 396 mg	Dentsply Caulk, USA.
Adhesive bonding agent	Adper ScotchBond Multi-Purpose dual cure	*Etchant:* 10% maleic acid pH 1.2 *Activator:* ethanol based solution of a sulfinic acid salt and a photo initiator component. *Primer:* aqueous solution of HEMA and polyalkenoic acid copolymer *Adhesive:* Bis-GMA and HEMA resin combined with a novel initiation system.	3M ESPE, USA.
Glass-ionomer cement	Fuji plus - chemical cure, Luting cement.	Powder: Aluminofluoro-silicate glass.	GC Corporation, Japan.

		Liquid: Polyacrylic acid, tartaric acid, distilled water, camphoroquinone in an aqueous solution of a modified polyalkenoic acid	
Resin cement	Panavia F-dual cure	*ED Primer A:* HEMA, MDP, 5-NMSA *ED Primer B:* 5-NMSA *Paste A:* MDP, Bis-GMA, filler, benzoyl peroxide, photo initiator *Paste B:* Bis-GMA, filler, sodium fluoride, amine.	Kuraray Medical Inc Japan.
Cavity varnish	Polyvar	*Finest purified gum Copal*	Young Dental Manufacturing. USA.

Table 2: List of other materials used.

S.No	Materials
1	Domestic PVC electrical pipe 20 mm diameter.
2	Orthocryl, Dentaurum-Germany.
3	Flat end long fissure diamond bur # FG 544-018 (Horico, Germany).
4	Microbrush Tips, 3M ESPE, USA.
5	Disposable plastic coated mixing pad.
6	26mm, 18 gauge flat head nails.
7	Amalgam carrier, Condenser, Ball burnisher (double head).

4.5 METHOD

The Winkler, Rhodes and Moore method as described in 2000 was adapted for this study. The teeth were randomly selected and later assigned into 3 test groups and 1 control group of 20 teeth each.
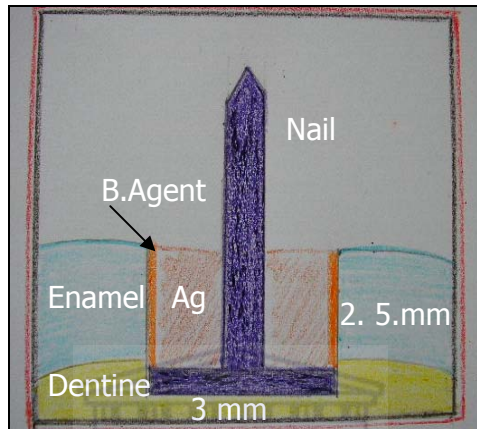
Fig. 5: Adapted from Winkler, Rhodes and Moore (2000)

Group-1 is the control group with conventional amalgam restorations without any bonding agent.

Group-2 bonded amalgam restorations with an adhesive bonding agent (Adper ScotchBond Multi-Purpose, dual cure).

Group-3 bonded amalgam restorations with a glass ionomer cement (Fuji-plus- chemical cure, luting cement).

Group-4 bonded amalgam restorations with a resin cement (Panavia F- dual cure).

Cavities were prepared on the buccal surfaces of all the teeth in the control and the test groups. To minimize variation between and within preparations, all the cavities were prepared under water spray using a high-speed dental headpiece attached to an air-rotor unit (Kavo-systemica, Kavo. Germany). The preparations were standardized to be2.5 mm deep and 3 mm wide at the pulpal floor.

A plastic pipe used for domestic electrical works was cut into 20 mm pieces. The pieces of pipe were filled with different colours of orthodontic acrylic material (Orthocryl, Dentaurum-Germany) and the selected groups of teeth were embedded in this acrylic material. The pipe had a 20 mm diameter.

Immediately prior to placing the restorations, the teeth were rinsed with a water spray for 20 seconds. A 26 mm, 18-gauge flat-headed wire nail was placed in the cavity with its head against the pulpal floor of the preparation. The tail of the nail was bent to hold the grip hook that was attached to the upper member of the Zwick testing machine. All the nail heads were coated with cavity varnish (Polyvar, Young Dental Mfg. USA) one day prior to the experiment to prevent bonding between the nail and the floor of the preparation. The diameter of the head of the nail was closely matched to the diameter of the preparation at the pulpal floor, so that the bonding between the amalgam and the tooth was limited to the walls of the preparation. For each test group the selected bonding material was applied to the walls of the prepared cavities according to the manufacturer's instructions followed by the placement of the amalgam restorations.

All the restored teeth were stored in distilled water at 37 °C. After storage for 5 days, all samples were thermo-cycled for 500 cycles between 5°C and 55°C with a dwell time of 30 seconds.

One week after placement of the amalgam restorations, the specimens were tested in tension using a Zwick/Material testing machine, model no 1446 (Zwick GmbH & Co, D-7900 Ulm, Germany). Analysis of the results was done using a SAS computer package (SAS Institute Inc., Cary, NC, USA).

4.5. a Group 1 (conventional amalgam restorations): 20 teeth were prepared in this group.
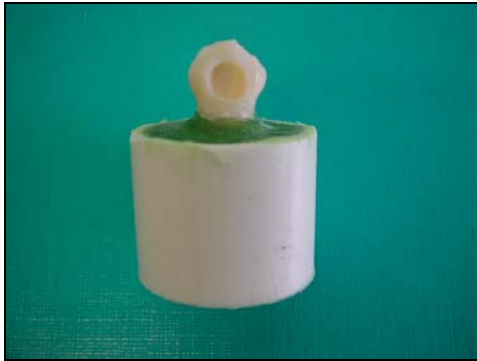
Fig.6: Cavity preparation   *Fig.7: Finished Ag restoration*
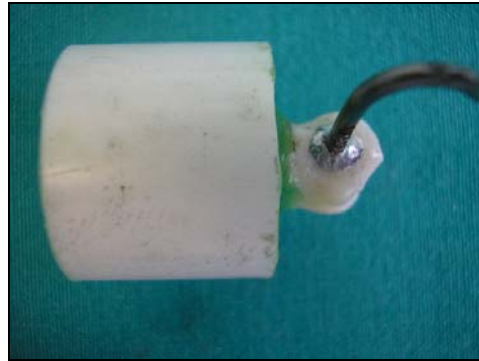
Step 1

A plastic pipe used for domestic electrical works was cut into 20 mm pieces and the selected group of teeth were embedded in orthodontic acrylic material (green colour) (Orthocryl, Dentaurum-Germany). The pipe had a 20 mm diameter.

Step 2

All the teeth had standard cavities prepared on their buccal surfaces measuring 2.5 mm deep and 3 mm wide by using a high-speed air rotor with water spray. A flat end long fissure diamond bur # FG 544-018(Horico, Germany) was used to prepare the cavities. All the prepared cavities were cleaned with distilled water and gently dried with air.

Step 3

A 26 mm, 18-gauge flat-headed wire nail was placed in the cavity with the head of the nail against the pulpal floor of the preparation. All the nail heads were coated with cavity varnish (Polyvar, Young Dental Mfg. USA) to prevent

bonding between the nail and the floor of the preparation. The diameter of the head of the nail was closely matched to the diameter of the preparation at the pulpal floor, so that the bonding between the amalgam and the tooth was limited to the walls of the preparation only.

Step 4

Amalgam (Dispersalloy, regular set, dispersed phase alloy- Dentsply Caulk, USA) capsule was triturated for 8 seconds in a mechanical amalgamator (Silamat, Vivadent, Germany) and the amalgam was then condensed immediately into the preparation around the nail.

Step 5

The amalgam restorations were burnished and finished using a small ball burnisher.

Step 6

All the restored teeth were stored in distilled water at 37 º C. After storage for 5 days, all samples were thermo-cycled for 500 cycles between 5ºC and 55ºC temperature with a dwell time of 30 seconds.

Step 7

One week after placement of the amalgam restorations, the specimens were tested in tension using a Zwick/ Material testing machine, model no 1446 (Zwick GmbH & Co, D-7900 Ulm, Germany). Analysis of the results was done using a SAS computer package (SAS Institute Inc., Cary, NC, USA).

4.5. b Group 2 (Bonding adhesive- Adper ScotchBond Multi-Purpose, dual cure): 20 teeth were prepared in this group.
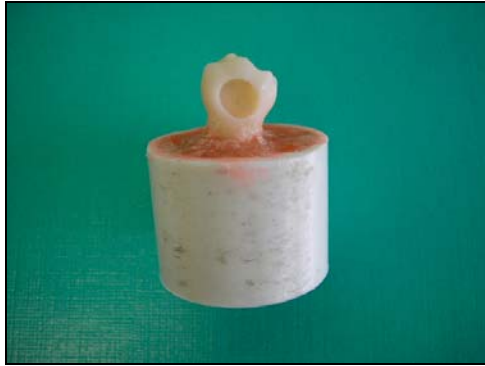
Fig.8: Cavity preparation
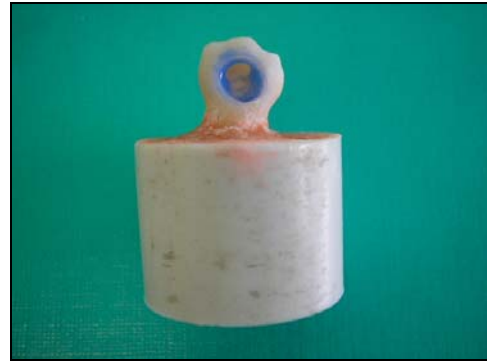
Fig.9: Acid etching
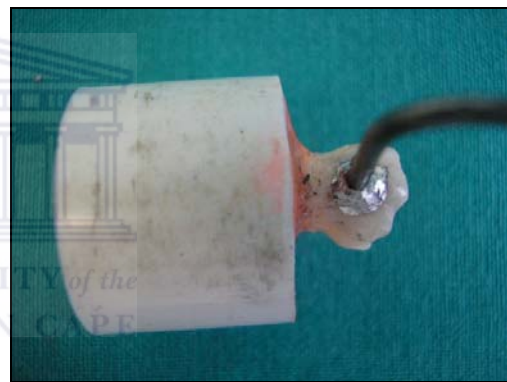
Fig.10: Ag filling placed after adhesive bonding

Fig.11: Finished Ag restoration

Step 1 & 2

The mounting of the teeth and the preparation of the cavities was the same as for group 1

Step 3

The teeth were etched for a period of 15 seconds each with ScotchBond etchant to etch the enamel and remove the dentinal smear layer in preparation for bonding. ScotchBond etchant contains 10% maleic acid. The maleic acid

etchant has a pH of approximately 1.2. The etchant was rinsed and dried using a brief, gentle air stream leaving a slightly moist surface after rinsing as recommended by the manufacturer.

Step 4

A 26 mm, 18-gauge flat-headed wire nail was placed in the cavity with the head against the pulpal floor of the preparation. All the nail heads were coated with cavity varnish (Polyvar, Young Dental Mfg. USA) to prevent bonding between the nail and the floor of the preparation. The diameter of the head of the nail was closely matched to the diameter of the preparation at the pulpal floor, so that the bonding between the amalgam and the tooth was limited to the walls of the preparation only.

Step 5

A single coat of ScotchBond Multi-Purpose activator was applied to the cavity walls and allowed to dry. No waiting time was required before drying. A gentle air stream was applied over the application as recommended by the manufacturer.

Step 6

A single coat of ScotchBond Multi-Purpose primer was applied gently with a clean brush tip and air dried.

Step 7

One drop of ScotchBond Multi-Purpose plus catalyst and adhesive were mixed and a single coat of this resin mixture was applied to the preparation.

Step 8

Amalgam (Dispersalloy, regular set, dispersed phase alloy- Dentsply Caulk, USA) capsule was triturated for 8 seconds in a mechanical amalgamator (Silamat, Vivadent, Germany) and the amalgam was then condensed immediately into the preparation around the nail before the bonding material had fully set.

Step 9

The amalgam restorations were burnished and finished using a small ball burnisher.

Steps 10 & 11

The storage and testing of the specimens was the same as for group 1.

4.5. c. Group 3(Glass-ionomer-Fuji plus-chemical cure, luting cement): 20 teeth were prepared in this group.

Fig.12: Cavity preparation

Fig.13: Ag filling placed after GIC bonding   *Fig.14: Finished Ag restoration*

Step 1, 2 & 3

The mounting of the teeth and the preparations of the cavities was the same as for group 1.

Step 4

The glass ionomer cement (Fuji plus-luting cement-chemical cure) was mixed according to the manufacturer's instructions. Equal amounts of power and liquid were mixed on a clean cool mixing glass slab with a clean plastic spatula.

Step 5

By using a clean disposable brush tip the mixed glass ionomer cement was applied to the cavity walls.

Step 6

Amalgam (Dispersalloy, regular set, dispersed phase alloy- Dentsply Caulk, USA) capsule was triturated for 8 seconds in a mechanical amalgamator (Silamat, Vivadent, Germany) and the amalgam was then condensed immediately into the preparation around the nail before the glass ionomer cement had set.

Step 7

The amalgam restorations were burnished and finished using a small ball burnisher.

Step 8 & 9

The storage and testing of the specimens was the same as for group 1.
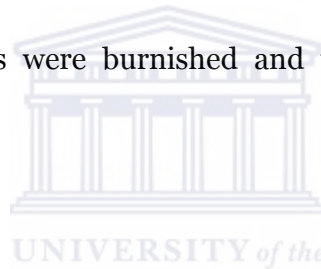
4.5. d Group 4 (Resin cement-Panavia F-dual cure): 20 teeth were prepared in this group.
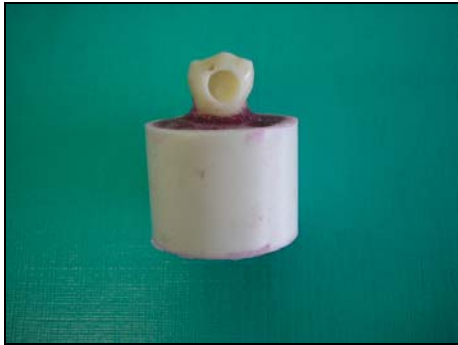
Fig.15: Cavity preparation
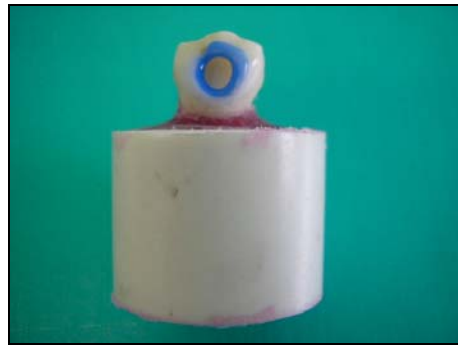
Fig.16: Acid etching
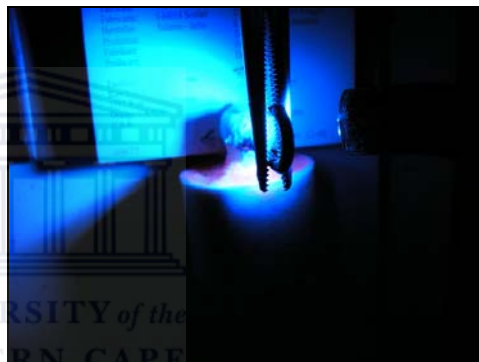
Fig.17: ED primer, Paste A & B applied and Ag placed and light cured

Fig.18: Finished Ag restoration

Step 1 & 2

The mounting of the teeth and the preparations of the cavities were the same as for group 1.

Step 3

The teeth were etched for a period of 15 seconds each with etchant according to manufacturer's instructions. The etchant contains 35% phosphoric acid, and was supplied by the manufacturer.

Step 4

A 26 mm, 18-gauge flat-headed wire nail was placed in the cavity with its head against the pulpal floor of the preparation. All the nail heads were coated with cavity varnish (Polyvar, Young Dental Mfg. USA) to prevent bonding between the nail and the floor of the preparation. The diameter of the head of the nail was closely matched to the diameter of the preparation at the pulpal floor, so that the bonding between the amalgam and the tooth was limited to the walls of the preparation only.

Step 5

Primer A and primer B were mixed in equal amounts in a clean cool plastic dish, that was supplied by the manufacturer. The mixed liquid was then applied to the walls of the cavities with a clean disposable brush tip. The excess was dried using an air stream gently.

Step 6

Equal amounts of paste A and paste B were mixed on a clean disposable plastic coated mixing pad, that was supplied by the manufacturer.

Step 7

Using a clean disposable brush tip the mixed cement was applied to the walls of the cavities.

Step 8

Amalgam (Dispersalloy, regular set, dispersed phase alloy, Dentsply Caulk, USA) capsule was triturated for 8 seconds in a mechanical amalgamator (Silamat, Vivadent, Germany) and the amalgam was then condensed immediately into the preparation around the nail before the resin cement had set.

Step 9

Excess cement on the cavity margins was removed and the restorations were burnished and finished using a small ball burnisher.

Step 10

All the restorations were light cured for 20 seconds at the margins using a conventional light cure unit (Dentsply-Caulk, USA).

Step 11 & 12

All the teeth were stored and tested as in group 1.
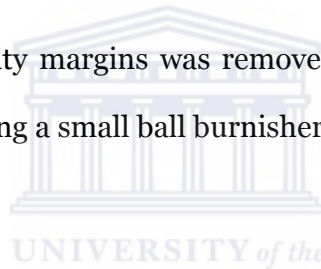
4.6. THERMO-CYCLING AND FATIGUE TESTING

Fig.19: Thermo-cycling with 30 sec. dwell time
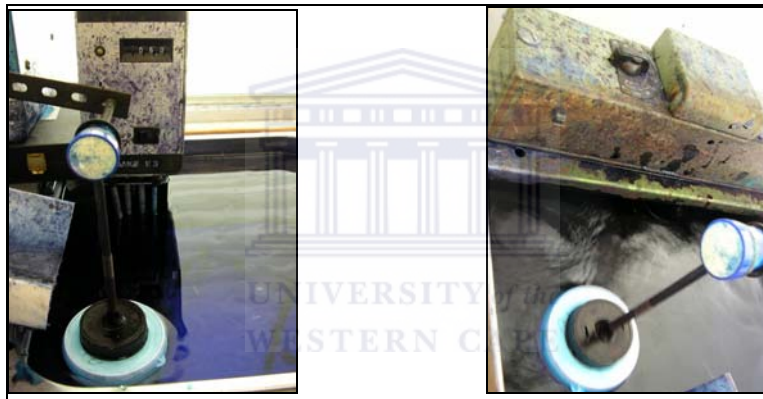
Fig.20: Thermo-cycling at 5⁰C   *Fig.21: Thermo-cycling at 55⁰C*

Fig.22: Zwick fatigue testing machine   *Fig.23: Upper member-hook holding nail*

Fig.24: Debonding of nails after fatigue test: Group 1 and Group 2

Fig.25: Debonding of nails after fatigue test: Group 3 and Group 4

CHAPTER

5

RESULTS

5. RESULTS

In this study all the restored teeth in Group 1, Group 2, Group 3 and Group 4 were stored in distilled water at 37 ^{o} C. After storage for 5 days, all the samples were thermo-cycled for 500 cycles at temperatures of 5°C and 55°C with a dwell time of 30 seconds.

One week after placement of the amalgam restorations, the specimens were tested in tension using a Zwick/Material testing machine, model no 1446 (Zwick GmbH & Co, D-7900 Ulm, Germany). The results were captured in an excel spreadsheet and an analysis was done using a SAS (SAS Institute Inc., Cary, NC, USA) computer package.

The mean peak loads at failure in Kg for the retention tests are listed in table 1 and are derived from the raw data in appendix I. The comparison tests revealed that there were statistically highly significant differences between group 1, 2, 3 and 4. Between these four groups, groups 4, 3 and 2 representing the bonded amalgam restorations that were bonded with different adhesive materials exhibited statistically significantly higher peak loads at failure compared to group 1 representing the conventional amalgam restorations without any bonding.

5.1. Statistical analysis

The results were subjected to a statistical analysis with a SAS computer programme using the General Linear Models (GLM) procedure.

Amongst all the groups tested the restorations in group 4 showed the best scores compared to the other groups. The restorations in group 3 restorations demonstrated higher retentive values compared to restorations in groups 2 and 1 respectively.

In an ANOVA test differences between group 4 and other groups was found to be statistically significant at a 99% level of confidence.

Table 3: ANOVA - Mean peak loads at failure

Groups	Mean peak load at failure Kilograms *(standard deviation)*
Group 1	7.318 *(0.703)*
Group 2	21.245 *(1.896)*
Group 3	35.650 *(2.284)*
Group 4	42.140 *(1.603)*
Sample size = 20 *p<0.0001*	

Using Levene's test for homogeneity of variances, it was found that the null hypothesis of equal variances was rejected (p=0.0019). This implies that there is sufficient evidence to suggest that the variances of the four groups are not the same. With this in mind a Welch's ANOVA test was used to test the null

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hypothesis that no differences existed in the group means. The results showed a value for p<0.0001 and from this it can be concluded that there are indeed significant differences statistically among the group means. A Tukey's multiple comparison method, found that each group mean was statistically significantly different when compared to the others. The p-value for each pair-wise comparison is less than 0.0001 implying statistically significant differences between the groups when compared two at a time.

Table 4: Tukey's Studentized Range (HSD) Test for force
(Comparison of Load at Failure for Various Bonding Agents)

Group Comparison	Difference between Means (kg)
4 - 3	6.4895
4 - 2	20.8940
4 - 1	34.8220
3 - 4	-6.4895
3 - 2	14.4045
3 - 1	28.3325
2 - 4	-20.8940
2 - 3	-14.4045
2 - 1	13.9280
1 - 4	-34.8220
1 – 3	-28.3325
1 - 2	-13.9280

In the pair-wise comparison using a Tukey's multiple comparison method, the restorations in group 4 showed five times higher retentive values compared to the restorations in group 1; two times higher retentive values compared to the restorations in group 2 and slightly higher retentive values compared to the restorations in group 3 respectively

The restorations in group 3 showed five times higher retentive values compared to the restorations in group 1; two times higher retentive values compared to the restorations in group 2 and slightly lower retentive values compared to the restorations in group 4.

The restorations in group 2 showed lower retentive values that were close to half the retentive values of groups 4 and 3, however double the retentive values compared to the restorations in group 1.

The restorations in group 1 showed significantly p-value the lowest retentive values compared to all the other test groups tested.
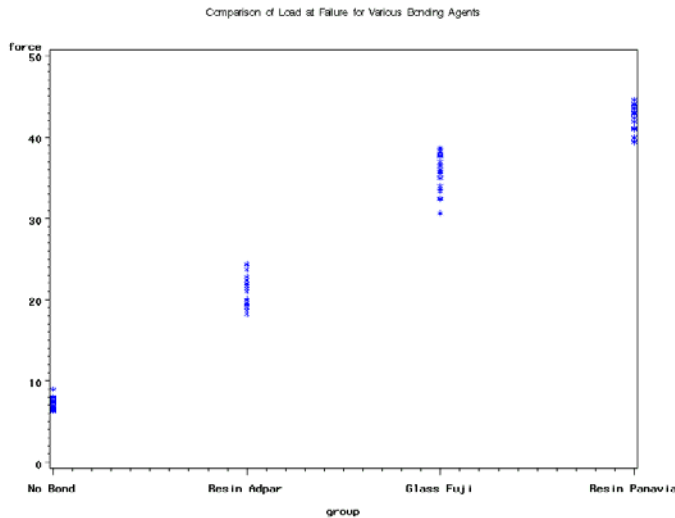
Fig. 25: Plots showing peak loads at failure according to Tukey's (HSD) test

CHAPTER

6

DISCUSSION

6. DISCUSSION

The aim of this study was to investigate the retentive strength of bonded amalgam restorations when compared to non-bonded amalgam restorations. In this *in vitro* study, an adhesive resin (ScotchBond Multi-Purpose, dual cure); a glass ionomer cement (Fuji plus-luting cement, chemical cure); and a resin cement (Panavia F, dual cure) were evaluated as bonding agents for amalgam restorations. Their use has been previously recommended as a routine clinical procedure for bonding amalgam restorations (Christensen. 1994; Pilo *et al.* 1996; Toledano *et al.* 2000).

The results demonstrated a statistically significant difference between the three test groups of bonded amalgam restorations that were bonded with an adhesive resin (group 2), a glass ionomer cement (group 3) and a resin cement (group 4) when compared to the control group of conventional (non-bonded) amalgam restorations. The retention values were the highest in the bonded amalgam restorations that were bonded with Panavia F (42.140 Kg) and the bonded amalgam restorations that were bonded with Fuji Plus glass ionomer luting cement (35.650 Kg) as compared to the bonded amalgam restorations that were bonded with Adper SctochBond Multi-Purpose resin adhesive (21.245 Kg). The conventional (non-bonded) amalgam restorations without any bonding agent exhibited statistically significantly lower values (7.318 Kg) for retention compared to the bonded groups.

This finding is in agreement with the results obtained by Winkler, Rhodes and Moore. 2000, despite the difference in the materials used for the bonding and the experimental methods adopted. The bonded amalgam restorations also demonstrated less marginal breakdown and this could also result in an increase

in the longevity of the restoration. Furthermore they found that the bonded amalgam restorations were more retentive compared to the conventional amalgam restorations and also showed less microleakage and a reduction in post-operative sensitivity. They recommended that based on their results all the amalgam restorations in future should be bonded to increase the retentive strength of the restorations and to enhance the life expectancy of the restorations (Winkler, Rhodes and Moore. 2000).

Furthermore the results from this study also supported the findings that the preparations bonded with a resin cement (42.140 Kg) and a glass ionomer cement (35.650 Kg) yielded a significant difference in resistance to the fracture load compared to preparations bonded only with a dentine adhesive (21.245 Kg). The conventional (non-bonded) amalgam restorations (7.318 Kg) showed the least resistance in the fracture load tests. These findings are in agreement with those reported in the study by Eakle, Staninec and Lacy, in spite of the different materials that were tested (Eakle, Staninec and Lacy. 1992).

For bonding amalgam to dentin, glass ionomer cements can be an effective bonding agent due to their chemical adhesion to the tooth surface. If the glass ionomer material is used in bonded amalgam restorations before it has fully set the amalgam projections of the unset enhance micromechanical retention by producing tag formations that ultimately enhance the bond. This enhanced bond results better retentive values for the amalgam restorations. One of the goals of an ideal restoration is to be retained in the cavity with sufficient retentive strength to withstand occusal forces and this may be achieved with bonded amalgam restorations (Cenci *et al*. 2004).

For the amalgam bonded restorations the retentive strength of the restorations depends on the bonding ability of the bonding material to tooth structure as well as to the amalgam restoration. In a five-year study for complex amalgam restorations, the bonding of amalgam appeared to be a viable alternative compared to the mechanical retention achieved with conventional restorations (Summit *et al.* 2001).

Bonded amalgam restorations can be used successfully in conventional preparations and especially in non-retentive preparations where they can be expected to lost at least five years (Mach *et al.* 2002).

More teeth are restored with dental amalgam than with any other material. Amalgam affords no adhesion to the walls of the cavity preparation (Andrews and Hembree. 1975; Derkson, Pashley and Derkson. 1986). Therefore, poor adaptation and lack of adhesion to the dental structure are the two disadvantages associated with conventional amalgam restorations (Staninec and Holt. 1988), when compared to composite resin restorations. There is no chemical link between the amalgam and the tooth structure, and the mechanical retention necessary for amalgam restorations often results in further weakening of the remaining tooth structure (Mondelli *et al.* 1980). In an attempt to minimize tooth reduction, to prevent the breakdown at the margins of the restorations, to increase the retention and to decrease the microleakage associated with conventional amalgam restorations, bonding of amalgam restorations with different bonding materials has been advocated (Toledano *et al.* 2000).

The use of multipurpose adhesive materials is also recommended for bonding amalgam and composite, to tooth structures. Micromechanical and/or chemical

means can provide retention and enhance the marginal seal (Goracci, Mori and Bazzucchi. 1995).

When Panavia resin cement is used, acid-etching is not required, but the conditioning of dentin and the etching of enamel were performed using the primer, a phosphoric acid ester monomer 10-MDP and 5-NMSA (*N*-methacryloyl-5-aminosalicylic acid). The inclusion of phosphate esters in the primer may permit hydrolysis from the phosphoric acid that could decalcify dentin and enamel (Eliades and Vougiouklakis. 1989). 5-NMSA may also increase micromechanical bonding; although ionic bonding to Ca21 is probably a less important factor in adhesion, ionic interactions may contribute to bonding by NMSA (Perdiga and Swift. 1994). Conditioning with these priming agents demineralizes the dentin surface to a certain depth leaving behind a collagen-rich meshwork that can assist in bonding to the dentin surface (Van Meerbeek, Inokoshi and Braem. 1992).

The dentin bonding systems that do not require acid-etching will not cause a discrepancy between the depth of demineralization and the depth of resin infiltration, as both the processes occur simultaneously. Acidic conditioners penetrate through the smear layer and demineralize the dentin leaving a collagen-rich mesh network that the adhesive hydrophilic monomer impregnates at the same time; forming a uniform interface (Watanabe, Nakabayashi and Pashley. 1994). The mechanism of adhesion to tooth structure involves a negatively charged phosphate ester (with a long hydrophobic carbon chain and a short hydrophilic phosphate group) that has strong ionic interactions with the positively charged calcium ions on the tooth and alloy surface (Kubo, Finger and Muller. 1991).

The mechanism of adhesion to cast metal surfaces consists of mechanical retention as well as chemical interaction mainly due to hydrogen bonding, and presumably the mechanism of adhesion to the amalgam restoration is similar. When an amalgam restoration bonds to resin, it appears as a mechanical interlocking and the adhesion is mediated by Van der Waals forces between the adhesive resin and the amalgam restoration (Wang and Nakabayashi. 1991).

It seems that the phosphate ester monomer (10- MDP) component of Panavia resin cements covalently links to the resin through a long carbon chain and bonds to the positively charged metallic ions on the alloy surface (Souza, Retief and Russell. 1994). However, the existence of a true chemical bond between the amalgam restoration and the adhesive resin has not been verified (Goracci, Mori and Bazzucchi. 1995; Pilo *et al.* 1996). One other consideration is that Panavia F is a dual-cure resin, that permits the amalgam to be incorporated into its body while the amalgam restoration is being condensed, and the resin is still unset. The development of a large cement tag formation in the amalgam structure, when it is condensed into the cavity while the adhesive cement is still plastic, demonstrates that mechanical interlocking does occur. (Nobilo, Consani and de Goes. 1997; Eakle, Staninec and Lacy. 1992; Charlton, Murchison and Moore. 1991).

For bonding amalgam restorations to dentin, Amalgambond bonding agent can be an effective sealing agent that reduces microleakage, dentin hypersensitivity, and secondary decay at the tooth-restoration interface. Some other advantages of using Amalgambond or another bonding agent with amalgam restorations is the increase in bond strength that results from the procedure (Nakabayashi and Takarada. 1992).

ScotchBond Multi-Purpose bonding agent contains 5% of 4-META in its monomer. Each molecule of 4-META has a hydrophilic and a hydrophobic component that penetrates the dentinal tubules and infiltrates the peritubular and intratubular dentin. This 4-META/methylmalonic acid resin polymerizes and forms a defined zone called the hybrid layer that is highly acid resistant and almost impermeable. This layer is responsible for improving the bond strength, sealing the tooth, and hence decreasing microleakage and the resultant postoperative sensitivity (Chang *et al*. 1996).

Calcium hydroxide has been widely used for pulp protection in deep cavities under both amalgam and composite restorations. Its capacity for stimulation of sclerotic, reparative dentine and dentine bridge formation as well as its transient antimicrobial effect has established the use of calcium hydroxide cements for pulp protection (Foreman and Barnes. 1990).

Newer dentine bonding agents have been shown to penetrate into dentine tubuli and entangle with the collagen and carbonated hydroxyapatite of the intertubular dentine, providing a zone of altered dentine called the hybrid layer (Wang and Nakabayashi. 1991; Nakabayashi and Takarada. 1992). The hybrid layer may isolate the vital dentin from the bacterial penetration associated with the microleakage. There are two major concerns about the biocompatibility of the bonding resins. Firstly it involves the application of an organic or inorganic acid to remove the smear layer. Secondly, the chemical cytotoxicity of the bonding resins may lead to pulp inflammation and possible pulpal necrosis. Some studies employing different commercially available dentine bonding agents have measured the pulp response histologically on non-exposed human or primate cavities and found varying results (Subay *et al*. 2000).

SctochBond Multi-Purpose Plus did not seem to cause significant deleterious effects on the human pulp tissue. No teeth sealed with SMPP exhibited severe pulp inflammation histologically during the test periods (Elbaum, Pignoly and Brouillet. 1991; Elbaum, Remusat and Brouillet. 1992).

The study however demonstrated that the preparations filled with a restoration with an adhesive resin luting agent yielded a significant difference in resistance to the fracture load (37.9 kg) as compared to preparations that had restorations without any adhesive system (26.16 kg). These findings are in agreement with those from the study by Eakle, Staninec and Lacy. 1992 (Eakle, Staninec and Lacy. 1992), in spite of the different materials that were tested. The maximum vertical force to which a natural tooth is normally subjected to is 200 N (20.4 kg).This shows that such a magnitude of force may be capable of fracturing a premolar tooth with an MOD amalgam restoration and a cusp approximately 2 mm thick at the base, with a minimum fracture force of 19.5 kg. Based on the results of this study the minimum vertical force required to fracture an adhesively restored tooth ranging from 24.0 to 32.0 kg and this is higher than that normally experienced by a natural tooth *in vivo* (20.4 kg). Such fractures however might, still occur when teeth are subjected to lateral forces generated during para-function (Waters. 1980; Rasheed, 2005).

A dowel-and-core restoration may fail due to failure at either the dowel-tooth or dowel head–core material interface. Long-term clinical success of a dowel-and-core restoration depends on the retention of both the dowel to the tooth and the dowel head to the core material. Thus, strengthening of the dowel head–core interface is important. All of the bonded cores exhibit stronger post-head retention values when compared to the non-bonded cores of the same material.

This observation demonstrates the strengthening effect of adhesive bonding on the retention between dowel head and core material. The use of adhesive agents has been reported to improve the strength of silver amalgam restorations to either dentin surfaces or dowel heads (Donald *et al.* 1997; Sen, Nayir and Cetiner. 2002).

CHAPTER

7

CONCLUSION

7.1. CONCLUSION

Within the limits of this *in vitro* study it is concluded that the bonded amalgam restorations are more retentive compared to the conventional (non-bonded) amalgam restorations. Different materials can be used to bond the amalgam restorations and this study found that particularly resin cements and glass ionomer cements can be highly advantageous for bonding amalgam restoratios because of their high retentive strength, reduced microleakage and the ability to minimize the potential for secondary caries.

Recommendations

1. It is recommended that all amalgam restorations should be bonded for better retention, decreased microleakage and a longer survival life in the oral environment.

2. Glass ionomer cements are highly recommended due to their less technique sensitivity, less armamentarium, low cost and easy manipulation when compared to the other types of bonding agents for bonding amalgam restorations.

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APPENDICES

7.3. APPENDIX - I

Table. 1: Peak loads at failure of four test groups at Kg

No of the Specimen	GROUP - 1	GROUP - 2	GROUP - 3	GROUP - 4
1	6.45	18.67	35.79	39.42
2	7.02	22.47	32.47	40.96
3	6.34	21.93	37.65	41.03

4	7.67	24.41	30.65	42.89
5	6.86	18.97	37.92	39.91
6	7.98	22.83	33.65	41.87
7	6.43	19.17	35.43	39.99
8	7.78	18.23	38.15	42.43
9	8.03	22.87	36.03	43.09
10	6.55	22.03	35.67	44.01
11	6.97	22.06	33.35	42.98
12	6.57	24.34	36.47	41.91
13	8.01	19.97	38.67	43.01
14	6.91	21.65	32.34	43.47
15	7.47	19.64	33.97	44.07
16	7.51	21.03	38.45	44.56
17	7.31	19.47	37.77	39.47
18	8.99	20.09	36.63	41.09
19	7.47	21.34	34.97	42.98
20	8.03	23.74	36.97	43.65

Group – 1: Conventional Amalgam restorations with out any bonding.

Group – 2: Amalgam restorations bonded with Resin adhesive – Adpar ScotchBond MultiPurpose, dual cure, 3m ESPE. USA.

Group – 3: Amalgam restorations bonded with Glass ionomer cement – Fuji Plus luting cement, chemical cure, GC Corporation. Japan.

Group – 4: Amalgam restorations bonded with Resin cement – Panavia F – dual cure. Kuraray Medical Inc. Japan.

APPENDIX - II

Table. 2

Comparison of Load at Failure for Various Bonding Agents

Analysis Variable: force (Kg)

Group	N Obs	N	Mean	Median	Std Dev	Minimum	Maximum
Group 1	20	20	7.318	7.390	0.703	6.340	8.990

Non-bonded

Group 2 ScotchBond	20	20	21.245	21.495	1.896	18.230	24.410
Group 3 Fuji Plus	20	20	35.650	35.910	2.284	30.650	38.670
Group 4 Panavia F	20	20	42.140	42.660	1.603	39.420	44.560

APPENDIX - III

Table. 3

Dependent Variable: force

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	3	14477.26945	4825.75648	1625.54	<.0001

Error	76	225.62197	2.96871		
Corrected Total	79	14702.89142			

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Group	3	14477.26945	4825.75648	1625.54	<.0001

Table. 4

Levene's Test for Homogeneity of force Variance

ANOVA of Squared Deviations from Group Means

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Group	3	211.6	70.5495	5.46	0.0019
Error	76	982.1	12.9228		

Table. 5

Welch's ANOVA for force

Source	DF	F Value	Pr > F
Group	3.0000	3210.47	<.0001
Error	37.6239		

APPENDIX - IV

Table. 6

Tukey's Studentized Range (HSD) Test for force

NOTE: This test controls the Type I experiment wise error rate.

Alpha	0.05
Error Degrees of Freedom	76

Error Mean Square	2.96871
Critical Value of Studentized Range	3.71485
Minimum Significant Difference	1.4312

Comparisons significant at the 0.05 level are indicated by ***

Group Comparison	Difference between Means	Simultaneous 95% Confidence Limits	
4 - 3	6.4895	5.0583	7.9207 ***
4 - 2	20.8940	19.4628	22.3252 ***
4 - 1	34.8220	33.3908	36.2532 ***
3 - 4	-6.4895	-7.9207	-5.0583 ***
3 - 2	14.4045	12.9733	15.8357 ***
3 - 1	28.3325	26.9013	29.7637 ***
2 - 4	-20.8940	-22.3252	-19.4628 ***
2 - 3	-14.4045	-15.8357	-12.9733 ***
2 - 1	13.9280	12.4968	15.3592 ***
1 - 4	-34.8220	-36.2532	-33.3908 ***
1 - 3	-28.3325	-29.7637	-26.9013 ***
1 - 2	-13.9280	-15.3592	-12.4968 ***

APPENDIX - V

Table. 7

Least Squares Means

Least Squares Means for effect group

Pr > |t| for H0: LSMean (i) = LSMean (j)

Dependent Variable: force

i/j	1	2	3	4

1		<.0001	<.0001	<.0001
2	<.0001		<.0001	<.0001
3	<.0001	<.0001		<.0001
4	<.0001	<.0001	<.0001	

NOTE: To ensure overall protection level, only probabilities associated with pre-planned comparisons should be used.