

https://dspace.org/

Bond strengths of four different dental gements: an in vitro study

Retief, Vasti

2014-03-26
http://hdl.handle.net10539/14333

Downloaded from a DSpace repository. https://dspace.org/

BOND STRENGTHS OF FOUR DIFFERENT DENTAL CEMENTS. AN IN VITRO STUDY

V. RETIEF

Bond strengths of four different dental cements
- an *in vitro* study.

Vasti Retief

A research report submitted to the Faculty of Health Sciences, University of the Witwatersrand, Johannesburg, in partial fulfilment of the requirements for the degree of Master of Dentistry in the branch of Orthodontics.

Johannesburg
March 1999

I, Vasti Retief, declare that this research report is my own unaided work. It is being submitted in partial fulfilment of the requirements for the degree of Master of Dentistry in the branch of Orthodontics at the University of the Witwatersrand, Johannesburg. It has not been submitted before for any degree or examination at any other university.

Vasti Retief

23 day of June 1999

To my family.

Acknowledgements

I wish to express my sincere thanks to:

Professor W.G. Evans (Head, Department of Orthodontics, University of the Witwatersrand, Johannesburg), my supervisor, for his advice and guidance in the undertaking of this investigation and his motivation in the preparation of this research report.

Professor P Cleaton-Jones (Director, Dental Research Institute, MRC/University of the Witwatersrand, Johannesburg), for his practical assistance and advice in the use of the Instron Universal testing machine and the facilities at the Research Institute.

Professor E Mizrahi, Visiting Professor, for suggesting that I undertake this investigation and for his motivation and guidance.

Dr. Piet Becker for his invaluable assistance with the statistics.

Messrs Reinor for providing the OptiBand cement used in this investigation.

The Department of Orthodontics of the University of the Witwatersrand for providing the zinc oxyphosphate, polycarboxylate and glass ionomer cements used in this study.

To my children: Magrietha, Petrus and Jacobus for allowing me to complete my studies.

Table of Contents

	Page
Declaration	i
Dedication	ii
Acknowledgements	iii
Table of contents	iv
List of figures	viii
List of tables and graphs	ix
List of abbreviations	x
Abstract	xi
Chapter 1	
1.1 Introduction	1
1.2 Dental cements	3
1.2.1 Zinc oxyphosphate cement	3
1.2.2 Polycarboxylate cement	6
1.2.3 Glass ionomer cement	8
1.2.4 Hybrid cement	12
1.3 Summary of the characteristics of cements	14
1.4 Sandblasting	15
1.5 Comparative studies	17
1.6 Objectives	22

Page

Chapter 2 23

2.1 Materials and method 23

2.1.1 Outline of procedure 23

2.2 The sample 24

2.3 Mounting specimens 24

2.4 Banding procedure 25

2.5 Measuring surface area of the band 26

2.6 Cementing procedure 26

2.7 Calibration of Instron Universal testing machine 30

2.8 Statistical methods and analyses 33

2.8.1 Statistical evaluation of intra-operator error 33

2.8.1.1 Coefficient of variance of intra-operator error 33

2.8.2 Descriptive analyses 35

2.8.3 Comparative analyses 35

2.8.3.1 One way analysis of variance (ANOVA) 35

2.8.3.2 Significant pairwise differences among the means 35

Chapter 3 36

3.1 Results 36

3.2. Statistical analysis 36

Page

3.2.1 Statistical analysis of intra-operator error 36

3.2.2 Descriptive data 37

3.2.3 Comparative analyses 37

3.2.3.1 One way analysis of variance 37

3.2.3.2 Significant pairwise differences among the means 38

Chapter 4 43

4.1 Discussion 43

4.1.1 Statistical analysis of intra-operator error 43

4.1.2 Descriptive data 44

4.1.3 Comparative analyses 44

Chapter 5 48

5.1 Conclusions 48

References 49

Page

Appendix A

Tensile force in kilograms for four dental cements in securing sandblasted stainless steel bands 53

Appendix B

Tensile force in kilograms for four dental cements in securing non-sandblasted stainless steel bands 54

Appendix C

Tensile bond strength in megapascals for four dental cements in securing non-sandblasted stainless steel bands 55

Appendix D

Tensile bond strength in megapascals for four dental cements in securing sandblasted stainless steel bands 56

List of figures

	Page
Figure 1 : Extracted premolar tooth	25
Figure 2 : Tooth-assembly attached to the Instron testing machine	27
Figure 3 : Kontron Image Analyser and Panasonic video camera	28
Figure 4 : Scientific balance	29
Figure 5 : Precision pipette	30
Figure 6 : Dissecting microscope	32
Figure 7 : Instron testing machine to which a tooth is secured	34

List of Tables and Graphs

Page

Table 1.1 Physical properties of four different dental cements 14

Table 3.1 Tensile force in kilogram for ten teeth tested in order to establish intra-operator error 37

Table 3.2 Tensile bond strengths (MPa) for four different cements 40

Table 3.3 Analysis of variance (ANOVA) for force 40

Table 3.4 Analysis of variance (ANOVA) for residual cement 40

Graph 3.1 Effect of sandblasting on mean tensile strength 41

Graph 3.2 Effect of sandblasting on the amount of residual cement 41

Graph 3.3 Tensile bond strengths of four different dental cements when used to secure non-sandblasted and sandblasted stainless steel bands 42

Graph 3.4 Percentage residual cement remaining on non-sandblasted and on sandblasted stainless steel bands 42

List of abbreviations

ANOVA	:	One way analysis of variance
LSD	:	Least significant difference
mm^2	:	millimeter squared
cm^2	:	centimeter squared
kg	:	kilogram
MPa	:	megapascals
Pa	:	pascals
N	:	Newton
N/m^2	:	Newton per meter squared
GIC	:	glass ionomer cement
ZnP	:	zinc oxyphosphate cement

Abstract

Standard practice in orthodontics has been the securing of stainless steel bands to posterior teeth using appropriate cements. Through the years different cements have been developed with varying properties. Some of the main requirements of orthodontic cements are: that the cement should attach the band to the tooth; should be sufficiently strong to withstand normal occlusal forces; and should prevent demineralization of enamel. For the latter reason, the inclusion of fluoride became standard, although this did not always enhance the other properties of the cement. The development of glass ionomer cement in 1969 by Wilson and Kent was thus a break-through for this formulation effected a slow fluoride release. The latest development in the field of orthodontic cements is the hybrid cements which are a combination of resin and glass ionomer in various ratios. This study sets out to evaluate some of the performance criteria of selected cements.

The tensile bond strengths of four popular dental cements were tested when securing non-sandblasted and sandblasted stainless steel bands to extracted premolar teeth. The data for the four cements were compared, and the effect of sandblasting on tensile bond strength was established. Light microscopy examination was carried out on all the dislodged bands to establish the interface of fracture of the cement and how sandblasting affected the site of fracture.

Mean bond strengths were found to be significantly greater when sandblasted stainless steel bands were used. Sandblasting had the greatest effect on the tensile bond strength of the hybrid cement, OptiBand. However this cement recorded low levels of tensile bond strengths in this study and

even when sandblasted bands were used, was less effective than that of the next weakest cement (zinc oxyphosphate), without sandblasting. This *in vitro* study found that glass ionomer cement has the highest tensile strength irrespective of sandblasting of the bands and OptiBand the lowest.

The evaluation of adherence of residual cement to the stainless steel bands revealed that there was a significant difference between cements and that sandblasting the bands exerted a significant effect on the amount of cement adhering. It was found that OptiBand adheres the best to the stainless steel bands, whether sandblasted or not. Glass ionomer recorded the least residual adherence.

In the clinical situation it is suggested that the glass ionomer cement remains the cement of choice because of its favourable tensile bond strength, its adherence to the tooth structure and its sustained release of fluoride.

Chapter 1

1.1 Introduction:

Since Edward H. Angle first introduced 'fixed' orthodontic treatment at the turn of the 19th century, the conventional appliance has involved the cementation onto teeth of metal bands carrying soldered or welded attachments.[1] Much earlier, in 1819, Delabarre, a French dentist, had used a wire 'clasp' as a means of anchoring appliances to teeth.[2] Strang (1933)[2] suggested that this was one of the first attempts to use a 'band-like' attachment[3]. In the early 1900's adjustable bands were tightened around the teeth with clamping screws. The first bands, made of gold, distorted easily. Later development resulted in stainless steel bands which were much more rigid and strong and the use of this material has persisted to today. Since the 1960's seamless preformed stainless steel bands, contoured to the anatomy of the crown of each tooth, have been available. Whilst 'full fixed appliance treatment' involved banding all the teeth, the invention of the direct bonding technique [4] has reduced dependance on the orthodontic band and commonly today only the molars and sometimes the premolars may be banded, direct bond attachments being placed on the other teeth. Nevertheless, bands remain an important and useful component of the orthodontic armamentarium.

It has been shown by Underwood, Rawls and Zimmerman (1983)[5] and by Noreval, Marcusson and Persson (1996)[6] that the most frequent failures of the direct bonding technique occur on premolars, especially the lower second premolars. Such failures have been explained by the sensitivity of the acid-etch technique to moisture contamination (Zachrisson, 1976 and 1977)[7,8]

Recognizing these problems, more than 85% of orthodontists routinely bond brackets from first bicuspid to first bicuspid - but band posterior teeth from second premolar distally.[9] Premolars may also be banded for other reasons, for example: grossly rotated teeth (where lingual as well as buccal attachments are required), short clinical crowns, on porcelain or gold crowns, and when fluorosis is evident. Hence, banding of premolars remains a highly relevant option in modern orthodontics.

Successful retention of well-fitting orthodontic bands depends largely on the properties of the materials used for cementation.[10] Orthodontists rely on the cement to secure the band throughout the treatment period against the forces of mastication, tooth brushing and appliance activation. Therefore, favourable continuity of orthodontic treatment is largely dependent upon the adhesion or mechanical bonding characteristics of the cement. Tensile strength, brittleness, solubility, acidity, lutability and working and setting times, are all properties influencing the clinical efficacy of orthodontic cements, as does also the fluoride content.

Cemented stainless steel orthodontic bands may fail from time to time during treatment, prolonging treatment and increasing chairside time. Sandblasting (microetching) the internal surface of a band should increase its retentive surface area by roughening the surface of the metal, thus decreasing the likelihood of failure.

Numerous *in vitro* and *in vivo* studies on the failure rates of bands on teeth have been undertaken. Results vary depending on time span, whether it is an *in vivo* or *in vitro* study, and the materials used. Mizrahi (1977) suggested that the major factors having an effect on retention of orthodontic

bands will be related either to the operator or to the patient.[3]

In this study some of the factors which may be influenced by the operator will be investigated, including the use of various cements, the selection of bands and the efficacy of the cementing technique. It is important to compare the older proven cements with new cements that have come on the market. In this study such a new cement, OptiBand,* will be tested and compared with more traditional cements and the technique of sandblasting and its effect on cement performance will be investigated.

1.2 Dental Cements

1.2.1 Zinc Oxyphosphate (ZnP)

In 1878, zinc oxyphosphate cement was introduced as a dental cement.[11] It became the standard cement and has been used for over a hundred years in the placement of orthodontic bands. In the 1960's fluoride was incorporated into the cement to impart anticariogenic properties.[11] The addition of fluoride, however, served also to weaken the cement [12], and present day formulae have reverted essentially to those used in about 1920.[13] According to Lee, Orlowski, Elwell and Tate (1973) zinc oxyphosphate has maintained its market position because of its high compressive (crushing) strength.[14] The retentive performance of the zinc oxyphosphate cements is mainly due

* ORMCO, a subsidiary of Sybron, Dental Specialities, Inc. Glendora, CA 91740.

to mechanical interlocking between the band and enamel. It is purely a luting cement, filling voids and irregularities to gain a physical retention.[3, 11] Zinc oxyphosphate cement contains 40%-50% of free phosphoric acid after mixing. Three minutes after the start of mixing, the ph of the cement is in the range of three to five. Acidity is especially high with a thin cement mix.[15] The zinc oxyphosphate cements, however are self-neutralizing and the acidity falls steadily until neutrality is reached within three to six days.[16]

Lefkowitz[17] felt that phosphoric acid in such quantity may be responsible for decalcification of the enamel, especially in children, as adult, mature teeth have reduced permeability. It has been shown that decalcification associated with cement is dissimilar to the decalcification of caries. Histological studies of these differences enabled Lefkowitz to conclude that zinc phosphate cement of itself does decalcify human enamel[17]. In contrast, Wisth (1970)[18] believed that zinc phosphate does not cause decalcification of enamel and indeed on the contrary seems to protect it. In a later study, however, Wisth[19] found that low molecular weight substances rapidly penetrate the zinc phosphate cements and that these cements have a tendency to shrink and to leak along the margins. Decalcification is then a real possibility.

Mixing:

Paffenbarger, Sweeney and Isaacs [20] claimed in 1933 that the heavier mixes have faster setting times and that prolonged mixing increases the setting time. Also thicker mixes are stronger than the thin ones but heavy putty-like mixes are no stronger than more plastic mixes. Cements shrink appreciably on setting. Paffenbarger and associates [20] concluded in 1933 that the manufacturers' directions for mixing orthodontic cements were neither adequate nor accurate.

Advantages of zinc oxyphosphate cements:

* good manipulative characteristics
* compressive strength of 80-130 MPa, depending on powder to liquid ratio
* ideal setting time (four to ten minutes)
* easy removal of excess cement.
* tensile strength 5 - 7 MPa [21]

Disadvantages of zinc oxyphosphate cement:

* brittle
* high solubility in the mouth - due to organic acids
* weak adherence to tooth substance
* high initial acidity
* can lead to decalcification of enamel
* relatively low compressive strength[12]. Hamula, Hamula and Brower (1993)[12] observed that posterior teeth are subject to the greatest forces of mastication, and therefore the compressive strength of a cement is probably the most important property in resisting the biting forces that can loosen molar bands.

After almost a hundred years of zinc phosphate cement use, new cements were developed by researchers aiming to overcome the drawbacks of zinc phosphate. One such cement is polycarboxylate.

1.2.2 Polycarboxylate cement

In 1968, Smith replaced phosphoric acid liquid with polyacrylic acid in a heterogeneous mix with zinc oxide powder. From this mixture polycarboxylate cement evolved.[22] This new cement is dependent for its bonding not only on mechanical retention, but also on a complexation (*sic.*) reaction that occurs with the calcium of the enamel and with other metals having a suitable reactivity. It is the first dental cement which has the ability to chelate calcium ions in tooth enamel, and to form bonds to metallic ions in stainless steel.[23] Setting is accomplished by a chemical reaction in which zinc ions link adjacent polyacrylic acid molecules, providing a large cross-linked chelated structure, the molecules of which have the ability to chelate to calcium ions in the tooth enamel and to form ionic bonds to stainless steel.

Smith described polycarboxylate cement as the first dental cement which does not rely solely upon irregularities of the adjoining surfaces to gain mechanical retention.[24] It has been suggested that the bond strength of carboxylate cement is actually decreased by an irregular enamel surface. This means that on a tooth with a smooth enamel microsurface the polycarboxylate cement may perhaps bond more strongly than it would on a rough enamel microsurface. The opposite is true for zinc phosphate which would achieve greater mechanical adhesion to a rough enamel surface than to a smooth one. This suggests that the polycarboxylate cements are highly suitable for use as a cementing medium in orthodontic treatment.

However, even though carboxylate cements achieve a chemical bond with the tooth enamel, they have not been shown to be markedly superior to zinc oxyphosphate in adhesive properties.[25] Indeed, some physical property studies on carboxylate cement have shown it to be slightly inferior to zinc oxyphosphate cement in both compressive and tensile strengths. According to Knibbs, Plant and Shovelton (1986), the polycarboxylate cements have a compressive strength of 55-85 MPa and a tensile strength of 8-12 MPa.[26] Polycarboxylate cements gain strength rapidly, attaining 75% of the 24 hour value in 15 minutes and 90% in one hour.[24]

It is a useful cement because its solubility in water is low and because fluoride has been successfully added. It has been shown that fluoride is released from set polycarboxylate cement resulting in significant increases in fluoride content of adjacent enamel,[27] thereby rendering the enamel less soluble after 2 weeks of contact with the cement.[28]

Mixing:

The handling properties of polycarboxylate cement have been found to be very similar to those of glass ionomer cement[27]. The correct proportion of powder/liquid is important if optimum properties are to be achieved. The problem of the high viscosity of liquid polycarboxylate acid has been reduced by incorporating vacuum dried acid into the powder. The liquid component may then be a much lower viscosity aqueous solution (usually distilled water), which may readily be measured, thereby reducing errors in the powder to liquid ratio.

Advantages of Polycarboxylate cement:

* low irritancy

* chemical bond to tooth substance and metallic alloys

* easy manipulation

* solubility comparable to zinc oxyphosphate

* tensile strength 8-12 MPa

Disadvantages of Polycarboxylate cement:

* demands accurate proportions in mixing for optimal properties

* great viscoelasticity

* short working time

* need clean surfaces for utilizing maximum adherence potential

* lower compressive strength than zinc oxyphosphate

* compressive strength: 55-85 MPa

1.2.3 Glass Ionomer Cement (GIC)

Glass ionomer cements are a relatively new class of dental cement and possess a unique combination of properties. They were introduced by Wilson and Kent in 1972 (developed in 1969 but marketed in the United States only since 1977). The cement is a combined ion-leachable glass (an aluminosilicate with a high fluoride content formed by the fusion of quartz alumina cryolite, fluorite, aluminium trifluoride and aluminium phosphate) and polyacrylic

acid.[29] These cements adhere to the enamel surface without the need for acid etching or other enamel surface conditioning.[30]

With the newer glass ionomers, both active components (ion-leachable glass and polyacrylic acid) are included in the powder. The polyacrylic acid is vacuum-dried and the whole mixture is activated simply by the addition of water. This has eliminated the risk of incorrect proportioning of traditional powder/liquid and the consequent increase in acidity because the proportion of active ingredients is now predetermined in the powder.[22] Freshly mixed glass ionomer cement has a ph of 2.6 which is slightly less acidic than are the phosphate-bound cements.[30]

On addition of liquid to the powder, the surface of the glasses is attacked by the hydrated protons of the acid, causing a hardening reaction between an aqueous solution of homo- or co-polymers of acrylic acid and a powdered calcium aluminosilicate glass. Aluminium and calcium ions are released, metallic salt bridges are formed, and a gel matrix surrounds the unreacted glass particles.[29] Glass ionomer cement can thus be defined as a cement that consists of a basic glass and an acidic polymer which sets by an acid-base reaction between these components.[31] The affinity of polyacrylate ions for calcium also contributes to the adhesive properties of the materials.

Glass ionomer cement provides a strong bond strength to teeth due to the formation of calcium bridges, hydrogen bonds, Van der Waal forces and phosphate substitution.[32] The most important bonding mechanism is the latter. Glass ionomers provide a stronger bond strength and are not

as easily leached out as are conventional cements.[33] McLean and Wilson (1977) concluded that glass ionomer becomes attached to enamel via ionic and polar bonds.[34] The polyacrylic acid has the ability to form ionic bonds to stainless steel and to chelate to the calcium ions in the tooth enamel. It has thus been demonstrated that glass ionomer cements adhere chemically to tooth enamel and dentine as well as to stainless steel, suggesting their suitability as orthodontic luting cements. A luting agent that does not adhere by molecular interactions would leave gaps between the cement and tooth. Therefore, even if such a luting agent were to release fluoride, ion exchange would be inhibited. An intimate molecular contact facilitates fluoride ion exchange with hydroxyl ions in the apatite of the surrounding enamel.

Mixing:

The manufacturer's instructions for the mixing of these cements relate to their application in restorative dentistry (fillings/liners/bases). In order to enhance their use in orthodontics a powder-liquid ratio should be developed that will provide adequate flow properties of the material while optimizing bond strength. Hamula and co-workers (1993) suggest a strong mix with a workable viscosity (smooth creamy mix).[12]

The glass ionomers have lower viscosity than polycarboxylates and in consistency are very similar to the zinc phosphate cements. After mixing, glass ionomers should have a glossy appearance, for this indicates that sufficient free carboxylic acid groups are present to provide adequate wetting of the enamel surface for an effective bond. At room temperature glass ionomer has a short mixing time of 20 seconds and a working time of two and a half to three minutes. The slower setting of glass ionomer evidently allows for adhesive interaction with

enamel and this allows the bond to improve with time.[21] The bond strength of glass ionomer has been shown to increase more than 50% between 10 and 20 minutes after setting.[35] Optimal bond strength is achieved at 24 hours.[36]

Glass ionomers offer clinical protection to the enamel due to their adherence to the enamel, even under loose - fitting bands. Koch and Hatibovic-Kofman(1990) also showed that the prevalence of *treptococcus mutans* in the saliva decreased after placement of a glass ionomer restoration,[37] a particular advantage. Appliances that are under enhanced mechanical strain will probably be more secure when cemented with glass ionomer. Abnormal crown morphology which complicates band adaptation may also be an indication for the use of glass ionomer cements.

Advantages of glass ionomers:

* prevents decalcification of enamel
* actively initiates remineralisation of enamel
* co-efficient of thermal expansion is similar to that of natural tooth structure
* exhibits a slow release of fluoride
* prevents secondary caries[38]
* gains a physiochemical bond to both enamel and dentine
* enamel loss on debanding is less than with composites
* fewer band failures clinically than with zinc phosphate or polycarboxylate cements[3, 39, 40]
* fails at cement/orthodontic band interface - this location is considered to be most favourable, as the fluoride-releasing cement continuing to adhere to the tooth may still offer protection against decalcification under loose bands[37]

* can be used with oversized bands

* the cement is insoluble in the mouth

* long shelf life

* radiopaque

Disadvantages of glass ionomers:

* short setting time - actually, this is quite convenient today as fewer bands are cemented at one time

* cement very hard - removal may be time consuming

* rate of gain of strength is initially slow[21]

1.2.4 Hybrid Cement

The bis-GMA epoxy resins (aromatic dimethacrylate) are widely used today for direct bonding of brackets. Sadowsky and Retief (1976) welded an orthodontic bracket to a segment of band material to which a wire mesh had been attached[10]. They used this assembly to test the bond strength of epoxy resin. Clark, Phillips and Norman in 1977 evaluated the resin, 'Bracket bond*', using stainless steel bands in an *in vitro* study[41]. They found the bond strength to be comparable to that of silicophosphate cement (a combination of zinc oxide and silicate cement). Other researchers also tested the bond strength of acrylic resin and epoxy resins but, being mainly prosthodontists, did not use stainless steel bands in their tests.

* Manufacturer: Dental Corporation of America, Washington, D.C.

More recently (1988)[42] a class of cements has been evolved for banding and bonding which combines a resin and a glass ionomer. These set partly via the acid-base reaction (typical of glass ionomer cement) and partly via photochemical polymerization.[42] Atonucci, one of the developers, coined the descriptive term: resin-modified glass ionomer cements.[42] Such a cement has sufficient acid and base to allow a neutralization reaction to take place within a reasonable time. In other words it can set in the dark albeit more slowly and yielding a cement that is inferior to those obtained by photocuring. These cements vary in composition but are often more closely related to the resin. This combination may offer advantages and evaluation of their performance will be useful. OptiBand* is such a hybrid cement and is partly glass ionomer and partly composite. The latter is a combination of an aromatic dimethacrylate with other monomers. On mixing polymerization of the monomer constituents occurs, leading to a highly crosslinked composite resin structure. OptiBand is a hydrophilic adhesive which absorbs small amounts of water and creates a pathway for the release of fluoride ions. The manufacturers describe OptiBand as having the ability to 'wet' and to bond chemically to metal surfaces thus establishing a very efficient bond. The cement has a high compressive strength.

There is thus a spectrum of these 'hybrid' materials stretching from true glass ionomer cements at the one end and to true composite resin at the other. In between are a variety of blends, employing different properties of acid-base and free-radical reactions to bring about cure.

* ORMCO, a subsidiary of Sybron, Dental Specialities, Inc. Glendora, CA 91740.

Advantages of OptiBand

* high tensile and compressive strengths

* easy to use

Disadvantages of OptiBand

* expensive

* more difficult to remove from enamel

Table 1.1 Physical properties of four different dental cements

Cement	Tensile strength	Compressive strength	Reference
Zinc oxyphosphate	5-7 MPa	80-110 MPa	Maijer & Smith[33]
Polycarboxylate	8-12 MPa	55-85 MPa	Maijer & Smith[33]
Glass ionomer	5-7 MPa	140 MPa	Maijer & Smith[33]
Hybrid cement	32-41 MPa	198-213 MPa	Moskowitz et al[43]

1.3 Summary of the characteristics of the four cements

Glass ionomer cements have good compressive strengths (140 MPa) when compared with zinc phosphate (80-110 MPa) or polycarboxylate (55-85 MPa) cements. A high compressive strength is considered advantageous for a dental luting cement.[1] The tensile strength of glass ionomer cement is similar to zinc oxyphosphate, in the range of 5-7 MPa.[21]

The glass ionomer cement acts as a reservoir of fluoride ions without any loss of strength.[3] Glass ionomer leaches fluoride for at least 12 months. The interface of failure of the glass ionomer cement, which is distinctly different from that of zinc phosphate and polycarboxylate cements, make this cement a clinical favourite for cementing bands (non-sandblasted), as the residual cement adheres to the tooth, preventing demineralization of enamel.

1.4 Sandblasting

Sandblasting has become the preferred surface treatment in the bonding of metal brackets today. Aluminium oxide particles of 50 micrometers have been found to be the most desirable for use in sandblasting. The procedure results in excellent bond strengths.[44] It has been found to roughen the surface of all metals and as a result to increase the surface area for both chemical and mechanical bonding. Sandblasting also reduces the thickness of the oxide layer, leaving a more firmly attached layer for bonding. A thin layer of oxide, however, is needed for good wetting and bonding to the metal, according to Wood, Paleczny and Johnson (1996); the complete removal of this layer would result in inadequate bond strengths.[44]

Gűray and Karaman[45] (1997) found that the interface of bond failure changes after sandblasting and roughening the internal surface of orthodontic bands. The interface of bond failure for glass ionomer changes from cement-band to cement-enamel, leaving cement adherent to the band. The study by Miller and Zernik (1996),[46] proved that bond strengths were significantly greater for all the cements tested (various glass ionomers and zinc phosphate) after sandblasting. Miller and

Zernik (1996)[46] used 150 bovine incisors which had been stored in sterile saline water. The labial surfaces were flattened with Sof-Lex discs*. Round discs of stainless steel material were either left untreated or were sandblasted with aluminium oxide. Fifteen treated and fifteen untreated discs were cemented with each of the five cements (four different glass ionomers and a zinc phosphate cement).The specimens were stored in a humid plastic bag. An Instron Universal testing machine with a cross-head speed of 1mm/minute was used to debond the discs. It was found that after sandblasting, the bond strengths were significantly greater for all five cements. The strengths of band/cement interface of glass ionomer improved as indicated by the change in the Adhesive Remnant Index Score,[47] a tool useful in measuring the percentage of bond failure sites. Sandblasting did not have much effect on the mode of failure of the zinc phosphate cements. The authors concluded that sandblasting combined with the use of glass ionomer cements provides a clear clinical advantage. Miller and Zernick (1996) tested the bond strengths of these cements on bovine incisors which may be structurally different to human enamel.[46] Indeed, Whitaker (1982)[48] suggested that structural variations in the surface zone of human enamel (observed by scanning electron microscopy), and bovine enamel are likely to lead to variations in bond strength values. A comparative study by Nakamichi, Iwaku and Fusayama[49] found however that bovine enamel and human enamel showed no statistically significant differences with regard to the retention of five different cements. They conclude that bovine teeth are useful in adhesion tests as substitutes for human teeth.

* 3M Unitek, 27245. Peck Road Monrovia, CA 91016.

1.5 Comparative studies

In 1965, Williams, Swartz and Phillips[50] devised a method of measuring the retention of orthodontic bands on extracted human teeth, (8 maxillary central incisors) using 3 different types of cement. They re-used the teeth and bands in order to minimize variability. The bands were reinforced with solder in order to allow them to be repeatedly removed without distortion. In addition to measuring the force required to dislodge the bands, the amount of residual cement left on the tooth was determined as compared with that on the band. They demonstrated that zinc phosphate and silicophosphate cements recorded similar performance in retaining orthodontic bands and that the retentive strengths of these two cements was slightly more than twice that of Ethoxybenzoic acid (EBA) cement. The EBA cement was a further attempt to improve the basic zinc oxide - eugenol system.

Mizrahi, Cleaton-Jones and Austin[51] (1981) used 40 caries-free adult human maxillary central incisors in their study to evaluate the effect of surface contamination on band retention. The different surface treatments were tested in the following sequence: (1) cleaned pumiced enamel, (2) crowns dipped in freshly collected unstimulated saliva, (3) crowns dipped in freshly collected unstimulated saliva and then gently air dried, (4) crowns dipped in liquid paraffin for 1 minute. Four different cements were tested - zinc phosphate, silicophosphate and two types of carboxylate cement. For each cement, the tooth surfaces were pretreated prior to cementation. A hole was drilled transversely through the middle of the root in a mesiodistal direction in order to attach the tooth to the specialized jig with a steel rod. Preformed stainless steel bands with

seating lugs spot-welded on the labial and palatal surfaces were adapted and fitted to each tooth. A 55 mm length of stainless steel band tape (3.8 x 0.13 mm) was spot-welded to the outside of the mesial and distal surfaces of each band to form a loop. The band was cemented to the tooth and the loop was used to suspend the banded tooth in the Instron testing machine*. The specimens were subjected to tensile loading with a cross-head speed of 1 mm per min, until the band was dislodged. Ten teeth were allocated to each cement group. After each experiment the same teeth were carefully handscaled and pumiced. New bands of the same sizes were fitted for each tooth in preparation for the next test. The presence of dry saliva and liquid paraffin significantly reduced the retention of bands. It was found that the retention of bands cemented with zinc oxyphosphate and silicophosphate was unaffected by surface contamination.

Rich, Leinfelder and Hershey[25] (1975) used 10 extracted human premolar teeth in order to test the retentive strengths of zinc oxyphosphate, carboxylate and red copper phosphate cements. Each tooth was embedded in self-curing acrylic up to the cervical line. After fitting the bands a collar of acrylic was built around each tooth to conform to the gingival contour of the band. This created a positive stop. Thus with subsequent cementation each band was seated to precisely the same occlusogingival height. Tie buttons were spot welded to the bands to facilitate attachment of the band to the Instron machine. Cement mixing procedures were performed under rigidly standardized conditions. The tensile bond strengths were determined with the Instron testing machine at a crosshead speed of 0.2mm/min. Bands were used only once, but each tooth was used fifteen times, being thoroughly cleansed between trials. After testing, each band was

* Instron Universal testing machine (TM) Model 1026 Tensile Tester, Instron Corp., Canton, Mass.

inspected to determine the interface of fracture. Rich and co-workers (1975) concluded that the mean variations in the retentive value for each cement on each tooth indicate there is a non-parallelism of performance between the different premolars. Their results revealed that there was no significant difference in the retentive strengths of zinc oxyphosphate as compared with red copper phosphate cements; nor was there a difference between red copper phosphate and carboxylate cements. However, there was a significant difference between the retention provided by zinc oxyphosphate when compared with polycarboxylate cement at a 0.95 level of confidence. The polycarboxylate cement had the least retentive strength of all the cements tested.

In 1977, Clark, Phillips and Norman[41] did an *in vitro* study to test the band cementation strengths of four dental cements. Extracted maxillary incisors were used, preformed bands were selected for each tooth, and each band reinforced by a layer of solder on the outer surface. The bands were cemented with representative products of four types of cement viz. zinc oxyphosphate, zinc silicophosphate, zinc polycarboxylate and resin. The teeth with bands cemented were placed in tap water for 24 hours prior to measuring the bond strength. Tests were done with a Riel testing machine at a crosshead speed of 0.02 inch/min. Each cement was tested on twenty four teeth, and each tooth was tested four times with each of the cements. The results identified the performance of zinc silicophosphate as excellent. A clinical investigation followed - excluding the resin because its short working time made multiple band cementation difficult and its adhesion rendered the removal of excess cement virtually impossible. Clark and associates (1977) concluded that zinc silicophosphate cement was proven to be comparable with zinc oxyphosphate cement in its bond strength to enamel.

In a study by Norris, McInnes-Ledoux, Schwaninger and Weinberg[11] (1986) 180 extracted human molar teeth were divided into three groups and thermocycled in synthetic saliva. Three cements were tested namely, zinc oxyphosphate, glass ionomer and polycarboxylate. An Instron testing machine was used at a crosshead speed of 0.2mm/min. They concluded that the bond retentive strengths of all three cements are similar. The mean retentive strengths for polycarboxylates are lower than those for zinc oxyphosphate and for glass ionomer although not significantly so.

The literature suggests that band failure occurs due to mechanical stress on the band-tooth combination (Smith, 1983)[52] and that the band also undergoes chemical and thermal stresses in the mouth (Norris et al, 1986).[11] Durning, McCabe and Gordon (1994)[53] tested cements whilst mechanical stress was applied to the bands (ie. simulating occlusal forces). They concluded that the newer cements (glass ionomers) performed superiorly. The cements were mixed to previously clinically determined powder/liquid ratios. They used 20 freshly extracted human molars for each cement. The teeth were stored in formol saline at 23 °C. An Instron Testing machine set at a crosshead speed of 1 cm/min was used for the tests. Durning and associates (1994) felt that *in vitro* studies gave little useful information about bond retentive strengths unless environmental stress conditions were recreated. They consider that the true level of mechanical stress to which a bond/tooth system is subject still requires evaluation under varying conditions of occlusal function and treatment force levels.

Wood, Paleczny and Johnson (1996)[44] used sandblasted and non-sandblasted stainless steel bands to test the difference in bond strengths of zinc oxyphosphate and a glass ionomer hybrid

cement, 'Band Lok'.* Thirty human mandibular third molars were embedded in resin cubes and the stainless steel bands were fitted to a predetermined level. The Instron testing machine was adjusted to a crosshead speed of 0.02 inches/minute and the force required to dislodge the bands was measured. Ten of the teeth embedded in the epoxy resin suffered crown or root fractures during testing. The final sample contained 20 teeth that could be tested completely. In this study the same bands were fitted and adapted 6 times over in the course of the experiment. The conclusion was that the forces required to remove standard bands cemented with zinc oxyphosphate and polycarboxylate were similar whilst those cemented with glass ionomer cement required 20% more force. With sandblasted bands the mean force required to deband was approximately doubled for glass ionomer and zinc phosphate and more than doubled for polycarboxylate.

Güray and Karaman[45] used different ways of roughening stainless steel bands and found no significant influence by varying roughnesses on the retention of bands on fifteen extracted human maxillary premolars. They used a microetcher with 50μm and 90μm aluminium oxide particle, a tungsten carbide bur and a green stone. Roughening the inside surfaces of stainless steel bands changes the interface of cement fracture for glass ionomer cements from between the band and the cement to between the cement and enamel surfaces as has already been noted. In other words, the mechanical retention of the glass ionomer to the bands appears to be increased by roughening the surfaces.

A clinical study by Seeholzer and Dasch[54] found that sandblasting stainless steel bands resulted in a 30% increase in adhesion to the steel for glass ionomer cements. Whilst it may be advisable

* Reliance Orthodontic products, P.O. Box 678, Itasca, IL 60143.

to sandblast the inside of stainless steel bands it should be recognized that bands which were cemented with glass ionomer will probably have residual cement adhering to any loose band. The protective effect of residue on the tooth will have been forfeited.

1.6 Objectives

With the development of new cements there appears to be reason to evaluate and re-test cements in order to compare the new cements with the older cements. The influence of surface treatment on tensile bond strength of a cement is also a concept of importance.

The purposes of this study are therefore:

1. to conduct an *in vitro* study on four different dental cements (zinc oxyphosphate, polycarboxylate, glass ionomer and a hybrid of resin and glass ionomer) in order to test their tensile bond strengths in an orthodontic milieu.

2. to repeat the tests, using the same sized stainless steel bands after sandblasting the internal surfaces for 10 seconds with aluminium oxide particles.

3. to examine the sites of bond fracture and to estimate the amount of residual cement adhering on the internal surface of the band to the nearest 25%.

4. to compare the performance of the various cements.

Chapter 2

2.1 Materials and Methods

2.1.1 Outline of procedure

Forty intact human premolar teeth, extracted for orthodontic reasons, were kept in distilled water at room temperature. The teeth were cleansed of periodontal ligament fibre debris and the crowns were pumiced in preparation for their use in the study. Preformed Unitek stainless steel bands* were selected for each tooth, ensuring a tight, snug fit. The level of the gingival margin of the band was marked on the tooth using a fine diamond bur. This scribe line was emphasised by the use of a black permanent marker pen. The bands were removed and a length of stainless steel band material was welded to the mesial and distal surfaces on the outside to form a loop which could be used to suspend the band - tooth assembly later during tension applied by the Instron testing machine. A diamond bur was used to drill a hole transversely through the root of each tooth to allow a purchase with which to secure the tooth to the Instron testing machine. Following the surface cleansing of the crowns by polishing with pumice, the prepared bands were cemented, using zinc oxyphosphate cement for the first trial. Five minutes after cementation the band - tooth - assembly was again placed in distilled water. One week later a tensile strength test was performed on the specimens using the Instron testing machine,

* Unitek, 950 Royal Oaks Drive, Monrovia, California

recording the force required to just dislodge the band. The inner surface of each dislodged band was inspected using a dissecting microscope with a magnification of 20. The proportion of adherent cement remaining was estimated to the nearest 25 percent. The teeth were then re-prepared, testing the same sized bands for each tooth but, prior to fitting, the internal surface of the band was sandblasted. Four series of such tests, on sandblasted and on non-sandblasted bands, were then completed for zinc oxyphosphate, polycarboxylate, glass ionomer and a hybrid of resin and glass ionomer cements.

2.2 The sample

Each tooth was inspected to ensure that it was free of decay or damage and that no unusual morphology was presented. Ethical clearance (clearance number M980544) had been obtained for the use of these teeth, both patient and parents having given their consent. The teeth were cleansed of all debris by rotary polishing with a slurry of pumice in a rubber cup and by scraping the roots with a universal scaler to remove all remnants of the periodontal ligament.

2.3 Mounting specimens

On each premolar, a hole was drilled transversely through the middle of the root in the manner described by Mizrahi, Cleaton-Jones and Austin (1981).[51] The position of the hole was selected

to ensure that there would be no interference with the mounting device (Fig. 1). Through the hole a steel rod was placed to offer attachment to the Instron testing machine (Fig. 2).

2.4 Banding procedure

Each premolar in turn was secured in a small table vice and a seamless Unitek stainless steel band of the appropriate size was tightly fitted. The reference size number of each band for each premolar was recorded so that each tooth could be fitted with the same size of new band for each test procedure. On the lingual and buccal surfaces of the stainless steel bands, premolar cleats were spot-welded to provide seating lugs. On the outer surface of the mesial and distal

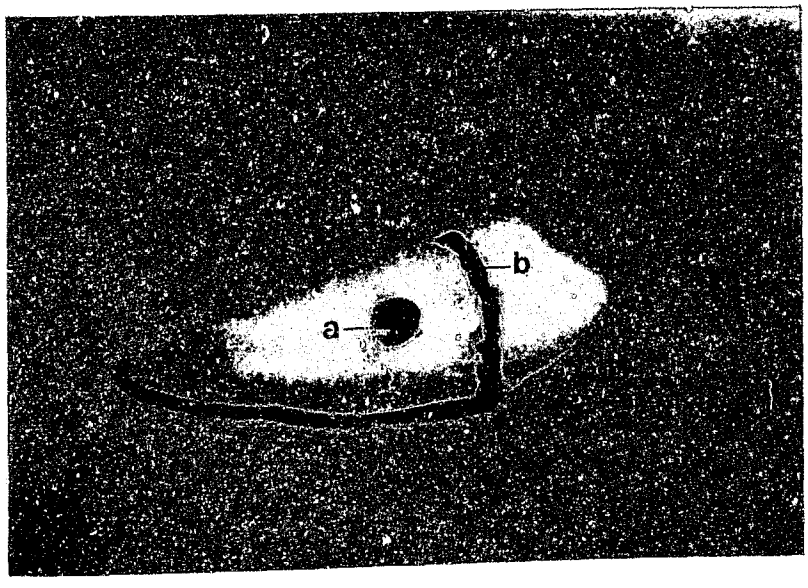


Figure 1: Extracted premolar tooth
a: hole drilled through root transversely
b: demarcation of stainless steel band position

aspect of each of the bands a loop of stainless steel band tape (3.8 mm x 0.13 mm) of 55 mm in length, was spot-welded. This loop enabled the suspension of the tooth from the load cell coupling hanger. The bands were seated to a level just below the marginal ridges. The enamel was scored at the gingival margin of the bands with a diamond bur in a high speed handpiece. The bands were then removed and the scored line was enhanced using a fine tip fibre pen (Fig.1).

2.5 Measuring surface area of the band

After the band removal and assessment of the residual cement on the tooth, the band was cut open with a pair of scissors and splayed out flat on a white surface illuminated by four Osram lights*. With a pointer on the Digicad plotter ¶, the circumference of the band was traced following the enlarged image provided by a Panasonic video camera# (4x magnification) on a computer with a videoplan image processing system¶. A computerised calculation then determined the surface area in mm^2. A correction was made for the enlargement and the actual surface area was thus determined (Fig. 3).

2.6 Cementing procedure

Four different cements were tested to ascertain their tensile bond strength: zinc oxyphosphate (Elite cement 100ᵍ), polycarboxylate (PolyF Plus ‡), glass ionomer (AquaCem ¥) and a mixture

* Nitraphot BR, Germany 220-230V 55W.
¶ Manufactured by Kontron Munich, Germany
# Panasonic F10 II CCD video camera (WVPS031G) from Matsushita Yokohama Japan.
ᵍ GC Corporation 76-1 Hasumuma-cho, Itabashi-ku, Tokyo 174. Japan.
‡¥ Detrey Dentsply. Hamm Moor Lane, Addlestone UK-Wedbridge Surrey KT 152SE.

of glass ionomer and resin cement.(OptiBand §) Each cement was mixed on a glass slab at room temperature, according to the specifications of the manufacturers.

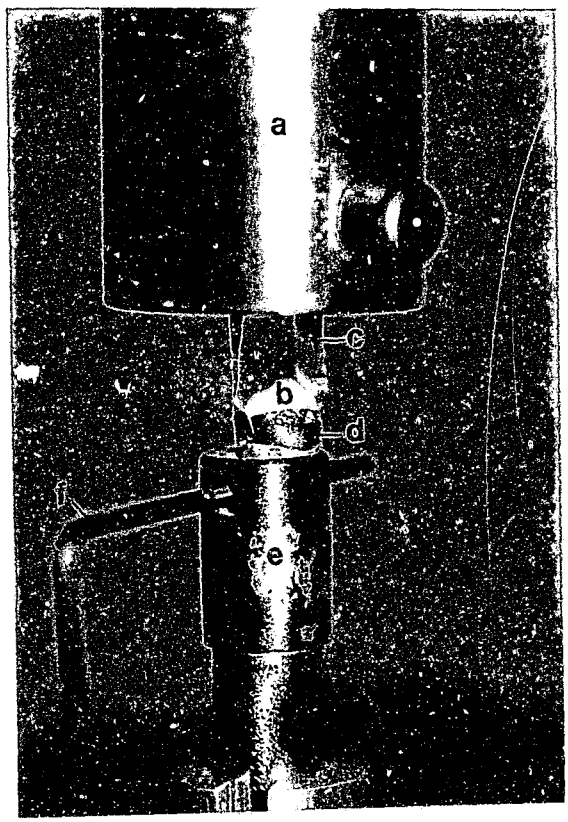


Figure 2: Tooth-assembly attached to the Instron testing machine
a: freely rotating arm, incorporating roller bearings
b: tooth
c: loop of band material
d: Unitek stainless steel band
e: specialized jig to provide attachment for tooth
f: steel rod transversely through steel tubing of jig and the enclosed root
g: universal joints

Previous researchers (Paffenbarger, Sweeney and Isaacs (1933)[20], Millet and McCabe (1996)[35], Durning, McCabe and Gordon(1994),[53] Hamula, Hamula and Brower (1993)[12] suggested that

§ ORMCO, a subsidiary of Sybron, Dental Specialities, Inc. Glendora, CA 91740.

the proportions recommended by the respective manufacturers are not necessarily precisely correct for cementing bands. Therefore, a mix was established by trial and error that resulted in a smooth, thick, creamy consistency considered clinically suitable for cementing bands. By careful weighing of the powder and the liquid it was then possible to determine that most favourable ratio of powder to liquid. This ratio was maintained throughout all further cementation procedures.

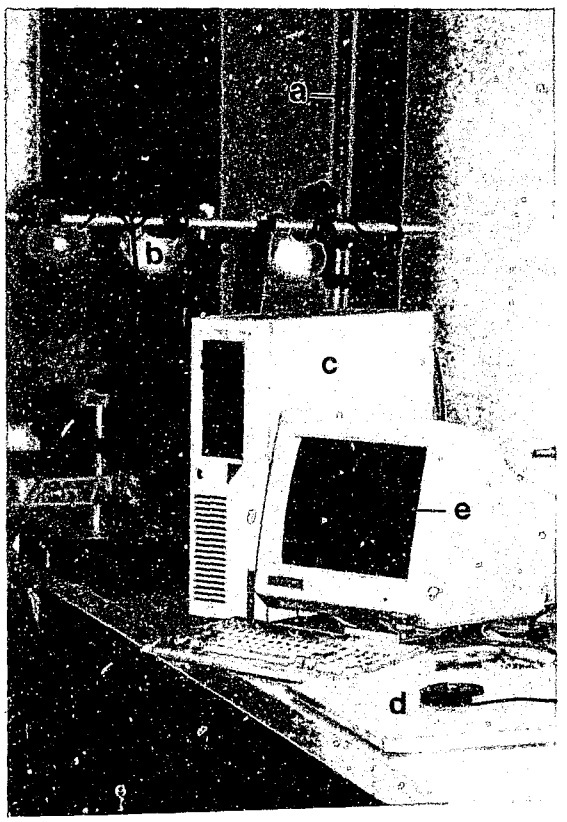


Figure 3: Kontron Image Analyser and Panasonic video camera used to determine surface area.
a: Stand for Panasonic video camera
b: OSRAM lights
c: Computer with imaging program
d: Digicad plotter
e: Computer screen

In the cases of zinc oxyphosphate, glass ionomer and polycarboxylate cements, the powder was weighed on a scientific balance* and the liquid dispensed with a precision pipette#. In this way the mix was standardized for each cement (Fig. 4; Fig. 5). The hybrid cement was extruded by using the twin

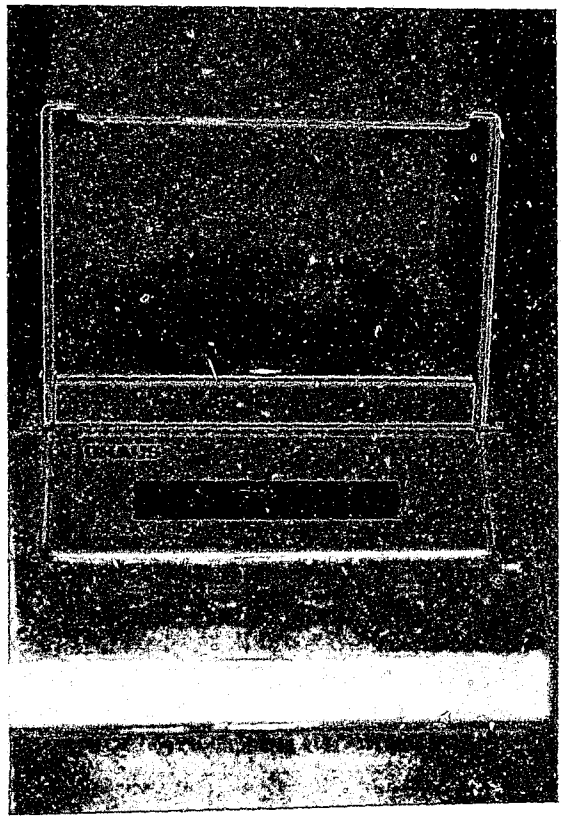


Figure 4: Scientific balance

tube simultaneous extrusion syringe, and then mixed with the spatula on a mixing pad provided in the kit. Each band was thoroughly cleansed in alcohol, dried, and the inner surface loaded with mixed cement. The band was placed by hand and then seated by force with a band seater to the predetermined level demarcated by the scribed line on the enamel

* OHAUS Precision *Plus* electronic balances, Model TP400D, Giessen Germany.
# Pluripet Fixopet, Kartell 120082 Noviglio (Milano)

when the bands had been initially fitted. Excess cement was carefully removed with a universal scaler. The cement was allowed to set for 5 minutes, and the teeth were then stored in distilled water for one week at room temperature.

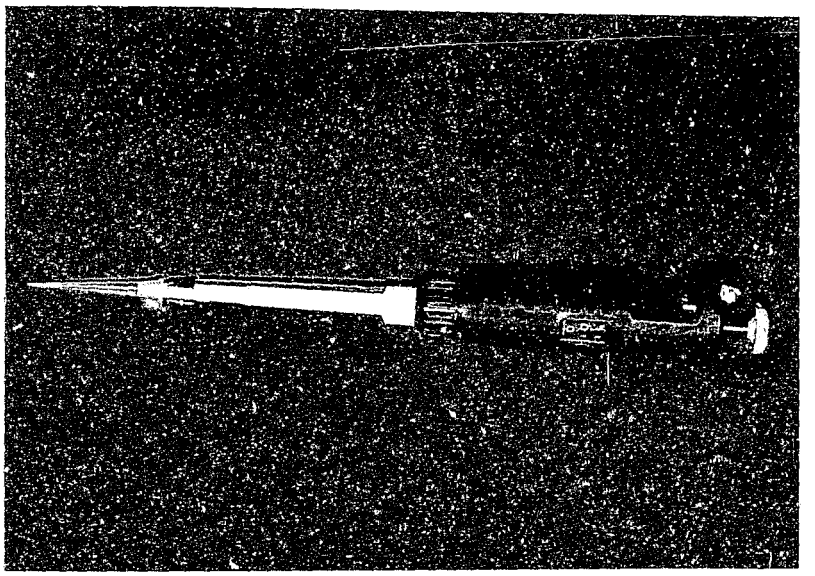


Figure 5: Precision pipette

2.7 Calibration of Instron Universal testing machine

A 50 kg load cell was mounted and the Instron Universal testing machine* (table model) was set to a crosshead speed of 1mm/minute. The machine was calibrated according to the manufacturers instructions, and then, following their recommendation, was activated for 15-20 minutes prior to sample testing, to ensure load cell stability.

A coupling hanger and a universal jig were attached to the load cell. This assembly allowed vertical forces to be applied to the test specimen with no torsional force effect. A special jig

* Instron Universal testing machine (TM) Model 1026 Tensile Tester, Instron Corp., Canton, Mass.

was attached to the base of the Instron testing machine to which the tooth was secured by the steel rod which had been placed transversely through the root (Fig.2). The welded stainless steel loop attached to the band was suspended from the load cell via the coupling hanger. A vertical force could then be applied to the loop, resulting in a traction on the cemented band.

Each banded specimen was secured in this way in turn on the test apparatus and the traction force applied until the band dislodged, just revealing the enamel surface above the gingival demarcation score line described above. The testing machine was set up to cease recording tensile force immediately the cement yielded. This force was recorded in kilograms. The force values were converted to Newtons and then divided by the area of internal surface of the band to give the tensile force per unit area (N/m^2) at fracture of the tooth-cement-band junction.

Example:

The recorded force value on the Instron testing machine was 17 kg, and the area of the internal band surface was 162.73 mm^2.

Conversion of kilograms to Newtons = 17 kg x 9.80556

$= 166.7\ N$

Unit area of the internal surface of band in m^2 $= 162.73\ mm^2 \times 10^6$

$= 162.73 \times 10^6\ m^2$

Tensile bond strength per unit area $= 166.7\ N / (162.73 \times 10^6\ m^2)$

$= 1.02 \times 10^6\ N/m^2$

$= 1.02 \times 10^6\ Pa$

$= 1.02\ MPa$

The force values were converted to Newtons and that figure was then divided by the area of the internal surface of the band. A Newton per meter squared (N/m^2) is a unit of measure of pressure (the S.I. unit being Pascals - Pa). The values were finally displayed in megapascals (MPa).

The debanded specimens were examined under a dissecting microscope with a magnification of 20, in order to determine the interface of fracture (Fig. 6). The proportional area of the inner band surface still carrying residual cement was recorded for each specimen to the nearest 25 percent.

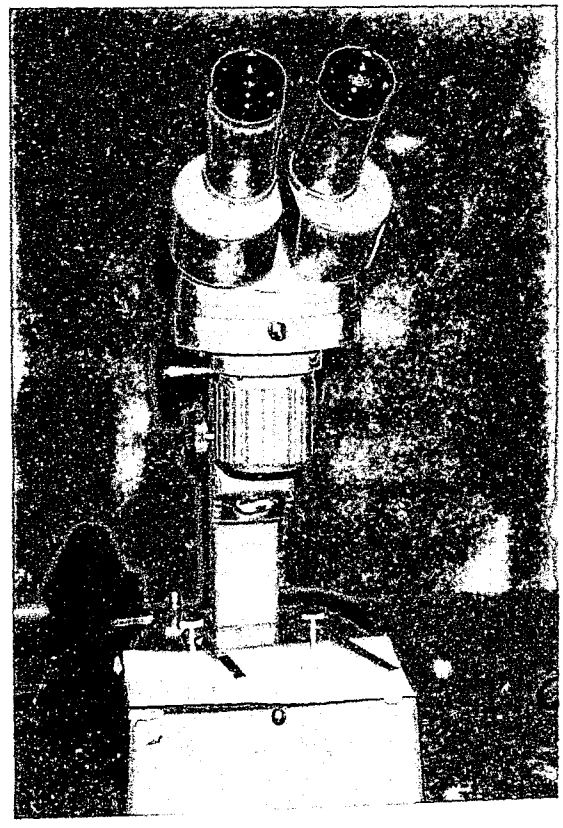


Figure 6: Dissecting microscope used to estimate residual cement on bands

The tests were then repeated using the same size band as had been recorded previously for each tooth. Prior to cementation the inner surface of each band was sandblasted for 10 seconds, using 50μ aluminium oxide particles and a Microetcher.* The specimens were mounted and the forces required to dislodge the bands determined as before. All data were recorded for subsequent analysis.

2.8 Statistical methods and analyses

Statistical advice and analysis of data was performed by Dr. Piet Becker, senior statistician at the Medical Research Council. The study was performed as a two factor (sandblasted/non-sandblasted and cement variety) within-subject design with two response variables, ie. force and residual cement. The data were subjected to the following statistical analyses:

2.8.1 Statistical evaluation of intra-operator error

2.8.1.1 Coefficient of variance of intra-operator error

i. The coefficients of variance were determined for measuring the surface area of two stainless steel bands at 15 minute intervals 10 times through one day in order to establish how consistent the operator was in measuring the surface area.

* Danville Engineering, 1901 San Ramon Valley Blvd, San Ramon, CA 94583. Danville, California

ii. Four teeth were repeatedly used, testing the four different cements ten times each. The teeth were prepared exactly as was done for the main study. After cementing a band, the tooth was placed in water for 24 hours before dislodging the band with the Instron machine. The data were collected and the coefficients of variance were established for the tensile strengths of the various cements in order to establish the accuracy with which the operator executed the procedures.

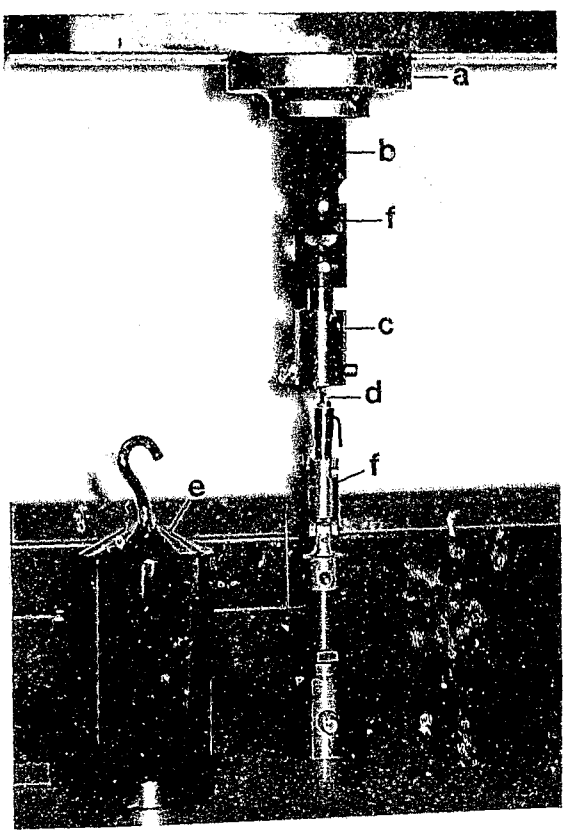


Figure 7: Instron testing machine to which a tooth is secured.
a: load cell
b: coupling hanger
c: freely rotating arm, incorporating roller bearings
d: tooth
e: calibration weight
f: universal joints

2.8.2 Descriptive analyses

For each test, the data were pooled and the mean, standard deviation and range calculated.

2.8.3 Comparative analyses

2.8.3.1 One Way Analysis of Variance (ANOVA)

The variables, Force and Residual Cement, were analysed in an appropriate analysis of variance using the STATA statistical software. The overall F-test was performed at the 95% confidence level to determine whether bond strengths and residual cement would be unchanged for all four cements regardless of whether the stainless steel bands were sandblasted on the inside or not.

2.8.3.2 Significant pairwise differences among the means

Specific differences reflecting the interactions between the main effects were established employing the least significant differences test (LSD).

Chapter 3

3.1 Results

The results of the experiment are summarised in Tables 3.1, 3.2, 3.3 and graphs 3.1, 3.2, 3.3, 3.4 and 3.5. The raw data are presented as appendices A, B, C and D.

3.2 Statistical analyses

3.2.1 Statistical analysis of intra-operator error

i. The coefficients of variance for the repeated measurements of the internal surface of the stainless steel bands showed that the operator displayed a high repeatability. For one band a coefficient of variance of 2.26 was obtained and for the other, a coefficient of variance of 1.3 was recorded.

ii. The coefficients of variance were established for the measurements of the tensile strengths of four different cements using four teeth repeatedly ten times each. From these tests it was found that an operator error of 20.2% was present for glass ionomer cement, 28.3% for OptiBand, 16.1% for polycarboxylate and 8.3% for zinc oxyphosphate.

Table 3.1 Tensile force in kilogram for ten teeth tested in order to establish intra-operator error

Tooth	1	2	3	4	5	6	7	8	9	10
GIC	29.5	23.5	36	31	33	35	22	34	20	25
Polycarboxylate	32	19	33	26	30	32	35	36	31.5	30
Zincoxyphosphate	37,5	27,5	28,5	34,4	28	27	29	33	34	28
OptiBand	14	15	8.5	14.5	7	16	11	15	8	10

3.2.2 Descriptive data

The mean tensile bond strengths for sandblasted and non-sandblasted bands were highest for glass ionomer at 1.7113 and 1.6546 MPa respectively. OptiBand had the lowest mean band strength with means of 1.1262 and 0.8703 MPa for sandblasted and non-sandblasted band respectively. The mean value for sandblasted and non-sandblasted bands for zinc oxyphosphate and polycarboxylate were almost equal. All the cements (whether bands were sandblasted or not) show large ranges of bond strength and relatively high standard deviations (Table 3.2).

3.2.3. Comparative analyses

3.2.3.1 One way analysis of variance

It was found from the ANOVA evaluation that sandblasting and non-sandblasting resulted in significant differences between the mean tensile bond strengths ($p<0.0102$). In particular it followed from Fisher's least significant difference test (LSD) for pairwise comparisons that sandblasted and non-sandblasted

data are significantly different. The four cements (zinc oxyphosphate, polycarboxylate, glass ionomer and the hybrid cement) were also shown to produce significant differences in mean bond strengths ($p<0.0001$).

Although the interaction between sandblasting and cement type was not significant ($p=0.3017$), it was noticeable from the pairwise comparisons of means of strength by cement that sandblasting had the greatest effect on strength in the case of OptiBand (Graph 3.1).

Retention of residual cement on the stainless steel bands was significantly affected ($p<0.000$) by sandblasting. All the cements recorded an increased mean retention on the stainless steel bands after sandblasting (Graph 3.2). OptiBand was retained on the stainless steel bands to a much greater extent than any of the other cements, irrespective of whether the band was sandblasted or not. The increase in cement retention after the band was sandblasted was only 14% for OptiBand. Glass ionomer cement tended to adhere to the stainless steel band to a lesser extent (Graph 3.2). Graph 3.3 gives an indication of how sandblasting affected retention of the cement to the stainless steel bands, and Graphs 3.4 and 3.5 how it affected the mean tensile strengths of the different cements. It was found that after sandblasting the increase in retention of cement to the inside of the band was 44% for zinc oxyphosphate, 48% for glass ionomer, 56% for polycarboxylate and 14% for OptiBand.

3.2.3.2 Significant pairwise differences among the means

It followed from Fisher's least significant difference test (LSD) for pairwise comparisons that sandblasting and non-sandblasting were significantly different. By using the same LSD tests on the data for the cements, it was found that the mean tensile strengths of glass ionomer cement and zinc

oxyphosphate were significantly different, while the tensile strength of OptiBand differed significantly from all of the other three cements.

From this study it was found that mean tensile strength did not increase to any extent after sandblasting, except in the case of Optiband (increased by 23%). Polycarboxylate mean tensile bond strength increased by 2.1%, glass ionomer by 3.4% and zinc oxyphosphate by 6.1%.

Table 3.2

Tensile bond strengths (MPA) for four different dental cements

Cement	Non-sandblasted stainless steel bands			Sandblasted stainless steel bands		
	Mean	Standard deviation	Range	Mean	Standard deviation	Range
Zinc oxyphosphate	1.4788	0.423	0.4953-2.1924	1.5749	0.523	0.2695-2.6165
Poly-carboxylate	1.5514	0.423	0.3593-2.5236	1.5843	0.321	0.9281-2.3659
Glass ionomer	1.6546	0.389	1.0887-2.5236	1.7113	0.349	1.0316-2.6218
Hybrid cement	0.8703	0.239	0.4047-1.2817	1.1262	0.414	0.4646-2.127

Table 3.3

Analysis of variance (ANOVA) for force

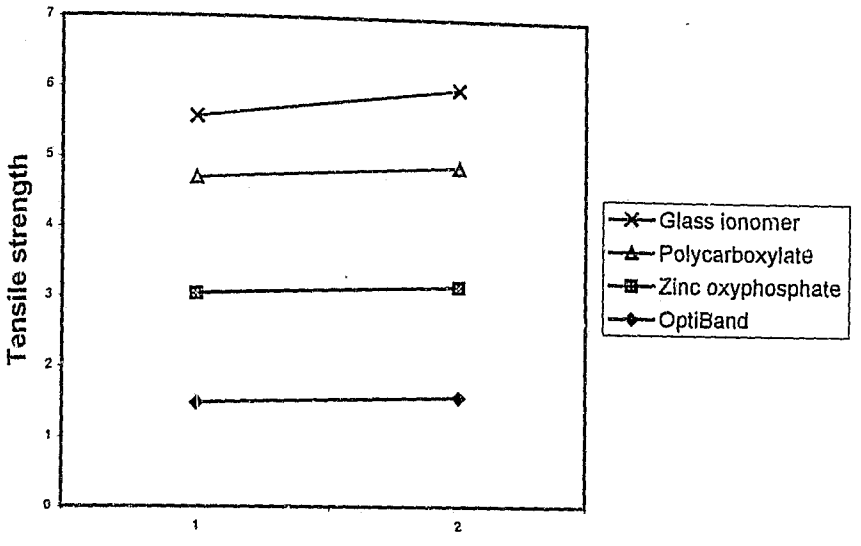
Source of variation	Degree of freedom (DF)	F-test	P-value
Teeth	34	2.93	0.0000 (<0.05)
BLAST (B)	1	6.71	0.0102 (<0.05)
CEMENT (C)	3	51.03	0.0000 (<0.05)
B * C	3	1.39	0.2458 (>0.05)

Table 3.4

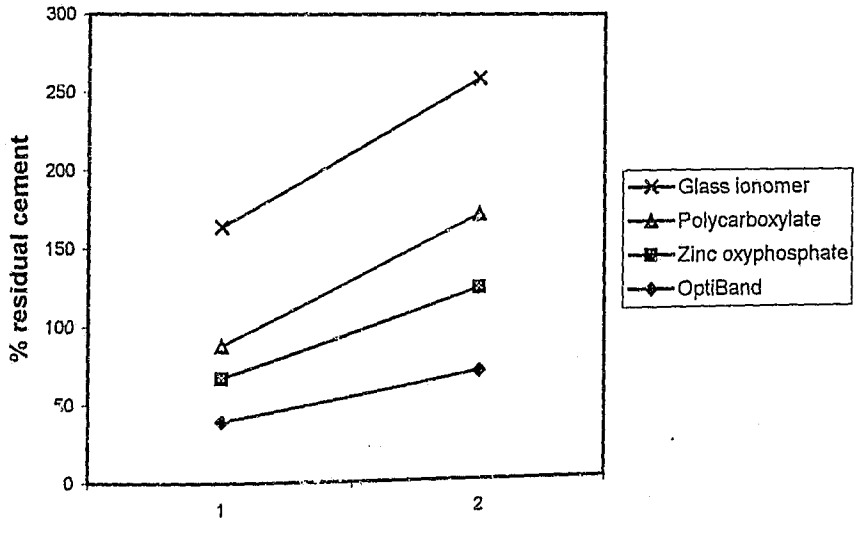
Analysis of variance (ANOVA) for residual cement

Source of variation	Degree of freedom (DF)	F-test	P-value
Teeth	34	0.86	0.6932 (>0.05)
BLAST (B)	1	54.42	0.0000 (<0.05)
CEMENT (C)	3	43.28	0.0000 (<0.05)
B * C	3	1.56	0.1977 (>0.05)

Graph 3.1 Effect of sandblasting on mean tensile strength



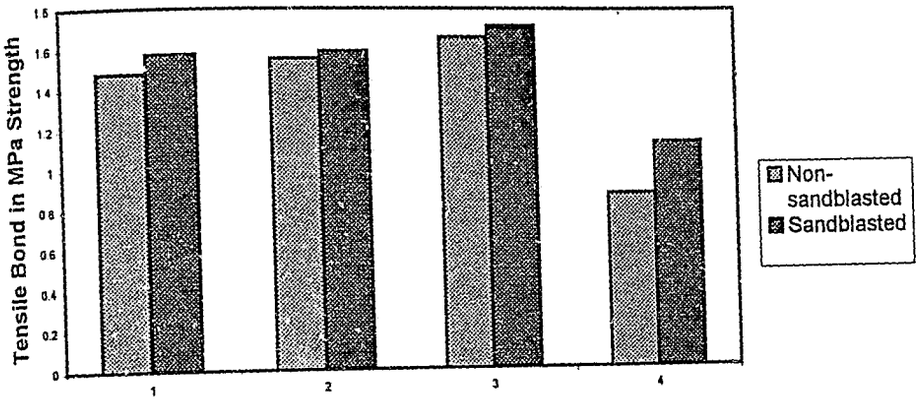
Graph 3.2 Effect of sandblasting on the amount of residual cement



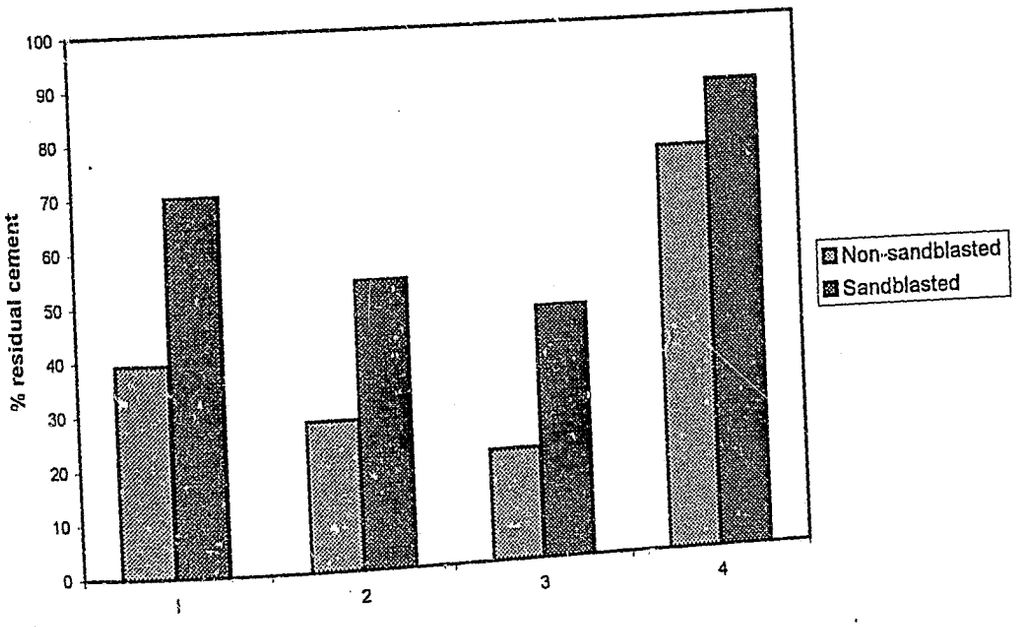
1 = Non-sandblasted

2 = Sandblasted

Graph 3.3 Tensile Bond strengths of four dental cements when used to secure non-sandblasted and sandblasted stainless steel bands



Graph 3.4 Percentage residual cement remaining on non-sandblasted and on sandblasted stainless steel bands



1 = Zinc oxyphosapate
2 = Polycarboxylate
3 = Glass ionomer
4 = OptiBand

Chapter 4

4.1 Discussion

With time new dental cements are developed and tested *in vitro* and clinically. The expectation is that these new products should have qualities which are an improvement over the older cements that had stood the test of time. The present study was undertaken in order to test a new hybrid light- cured dental cement 'OptiBand' by comparison with three older dental cements of known performance. The effect of sandblasting on band retention with each of the four dental cements was also tested and measured. The site of fracture of the dental cement is of importance as it has been found that cement retention to enamel protects the enamel in cases where bands become loose. For this reason glass ionomer cement has been highly rated clinically as an excellent dental cement. Once a band comes loose it acts as an effective plaque trap which cannot be cleaned by the patient. Retained cement on the enamel protects the enamel until the band is recemented.

4.1.1 Statistical analysis of intra-operator error

Measuring the surface area of the stainless steel bands was found to be very accurate. All the surface areas were measured in one day using the Kontron image analyser and video camera. The results were however very different when determining the accuracy of the tensile testing procedure.

The procedure to determine the tensile force consisted of multiple steps, each of which could possibly introduce some small error which may then accumulate into a significant intra-operator error. Unfortunately other authors do not mention testing repeatability of this determination and it is thus difficult to assess if the intra-operator error in this study was acceptable.

4.1.2 Descriptive data

As expected, glass ionomer had the largest tensile bond strength for sandblasted and non-sandblasted bands. Quite unexpectedly, the dual cured hybrid cement, OptiBand, recorded the lowest tensile bond strength of all the cements tested. The performance improved significantly (by ±30%) after sandblasting but the OptiBand data were still inferior to those of the next best cement, even without sandblasting the bands. The mean tensile strength did not increase as much after sandblasting as had been found in other studies. The mean tensile bond strength for OptiBand did increase by 23% and it thus appears beneficial to sandblast the stainless steel bands before using OptiBand, but the procedure seems to be of little consequence in the case of polycarboxylate cement where the increase in tensile bond strength was only 2.1%.

4.1.3 Comparative analyses

Very few studies on the new hybrid cements have been reported but from these it was expected that the cements would reveal high tensile strengths. Moskowitz and associates[43] found excellent results using the light cure cements Band Lok and Ultra Band Lok. The tensile and compressive

strengths were very high (Table 1.1 page 14). A study conducted by Lee and co-workers,[14] demonstrated high compressive and tensile bond strengths in a composite-type material, also found by Wood *et al* (1996).[44]

This study showed that there were significant differences between the mean data of the four different cements tested. Glass ionomer and zinc oxyphosphate had significantly different tensile bond strengths. The performance of OptiBand was totally different to that of all three of the other cements. OptiBand was revealed as rather a weak cement, not comparing very well to any of the other cements. This is contrary to what was expected from recent reports in the literature when the hybrid cements gave good results. It is understandable that the four cements react differently. Zinc oxyphosphate bonds by pure mechanical bond while glass ionomer and polycarboxylate achieve chemical bonds to both stainless steel and teeth. The hybrid cement has the ability to bond by both means and yet its tensile bond strength is the weakest.

Sandblasting has been proven by many authors to improve bond strengths of cements. Wood *et al*[44] used extracted third molars and tested zinc oxyphosphate, polycarboxylate and Band Lok (dual-cure hybrid glass ionomer cement). They found that 20% more force was required to remove bands luted with glass ionomer cement than with zinc oxyphosphate and polycarboxylate cement. After sandblasting the force required to deband was doubled for zinc oxyphosphate and glass ionomer and more than doubled for polycarboxylate.

Miller and Zernick (1996) also tested the effect of sandblasting stainless steel discs which were then secured to bovine enamel. They used four different glass ionomer cements and zinc oxyphosphate.[46] They found significant increases in bond strengths after sandblasting the discs.

The light cured glass ionomer achieved the highest increase of bond strength at an improvement of 75%. They also found that sandblasting resulted in much more adhesion to the stainless steel bands and the light cured glass ionomer cement received the highest score for adhesion to the inside of the stainless steel bands.

In the current study the greatest effect on the tensile bond strength after sandblasting was recorded when the hybrid cement, OptiBand, was tested. The tensile bond strength increased by almost 30%. The other three cements did not give such positive results and the increases were rather small, especially for polycarboxylate which showed an enhancement of approximately 2%. Even though the bond strength of OptiBand increased significantly it is still very low, even lower than those recorded by the other cements on non-sandblasted bands.

Miller and Zernick also found that sandblasting did not much affect the failure modes of the zinc oxyphosphate cements.[46] That conclusion does not correspond with the findings from this study, which has found that the amounts of residual cement on the inner surface of the bands were significantly affected by sandblasting, especially in the cases of polycarboxylate, glass ionomer and zinc oxyphosphate.

According to Miller and Zernick,[46] sandblasting provides a clear clinical advantage when combined with glass ionomer cements. However, this study proves that more advantage is gained for OptiBand than for any of the other three cements tested. Unfortunately, Miller and Zernick do not distinguish between traditional glass ionomer cements, which react only via an acid-base reaction, and the hybrid cements, where some degree of polymerisation occurs. The

Tri-cure Vitremer glass ionomer cements and the Fuji II LC fall in the latter category where some polymerisation due to light activation occurs. The conclusion of Miller and Zernick may therefore be based on the hybrid cements and not on the pure glass ionomer.

A variety of storage mediums for the tooth specimens have been used in previous studies, including tap water, de-ionised water, distilled water, ethyl alcohol and formol saline.[45,53] Thymol has been added at a 0.1% dilution with the intent of controlling bacterial growth. Whilst it is possible that these alternative storage mediums may have influenced the study, nevertheless, many of the authors whose work has formed the basis for comparisons relied upon tap or distilled water.[41,51]

An important consideration that was not anticipated before commencing the study was the possibility of change of the sandblasted surface with time. It could be that the sandblasted surfaces change after a time period and that the bond strength would then be adversely affected as was suggested by Wood, Paleczny and Johnson[44] when they quote the work of Hofstede and McConnell.[55] The latter found that sandblasting decreases the oxide layer of the stainless steel rendering it much firmer for bonding, but that if it was left for one week a thicker oxide layer was laid down again and thus resulted in a weaker bond.

Chapter 5

5.1 Conclusions

1. The *in vitro* testing of the tensile bond strengths of four dental cements revealed that glass ionomer presented with the highest mean tensile strength. Zinc oxide and polycarboxylate have similar mean tensile strengths but the mean values for glass ionomer and zinc oxide are significantly different. OptiBand differs significantly from all the cements and has the lowest mean tensile bond strength.

2. The *in vitro* tensile bond strengths of zinc oxyphosphate, polycarboxylate, glass ionomer and OptiBand (dual cure hybrid cement) are significantly greater after sandblasting the inside of the stainless steel bands for 10 seconds with 50μm aluminium oxide particles.

3. The amount of residual dental cement adhering to the stainless steel bands was significantly increased by sandblasting for all four cements.OptiBand demonstrated the greatest increase in residual adherence and glass ionomer cement, the least.

4. It is advisable to sandblast the inside of the stainless steel bands if OptiBand is used.

5. This study has shown that in terms of performance and convenience, glass ionomer remains the cement of choice.

References

1. Proffit, W. (1993) Contemporary Orthodontics, 2nd edition, St Louis: CV Mosby, page 342.

2 Strang R.H.W. (1933) *Text Book of Orthodontia*, London: Henry Kempton, page 193.

3. Mizrahi, E. (1977) Retention of the conventional orthodontic band. *British Journal of Orthodontics*, 4 : 133 -137.

4. Buonocore, M.G. (1955) A simple method of increasing the adhesion of acrylic filling material to enamel surfaces. *Journal of Dental Research*, 34 : 839 - 853.

5. Underwood, M.L., Rawls, H.R. and Zimmerman, B.F. (1983) Clinical evaluation of a fluoride - exchanging resin as an orthodontic adhesive. *American Journal of Orthodontics*, 2 : 93 -99.

6. Noreval, L.I., Marcusson, A. and Persson, M. (1996) A clinical evaluation of a glass ionomer cement as an orthodontic bonding adhesive compared with an acrylic resin. *European Journal of Orthodontics*, 4 : 373-384.

7. Zachrisson, B.U. (1976) Direct bonding in orthodontic treatment and retention. A post - treatment evaluation. *Transactions of the European Orthodontic Society*, pages 291 - 301.

8. Zachrisson, B.U. (1977) A post- treatment evaluation of direct bonding in orthodontics. *American Journal of Orthodontics*, 71 : 173 - 189.

9. Gottlieb, E.L., Nelson, A.H. and Vogels, D.S. (1986) J.C.O. study of orthodontic diagnosis and treatment procedures. *Journal of Clinical Orthodontics*, 20 : 612 - 625.

10. Sadowsky, P.L. and Retief, D.H. (1976) A comparative study of some dental cements used in orthodontics. *Angle Orthodontist*, 46 : 171 - 181.

11. Norris, S.D., McInnes - Ledoux, P., Schwaninger, B. and Weinberg, R. (1986) Retention of orthodontic bonds with new fluoride - releasing cements. *American Journal of Orthodontics*, 89 : 206 - 211.

12. Hamula, W., Hamula, D.W. and Brower, K. (1993) Glass ionomer update. *Journal of Clinical Orthodontics*, 27 : 420 - 425.

13. Kvan, E., Broch, J. and Nissen-Meyer, I.H. (1983) Comparison between a zinc phosphate cement and a glass ionomer cement for cementation of orthodontic bands. *European Journal of Orthodontics*, 5 : 307 - 313.

14. Lee, H.L., Orlowski, J.R., Elwell, R.B. and Tate, A. (1973) A new high - strength composite - type cement for orthodontic bands. *Journal of Clinical Orthodontics,* 7 : 514 -519.

15. Mizrahi, E. (1982) Enamel demineralization following orthodontic treatment. *American Journal of Orthodontics,* 82 : 62 - 67.

16. Crowell, W. S. (1927) Physical chemistry of dental cements. *Journal of the American Dental Association,* 14 : 1030 - 1048.

17. Lefkowitz, W. (1940) Histological evidence of the harmful effect of cement under orthodontic bands. *Journal of Dental Research,* 19 : 47 - 55.

18. Wisth, P.J. (1970) The role of zinc phosphate cement in enamel surface changes on banded teeth. *Angle Orthodontist,* 40 : 329 - 333.

19. Wisth, P.J. (1972) The ability of zinc phosphate and hydro phosphate cements to seal band spaces. *Angle Orthodontist,* 42 : 395 -398.

20. Paffenbarger, G. C., Sweeney, W. T. and Isaacs, A. (1933) A preliminary report on the zinc phosphate cements. *Journal of the American Dental Association,* 20 : 1960 -1982.

21. Maijer, R. and Smith, D.C. (1988) A comparison between zinc phosphate and glass ionomer cement in orthodontics. *Angle Orthodontist,* 49 : 273 - 279.

22. Atkinson, A.S. and Pearson, GI (1985) The evolution of glass-ionomer cements. *British Dental Journal,* 159 : 335 - 337.

23. Kocadereli I. and Ciger, S. (1995) Retention of orthodontic bands with three different cements. *Journal of Clinical Pediatric Dentistry,* 19 : 127 - 130.

24. Smith, D.C. (1971) A review of the zinc polycarboxylate cements. *Journal of the Canadian Dental Association,* 1 : 22 - 29.

25. Rich, J.M., Leinfelder, K.F. and Hershey, H.G. (1975) An *in vitro* study of cement retention as related to orthodontics. *Angle Orthodontist,* 45 : 219 - 225.

26. Knibbs, P.J., Plant, C.G. and Shovelton, D.S. (1986) The performance of a zinc polycarboxylate luting cement in general practice. *British Dental Journal,* 160 : 13 - 15.

27. Greenland, L. , Hargreaves, J.A., Smith, D.C. and Beagrie, G. S. (1974) Fluoride uptake by enamel from polycarboxylate cement. *Journal of Dental Research,* Programme of Abstracts, 53, IADR Abstract number 918.

28. Duperon, D.F. and Jedrychonski, J. (1980) Release and enamel uptake of fluoride from fluoride-containing polycarboxylate cements. *Journal of Periodontics*, 4 : 294.

29. Wilson, A.D. and Kent, B.E. (1972) A new translucent cement for dentistry: the glass ionomer cement. *British Dental Journal*, 132 : 133 - 135.

30. Walls, A.W.G. (1986) Glass polyalkenoate (glass-ionomer) cements : a review. *Journal of Dentistry*, 14 : 231 - 246.

31. Mc Lean, J.W, Nicholson, J.W and Wilson, A.D. (1994) Guest Editorial. Proposed nomenclature for glass-ionomer dental cements and related materials. *Quintessence International*, 25 : 587-589.

32. Akkaya, S., Üner, O., Alaqam, A. and Degim, T. (1996) Enamel fluoride levels after orthodontic bond cementation with glass ionomer cement. *European Journal of Orthodontics*, 18 : 81 - 87.

33. Rezk-Lega, F., Ogaard, B. and Arends, J. (1991) An *in vivo* study on the merits of two glass ionomers for the cementation of orthodontic bands. *American Journal of Orthodontics*, 99 : 162 - 167.

34. McLean, L.W. and Wilson, A.O. (1977) The clinical development of glass ionomer cements II Some clinical applications. *Australian Dental Journal*, 22 : 120 - 127.

35. Millet, D.T. and Mc Cabe, J.F. (1996) Orthodontic bonding with glass ionomer cement: a review. *European Journal of Orthodontics*, 4: 385 - 399.

36. Tavas, M.A. and Salem, N.S. (1990) Glass ionomers for direct bonding: an *in vitro* assessment. *Journal of Orthodontics*, 17 : 223 - 228.

37. Koch, G. and Hatibovic- Kofman, S (1990) Glass ionomer cements as fluoride release system *in vitro*. *Swedish Dental Journal*, 14 : 267 - 273.

38. Marcushamer, M., Garcia-Goday, F. and Chan, D.C.N. (1993) Caries protection after orthodontic band cementation with glass ionomer. *Journal of Dentistry for Children*, 60 : 300 - 303.

39. Mc Carthy, M.F. and Honfram, S.O. (1994) Mechanical and bond strength properties of light-cured and chemically cured glass ionomer cements. *American Journal of Orthodontics and Dentofacial Orthopaedics*, 105 : 135 - 141.

40. Mizrahi, E. (1967) Retention of the [illegible] orthodontic band. *British Journal of Orthodontics*, 4 : 133 -137.

41. Clark, R.J., Phillips, R.W and Norman, R.D. (1977) An evaluation of silicophosphate as an orthodontic cement. *American Journal of Orthodontics and Dentofacial Orthopaedics*, 71 : 190 -196.

42. Atonucci, J.M., McKinney, J.E. and Stansbury, J.W. (1988) Resin-modified glass-ionomer cement. US Patent Application 160856.

43. Moskowitz, E.M., Muñoz, A.M. and Tovilo, K. (1996) Band cementation with no-mix, light-cured glass ionomer cement. *Journal of Clinical Orthodontics*, 30 : 576 - 577.

44. Wood, D.P., Paleczny, G.J., and Johnson, L.N. (1996) The effect of sandblasting on the retention of orthodontic bands. *Angle Orthodontist*, 3 : 207 - 214.

46. Miller, D.T. and Zernik, J.H. (1996) Sandblasting of bands to increase bond strength. *Journal of Clinical Orthodontics*, 4 : 217 - 222.

45. Güray, E. and Karaman, A.I. (1997) Effects of different roughening methods on band retention. *Journal of Clinical Orthodontics*, 31 : 361 - 366.

47. Årtun, J. and Bergland, S. (1984) Clinical trials with crystal growth conditioning as an alternative to acid - etch enamel pretreatment. *American Journal of Orthodontics*, 85 : 333 - 340.

48. Whitaker, D.K. (1982) Structural variations in the surface zone of human enamel observed by scanning electron microscopy. *Archives of Oral Biology*, 27 : 383 - 392.

49. Nakamichi, I., Iwaku M., and Fusayama, T. (1983) Bovine teeth as possible substitutes in the adhesion test. *Journal of Dental Research*, 62 : 1076-1081.

50. Williams, LD., Swartz, M.L. and Phillips, RM. (1965) Retention of orthodontic bands as influenced by the cementing media. *Angle Orthodontist*, 35 : 278 - 285.

51. Mizrahi, E., Cleaton-Jones, P.E. and Austin, J.C. (1981) Effects of surface contamination on band retention. *American Journal of Orthodontics*, 79 : 390 - 398.

52. Smith, D.C. (1983) Dental cement - current status and future prospects. *Dental Clinics of North America*, 6 : 763 - 792.

53. Durning, P., McCabe, J.F. and Gordon, P.H. (1994) A laboratory investigation into cements used to retain orthodontic bands. *British Journal of Orthodontics*, 21 : 27 - 32.

54. Seeholzer, H.W. and Dasch, W. (1988) Banding with a glass ionomer cement. *Journal of Clinical Orthodontics*, 22 : 165 - 166.

55. Hofstede, T. and McConnell, R.J. (1990) Bond strengths of Panavia-treated surfaces. *Journal of Dental Research*, 69 : 172.

Appendix A
Results obtained from sandblasted stainless steel bands

Tooth	Force in kilograms				Residual cement to the nearest 25%			
	Zinc oxyphosphate	Polycarboxylate	Glass ionomer	Hybrid cement	Residual zinc oxyphosphate	Residual Polycarboxylate	Residual Glass ionomer cement	Residual Hybrid cement
1	19	27	24	8.5	100	75	100	100
2	35	29	27.5	23.5	100	50	75	100
3	3	22	12	10	50	50	75	75
4	Failure	Failure	Failure	Failure	Failure	Failure	Failure	Failure
5	24.5	26	43	27	75	100	75	0
6	23.5	32	25	16	100	75	50	0
7	22	33.5	38.5	26	100	75	50	50
8	26	26.5	21	16	50	50	50	75
9	15	27	28	17	100	25	0	100
10	19.5	19.5	36	17.5	50	50	0	100
11	35	22.5	27.5	30	0	25	75	100
12	30	32.5	30	21.5	100	100	50	100
13	Failure	Failure	Failure	Failure	Failure	Failure	Failure	Failure
14	41.5	29.5	36	18.5	0	75	75	100
15	11.5	20.5	39.5	7	75	75	50	100
16	28	31.5	32	Failure	50	50	50	Failure
17	16.5	24.5	20.5	10.5	50	75	50	100
18	24	25.5	28	22.5	100	50	25	75
19	27	31.5	39.5	10	75	50	50	100
20	27	21.5	31	20	100	50	100	100
21	Failure	Failure	Failure	Failure	Failure	Failure	Failure	Failure
22	24.5	32	28	14.5	50	25	25	100
23	34	28	32.5	26	100	50	50	100
24	36	14.5	27.5	14	25	75	25	100
25	25.5	29.5	22.5	20.5	75	50	0	100
26	27	26	23.5	8	100	25	50	100
27	32	33	20	13.5	75	75	50	100
28	36	16.5	23	19	0	75	25	100
29	32.5	23.5	30	16.5	25	25	25	100
30	26.5	23.5	29	12	75	75	50	100
31	23	24	24	28.5	100	25	25	75
32	32.5	19.5	29.5	15	100	50	50	100
33	25	29	22.5	11	100	50	75	100
34	33.5	31	38	18.5	50	50	50	75
35	34	37.5	30	26	100	50	0	100
36	Failure	Failure	Failure	Failure	Failure	Failure	Failure	Failure
37	21	21.5	27	22	100	100	50	50
38	10.5	27	30	25	50	0	50	100
39	32	29	27.5	32.5	0	0	50	100
40	32	25.5	30	27	100	25	50	100

Appendix B
Results obtained from non-sandblasted stainless steel bands

Tooth	Force in kilograms				Residual cement to the nearest 25%				Surface area mm 2	
	Zinc oxyphosphate	Polycarboxylate	Glass ionomer	Hybrid cement	Zinc oxyphosphate	Polycarboxylate	Glass ionomer cement	Hybrid cement	Measured once	Measured twice
1	19.5	17	21	8	25	0	75	100	162.33	163.12
2	35	27.5	39	20.5	0	25	50	0	155.34	158.33
3	12	4	17.5	8.5	25	75	25	100	112.75	106.28
4	Failure	Failure	Failure	Failure	Failure	Failure	Failure	Failure	Failure	Failure
5	16.5	25.5	27.5	15	25	50	25	75	193.59	196.41
6	23.5	29.5	20	14.5	25	25	25	75	149.83	151.7
7	29	27.5	32	19	0	0	25	75	191.33	195.04
8	36.5	41	29.5	17.5	0	0	50	100	182.73	182.46
9	15.5	16.5	26.5	15	75	25	25	50	150.42	153.44
10	33.5	30	21.5	11	0	25	50	75	190.25	197.04
11	33.5	35	24.5	19.5	25	25	50	100	158.57	164.44
12	22	25	21.5	11	25	50	25	50	167.95	163.73
13	Failure	Failure	Failure	Failure	Failure	Failure	Failure	Failure	Failure	Failure
14	30	33.5	37	19.5	25	0	0	100	192.22	189.54
15	12	21	23	6.5	25	25	25	100	149.52	145.34
16	9	22	21	Failure	25	25	25	Failure	175.6	180.64
17	17.5	23	24.5	20.5	75	25	25	50	175.91	175.56
18	33	18	26	10.5	0	25	25	100	186.93	188.43
19	17	33	36	20	75	25	25	100	185.18	182.77
20	32.5	25.5	38.5	6	0	0	0	100	144.26	145.46
21	Failure	Failure	Failure	failure	Failure	Failure	Failure	Failure	Failure	Failure
22	22	28	30.5	18	50	0	0	100	165.45	169.74
23	27	37.5	22	17.5	75	0	0	100	161.36	159.69
24	21.5	20.5	25.5	8.5	50	0	0	100	132.59	137.25
25	33	29.5	26	17.5	50	25	25	75	158.57	167.74
26	22	24.5	20	17.5	25	0	0	100	161.55	162.76
27	41	25	36	10.5	100	25	25	100	151.83	159.32
28	32	24	37	21	0	0	0	75	171.53	175.97
29	27.5	20	38	14	25	25	25	100	172.82	171.86
30	18	33	21	11.5	75	25	25	50	149.33	156.17
31	20	18.5	16.5	8	25	0	0	75	130.24	132.72
32	29	20	31	16.5	50	0	0	25	157.30	164.63
33	30	34	27.5	16.5	75	25	25	50	209.74	217.98
34	25	36.5	26	12	25	0	0	50	177.05	177.38
35	20	40	20	18.5	75	25	25	75	156.71	154.84
36	Failure	20.5	29.5	Failure	Failure	50	Failure	Failure	Failure	Failure
37	30,5	27	37	16	25	0	0	25	156.79	158.78
38	30	20.5	34	16 5	75	50	50	100	172.31	178.27
39	28	23	27	17	75	0	0	25	147.45	152.21
40	23	21	26	13	75	0	0	75	139.18	

Appendix C

Results obtained from non-sandblasted stainless steel bands

Tooth	Tensile force in megapascals			
	Zinc oxyphaosphate	Polycarboxylate	Glass ionomer	Hybrid cement
1	1.175	1.024	1.265	0.482
2	2.188	1.719	2.438	1.282
3	1.077	0.359	1.572	0.764
4	Failure	Failure	Failure	Failure
5	0.83	1.282	1.383	0.754
6	1.528	1.919	1.301	0.943
7	1.472	1.396	1.624	0.964
8	1.96	2.202	1.584	0.94
9	1.0	1.065	1.71	0.968
10	1.696	1.519	1.089	0.557
11	2.033	2.124	1.487	1.184
12	1.329	1.51	1.299	0.664
13	Failure	Failure	Failure	Failure
14	1.541	1.721	1.901	1.002
14	0.797	1.394	1.527	0.431
16	0.495	1.211	1.156	Failure
17	0.977	1.283	1.367	1.144
18	1.724	0.94	1.358	0.549
19	0.906	1.759	1.919	1.066
20	2.192	1.72	2.597	0.405
21	Failure	Failure	Failure	Failure
22	1.283	1.633	1.779	1.05
23	1.649	2.29	1.344	1.069
24	1.563	1.49	1.853	0.618
25	1.983	1.773	1.563	1.052
26	1.333	1.485	1.212	1.061
27	0.693	1.576	2.269	0.662
28	1.8	1.35	2.081	1.181
29	1.565	1.138	2.162	0.797
30	1.156	2.119	1.348	0.738
31	1.491	1.38	1.231	0.597
32	1.767	1.218	1.889	1.005
33	1.375	1.559	1.261	0.757
34	1.383	2.02	1.439	0.664
35	1.262	2.524	1.262	1.167
36	Failure	Failure	Failure	Failure
37	1.899	1.681	2.304	0.996
38	1.678	1.147	1.902	0.923
39	1.833	1.505	1.767	1.113
40	1.616	1.476	1.827	0.914

Appendix D

Results obtained from sandblasted stainless steel bands

Tooth	Tensile force in MegaPascals			
	Zinc oxyphaosphate	Polycarboxylate	Glass ionomer	Hybrid cement
1	1.449	1.627	1.446	0.512
2	2.188	1.813	1.719	1.469
3	0.27	1.976	1.078	0.898
4	Failure	Failure	Failure	Failure
5	1.232	1.307	2.162	1.358
6	1.528	2.081	1.626	1.041
7	1.117	1.7	1.954	1.32
8	1.396	1.423	1.128	0.859
9	0.968	1.742	1.807	1.097
10	0.987	0.987	1.823	0.886
11	2.185	1.366	1.669	1.821
12	1.812	1.963	1.812	1.299
13	Failure	Failure	Failure	Failure
14	2.131	1.515	1.849	0.95
14	0.763	1.361	2.622	0.465
16	1.541	1.734	1.761	Failure
17	0.921	1.367	1.144	0.586
18	1.254	1.332	1.463	1.175
19	1.439	1.679	2.105	0.533
20	1.821	1.45	2.091	1.349
21	Failure	Failure	Failure	Failure
22	1.429	1.867	1.633	0.846
23	2.077	1.71	1.985	1.588
24	2.617	1.054	1.999	1.018
25	1.533	1.773	1.352	1.232
26	1.636	1.576	1.424	0.485
27	2.017	2.08	1.261	0.851
28	2.025	0.928	1.294	1.069
29	1.849	1.337	1.707	0.939
30	1.701	1.509	1.862	0.77
31	1.715	1.79	1.79	2.126
32	1.98	1.188	1.797	0.914
33	1.146	1.33	1.032	0.504
34	1.854	1.715	2.103	1.024
35	2.145	2.366	1.893	1.64
36	Failure	Failure	Failure	Failure
37	1.308	1.339	1.681	1.37
38	0.587	1.510	1.678	1.4
39	2.094	1.898	1.8	2.127
40	2.249	1.792	2.108	1.898

Author Retief V
Name of thesis Bond Strengths Of Four Different Dental Cements - An In Vitro Study Retief V 1999

PUBLISHER:
University of the Witwatersrand, Johannesburg
©2013

LEGAL NOTICES:

Copyright Notice: All materials on the University of the Witwatersrand, Johannesburg Library website are protected by South African copyright law and may not be distributed, transmitted, displayed, or otherwise published in any format, without the prior written permission of the copyright owner.

Disclaimer and Terms of Use: Provided that you maintain all copyright and other notices contained therein, you may download material (one machine readable copy and one print copy per page) for your personal and/or educational non-commercial use only.

The University of the Witwatersrand, Johannesburg, is not responsible for any errors or omissions and excludes any and all liability for any errors in or omissions from the information on the Library website.