

Push out strengths of a double tapered post system with 3 different cements

Dr Alwyn Fortuin
Student Number: 2380863

A mini-thesis submitted in partial fulfilment of the requirements for
the degree of Magister Chirurgiae Dentium (MChD) in the
Department of Restorative Dentistry, Faculty of Dentistry,
University of the Western Cape.

UNIVERSITY of the
WESTERN CAPE

Supervisor: Dr N. Patel

Co-supervisors: Professor S. Grobler and Dr R. Rossouw

October 2012

Declaration

I, Alwyn Fortuin, declare that the work contained in this research report is my own original work. I have not previously submitted this research report to any university or institution for a degree or examination.

Alwyn Fortuin

_____ Day of _____ of 2012



Acknowledgements

I would like to thank my supervisors, family and friends for their involvement in making the completion of this work possible.

Sincere thanks to my mentor, supervisor and friend, Dr Naren Patel, who supported me throughout my undergraduate and postgraduate academic career.

Special thanks to the following individuals for their input and time:

- Professor Y. Osman: Financial assistance
- Dr T. Kotze: Statistical analysis
- Professor S. Grobler: Testing of samples and statistical interpretation
- Dr R. Rossouw: Testing of samples
- Ms M. Klink: Overseeing academic writing



Dedication

I dedicate this work to my wife, best friend and teacher, Marghreette. Your belief and support throughout my academic career made everything possible.



Abstract

Aim: The aim of the study was to determine which of the three resin cements would produce the highest debond stress values with a double-tapered fibre post system.

Background: In the past, conventional parallel- sided prefabricated or cast metal posts have been used, which has considerable mechanical strength but lacks aesthetic capabilities. Post preparation techniques usually compromise the fracture strength of the treated anterior tooth. Double- tapered post systems ensure that anterior mutilated teeth can be restored and retained without compromising aesthetics or excessively weakening the remaining dental tissues.

There are in-vitro results that support the strength of the double- tapered design, as well as the aesthetics of the material but there is little evidence regarding the retentive capabilities of the posts and which cement will ensure the best results (Grandini et al., 2008; Nakamura et al., 2005). Literature suggests that the two main causes for failure of a post system are root fracture and debonding of the post in the root canal (Toman et al., 2009; Radovic et al., 2008). The type of cement and cementation technique will have a significant influence on the treatment success of post and core restorations. This study compared the debond stresses required to remove a double- tapered post system from a prepared post space with 3 different cements to assess which cement will be most resistant to the post debonding.

Methods: Thirty maxillary central incisors were endodontically treated and randomly divided into three groups of ten teeth each according to the cements used. Group 1 consisted of teeth cemented with RelyX Ultimate (3M ESPE); Group 2 consisted of Calibra (Dentsply) and Group 3 consisted of Panavia F2.0 (Kuraray). The teeth were sectioned in 2mm slices to obtain one slice in the coronal, middle and apical areas of each tooth. A thin slice push- out

test with the use of a Zwick 1446 universal testing machine was performed on coronal, middle and apical sections of each tooth per group to assess the de-bond stresses required to dislodge the post from the specimens. The relevant data was interpreted with ANOVA (Tukey Kramer test) on a 5% basis ($p \leq 0.05$). The mode of fracture was analysed with a stereomicroscope under 45 times magnification.

Results: RelyX Ultimate (3M ESPE) produced significantly higher median de-bond stress values ($p < 0.05$) in the overall performance of the cement (8.82 MPa), as well as in the coronal (8.18MPa), middle (9.4 MPa) and apical (8.52MPa) sections of the teeth compared to Calibra (Dentsply Caulk) for the overall performance of the cement (1.2 MPa) as well as the coronal (2.45 MPa), middle (0.99 MPa) and apical (0.66 MPa) sections. Panavia F2.0 (Kuraray) produced significantly lower median de-bond stress values ($p < 0.05$) than RelyX Ultimate (3M ESPE) for the overall performance of the cement (2.57MPa) as well as the coronal (2.77MPa), middle (2.35MPa) and apical (2.21 MPa) sections. Panavia F2.0 (Kuraray) produced higher values than Calibra (Dentsply Caulk) but the difference was not statistically significant ($p > 0.05$).

Conclusion: RelyX Ultimate (3M ESPE), which is a self-etching adhesive resin cement, produced the highest debond stress values.

Keywords: push out test, double-tapered post, dental cements, retentive failure.

Contents

Declaration	i
Acknowledgements	ii
Dedication	iii
Abstract	iv
Table of contents	vi
Chapter 1: Introduction and literature review	1
1.1. Introduction	1
1.2. Statement of the problem	1
1.3. Literature review	3
1.3.1 Introduction	3
1.3.2. Classification of endodontic posts	5
1.3.2.1. Active and passive post systems	5
a) Active posts	6
b) Passive posts	6
1.3.2.2. Metal- free post materials	7
a) Ceramic materials	8
b) Composite materials	9
1.3.3. Properties of an ideal post material for anterior teeth	11
1.3.3.1 Fracture resistance of different post materials	11
1.3.3.2. Stress distribution of post materials in anterior teeth roots	12



1.3.3.3. Effect of post material on post removal	13
1.3.4. Comparison of different fibre posts	14
1.3.4.1. Mechanical properties	14
a) Flexural strength comparison	14
b) Fatigue resistance of different post system	15
1.3.4.2. Post design	16
1.3.5. Classification of dental cements	18
1.3.6. An overview of resin cements	20
1.3.6.1. Etch and rinse adhesive (total etch technique)	20
1.3.6.2. Self-etch adhesives	21
1.3.6.3. Self-adhesive cements	22
1.3.7. Discussion of the cements	22
1.3.7.1. RelyX Ultimate (3M ESPE)	22
1.3.7.2. Calibra (Dentsply Caulk)	24
1.3.7.3. Panavia F2.0 (Kuraray)	25
1.3.8. Cement-dentine interface	26
1.3.8.1 Ethylenediaminetetracetic acid (EDTA) treatment	27
1.3.8.2 Ethanol application	27
1.3.9. Post- cement interface	28
1.3.10. Conclusion	30
Chapter 2: Materials and Methodology	31



2.1. Aim of the study	31
2.2. Objectives	31
2.3. Study design: In vitro study	31
2.3.1. Teeth preparation	31
2.3.2. Cementation technique	33
2.4. Push out test	37
2.5. Microscopic analysis	39
2.6. Data analysis	40
Chapter 3: Results	41
3.1. Comparative de-bond stress values between all cements	41
3.2. Comparative de-bond stress values between coronal sections of the cements	45
3.3. Comparative de-bond stress values between middle sections of the cements	48
3.4. Comparative de-bond stress values between apical sections of the cements	51
3.5. Summary of the results	54
3.6. Microscopic evaluation	55
Chapter 4: Discussion	59
4.1. Influence of bonding system relative to strength of cement	60
4.2. Influence of application technique relative to strength of cement	61
4.3. Strength of cements relative to root section	63
4.4. Analysis of interface of failure	64

4.5. Shortcomings of study	65
Chapter 5: Conclusion	67
References	68
Appendix A: Raw data	72
Appendix B: Material specifications	76
Appendix C: Ethical clearance certificate	77

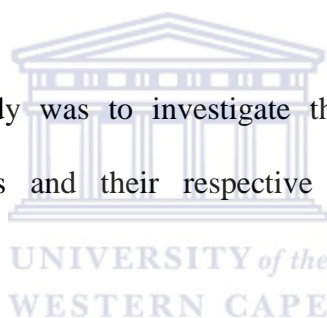


Chapter 1: Introduction and literature review

1.1. Introduction

Technological developments in contemporary dentistry did not only simplify the replacement of lost teeth with the use of implants, but provided clinicians with several options to restore teeth with severe loss of tooth structure. Adhesive technology and improvement in materials to restore teeth made it possible to retain teeth, which were previously deemed as having a hopeless prognosis.

Therefore, the aim of this study was to investigate the retentive capabilities of three commercially available cements and their respective adhesive approaches.



1.2. Statement of the problem

Loss of teeth in the anterior aesthetic zone leads to bone resorption and treatment methods to mimic or replace lost hard tissues are either unpredictable or lack aesthetic replication. Currently, clinicians aim to preserve anterior teeth for as long as possible. This often includes root canal treatment, as well as post and core management with an extra coronal restoration. The double-tapered post design and preparation technique is aimed at minimal removal of dentine in the root canal space, therefore ensuring bulk thickness of the apical dentinal walls of the canals.

The retentive capabilities of posts are crucial to prevent failure of the restoration. Push out strength tests are used to determine the retentive capabilities and adhesive strength of cements in dentine. Currently, different cements and cementation techniques are advocated to prevent post de-bonding. There is no clear evidence on which cement would produce reliable and predictable results clinically.

In the current study, the adhesive properties of a total-etch adhesive cement (Calibra, Dentsply) was compared with cements which are classified as self-etching adhesive cements (RelyX Ultimate, 3M ESPE and Panavia F2.0, Kuraray) to verify which system provided the best retentive capabilities with a double tapered post system.

It is imperative to understand that a true clinical simulation of teeth in the oral environment and forces subjected during mastication on the interaction of the post, cement and root during function is not possible. The results lead to a discussion on adhesion and adhesive systems and explain to clinicians the qualities necessary to increase long term reliable clinical outcomes.

1.3. Literature Review

1.3.1 Introduction

The recent developments in surgical and prosthodontic treatment techniques (implants) have made the replacement of missing teeth less complicated than in the past, but it is still universally accepted that the patient's natural dentition should be retained if the prognosis is acceptable (Roda and Gettleman, 2006). The reasons for the authors' statement are twofold. Firstly, the major difference between teeth and implants is the amount of micromovement permitted by the periodontal ligament complex present in natural teeth and the ankylosed nature of implants (Tiosso et al., 2011).

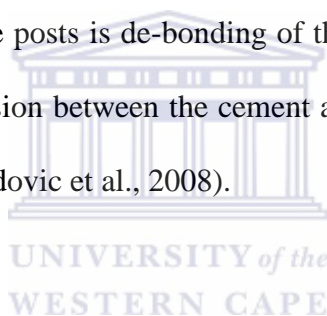
Secondly, implant therapy in the maxillary aesthetic zone presents several challenges due to the pre-existing anatomy which comprises the tissue changes that commence after the loss of the tooth to be replaced (Buser, Martin and Belser, 2004).

Endodontic treatment and subsequent restoration can be deemed as the last viable treatment option to retain a compromised tooth. Any deterioration after this treatment usually leads to the removal of the tooth and replacement with a prosthesis or implant therapy.

There is uncertainty concerning restorative techniques to ensure longevity of the remaining dental tissue after endodontic treatment has been performed. Endodontically treated teeth are usually more brittle and prone to fracture. In the past, the most accepted restorative option has

been the cast metallic core because of its inherent ability to fit into the treated canal its toughness. However, this restorative option creates undesirable stress concentrations generated inside the apical region of the tooth due to its rigidity (De Castro Albuquerque et al., 2003). These stress concentrations lead to an increased likelihood of unfavourable root fractures. To alleviate this complication, fibre posts with an elastic modulus close to dentine and a high flexural strength were developed. These characteristics ensure an even distribution of forces on the tooth and strengthen the core restoration (Galhano et al., 2005).

Although fibre posts are a capable replacement to metallic posts, they have the ability to fail. The main cause of failure of fibre posts is de-bonding of the post in the prepared post space. This is due to the failure of adhesion between the cement and the dentine as well as between the post and cement interface (Radovic et al., 2008).



The key factor for clinical success of fibre posts is resistance to displacement. The thin slice push out test is designed to measure the displacement resistance of cemented posts by expressing the total de-bond stress required to dislodge the post from the bonded post space. Other methods to analyse this interface, like the pull out test, measure tensile forces rather than shear forces due to a parallel load on the post. This is why this method better simulates clinical situations because a post is usually de-bonded by a single compressive load (Toman et al., 2009).

1.3.2. Classification of endodontic posts

There are several diverse classification systems for posts. Posts can be classified as active or passive, parallel or tapered and by material composition (Scwartz and Robbins, 2004). For the purpose of this study, posts will firstly be classified, after which metal-free-post systems will be classified according to the material it is fabricated from.

1.3.2.1. Active and passive post systems

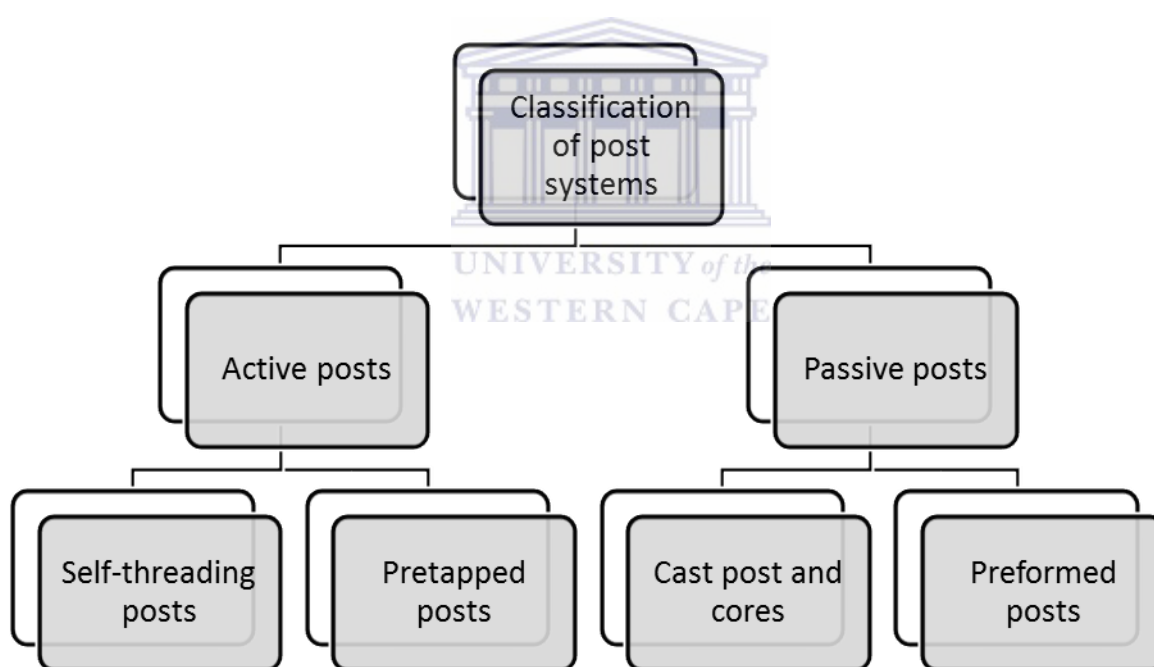


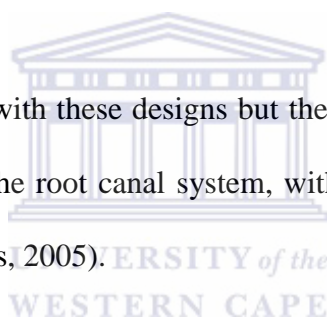
Figure 1: Classification of post systems according to retentive mechanism (Scwartz and Robbins, 2004)

a) Active Posts

Self-threading and pretapped posts

Self-threading posts have an active cutting thread that cuts the root canal wall as it is screwed into the canal. This design requires that the post diameter be larger than the canal. The post is secured into the canal by using an instrument with a cutting thread to prepare the root dentine. The post is then inserted into the canal by following the thread pattern that was created by the instrument (Helvey, 2009).

The post retention is maximised with these designs but the stresses generated with the use of these systems are severe within the root canal system, with subsequent susceptibility to root fracture (Rickets, Tait and Higgins, 2005).



b) Passive posts

i. Cast Post and Cores

Balkenhol et al. (2007) conducted a 10 year retrospective longitudinal study on the survival rates of cast post and cores. They prepared the root canals of endodontically treated teeth with a post preparation kit. Root canal filling material was removed until 3-4mm of the material was left in the apex of the root. A plastic burnout post was used to take the impression, which was cast in die stone for the fabrication a post and core in a dental laboratory. The authors

concluded in their study that this technique has a good success rate with loss of retention as the most frequent reason for failure.

The disadvantages of this technique are that more clinical visits are required, the use of laboratory procedures, higher costs and additional healthy tooth structure removal to eliminate undercuts when compared to the use of prefabricated posts with core build ups. (De Castro Albuquerque et al., 2003).

ii. Preformed posts

This post design is dependent on cement for retention and is less retentive than the active posts but induces less stress on the root during function. Passive posts have different shapes and surface characteristics to enhance their retentive capabilities (Terry and Swift, 2010). Preformed or prefabricated passive posts can further be divided into metallic and non-metallic posts. They add that the metallic materials used for prefabricated posts are mainly titanium alloys and stainless steel while there is a much larger variety for non-metallic or metal free posts (Toman et al., 2009).

1.3.2.2 Metal- free post materials

A revised classification of metal free posts was introduced by Mayur and Suzeschandra (2010) and is described as follows:

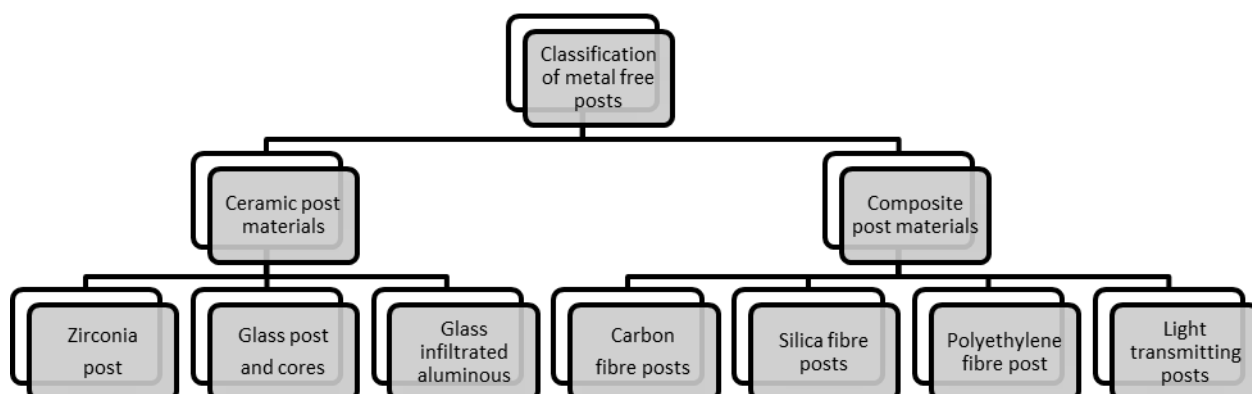


Figure 2: Classification of metal free posts (Mayur and Suzeschandra, 2010)

a) Ceramic materials

Posts made from ceramic materials are characterised by their fracture resistance, strength and aesthetics (Cheung, 2005). Despite this advantage, this group of posts have several shortcomings. The material is not as fracture resistant as metal and therefore require larger diameter posts, which entails aggressive post preparations (Schwartz and Robbins, 2004). The inelastic nature of zirconia posts is more likely to cause root fractures when compared to fibre posts (Goracci and Ferrari, 2011).

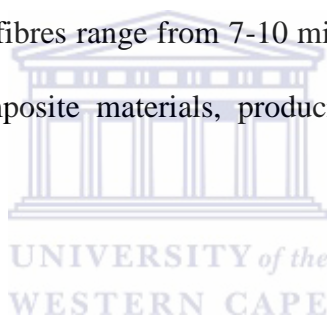
The polycrystalline ceramics, like zirconia, also have the inability to bond to composite core materials and form a weak bond with resin cements (Schwartz and Robbins, 2004). This aspect deems the restoration vulnerable from a long term perspective when it is subjected to occlusal forces (Schwartz and Robbins, 2004). Another complication of this material is that ceramic posts can only be removed with a bur if the tooth requires retreatment, which is a

tedious process that can lead to dentinal damage and subsequent root perforation (Schwartz and Robbins, 2004). Examples of zirconia posts are the Snowpost (Danville) and the Cosmopost (Vivadent) (Schwartz and Robbins, 2004).

b) Composite materials

i. Carbon fibre posts

These posts consist of carbon fibres embedded in a polymer resin matrix, most commonly epoxy resin. The diameter of the fibres range from 7-10 micrometers. The posts in this group were fabricated to bond to composite materials, producing a solitary unit with the root (Cheung, 2005).



The carbon reinforced posts have an elastic modulus close to dentine but the dark hue of the post influenced the aesthetics of the core material when this post system is used. Retrieval of the post for retreatment is relatively simple as well (Schwartz and Robbins, 2004). An example is the Composipost [RTD, Grenoble, France] (Goracci and Ferrari, 2011).

ii. Silica fibre posts

This group was introduced to enhance the aesthetic capabilities of the core without compromising on the advantages of the carbon fibre posts. This was achieved by replacing the carbon fibres in the polymer matrix with white or translucent fibres with similar properties

(Schwartz and Robbins, 2004). The fibres usually consist of quartz, glass or silicon. Examples of these posts are DT Lightpost, VDW [Quartz]; Parapost White, Coltene Whaledent [Glass] and Aestheti-Plus, RTD/Bisco [Quartz] (Schwarz and Robbins, 2004).

iii. Polyethylene fibres

These fibres are extremely high in molecular weight and are coated with dentinal adhesive to facilitate post and core construction (Goracci and Ferrari, 2011). The fibres are moulded to assume the shape of the prepared canal. This characteristic facilitates stress distribution through the root of the tooth (Goracci and Ferrari, 2011). Ribbond (Ribbon Inc.) is an example of this system (Mayur and Surescendra, 2010).



iv. Light transmitting posts

This group was initially developed to facilitate the treatment of wide and flared canals with composite restorative materials (Mayur and Suzeschandra, 2010). The composite should be placed in the canal and the post is used to transmit the ultraviolet light down the canal space to ensure the composite is cured in the canal. The post is then retracted and a metal or fibre post with identical shape is subsequently cemented into the canal. The post is fabricated from plastic. An example is the Luscent Anchor [Dentatus] (Mayur and Suzeschandra, 2010).

1.3.3. Properties of post materials for anterior teeth

The following section will review the properties of post materials used in the restoration of anterior teeth and will specifically focus on fracture resistance of posts and the implications thereof. Stress distribution of different materials to the remaining tooth structure will be discussed and post removal techniques in relation to the material will be reviewed.

1.3.3.1 Fracture resistance of different post materials

A comparative study was conducted by Padmanabhan (2010) between metal, carbon fibre posts and ceramic posts with parallel walls to determine the fracture resistance and location of fracture on endodontically treated maxillary central incisors when subjected to a simulated chewing device until a fatigue point is reached. He defined a favourable fracture as a fracture above the resin block in which the teeth was embedded (which represented the alveolar bone) thus producing a coronal fracture; he defined an unfavourable fracture as one below the resin level. He found that the parallel sided metal post was much more resistant to fracture, followed by the carbon fibre post and the ceramic post, which had significantly very low fracture resistance than the previously mentioned materials. The author does add however, that all the fractures of the metal posts were unfavourable while the carbon posts were favourable coronal fractures, which deemed the tooth restorable in comparison to the likelihood of root fractures in metal posts.

Nakamura et al. (2005) concur with this study and add that vertical root fractures are deemed a major complication with endodontically treated anterior teeth which in many cases lead to

the loss of anterior teeth. They claim that fibre reinforced posts reduce the likelihood of root fractures due to their modulus of elasticity, which is similar to that of dentine, which ultimately decreases stress in the root by evenly distributing stress along the root. This factor leads to the following property of an ideal post material: stress distribution in the roots of anterior teeth.

1.3.3.2. Stress distribution of post materials in anterior teeth roots

In a study by De Castro Albuquerque et al. (2003), the finite stress analysis technique was used to determine the influence of post shapes and post materials on the roots of endodontically treated incisors. The different materials, stainless steel, titanium and carbon fibre, were tested in a bisphenol-a-glycidyl methacrylate (Bis-GMA) matrix in different post designs (tapered, cylindrical and two stepped cylindrical). They applied a static load of 100N at a 45 degree angle to the vertical axis of the tooth on the palatal aspect and used an unprepared tooth as control. They concluded that the post shape did not produce any significant changes within this study but the post material made a substantial difference. They found that stainless steel post generated the most stresses, followed by titanium posts and carbon posts generating the least stresses (145% less than stainless steel) when loaded.

1.3.3.3. Effect of post material on post removal

There are three steps involved in the removal of a metal prefabricated or cast post: exposure of the post from the core and isolating the post, reduction of retention of the post with ultrasonic instruments and retrieval of the post with a post removal kit. However, this procedure is much easier described than implemented. During post exposure there is a possibility of thinning the coronal tooth structure with subsequent weakening of the tooth, root perforation during ultrasonic troughing and post fracture or root fracture when a post removal kit is used (Roda and Gettleman, 2006).

The most effective way of removal of an aesthetic post is to use the system supplied by the manufacturers of a specific post system. In a study by Lindemann et al. (2005), the efficiency of the ruddle system, ultrasonics and manufacturers systems were compared in the removal of Parapost Fiber White (Coltene/Whaledent), Luscent Anchors (Dentatus) and Aesthetiplus (RTD/Bisco) posts. They claim that the removal kits of the manufacturers were most efficient in the removal of the fibre posts the quickest, although the other systems were effective as well. They add that additional troughing removed any additional fibers that remained in the canals. The heat generated by the tips of the removal bur and the parallel nature of the fibres make retrieval simple (Roda and Gettleman, 2006).

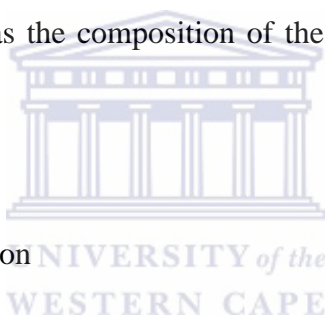
Stiffer materials have a higher modulus of elasticity which increases the risk of unfavourable fractures in teeth. This is not an exclusive characteristic to metal posts but includes ceramic posts, especially zirconia posts (Toman et al., 2009).

1.3.4. Comparison of different fibre posts

Since fibre posts are an aesthetic and feasible substitute for metal posts, a diverse range of fibre posts have flooded the market. The following section will discuss the mechanical properties and design principles of a fibre post (Grandini et al., 2008).

1.3.4.1. Mechanical properties

To evaluate the mechanical properties of posts, the flexural strength and fatigue resistance need to be investigated, as well as the composition of the fibre post that brings about these characteristics.



a. Flexural strength comparison

Galhano et al. (2005) evaluated the flexural strength of eight different fibre posts with the use of the three point bending test to determine which one has the highest flexural strength. They add that all the posts had a similar modulus of elasticity close to that of dentine. The posts were the C-post, Bisco (carbon fibre post), Aestheti post, Bisco (carbon fibre and quartz post), Aestheti plus, Bisco (opaque quartz fibre post), Light-post, Bisco (translucent quartz fibre post), D.T. Light post, Bisco (translucent quartz fibre post), Parapost White, Coltene (glass fibre post), Fibrekor, J Pentron (glass fibre post) and Reforpost, Angelus (glass fibre post).

Ten posts were tested in each group and the results were as follows: Aestheti posts had the highest flexural strength followed by the Aestheti plus post and the C-Post respectively. The D.T. Light post and the Light-post was almost identical and presented weaker values than the C- Post, but there was no statistically significant difference between these three groups or the Parapost Fibre White and the FibreKor. They explained that the amount of quartz fibres used for the Aestheti plus post and the D.T. Light post as well as the Light-post groups were similar, but the resin matrix was different (one opaque and the other translucent). They add that the C-post has a similar resin matrix to Aestheti plus post which explains the success of these groups. They concluded from these findings that the flexural strength of the post is dependent on the resin matrix and its bond to the fibres and not the fibre type.

b. Fatigue resistance of different post systems

Grandini et al. (2008) analysed the fatigue resistance of six post types by cyclic loading of 2 million cycles or fracture. The six post types were GC fibre post (double tapered post, 2mm diameter), Parapost Fibre white (cylindrical with serrations, 1,5mm diameter), FibreKor (cylindrical with serrations, 1,5mm diameter), D.T. Light post radio opaque (double tapered post, 2mm diameter), FRC Postec and Luscent Anchors (conical, 1,7mm diameter).

Ten posts in each group were tested. They found that the GC fibrepost and D.T. Light post did not have any failures after 2 million cycles followed by FRC Postec, which had one post failure but also had posts that resisted 2 million cycles.

They report that the number of fibres in the resin matrix definitely plays an important role in fracture resistance but more importantly, is the adhesion between the matrix and the fibres. They state that the reason for the success of the GC post and the D.T. Light Post is the manufacturing process whereby the fibres are prestressed, impregnated in resin and then cured. They add that FibreKor has high fibre content but the double tapered post design plays a significant role in the strength of the post compared to the conical design of FibreKor posts.

They further state that any sudden changes in the post morphology, like serrations on the surface, elicit a potential fracture area, which explains why the serrated posts had such a poor fatigue resistance. Homogeneity in design also plays a significant role in fracture resistance.

1.3.4.2. Post design

The passive fit of parallel posts were acceptable but the shape of the post necessitated over preparation of the apical third and the coronal portion of the canal usually had space due to the funnel shaped characteristics of a root canal preparation. This is the reason behind the development of tapered posts (Boudrais, Sakkal and Petrova, 2001).

They add that the development tapered posts were driven by the relatively uniform (2%) taper found at the apical third of most canals. The problem that existed was that these posts significantly obliterated the canal in the apical portion, but due to the coronal flaring of canals, there was very little contact with the coronal portion of the canal walls (Boudrais, Sakkal and Petrova, 2001).

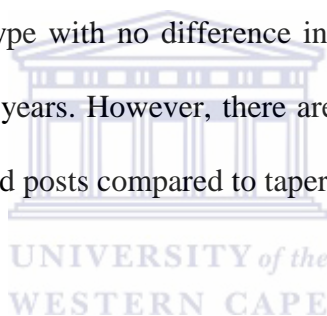
After reviewing the shortcomings of different post designs, Boudrais, Sakkal and Petrova, (2001) conducted a study to determine which post design will best suit the configuration of an endodontically treated tooth. They explain that 967 extracted teeth were divided in 11 categories and with the use of rotary instrumentation and conventional hand instrumentation; all the teeth were endodontically prepared. The amount of taper was measured and lead to the fabrication of 22 DT post prototypes. The authors tested the adaptation of these posts by cementing the posts in 367 extracted teeth which were further divided in 2 groups. Group 1 was sectioned sagittally and Group 2 was sectioned transversely and analysed for adaptation. After this evaluation, only 3 posts designs were regarded as appropriate for clinical use.

The double-tapered design makes sense because the post will intimately contact the coronal third, middle third and apical third of the canal, in comparison with parallel posts that had intimate contact with middle third and apical third with over preparation of the apical portion, and the tapered post which also had the same contact (middle third and apical third) but with less preparation due to the tapered design. This design (double-taper) should also lead to less root dentine removal. There are several clinical studies that compare tapered to parallel posts and their results are similar. These studies will be discussed in the following section.

Signore et al. (2009) conducted an 8 year retrospective study to determine the success rate of parallel compared to tapered glass fibre posts in maxillary teeth covered with full ceramic crowns with composite resin cores. The survival rate of the parallel posts was 98.6% and the

tapered posts was 96,8% with debonding of the post, being the complication in most cases. The reason could be that tapered posts were selected for most of the lateral incisors (98) compared with only a few (24) parallel posts for the same teeth. They concluded that both systems were viable options for post and core treatment and that there was no real difference in clinical performance between the two systems.

Naumann, Blankenstein and Dietrich (2005) conducted a 2 year prospective study comparing the success rates of tapered and parallel glass fibre reinforced posts with composite cores and found that two years after placement, they had an equal rate of survival. They report that post fractures were the main failure type with no difference in frequency of failure: 3,8% failed after a year and 12,8% after two years. However, there are no long- term clinical studies on the survival rates of double-tapered posts compared to tapered and parallel post designs.



1.3.5. Classification of dental cements

There is no set criteria in the classification systems used in the literature (Sumer and Deger, 2011). They summarised some of the classifications identified in their literature review on permanent luting cements as follows: they reported that Craig categorised cements according to their main ingredient; O'Brien classified cements according to their matrix bond type; Donovan compiled a classification by separating the cements in a conventional (Zinc Phosphate, Polycarboxilate and Glassionomer) and contemporary (Resin- modified glassionomers and Resins) founded on the clinical use of the materials. Simon and Darnell (2012) simply classified cements according to their type and use (table 1):

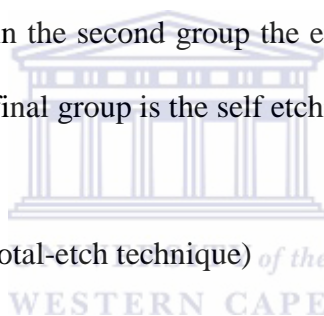
Types of dental cements and their application	
Type of cement	Application
Zinc phosphate	Cast alloy crown and bridge Ceramo-metal crown and bridge High-strength ceramic Cast metal posts
Zinc polycarboxylate	Cast alloy crown and bridge Ceramo-metal crown and bridge
Resin-modified glass ionomer (RMGI)	Cast alloy crown and bridge Ceramo-metal crown and bridge High-strength ceramic Implant-supported crown and bridge (Implant Restorations) Manufactured composites (Indirect)
Resin cement (dual- or self-cure)	All-ceramic crown and bridge, inlay, onlay, veneer Cast alloy crown and bridge Ceramo-metal crown and bridge High-strength ceramic Implant-supported crown and bridge Manufactured composites (Indirect) Fiber Posts Cast metal posts

Table 1: Classification of dental cements

1.3.6. An overview of resin cements

The constituents of resin cements are a mixture of polymerisable monomers of methacrylates, dimethacralates and polymethacrylates, which is comparable to the chemical make-up of composite restoration materials. The major difference between the two is the lesser amount of filler particles included in the chemistry of resin cements (Simon and Darnell, 2012).

The cementation methods used to condition root dentine with modern cements can be divided into three groups (Radovic et al., 2008). The first group employs the etch and rinse adhesive methods or total-etch technique; in the second group the enamel and dentine are conditioned with self etching primers and the final group is the self etching adhesive cements.



1.3.6.1. Etch and rinse adhesive (total-etch technique)

This technique involves the use of an acid (etchant) to condition the dentinal surface prior to the application of a primer and adhesive or simultaneous application of both depending on the system used (Erdemir et al., 2011). The acid (etch) removes the debris in the root canal space that was formed during the preparation by demineralising the dentine.

Zhang et al. (2008) reports that this technique is most frequently used to ensure an uncontaminated dentinal surface, which enhances the bonding capabilities of the adhesives used prior to cementation.

One of the leading causes of post failure is the loss of retention due to ineffective removal of root canal sealing materials prior to cementation of the post in the post space (Scotti et al., 2012). The use of acid etchant is a tried and tested technique to eradicate the smear layer and facilitate the bonding process (Scotti et al., 2012).

1.3.6.2. Self-etch adhesives

These are adhesive systems that do not require etching prior to application of a primer. The primer consists of non-rinsing acidic polymerizable monomers that serve as a conditioner and primer. This group can further be divided into a two-step and one-step (one bottle) system. The two-step method consists of a self-etching primer application followed by the application of an adhesive resin, while the one-step systems consists of a combination of self-etching primer and adhesive resins (Erdemir et al., 2011).

This technique was developed to simplify cementation procedures by eradicating etching, rinsing and drying steps. It is not recommended to etch the dentine prior to self-etching primer application due to the risk of excessive demineralisation that will cause weak links in the hybrid layer (Zhang et al., 2008). Endodontic irrigants should be used to facilitate the removal of the smear layer created by instrumentation of the post space (Zhang et al., 2008).

1.3.6.3. Self-adhesive cements

This group of materials was developed to simplify the cementation procedure by eradicating additional steps for the clinicians. These materials consist of acidic and hydrophilic monomers that have the unique chemical capabilities to condition, infiltrate and bond to enamel and dentine (Erdemir et al., 2011).

Onay, Korkmaz and Kiremitchi (2009) explain that the positive elements of various cements were combined into a single product so as to simplify cementation procedures.

1.3.7. Discussion of the cements



The following section will discuss the 3 different cements which were evaluated under laboratory conditions with a push-out strength test.

1.3.7.1 RelyX Ultimate (3M ESPE)

Composition

This cement consists of 2 pastes. The base paste contains methacrylate monomers, radioopaque silanated fillers, initiator components, stabilizers and rheological additives. The catalyst paste is made up of methacrylate monomers as well as radio-opaque alkaline fillers, initiator components, stabilizers, pigments rheological additives, fluorescence dye and a dark cure activator to couple with Scotchbond universal adhesive. The cement is dispensed with an

automix syringe and a unique delivery tip to ensure application of cement in the apex of the post preparation with a prescribed ‘back fill’ expression of the material to prevent air bubble entrapment (3M ESPE, 2012a).

Scotchbond Universal

This is a one bottle self etch adhesive system that contains ethanol, 2-hydroxyethyl methacrylate, 10-Methacryloyloxydecyl dihydrogen phosphate (MDP), dimethacrylate resins, patented copolymers, fillers, water, initiators and silane (3M ESPE, 2012a).

Indications

The cement system is used for cementation of indirect esthetic restorations fabricated from porcelain, all types of ceramics (oxide ceramics included), composite as well as porcelain fused to metal restorations and indirect metal restorations, endodontic posts and cementation of restorations to implant abutments (3M ESPE, 2012a).

Shades

There are four shades available, translucent, bleach 0.5, A1 and A3 opaque (3M ESPE, 2012a).

1.3.7.2. Calibra (Dentsply Caulk)

Composition

The base consists of Bis-GMA/Triethylene Glycol dimethacrylate resins, barium boron fluoroalumino silicate glass, polymerizable dimethacrylate resin, titanium dioxide and hydrophobic amorphous fumed silica (Dentsply Canada Ltd, 2005).

The catalyst contains Bis-GMA Triethylene Glycol dimethacrylate resins, benzoyl peroxide, stabilizers, glass fillers and amorphous silica. This product is recommended to be used only with Prime and Bond NT for ideal results (Dentsply Canada Ltd, 2005a;b).

Prime and Bond NT (Dentsply)

The manufacturer recommends that 34% tooth conditioner gel by Dentsply Caulk should be utilised prior to application. The composition consists of di- and trimethacrylate resins, PENTA (dipentaerythritol penta acrylate monophosphate), photoinitiators, stabilizers, nanofillers (amorphous silicon dioxide cetylamine hydrofluoride) and acetone (Dentsply International Inc., 2005b).

Indications

The product can be used to adhesively cement ceramic (oxide ceramics), porcelain and composite crowns, inlays, onlays, veneers, all metal crowns, bridges, PFM crowns and bridges, prefabricated and cast posts as well as resin-bonded retainer bridges (Dentsply International Inc., 2005a).

Shades

Five shades are available: translucent, light, medium, dark and opaque (Dentsply International Inc., 2005a).

1.3.7.3 Panavia F2.0 (Kuraray)

Composition

Paste A contains 10-methacryloyloxydecyl dihydrogen phosphate (MDP), hydrophobic aromatic dimethacrylate, hydrophobic aliphatic methacrylate, hydrophilic aliphatic dimethacrylate, silanated silica filler, Silanated colloidal silica, dl-camphorquinone, catalysts and initiators. Paste B contains sodium fluoride, hydrophobic aromatic dimethacrylate, hydrophobic aliphatic methacrylate, hydrophilic aliphatic dimethacrylate, Silanated barium glass filler, catalysts, accelerators and pigments (Kuraray Medical Inc., 2010).

ED primer

This consists of two bottles which should be mixed together in equal amounts. Liquid A contains 2-hydroxyethyl methacrylate, 10- methacryloyloxydecyl dihydrogen phosphate, water, n- methacryloyl-5-aminosalicylic acid and accelerators. Liquid B contains n-methacryloyl-5- aminosalicylic acid, water, catalysts and accelerators (Kuraray Medical Inc., 2010).

Indications

The product can be used for the cementation of precious and semi-precious metal crowns, PFM crowns, bridges, inlays, onlays, porcelain restorations, composite restorations, ceramic-oxide restorations, veneers, Maryland bridges, cores and prefabricated posts as well as amalgam bonding (Kuraray Medical Inc., 2010).

Shades

Panavia F2.0 is available in 4 shades: TC (tooth colour), light, white and opaque (Kuraray Medical Inc., 2010).

1.3.8. Cement-dentine interface



There are two interfaces that determine successful retention of fibre posts namely: 1) the adhesive area between the cement and the dentine and 2) the area between the post and the cement. They reported that the weakest point in fibre post luting is the adhesion between the cement and dentine (Farina et al., 2011).

The two most popular techniques to improve adhesion to dentine are the treatment of the prepared canal with ethylenediaminetetracetic acid (EDTA) and the use of ethanol. The next section will explain the rationale for the use of these two agents and its influence on dentine.

1.3.8.1 Ethylenediaminetetracetic acid (EDTA) treatment

Scanning electron microscopy shows evidence that remnants of endodontic therapy materials and dentinal debris form a tough smear layer after post space preparation that influences the penetrative ability of adhesives and cements. Sodium hypochloride breaks down into sodium, chloride and oxygen after irrigation of the post space and oxygen inhibits the polymerisation of resin materials, therefore interfering with resin tag formation. The use of ethylenediaminetetracetic acid (EDTA) after sodium hypochloride irrigation is advocated to remove the oxygen and to prevent this complication (Zhang et al., 2008).

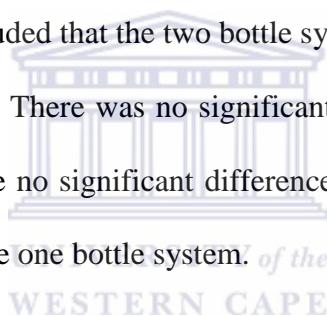
Rasimick et al. (2008) conducted a pull-out strength test with six different fibre posts with different post-space treatments to determine if the use of EDTA has a significant effect on post adhesion to root canal dentine. They concluded that a final rinse of EDTA did not improve the short- term retention of fibre posts.

1.3.8.2 Ethanol application

Carvalho et al. (2009) state that hydrophobic resins produce a more stable and durable long term bond to dental tissue, but residual water in conditioned dentine complicates the infiltration of hydrophobic monomers into the dentinal tubules to form a hybrid layer. They add that adhesive monomers are dissolved in water, ethanol and acetone. The purpose for this is to displace any residual wet dentine, prevent collapse of demineralised collagen fibrils and to facilitate the infiltration process of hydrophobic monomers.

Poggio et al. (2011) conducted a study to determine whether ethanol treatment of root canals before post cementation will improve bond strengths by facilitating adhesive infiltration in the dentine. They compared bond strength of fiber posts with and without treating the canal with ethanol prior to cementation with a single bottle total-etch system. They found that ethanol treatment of the post space did not influence the bond on the dentine.

Carvalho et al. (2009) compared the push-out bond strengths of ethanol treated post spaces with conventional total-etch techniques using a two bottle (separate primer and adhesive) and a single bottle system (primer and adhesive combined) with a dual cure cement with a two-step adhesive system. They concluded that the two bottle system had significantly higher bond strengths when ethanol was used. There was no significant difference between the groups in the one bottle system. There were no significant differences between the ethanol treated two bottle system and the groups of the one bottle system.



1.3.9. Post- Cement interface

The post-to-cement interface is a common cause of retentive failure in post systems (Zicari et al., 2012). Several treatment protocols of fibre posts have been prescribed by manufacturers prior to cementation. Fibre post surfaces are either micromechanically treated or chemically modified to enhance adhesion to cement. Micromechanical treatments involve sandblasting to roughen the surface. Chemical methods vary from acid etching the post, followed by the application of silane (Zicari et al., 2012).

Other methods involve coating the post with an adhesive. Another method to treat the post surface to enhance the bond strength to cement is the tribo-chemical coating process. This process involves the roughening of the surface area of the post with sandblasting, followed by the application of a silicate layer that is fused to the surface of the post (Zicari et al., 2012).

Rodig et al. (2010) conducted a push-out strength test evaluation to compare different pretreatment regimes for posts before cementation in a prepared post canal space. They used 80 D.T. Light posts and 80 FRC Postec Plus posts and divided them into sixteen groups with ten samples each. The posts were cemented with their corresponding advocated cements and divided into 4 groups: no treatment of the post, silanization, sandblasting and tribochemical coating. Forty D.T. Light posts were cemented with Calibra (Dentsply) and forty FRC Postec Plus were cemented with Variolink II (Ivoclar). The other posts were cemented with a third cement (Luxacore) and divided into the same groups as previously mentioned.

They concluded that a tribochemical coating of FRC postec with a self-etching adhesive compatible with Luxacore resulted in significantly higher bond strengths.

1.3.10. Conclusion

The technological advances in dentistry are astounding if the timeline of the literature is considered. Metal posts, which were regarded as the standard treatment modality, have been brought into question by a new material that underwent an evolution in the past years.

The advantages of fibre posts over metal posts are numerous in the anterior region of the mouth: a) it prevents root fractures, b) it shows favourable stress distribution over the root surface, c) it eases in retrieval and d) it has superior aesthetics.

Although the material and design of the post is essential, the adhesion to root canal dentine is of extreme clinical importance. The post and core should form a unified entity with the remaining root and tooth structure. This is achieved by the fibre post that elicits similar elastic properties as dentinal tissue, as well as adhesive capabilities of resin cements to form a monoblock entity. The latter not only mimics the natural tooth, but becomes fracture resistant. This can only be achieved with a durable, stable and effective bond between the post and the root. The ideal cement will have to present a predictable outcome with the least technique sensitive approach to eliminate a margin for error.

Chapter 2: Materials and Methodology

2.1. Aim of the study

The aim of the study was to determine which cement, RelyX Ultimate (3M ESPE); Calibra (Dentsply Caulk) or Panavia F2.0 (Kuraray), provided the highest displacement resistance value to a double tapered post system (DT post, VDW) when a push-out strength test was performed.

2.2. Objectives:

- To determine which cement requires the most push out force to remove the post from the prepared canal.
- To evaluate each specimen under a stereomicroscope to describe the interface of failure.



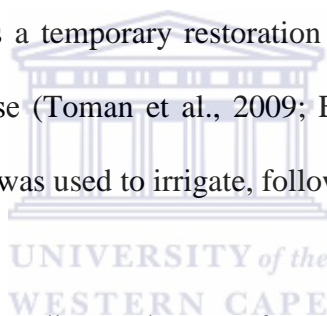
2.3. Study design: In vitro study

2.3.1. Teeth preparation

Ethical clearance for this project was obtained from the Senate Research Committee of the University of the Western Cape. Thirty freshly extracted maxillary central anterior incisors with fully closed apices were used, for which ethical clearance was obtained (Appendix C).

The teeth were extracted for periodontal reasons. Teeth with fractures and extensive damage beyond the cemento-enamel junction were excluded.

The teeth were sectioned below the cemento-enamel junction with a low speed diamond disc and the apical portions were removed to ensure a standardized root length of 14 mm (Toman et al., 2008). The teeth were instrumented with Protaper hand files (Dentsply) and irrigated with 2% sodium hypochlorite (Milton) (Farina et al., 2011). Obturation of the canal was done using the cold lateral condensation technique using Protaper gutta percha points (Dentsply) and AH Plus (Dentsply) root canal sealing cement (Onay, Korkmaz and Kremitci, 2009). Cavit (3M ESPE) was utilised as a temporary restoration while the teeth were stored in an aqueous solution at 37°C until use (Toman et al., 2009; Erdemir et al., 2011). During post preparation, sodium hypochlorite was used to irrigate, followed by a distilled water flushing.



The post spaces were prepared according to the manufacturer's instructions of D.T. Lightpost (VDW). The universal drill (D.T. Lightpost, VDW) was used to remove the gutta percha. This was followed with the red (1.25 mm) preparation drill. The yellow (1.8 mm) preparation was used afterwards. Final shaping was achieved with the blue (2.2mm) preparation drill. The preparation drills were changed after every 5 teeth to standardise the preparation and prevent dehydration and thick smear layers due to blunt drills. The root canals were cleaned with 2% sodium hypochlorite and were rinsed immediately with distilled water afterwards. The canals were dried with Protaper paper points (Dentsply).

The teeth were randomly divided into 3 groups and cemented strictly according to the manufacturers' instructions: Group 1: RelyX Ultimate (3M); Group 2: Calibra (Dentsply) and Group 3: Panavia F2.0 (Kuraray). After post cementation, the teeth were stored in saline for seven days at 37°C.

2.3.2. Cementation technique

RelyX Ultimate (3M ESPE)

a) Pre-treatment of fiber post

The post was cleaned with alcohol and air dried. A disposable applicator supplied by the manufacturer was used to agitate Scotchbond Universal Adhesive (3M ESPE) over the entire surface for 20 seconds. A gentle air stream was blown over the surface for 5 seconds.

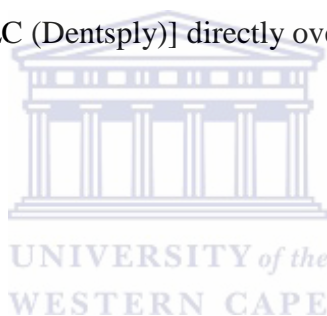
b) Application of adhesive

A disposable applicator was used to apply the adhesive to the entire tooth structure and it was agitated in for 20 seconds. An air stream was blown over the liquid for 5 seconds after which a paper point was used to remove any excess adhesive.

c) Application of cement

A customised endodontic application tip was used to disperse the cement in the canal by placing the tip as deeply as possible and applying the cement at the most apical region of the post space preparation. The tip was immersed in cement and slowly moved in a coronal direction while expressing the cement in the canal. The process was carried out slowly - 5-10 seconds - while the tip was slowly retracted from the canal. The post was placed in a rotating motion to prevent air bubble inclusion until the post was seated completely. The post was held in place with firm pressure followed by a 20 second light cure with a calibrated 650 watt halogen curing light [Demetron LC (Dentsply)] directly over the post.(3M ESPE, 2012b).

Calibra (Dentsply)



a) Preparation of root canal prior to cementation

The canals were etched with 34% Caulk tooth conditioner gel for 15 seconds and rinsed for 10 seconds. The canal and tooth was blotted dry without agitating with paper points.

b) Pre-treatment of fiber post

The post was cleaned with alcohol and air dried. Two drops of prime and bond NT were mixed with an equal amount of Self Cure Activator into a mixing well and mixed with a brush

tip. A single coat of the mixed bond was placed on the post, air dried for 5 seconds and subsequently light cured for 10 seconds.

c) Application of adhesive

The bond was applied to the post preparation with a generous amount entering the coronal part of the preparation, air-dried for 5 seconds and cured for 10 seconds. Excess was removed with paper points.

d) Application of cement

An equal amount of Calibra light base shade and regular viscosity catalyst was mixed for 20-30 seconds and applied to the post. The mixed cement was applied to the post space with a lentulo spiral as recommended by the manufacturer and the post was placed immediately afterwards with firm pressure until it was stable. The post was cured for 10 seconds to facilitate removal of excess cement. The post was cured for additional 20 seconds with a 650 watt halogen curing light [Demetron] (Dentsply International Inc., 2005a).

Panavia F2.0 (Kuraray)

a) Pre-treatment of fiber post

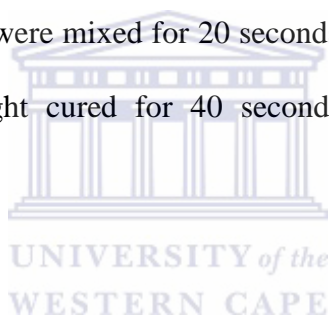
The post was cleaned with alcohol and air dried.

b) Application of adhesive

Equal amounts of ED primer II liquid A and B was mixed in the supplied mixing bowl and placed in the post space with a brush. A 30 second waiting period followed. The adhesive was air dried and excess was removed with a paper point, as per manufacturer's instructions.

a) Application of cement

Equal amounts of paste A and B were mixed for 20 seconds and applied to the post. The post was seated immediately and light-cured for 40 seconds (Kuraray Medical Inc., 2010).



2.4. Push- out test

All specimens were placed in a polyvinylsiloxane mould and clear autopolymerising resin was used to fabricate each specimen. These resin blocks facilitated the sectioning of the teeth into 2mm sections (figure 3) with a diamond saw (Minitom, Struers) under water cooling (Farina et al., 2011). The specimens were stored in marked bottles in distilled water at 37° C (Toman et al., 2009). Each slice was marked on the coronal side with a permanent marker and thickness measured with a digital calliper (0.01 accuracy) (Stihl) (Erdemir et al., 2011).

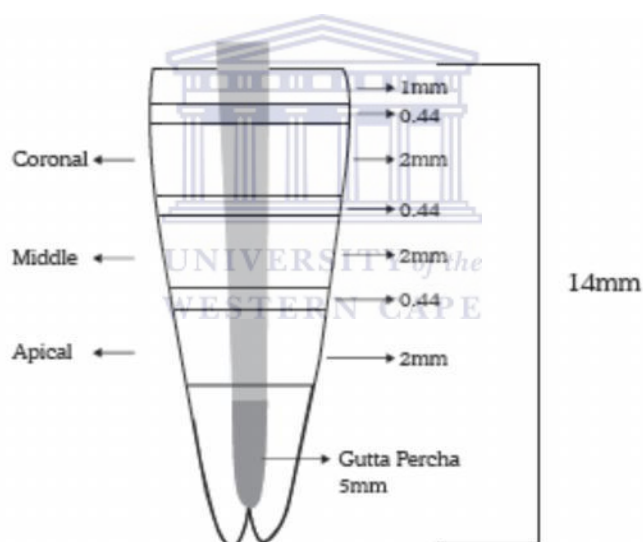


Figure 3: Schematic illustration of the preparation of the slices. (0.44 indicates the width of the blade)

A load was applied to the apical aspect of the slice with a universal testing machine (Zwick 1446) (Toman et al., 2009). A 1mm cylindrical plunger (figure 4) was utilised to apply a vertical load to the post. The plunger only contacted the post, without applying any shear stresses to the bonding surfaces. Loading forces were applied in apico-coronal direction in

order to move the post out to the wider diameter part of the root slice to prevent wedging of the post in the root space (Radovic et al., 2008). Loading was performed with a 0,5mm per minute speed until failure or expression of the post from the post space (Erdemir et al., 2011).

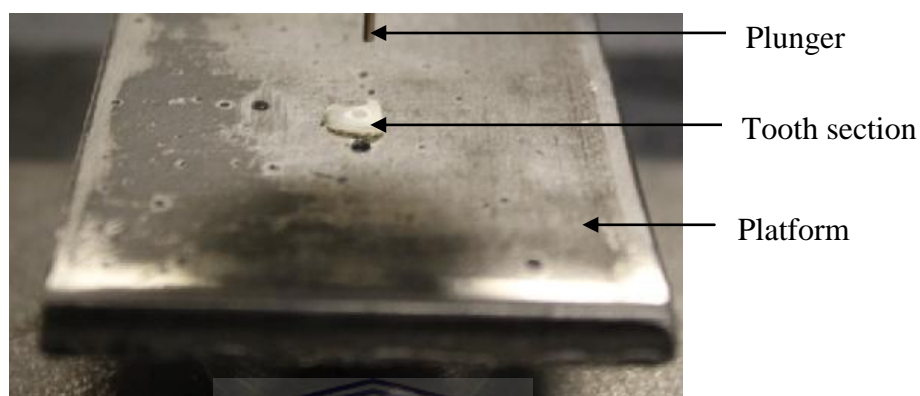


Figure 4: Illustrates the platform, plunger and tooth section

The debond force, which dislodged the post was recorded in Newton (N). The debond stress was calculated in megapascal (MPa) by dividing the debonding force (N) by the area of the post that was in contact with the tooth. This area was calculated by using the formula for surface area determination of a frustum (figure 5) due to the tapering shape of the post (Erdemir et al (2011)).

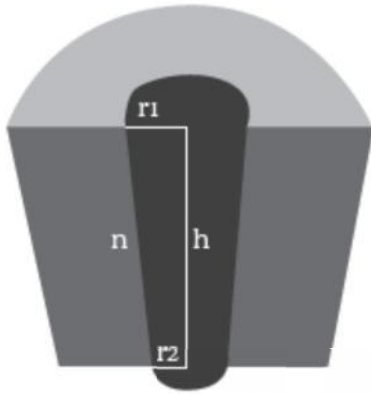


Figure 5: $\text{Area} = \pi(r_1 + r_2)\sqrt{(r_1 - r_2)^2 - h^2}$ (Erdemir et al, 2011)

The widest and coronal part of the post in the section is depicted in the figure as r_1 while r_2 represents the narrowest portion of the post in the section. These two values were measured with a digital calliper under a stereomicroscope and were recorded on a Microsoft Excel spread sheet. The precise thickness of the section was measured and represents the length or height of the post in the tooth section. The letter 'n' represents the dentinal surface of the section. These values are fed into the formula with the mathematical constant, pi, to calculate the surface area of the post that is cemented to the dentine.

2.5. Microscopic analysis

A stereomicroscope was utilised to examine the interfaces after the push-out test and failure types were classified as:

1. Adhesive failure between dentin and luting agent
2. Adhesive failure between luting agent and the post
3. Cohesive failure within the luting agent

4. Cohesive failure within the post
5. Cohesive failure in dentine
6. Mixed failure

[Radovic et al. (2008)]

2.6. Data analysis

Debond stress values (Newtons) were captured on Microsoft Excel. These values were divided by the area of the post which was in contact with the dentine to obtain the debond stress (megapascal) for each slice. The megapascal (MPa) values were submitted to Tukey Kramer analysis to determine the statistical significance of the debond stress values of the different cements. The microscopic analysis data was submitted to chi square testing to determine if there was a relationship between failure mode and debond stress.



Chapter 3: Results

3.1. Comparative de-bond stress values between all cements

Figure 6 shows a box and whisker plot of the debond stress (MPa) for these cements. The box represents the location of 50% of the values of the particular cement used in the study. The line between the box and the maximum or the minimum value represents the upper and lower 25% range. The line in the box represents the median debond stress value of each cement. The top lines for each cement shows the maximum and the bottom line the minimum debond stress (Mpa) values in a 25% limit of the 50% values in the box. This will exclude any outliers beyond this limit.

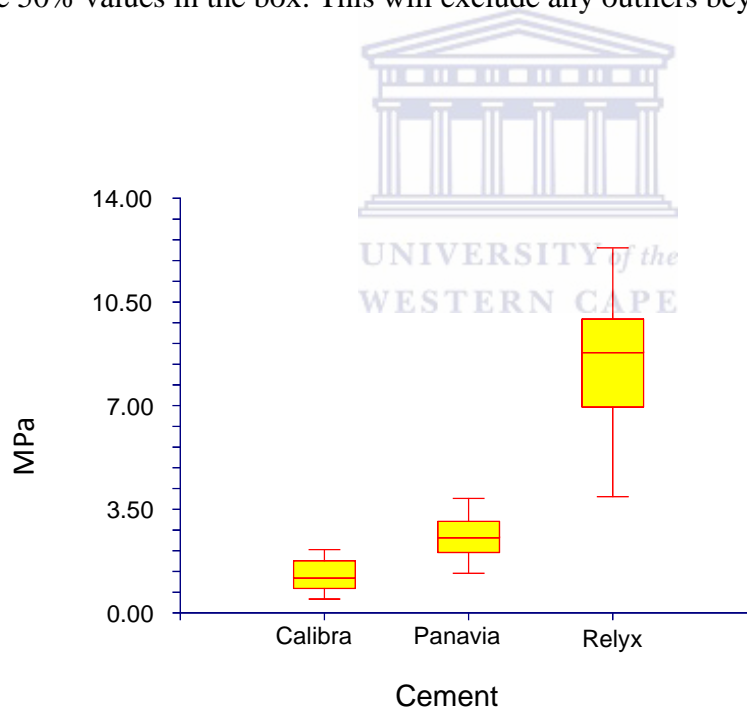


Figure 6: Box and whisker plot showing debond stress (MPa) for the three cements

The maximum debond stress value for RelyX Ultimate (3M ESPE), was 13.30 MPa, the minimum debond stress value was 3.49 MPa and the median value for all samples in this group was 8.82 MPa.

For Calibra (Dentsply Caulk), the maximum debond stress value was 3.02 MPa, the minimum debond stress value for this group was 0.66 MPa and the median value for all samples in this group was 1.21 MPa. As for Panavia F2.0 (Kuraray), the maximum value was 3.81 MPa, the minimum debond stress value was 1.24 MPa and the median value was 2.57 MPa.

RelyX Ultimate (3M ESPE) had a higher maximum debond stress value of 13.30 MPa compared to Panavia (Kuraray) and Calibra (Dentsply Caulk) with 3.81MPa and 3.02 MPa. The minimum debond stress values was highest for RelyX Ultimate (3M ESPE) with 3.49 MPa, followed by Panavia F2.0 (Kuraray) with 1.24 MPa and Calibra (Dentsply Caulk) with 0.66 MPa.

The median value was highest for RelyX Ultimate (3M ESPE) with 8.82 MPa followed Panavia F2.0 (Kuraray) with 2.57 MPa and Calibra (Dentsply Caulk) with 1.24 MPa. It is evident that there is a large variance in the RelyX Ultimate (3M ESPE) group which has widespread values around the median de-bond stress value, as illustrated in figure 6.

The difference between the mean and median values for Calibra (Dentsply Caulk) is small (table 2). Panavia F2.0 (Kuraray) has virtually identical mean and median values when these values are rounded off to two decimals, which is an indication of the consistency of the cement's performance in the current study. There is a large difference between the mean and median values for RelyX Ultimate (3M ESPE,) which is another indication for the large variance in the tested specimens. In the Calibra (Dentsply Caulk) group, two specimens were lost during testing due to fracturing of the specimens, before a reading could be observed.

In the RelyX Ultimate (3M ESPE) group, one was lost because the plunger was lowered too fast, which pushed out the post in the sample at a higher speed than prescribed by the methodological testing conditions.

Group	Specimens	Mean Debond Stress (MPa)	Median (MPa)	Standard Deviation (MPa)
Calibra	28	1.28	1.21	0.50
Panavia F2.0	30	2.57	2.57	0.65
RelyX Ultimate	29	8.10	8.82	2.53

Table 2: Mean and median debond stress values for all the three groups

UNIVERSITY of the
WESTERN CAPE

The Tukey-Kramer multiple comparison test was utilised to statistically test all groups in order to determine the statistical differences between group pairs (table 3). This test is very sensitive for pairwise comparison and was therefore utilised in this study.

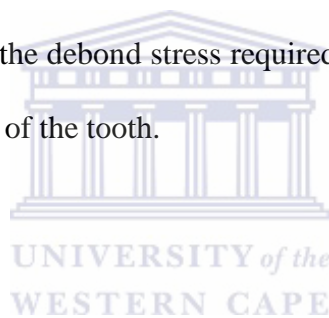
Group	Mean Debond Stress (MPa)	Different from groups
Calibra	1.28	RelyX Ultimate
Panavia F2.0	2.57	RelyX Ultimate
RelyX Ultimate	8.10	Calibra, Panavia F2.0

Table 3: Tukey-Kramer multiple- comparison test for all sections in all groups

RelyX Ultimate (3M ESPE) had statistically significantly higher debond stress values ($p < 0.05$) than Panavia F2.0 (Kuraray) and Calibra (Dentsply Caulk) respectively. Although Panavia F2.0 had higher debond stress values than Calibra (Dentsply Caulk), the difference was not statistically significant ($p > 0.05$).

The test samples were sectioned in three different regions of the tooth. The areas were divided in three categories representing the regional areas in the root of the tooth from which the section was attained.

The following sections will compare the debond stress required to remove a post from the post space for each cement relative to the region of the tooth.



3.2. Comparative de-bond stress values between coronal sections of the cement

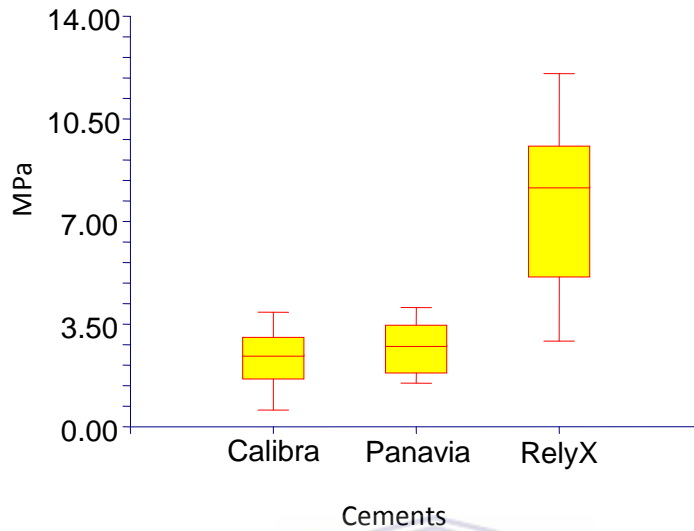


Figure 7: Box and whisker plot showing debond stress (MPa) for the coronal sections

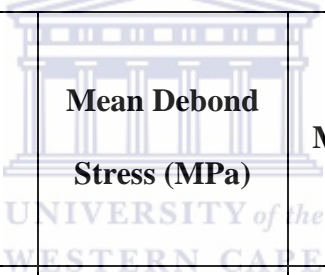
The above box and whisker plot (figure 7) shows the maximum debond stress value for coronal specimen for RelyX Ultimate, which was 12.04 MPa; the minimum debond stress value was 2.1 MPa and the median for all coronal sections was 8.18 MPa.

For Calibra, the maximum debond stress value was 3.9 MPa, the minimum was 0.98 MPa and the median was 2.45 MPa. As for Panavia F2.0, the maximum value was 4.06 MPa, the minimum was 1.49 MPa and the median was 2.77 MPa.

RelyX Ultimate had a higher maximum debond stress value (12.04 MPa) compared to Panavia and Calibra with 4.06 MPa and 3.9 MPa respectively. The minimum debond stress value was highest for RelyX Ultimate (2.1 MPa), followed by Panavia F2.0 (1.49 MPa) and Calibra (0.98 MPa).

The median value was highest for RelyX Ultimate (8.18 MPa), followed by Panavia F2.0 (2.77 MPa) and Calibra (2.45 MPa). There is a large variance in the RelyX Ultimate group, which had widespread values around the median as illustrated in figure 7.

The difference between the mean and median values for Calibra is relatively close (table 4). Panavia F2.0 has similar mean and median values with only slight differences between the two values. There is a large difference between the mean and median values for RelyX Ultimate, which is indicative of the large variance in the tested specimens. This is most likely due to the large debond stress values attained by the specimens under test conditions.



Group	Specimens	Mean Debond Stress (MPa)	Median (MPa)	Standard Deviation (MPa)
Calibra	10	2.31	2.45	1.83
Panavia F2.0	10	2.75	2.77	1.12
RelyX Ultimate	9	7.76	8.18	3.24

Table 4: Mean and median values for all coronal sections

The Tukey- Kramer multiple comparison test depicts in table 5 that RelyX Ultimate show statistically significantly higher debond stress values ($p < 0.05$) than Panavia F2.0 and Calibra. Although Panavia F2.0 had higher debond stress values than Calibra, the difference was not statistically significant ($p > 0.05$).

Group	Mean Debond Stress (MPa)	Different from groups
Calibra	2.31	RelyX Ultimate
Panavia F2.0	2.75	RelyX Ultimate
RelyX Ultimate	7.76	Calibra, Panavia F2.0

Table 5: Tukey-Kramer multiple- comparison test for coronal sections

3.3. Comparative de-bond stress values between middle sections of the cements

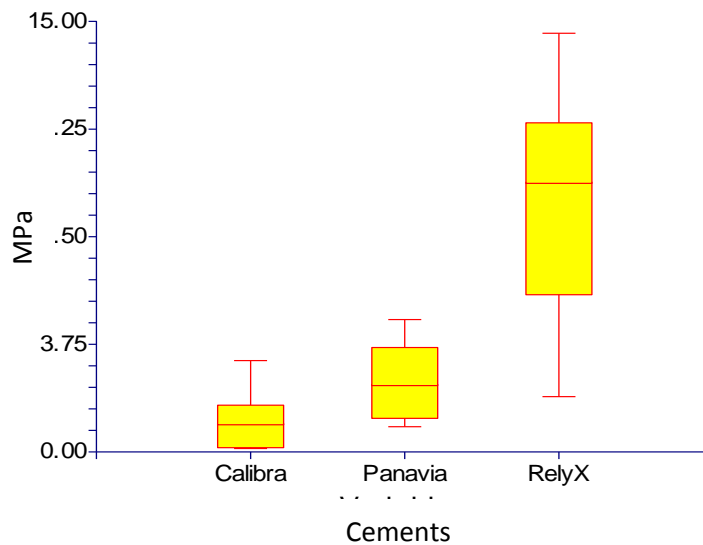


Figure 8: Box and whisker plot showing debond stress (MPa) for the middle sections

Figure 8 shows the debond stress box and whisker plots for the middle sections of the specimens. The maximum debond stress value for RelyX Ultimate was 14.58 MPa, the minimum was 1.51 MPa and the median was 9.4 MPa. For Calibra, the maximum debond stress value was 3.18 MPa, the minimum was 0.12 MPa and the median was 0.99 MPa.

As for Panavia F2.0, the maximum value was 4.61 MPa, the minimum was 0.88 MPa and the median was 2.35 MPa.

RelyX Ultimate (3M ESPE) had a higher maximum debond stress value of 14.58 MPa compared to Panavia and Calibra with 4.61 MPa and 3.18 MPa respectively. The minimum debond stress values was highest for RelyX Ultimate with 1.51 MPa, followed by Panavia F2.0 with 0.88 MPa and Calibra with 0.12 MPa. The median value was highest for RelyX Ultimate with 9.4 MPa followed by Panavia F2.0 with 2.46 MPa and Calibra with 0.99 MPa.

There is a large variance in the RelyX Ultimate (3M ESPE) group, which has widespread values around the median debond stress value as illustrated in figure 8.

The difference between the mean and median values for Calibra is small (table 6). Panavia F2.0 has mean and median values that are relatively close together. There is a large difference between the mean and median values for RelyX Ultimate which is indicative of the large variance in the tested sections.

Group	Specimens	Mean (MPa)	Median (MPa)	Standard Deviation (MPa)
Calibra	9	1.03	0.99	0.64
Panavia F2.0	10	2.46	2.35	1.58
RelyX Ultimate	10	8.82	9.4	4.17

Table 6: Mean and median values for all middle sections

The Tukey-Kramer multiple comparison test are shown in table 7. RelyX Ultimate had a statistically significantly higher debond stress value ($p < 0.05$) than Panavia F2.0 and Calibra as depicted in table 7. Although Panavia F2.0 had a higher debond stress value than Calibra, the difference was not statistically significant ($p > 0.05$).

Group	Mean	Different from groups
Calibra	1.03	RelyX Ultimate
Panavia F2.0	2.46	RelyX Ultimate
RelyX Ultimate	8.82	Calibra, Panavia F2.0

Table 7: Tukey-Kramer multiple-comparison test for middle sections



3.4. Comparative de-bond stress values between apical sections of the cements

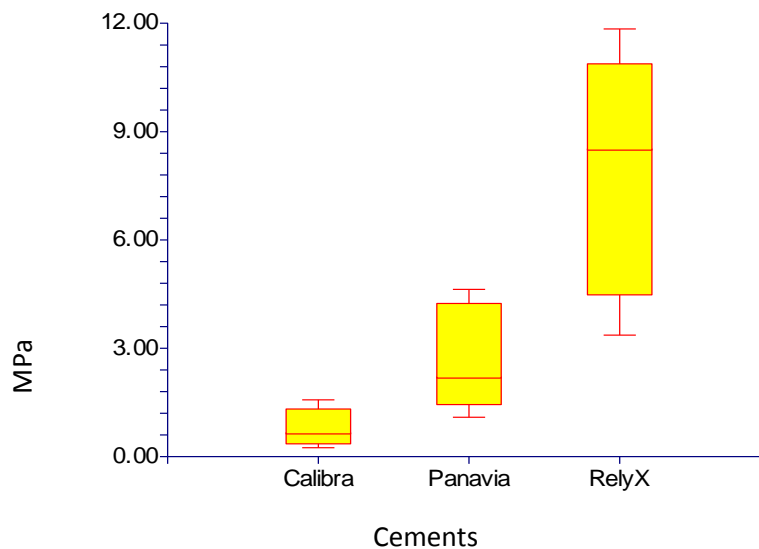


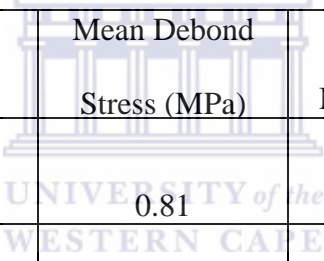
Figure 9: Box and whisker plot showing debond stress (MPa) for the apical sections

Figure 9 shows the box and whisker plots of the debond stress for the apical sections of the specimens. The maximum debond stress value for RelyX Ultimate, was 11.84 MPa, the minimum was 3.36 MPa and the median value was 8.52 MPa. For Calibra, the maximum debond stress value was 2.00 MPa, the minimum was 0.25 MPa and the median value was 0.66 MPa. Panavia F2.0, the maximum value was 4.63 MPa, the minimum was 1.09 MPa and the median was 2.21 MPa. RelyX Ultimate showed a higher maximum debond stress value of 11.84 MPa compared to Panavia and Calibra, with 4.63 MPa and 2 MPa respectively. The minimum debond stress values was highest for RelyX Ultimate with 3.36 MPa, followed by Panavia F2.0 with 1.09 MPa and Calibra with 0.25 MPa.

The median values were highest for RelyX Ultimate with 8.52 MPa followed by Panavia F2.0 with 2.21 MPa and Calibra with 0.66 MPa. There is a variance in all groups.

This is evident by the larger spread of debond stress values above the median value in the box plot figure 9 for Calibra and Panavia. RelyX Ultimate has the largest variance of all groups as presented in figure 9.

The difference in mean and median values deviate in all groups and is not as evenly spread for Calibra and Panavia, as it was for their coronal and middle sections depicting variance in the debond stress values among all groups (table 8). There is a large difference between the mean and median values for RelyX Ultimate.



Group	Specimens	Mean Debond Stress (MPa)	Median (MPa)	Standard Deviation (MPa)
Calibra	9	0.81	0.66	0.91
Panavia F2.0	10	2.63	2.21	1.58
RelyX Ultimate	10	7.96	8.52	2.99

Table 8: Mean and median values for all apical sections

The Tukey-Kramer multiple comparison test shows in table 9 that RelyX Ultimate had statistically significantly higher debond stress values ($p < 0.05$) than Panavia F2.0 and Calibra respectively. Although Panavia F2.0 had higher debond stress values than Calibra, the difference was not statistically significant ($p > 0.05$).

Group	Mean Debond Stress (MPa)	Different from groups
Calibra	0.81	RelyX Ultimate
Panavia F2.0	2.63	RelyX Ultimate
RelyX Ultimate	7.96	Calibra, Panavia F2.0

Table 9: Tukey-Kramer multiple- comparison test for apical sections



3.5. Summary of results

Table 10 presents the median values of the coronal, middle and apical sections in megapascals (MPa) within the group as well as among groups. A comparison of the median values is deemed as being the most statistically representative values due to the exclusion of outliers within the group (table 10).

Cement	All sections	Coronal	Middle	Apical
Calibra	1.21	2.45	0.99	0.66
Panavia	2.57	2.77	2.35	2.21
RelyX Ultimate	8.82	8.18	9.40	8.52

Table 10: Median de-bond stress values for all samples in all groups in MPa

RelyX Ultimate has statistically significantly ($p < 0.05$) higher debond stress values than Panavia and Calibra in the overall performance of the cement, as well as for the coronal, middle and apical sections of each group. Panavia had higher debond stress values than Calibra in the overall performance of the cement, as well as for the coronal, middle and apical sections of each group, but the difference was not statistically significant ($p > 0.05$).

Calibra and Panavia show a decline in debond stress from the coronal to the apical aspect of the tooth. In Calibra, there is a large difference from coronal to middle debond stress values. This pattern is similar for Panavia, but not as pronounced.

In the RelyX Ultimate (3M ESPE) group, the de-bond stress values increases from the coronal to the middle sections with a decline to the apical sections. The de-bond stress values for the apical sections are higher in the RelyX Ultimate group than the coronal sections for the cement.

3.6. Microscopic evaluation

For descriptive purposes, all samples were analysed under a stereomicroscope with 45 times magnification to determine the interface of failure. The failure interface was divided into one of the following categories: (1) adhesive failure between dentin and luting agent, (2) adhesive failure between luting agent and the post, (3) cohesive failure within the luting agent, (4) cohesive failure within the post, (5) cohesive failure within the dentine and (6) mixed failure according to the classification of Radovic et al. (2011).

The samples were classified according to the predominant failure type present. Table 11 summarises the failure types present in all groups:

Cement	Adhesive failure (between dentin and luting agent)	Adhesive failure (between luting agent and post)	Cohesive failure (luting agent)	Cohesive failure (post)	Cohesive failure (dentine)	Mixed failure	Total
RelyX Ultimate	10	1	0	3	10	5	29
Calibra	25	0	0	0	1	2	28
Panavia F2.0	22	0	0	0	4	4	30

Table 11: Failure mode of each sample under magnification

Adhesive failure between the dentin and luting agent were the most frequent failure type that occurred collectively for all specimens and therefore the other reasons for failure were collapsed. It is for this reason that this failure type was selected to compare if there is a correlation between adhesive failure between the dentin and luting agent and the cements used in each group. The Chi-square test was utilised to statistically test if the three proportions were different for this mode of failure based on the percentage of adhesive failure between dentin and the luting agent for each group (table 11).

Failure mode	RelyX Ultimate	Calibra	Panavia	Total
Adhesive failure (dentin and luting agent)	10	25	22	58
Other	19	3	8	29
Total	29	28	30	87
Chi-squared stat	21.3137			
Df	2			
p-value	0,00002353			
chi-squared critical 5%	5,9915			

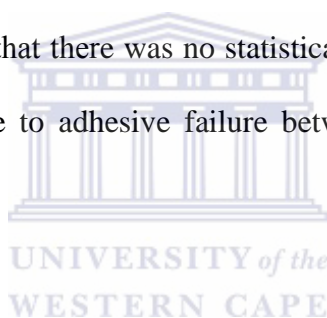
Table 12: Chi square test to establish significance between failure mode

The Chi- square test was performed to statistically determine if the percentage of failures is significantly different between the groups. The p-value for the Chi-square test was determined as 0.00002353 with $p < 0.05$. The test proved that there was a statistically significant difference between the number of posts that de-bonded due to adhesive failure between dentin and the luting agent for RelyX Ultimate compared to Calibra and Panavia .

Chi-square tests were pairwise performed among the three groups to determine if a statistically significant difference could be proved for adhesive failures between the luting agent and the dentine between the groups based on the percentage of failures at this interface.

The p-value for the pairwise Chi-square test between RelyX Ultimate and Calibra was determined as 0.00012 with $p < 0.05$. The test proved that there was a statistically significant difference between the number of posts that de-bonded due to adhesive failure between dentin and the luting agent for RelyX Ultimate compared to Calibra. The p-value for the pairwise chi-square test between RelyX Ultimate and Panavia was determined as 0.00011 with $p > 0.05$.

The test proved that there was a statistically significant difference between the number of posts that de-bonded due to adhesive failure between dentin and the luting agent for RelyX Ultimate compared to Panavia. The p-value for the pairwise Chi-square test for Calibra and Panavia was determined as 0.2036 with $p > 0.05$. The test proved that there was no statistically significant difference between the number of posts that de-bonded due to adhesive failure between dentin and the luting agent for Calibra compared to Panavia.



Chapter 4: Discussion

This study compared the bond strengths between the DT Lightpost system with three cements. This post system was selected because the manufacturer of the post system advocated the use of these posts with all three manufacturers. Recently, the manufacturer indicated that the post system should only be used with Calibra. It is for this reason that this post system was selected to avoid bias and to determine if Calibra is the only cement that will ensure predictable results.

The root canals were prepared according to a standardised protocol. No EDTA was used, because the manufacturers of RelyX Ultimate report that this irrigation agent leaves behind a residue which interferes with the bonding interface between dentine and the cement. Rasimck et al. (2008) report that a final rinse of EDTA in the post space did not improve the short-term retention of fibre posts with six different cements. They add that only the Parapost fibre White system improved, which is an active post type.

None of the manufacturers of the cements used in the current study claimed that the use of this agent was compulsory for the successful adhesion of their cements.

4.1. Influence of bonding system relative to strength of cement

Calibra (Dentsply) is classified as a total etch system while RelyX Ultimate (3M ESPE) and Panavia (Kuraray) is classified as self-etch adhesive cements (Erdemir et al 2011). There were no statistically significant difference in bond strengths between Panavia (Kuraray) and Calibra (Dentsply), but the RelyX Ultimate (3M ESPE) had significantly higher bond strengths than other groups for all root sections.

Onay, Korkmaz and Kremitci (2009) found that self-etch adhesive systems, proved significantly higher push-out strength values than total-etch adhesive systems, which is consistent with RelyX Ultimate and Calibra in the current study. They attributed these findings to the simultaneous demineralisation and infiltration of dentine. This factor causes a shallower but uniform hybridisation layer. They report that the hydrophobic solvent (ethanol) displaces residual water in the collagen matrix, which leads to a significantly larger resin infiltration area.

Scotti et al. (2012) add that there is a large difference between the bond strengths of various self-etch adhesive cements which could be attributed to the different functional monomers with different properties regarding acidity, hydrolytic stability and chemical interaction capacity. This could explain why RelyX Ultimate had significantly greater push out strength values than Panavia F 2.0, which are both self-etch adhesive cements.

Toman et al. (2009) reported that the demineralization of root canal dentine either with phosphoric acid or self-etching adhesive systems did not reveal any significant difference on bond strengths. This supports the findings that Calibra and Panavia has no statistical significant differences between

the groups. During the etching process of root canal dentine, it is difficult to determine if all the etchant has been removed and whether the canal is dry enough for primer and adhesive application.

Erdemir et al. (2011) explain that the ability of self-etching primers to penetrate thick smear layers remains questionable. They claim that ED Primer II in Panavia (Kuraray) relies on the acidic monomer 10-methacryloxydecyl dihydrogen phosphate (10-MDP), which does not have the ability to remove the smear layer but modifies it by mild demineralisation of dentinal tissues. The authors report that ED Primer II consists of two liquid bottles. Only liquid bottle A contains 10-MDP while liquid bottle B consists of chemical initiators. They explain that when the two are mixed, the concentrations of 10-MDP and photoinitiators are decreased which can result in a reduction of photopolymerisation and bonding ability.



Scotchbond Universal Adhesive system is a single bottle system with consistent photoinitiators, vitremer copolymer and 10-MDP. The pH of this adhesive system is 2,7. This acidity allows for ver efficient penetration.

4.2. Influence of application technique relative to strength of cement

The manufacturers of RelyX Ultimate advocate agitating the adhesive for 20 seconds into the dentine to facilitate the penetration of the resin into the surrounding dentinal tubules. After microscopic evaluation, there were dentinal chips present on all the sections, which indicate that the resin tags penetrated the dentine. The amount of dentinal chips varied among teeth but not among the sections. Another noteworthy observation was the absence of air voids in all specimens.

This can be accredited to the unique application tips, which allows the clinician to reach the apex of the tooth and with a backfill technique, gradually apply the cement from apical to coronal in a slow retracted action.

The manufacturers of Calibra advocates the application of the cement into the post space with a lentulo spiral. Toman et al (2009) supports this method and reports that fewer air voids were formed with this application technique when compared to placing the cement on the post prior to cementation. It must be noted that there were indeed a few samples with air voids.

Under microscopic evaluation it was noted that the amount of cement between the post and dentine were more in the Calibra group than the other two groups. This may be attributed to the influence the lentula spiral has on the setting reaction on the cement. The manufacturers of RelyX Ultimate claims that the lentulo spiral further mixes the cement and decreases the setting time, causing the cement to set faster than expected. This will inevitably cause the cement to set before the post can be seated completely in the post space, leading to a thicker cement layer between the post and the dentine.

The manufacturers of Panavia F2.0 do not have any specific recommendations for the use of their cement on fibre posts and therefore the clinical application technique for metal posts were followed. The manufacturers advocate that the cement should be placed on the post and not in the post space. After microscopic evaluation, there were very few specimens with air voids and relatively more samples with dentinal chips on the cement than Calibra. Therefore, it can be concluded that the application technique which had the least interference with the setting reaction of the cement showed superior results.

4.3. Strength of cements relative to root section

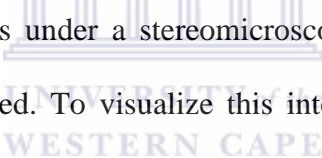
For Calibra and Panavia, the coronal sections displayed a higher displacement resistance than the middle sections, which in turn was higher than the apical sections. There was also a large decline in values from coronal to middle sections in the Calibra. This finding was consistent with the studies performed by Scotti et al. (2012), Farina et al. (2011), Onay, Korkmaz and Kremitci (2009) and Toman et al. (2009). Scotti et al. (2012) explain that the reasons for this are that there is no visibility in the deeper areas of the post space preparation where debris can collect and block the dentine tubules in the apical areas influencing the quality of the bond and the distance of the curing light from coronal to the apical area of the post, which affects the polymerisation of the cement. Onay et al. (2010) state that apical sclerosis and the cavity configuration of the apical area of the post space influences the quality of the hybrid layer in this area.

Farina et al. (2011) add that the management of humidity in the apical areas can be problematic, causing increased water in the dentinal tubules resulting in inefficient cement penetration in apical areas. Toman et al. (2009) state that the density of the dentinal tubules decreases significantly from coronal to apical, which in turn affects the infiltration of resin tags of the hybrid layer from coronal to apical. They add that the distance from the curing light should not have a negative effect on the hybrid layer due to dual curing properties of the cements in their study, which is similar to the cements used in the current study.

The RelyX Ultimate showed a variation in push out strength resistance with regard to the different sections. The middle sections showed the highest median values followed by the apical sections and the coronal sections proving the lowest median values. There was a decrease in the median value of the coronal sections compared to middle sections.

Zhang et al. (2008) state that the region of the root did not affect the bonding capabilities in their study, where they compared two self-etch adhesive systems. They explain that self-etching adhesive systems bond to the superficial layer of dentine and do not completely eradicate smear plugs and therefore the bonding efficacy may be more related to the formation of a uniform hybrid layer rather than deep penetrative resin tags Bitter et al. (2006) found that the apical areas of the self-etch adhesive system had greater bond strengths in their study after the samples were subjected to thermocycling before sectioning. The authors concluded that the bond strength to root canal dentine may be amplified in areas where solid dentine is present and the density of the dentinal tubules may not be a significant factor.

4.4. Analysis of interface of failure



After evaluation of all the specimens under a stereomicroscope, the presence of adhesive on the cement could not be reliably indicated. To visualize this interface, scanning electron microscopy should be utilised. The dominant interface of failure was loss of retention between the cement and dentine for all specimens tested. Rasimick et al. (2008) reported similar results in their stereomicroscopic evaluation and state that several studies proved similar findings. Rodig et al. (2008) reported in their study that total etch adhesive systems resulted in adhesive failures between dentine and resin cement, as well as cohesive failures within the resin cement. One of the total-etch adhesive systems tested in their study was Calibra cement with self-cure activated prime and bond adhesive using DT Lightposts.

It is noteworthy that RelyX Ultimate had only a third of the samples failing on this interface. There is a spread variety in the mode of failure of specimens for RelyX Ultimate, which explains the large variance among specimens.

One third of the samples had dentine chips covering the whole outer surface of the cement area after push-out tests were performed. The mixed fracture samples had dentine chips, fractured post segments, adhesive failure of the cement to post and cement to dentine interface as well as cohesive failures present on specimens.

It was statistically proven that there was a significant difference between the percentages of posts that debonded due to an adhesive failure between the luting agent and the dentine. RelyX Ultimate had significantly less failures at this interface than Calibra and Panavia. Panavia had fewer failures than Calibra at this interface but the difference was not statistically significant. This relationship was identical to the debond stress values, which indicates that there is a relationship between the bond between the dentine and the cement and the debond stresses of the cement. RelyX Ultimate performed better in the lower sections of the tooth, which is an indication that this cement is not reliant on the density of dentinal tubules. Therefore, it may be concluded from this study that the bond between the cement and the hydroxyapatite of intertubular dentine is of greater importance to longevity and strength of the post and core restoration than resin tags to secure the post in its position.

4.5. Shortcomings of study

There are several factors that could simulate clinical conditions. Toman et al. (2009) claims that thermocycling and mechanical cycling can be considered to simulate clinical conditions. They explain that there were no significant differences between thermocycled and nonthermocycled specimens regarding forces to cause post retention failure. However, they add that mechanical cycling has a negative influence on displacement resistance on posts in root canal dentine. Therefore mechanical cycling was not considered in the present study.

In this study, 2mm slices were preferred to the conventional 1mm slices in push-out strength tests due to the low values scored during pilot testing. The load cell could not interpret the apical values in some of the groups and therefore thicker slices were preferred for increased Newton values, but the Megapascal values remained constant.

More sections relative to the areas of the tooth can be made to increase statistical accuracy. To achieve this, natural maxillary teeth with roots longer than 18mm had to be attained, which is rare. In the study by Farina et al. (2011), canines were used to achieve this. Extracted natural canines are very rare.

Vanajasan, Dhakshinamoorthy and Rau (2011) explain that there is a difference in bond strength between human and bovine teeth due to larger dentinal tubules in the coronal portions of bovine teeth. Therefore human teeth were preferred in this study.

Toman et al. (2009) explain that sclerose dentine provided a less strong adhesion for resins compared to normal dentine due to repeated cycles of demineralization and remineralisation. The teeth used in this study were of varying age and therefore inconsistencies could be present in the specimens.

Measurements for the coronal and apical radii for each specimen were obtained under magnification of a stereomicroscope and a digital calliper. Discrepancies in these measurements are possible.

Chapter 5: Conclusion

The push-out test on sectioned teeth is a reliable method to ascertain the resistance of cements to debond stresses under compressive loads. However, it is difficult to refine these findings to clinical situations. The results do indicate to clinicians the mechanism of resistance to displacement and presents a comparison of bond strengths of 3 different cements and their mode of failure with a double-tapered post system.

Within the limitations of the current study it can be concluded that the self-adhesive resin cement, RelyX Ultimate had significantly higher bond strengths than Panavia and Calibra, which is a total-etch adhesive cement.



References

1. 3M,ESPE.(2012a). *RelyX Ultimate Adhesive Resin Cement: Technical Data Sheet*.
http://multimedia.3m.com/mws/mediawebserver?mwsId=SSSSSufSevTsZxtUo82Z4YvevUqevTSevTSevTSeSSSSSS--&fn=RelyX_Ultimate_TDS_US.pdf
Accessed: 01/11/2012.
2. 3M,ESPE.(2012b).*RelyX Ultimate Adhesive Resin Cement: Instructions for use*.
44000188118/02, Germany.
3. Balkenhol, M., Wostmann, B., Rein, C. and Ferger, C. Survival time of cast post and cores: a 10-year retrospective study. *Journal of Dentistry*. 2007; 35: 50 – 58.
4. Bitter, K. and Kielbassa, A. M. Post-endodontic restorations with adhesively luted fiber-reinforced composite post systems: a review. *American Journal of Dentistry*. 2007; 20: 353 – 360
5. Boudrias, P., Sakkal, S. and Petrova, Y. Anatomical post design meets quartz fiber technology: rationale and case report. *Compendium of Continuing Education in Dentistry*. 2001; 22: 337 – 340
6. Buser, D., Martin, W.C. and Belser, U.C. Surgical considerations for single-tooth replacements in the esthetic zone: Standard procedure in sites without bone deficiencies. In Belser, U., Martin, W., Jung, R., Hammerle, C., Schmid, B., Morton., D. and Buser, D. (2007) *ITI Treatment Guide Volume 1: Implant therapy in the esthetic zone: Single tooth replacement*. Quintessence Publishing: Berlin.
7. Cheung, W. A review of the management of endodontically treated teeth, post and core and the final restoration. *American Dental Association*. 2005; 136: 611-619.
8. Carvalho, C.A., Cantoro, A., Mazzoni, A., Goracci, C., Breschi, L. and Ferrari, M. Effect of ethanol application on post-luting to intraradicular dentine. *International Endodontic Journal*. 2009; 42: 129-135.
9. De Castro Albuquerque, R., De Abreu Polleto, L.T., Fontana, R.H. B. T. S. and Cimini Jr., C.A. Stress analysis of an upper central incisor restored with different posts. *Journal of Oral Rehabilitation*. 2003; 30: 936 – 943.
10. Dentsply Canada Ltd. (2005a). *Material safety data sheet*.
<http://www.dentsply.ca/media/basepaste.pdf> . Accessed 17/01/2012; 01h18.
11. Dentsply Canada Ltd. (2005b). *Material safety data sheet*.
<http://www.dentsply.ca/media/catalystpaste.pdf> . Accessed 17/01/2012; 01h20.

12. Erdemir, U., Sar-Sancakli, H., Yildiz, E., Ozel, S. and Batur, B. An in vitro comparison of different adhesive strategies on the micro push-out bond strength of a glass fiber post. *Medicina Oral Patologia Oral y Cirugia Bucal*. 2011; 16: 626-634.
13. Farina, A.P., Cecchin, D., Garcia, L.F., Naves, L.Z., Sobrinho, L.C. and Pires-de-Souza, F.C.P. Bond strength of fiber posts in different root thirds using resin cement. *Journal of Adhesive Dentistry*. 2011; 13: 179-186.
14. Lindemann, M., Yaman, P., Dennison, J.B. and Herrero, A.A. Comparison of the efficiency and effectiveness of various techniques for removal of fiber posts. *Journal of Endodontics*. 2005; 31:520-522.
15. Mayur, H and Suzeschandra, B. Esthetic posts- an update. *Endodontology*. 2010; 22: 100-107.
16. Nakamura, T., Ohyama, T., Waki, T., Soichiro, K., Wakabayashi, K., Mutobe, Y., Takano, N. and Yatani, H. Stress analysis of endodontically treated anterior teeth restored with different types of post material. *Dental Materials Journal*. 2005; 25: 145 – 150.
17. Naumann, M., Blankenstein F. and Dietrich, T. Survival of glass fibre reinforced composite post restorations after 2 years – an observational clinical study. *Journal of Dentistry*. 2005; 33: 305 – 312.
18. Onay, E.O., Korkmaz, Y. and Kiremitchi, A. Effect of adhesive system type and root region on the push-out bond strength of glass-fibre posts to radicular dentine. *International Endodontic Journal*. 2009; 43: 259-268.
19. Padmanabhan, P. A. Comparative evaluation of the fracture resistance of three different pre-fabricated posts in endodontically treated teeth: An in vitro study. *Journal of Conservative Dentistry*. 2010; 13: 124 – 128.
20. Poggio, C., Chiesa, M., Lombardini, M. and Dagna, A. Influence of ethanol drying on the bond between fiber posts and root canals: SEM analysis. *Quintessence International*. 2011; 42: e15-e21.
21. Polat, Z.F., Tacir, I.H., Eskimez, S. and Celik, M.Y. Retentive force of three fiber-reinforced resin composite posts and a zirconia post cemented with two adhesive luting agents: in vitro study. *Dental Materials Journal*. 2007; 26:672-676.
22. Radovic, I., Mazzitelli, C., Chieffi, N. and Ferrari, M. Evaluation of adhesion of fiber posts cemented using different adhesive approaches. *European Journal of Oral Science*. 2008; 116: 557-563.
23. Rasimick, B.J., Shah, R.P., Musikant, B.L. and Deutsch, A.S. Effect of EDTA conditioning upon the retention of fibre posts luted with resin cements. *International Endodontic Journal*. 2008; 41: 1101-1106.


24. Ricketts, D.N.J., Tait, C.M.E. and Higgins, A.J. Post and core systems, refinements to tooth preparation and cementation. *British Dental Journal*. 2005; 198: 533 – 541.
25. Roda, R.S. and Gettleman, B.H. Nonsurgical retreatment. In Cohen, S and Hargreaves, KM. *Pathways of the Pulp* (9th Ed) Mosby-Elsevier:Canada, 2006.
26. Rodig, T., Nusime, A.K., Konietscke, F. and Attin, T. Effects of different luting agents on bond strengths of fiber reinforced composite posts to root canal dentin. *The Journal of Adhesive Dentistry*. 2010; 12: 197- 205.
27. Scotti, N., Rota, R., Scansetti, M., Migliaretti, G., Pasqualini, D. and Berutti, E. Fiber post adhesion to radicular dentine: The use of acid etching prior to a one step self-etching adhesive. *Quintessence International*. 2012; 43 (7): 615-623.
28. Schwartz, R.S. and Robbins, J.W. Post placement and restoration of endodontically treated teeth: a literature Review. *Journal of Endodontics*. 2004; 30: 289-301.
29. Seefeld, F., Wenz, H., Ludwig, K. and Kern, M. Resistance to fracture and structural characteristics of different fiber reinforced post systems. *Dental Materials*. 2007; 23: 265 – 271.
30. Simon, J.F. and Darnell, L.A. Considerations for proper selection of dental cements. *Compendium of Continuing Education in Dentistry*. 2012; 33: 28- 35.
31. Sumer, E. and Deger, Y. Contemporary permanent luting agents used in dentistry: a literature review. *International Dental Research*. 2011; 1: 26-31.
32. Signore, A., Benedicenti, S., Kaitsas, V., Barone, S., Angiero, F. and Ravero, G. Long-term survival of endodontically treated, maxillary anterior teeth restored with either tapered or parallel-sided glass-fiber posts and full-ceramic coverage. *Journal of Dentistry*. 2009; 37: 115 – 121.
33. Terry, D.A. and Swift Jr, E.J. Post-and-Cores: Past to Present. *Dentistry Today* 2010; 29 (1): 132, 134-135.
34. Toman, M., Toksavul, S., Samkanat, M., Firidinoglu, K. and Akin, A. The evaluation of displacement resistance of glass frc posts to root dentine using a thin slice push-out test. *International Endodontic Journal*. 2009; 42: 802- 810.
35. Tioosi, R., Lin, L., Rodrigues, R., Heo, Y., Conrad, H., De Mattos, G., Ribeiro, R.E. and Fok, A. Digital image correlation analysis of the load transfer by implant supported restorations. *Journal of Biomechanics*. 2011; 44: 1008 – 1013.
36. Vanajasan, P.P., Dhakshinamoorthy, M. and Rau, C.V.S. Factors affecting the bond strength of self-etch adhesives: a meta-analysis of the literature. *Journal of Conservative Dentistry*. 2011; 14: 62-67.
37. Wrbas, K.; Altenburger, M.J.; Schirrmeister, J.F.; Bitter, K. and Kielbassa, A.M. Effect of adhesive resin cements and post surface silanization on the bond strengths of adhesively inserted fiber posts. *Journal of Endodontics*. 2007; 33: 840-843.

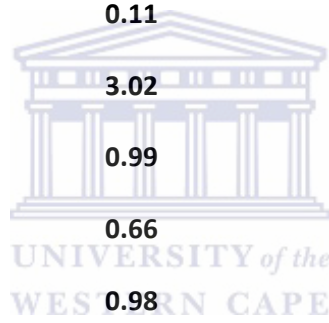
38. Zicari, F., De Munck, J.D., Scotti, R., Naert, I. and Van Meerbeek, B. Factors affecting the cement-post interface. *Dental Materials* 2012; 287-297
39. Zhang, L., Huang, L., Xiong, Y., Cheng, J.H. and Ferrari, M. Effect of post-space treatment on retention fiber posts in different root regions using two self-etching systems. *European Journal of Oral Science*. 2008; 116: 280-286



Appendix A: Raw data

Tooth				
Cement	sample	Debond stress (Mpa)	Section	Key
Relyx Ultimate (3M ESPE)	1.1	6.72	c	coronal=c
	1.2	9.02	m	middle=m
	1.3	6.14	a	apical=a
	2.1	8.19	c	
	2.2	10.86	m	
	2.3	10.66	a	
	3.1	2.10	c	
	3.2	1.51	m	
	3.3	2.53	a	
	4.1	8.14	c	
	4.2	10.60	m	
	4.3	4.33	a	
	5.1	12.97	c	
	5.2	13.30	m	
	5.3	10.17	a	
	6.1	12.04	c	
	6.2	8.28	m	
	6.4	11.84	a	
	7.1	9.84	c	
	7.2	6.00	m	
	7.3	7.12	a	
	8.1	9.21	c	

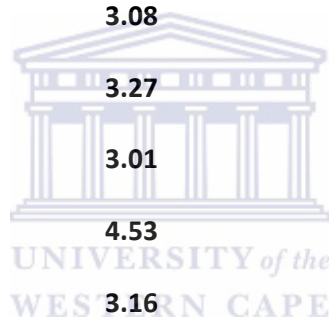
8.2	14.58	m
8.3	9.92	a
9.1	3.49	c
9.2	3.90	m
9.3	3.36	a
10.2	9.78	m
10.3	11.52	a
		
1.1	6.16	c
1.2	0.12	m
1.3	0.11	a
2.1	3.02	c
2.2	0.99	m
2.3	0.66	a
3.1	0.98	c
3.2	0.15	m
4.1	0.10	c
4.2	0.15	m
4.3	0.08	a
5.1	2.20	c
5.2	1.54	m
5.3	2.00	a
6.1	1.84	c
6.2	0.19	m
6.3	0.90	a



7.1	3.90	c
7.2	3.18	m
7.3	0.35	a
8.1	2.43	c
8.3	1.57	a
9.1	2.47	c
9.2	1.27	m
9.3	0.25	a
10.1	2.60	c
10.2	1.72	m
10.3	0.61	a
1.1	4.50	c
1.2	1.24	m
1.3	2.33	a
2.1	1.05	c
2.2	3.81	m
2.3	5.09	a
3.1	1.49	c
3.2	1.85	m
3.3	0.44	a
4.1	1.91	c
4.2	4.61	m
4.3	4.63	a
5.1	2.46	c



5.2	0.88	m
5.3	1.09	a
6.1	2.46	c
6.2	0.95	m
6.3	1.52	a
7.1	3.08	c
7.2	2.39	m
7.3	1.46	a
8.1	4.06	c
8.2	3.58	m
8.3	3.08	a
9.1	3.27	c
9.2	3.01	m
9.3	4.53	a
10.1	3.16	c
10.2	2.32	m
10.3	2.09	a



Appendix B: Material specifications

Material	Lot /Serial Number	Expiry date
Calibra (Dentsply Caulk)	110907	12/2012
Demetron LC (SDS Kerr)	66004713	
DT Lightpost (VDW)	1009000009 1009000009 1004000748	
Panavia (Kuraray)	051391	07/2013
RelyX Ultimate (3M ESPE)	480997	12/2013

Appendix C: Ethical clearance certificate



**Office of the Deputy Dean
Postgraduate Studies and Research**
Faculty of Dentistry & WHO Collaborating Centre for Oral
Health



UNIVERSITY OF THE WESTERN CAPE
Private Bag X1, Tygerberg 7505
Cape Town
SOUTH AFRICA

Date: 4th May 2012

**For Attention: Dr A Fortuin
Restorative Cluster**

Dear Dr Fortuin

STUDY PROJECT: Pull out strengths of a post system with different cements

PROJECT REGISTRATION NUMBER: 12/3/31

ETHICS: Approved

At a meeting of the Senate Research Committee held on Friday 30th March 2012 the above project was approved. This project is therefore now registered and you can proceed with the study. Please quote the above-mentioned project title and registration number in all further correspondence. Please carefully read the Standards and Guidance for Researchers below before carrying out your study.

Patients participating in a research project at the Tygerberg and Mitchells Plain Oral Health Centres will not be treated free of charge as the Provincial Administration of the Western Cape does not support research financially.

Due to the heavy workload auxiliary staff of the Oral Health Centres cannot offer assistance with research projects.

Yours sincerely

Professor Sudeshni Naidoo



UNIVERSITY *of the*
WESTERN CAPE