



Retreatability of Root Canals Obtured Using a Bioceramic Sealer and Gutta Percha

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SUMMARY

Statement of problem:

Although bioceramic endodontic sealer cements offer various advantages over conventional zinc oxide-based and resin-based cements, questions have been raised about the ability to retreat root canals that have been sealed using these cements.

Aims and Objectives:

The aim of the study was to determine the retreatability of root canals sealed using a bioceramic calcium silicate-based sealer cement. The objectives were to determine the possibility of achieving working length and apical patency when obturation is done with the master GP placed at working length and when it is short by 3mm. The time it took to achieve these parameters when it was possible to achieve them was also determined. The role of XP Endo Finisher R, a supplementary retreatment file, in achieving working length and apical patency was also to be evaluated. However, this latter aspect was eliminated after the pilot study, when it was found not to have an effect in regaining working length and apical patency.

Materials and methods:

This was a randomized controlled *in-vitro* study. One hundred and twenty extracted single rooted anterior and premolar human teeth obtained from the University of the Western Cape Tygerberg Oral Health Centre were used in the study. Teeth that had an initial apical size of greater than size number 30 were excluded. After de-coronation, the canals were initially instrumented with stainless steel files up to size 15 to create a glide path and then prepared using iRace Ni-Ti rotary files (FKG Dentaire SA, Switzerland). A size 10 stainless steel K file was used to confirm apical patency before and after the preparation. The teeth were then divided into four groups of 30 teeth each and subsequently obturated: the first group (Group 1) was obturated with TotalFill BC Points and TotalFill BC sealer (FKG Dentaire SA, Switzerland) with the master GP extending to the determined WL; the second group (Group 2) was obturated with TotalFill BC Points and TotalFill

BC sealer (FKG Dentaire SA, Switzerland) with the master cone GP 3mm short of the pre-determined WL; the third group (Group 3) was obturated using GP and AH plus with the master Gutta Percha (GP) at the pre-determined working length and the fourth group (Group 4) was obturated with AH Plus and GP with the master cone 3mm short of the working length. Canals in groups 1 and 2 were obturated using the basic hydraulic technique while those in groups 3 and 4 were obturated using the lateral condensation technique. After incubation in a moist environment at 37⁰ C for 28 days, the four groups of obturation materials in the canals were removed using both mechanical and chemical techniques, D-Race retreatment files (FKG Dentaire SA, Switzerland) and Endosolv (Saint-Maur-des-Fossés, France) respectively. The ability to establish working length, apical patency and the time taken to complete the procedure was determined. Any file fractures during the procedure were recorded. All the data was manually captured on a specially prepared data capturing sheet and later transferred onto an Excel Spreadsheet. The retreatability and the time it took to retreat were analyzed using a Kruskal-Wallis H test. A pairwise comparison between groups was performed using a Dunn's procedure with a Bonferroni correction for multiple comparisons to detect differences in retreatability based on the type of cement and the distance from the working length that the master GP was placed.

Results:

Working length was regained and apical patency achieved in all 30 canals (100%) in groups 1 and 3. Only 9 out of the 30 canals (30%) in group 2 and 25 out of 30 canals (83%) in group 4 were successfully retreated (working length regained and apical patency achieved). In the samples where working length was regained and apical patency achieved, it happened much faster in group 3 (median time = 5.8 minutes) followed by group 1 (median time = 9.6 minutes). Group 4 took the second longest time (median time = 14.5 minutes) while group 2 took the longest time (median time = 20.3 minutes). The Kruskal-Wallis H test, pairwise and comparison between groups showed that both the type of cement used for obturation and the distance from the working length that the master GP was placed influenced both the retreatability of the canal and the time it took to retreat the canal. The differences were statistically significant ($p < 0.005$) at a 95% CI.

Conclusions:

Retreatment of root canals sealed using bioceramic sealer cements is more difficult compared to canals sealed with a resin sealer and therefore takes a longer time to complete. In cases where the GP cone does not go the full length of the canal preparation, the chances of successive retreatment are low. This is because removal of the set cement from the canal to working length and achievement of apical patency, which are both pre-requisites for successive retreatment, is difficult with low chances of success.

CLINICAL IMPLICATIONS

Improper use of bioceramic sealers diminishes the chances of successful retreatment. The fully extended GP will guarantee a passage for retreatment instruments to the apical area of the canal, should a need to retreat arise. Therefore, the sealer and GP application technique during obturation should allow for full extension of the GP within the canal.

The use of bioceramic sealers to seal successfully retreated canals should be considered.

Keywords: Root canal sealers, Bioceramic sealers, Retreatment

DECLARATION

I, Godfrey Maronga, declare that this mini-thesis entitled, “Retreatability of Root Canals Obturated Using a Bioceramic Sealer and Gutta Percha”, which I herewith submit electronically to the University of the Western Cape in partial fulfilment of the requirements for the degree MSc (Restorative Dentistry); is my own original work and has neither been submitted for any academic award to this University, nor to any other institution of higher learning.

A handwritten signature in black ink, appearing to read 'Godfrey Maronga', written in a cursive style.

SIGNATURE

DATE: 1st. November 2019

QUOTATION

I preferred her to sceptre and throne,
And deemed riches nothing in comparison with her,
Nor did I liken any priceless gem to her,
Because gold, in view of her, is a bit of sand,
And before her, silver is to be accounted mire.
Beyond health and beauty I loved her,
And I chose to have her rather than the light,
Because her radiance never ceases.

(Wisdom 7: 9-10).

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CHAPTER 1: LITERATURE REVIEW

1.1. Successful endodontic therapy

The aim of endodontic treatment is to prevent peri-apical periodontitis or treat it when it is present. This is achieved through mechanical shaping, removal of infected and/or inflamed pulp tissue and chemical irrigation to eliminate micro-organisms and their products. This is followed by placement of a hermetic root canal obturation and a coronal seal. The radicular and coronal seals prevent micro-leakage of bacteria and their products that are responsible for persistent peri-apical inflammation (Torabinejad and White, 2015). A successful root canal treatment is one in which there are no symptoms and there are no clinical and radiographic signs of persistent or new peri-apical periodontal disease. This criteria of successful endodontic treatment has been extensively discussed (Estrela *et al.*, 2014).

In spite of the fact that there is considerable debate about which is more important between the root filling and the coronal seal, it can be concluded that both the coronal and root seals are important in preventing bacterial re-entry and recolonization of the root canal system and the surrounding peri-apical tissues. The seals entomb any bacteria that may not have been removed during canal space preparation and irrigation and prevents their re-entry from the oral cavity respectively (Tabassum and Khan, 2016).

1.2. Functions of the sealer

Conventionally, obturation of the root canal system is done using a solid core material, mostly Gutta Percha (GP) cones, with sealer cement which is in a paste form. The sealer flows and seals patent accessory canals, voids and apical deltas and ramifications which may be present in the root (Trope, Bunes and Debelian, 2015). The sealer serves as a canal lubricant facilitating placement of the core material. The sealer also helps to create a bonded interface between the core material and the root dentine. Together, the core material and sealer form a fluid-tight sealer that entombs any viable bacteria within the root canal system and prevents re-entry of new bacteria from the surrounding periodontal tissues (Flores *et al.*, 2011).

Since the most complex anatomical areas within the canal system are mostly occupied by the sealer cement, the development of new materials and techniques has been aimed at improving the sealer interface. The vertical and lateral condensation techniques were developed to minimize the sealer interface and increase adaptation of the sealer and the GP to the canal walls (Trope, Bunes and Debelian, 2015). Meanwhile, with improved sealer cement materials, simpler obturation techniques like the basic hydraulic condensation technique has been advocated (Chybowski *et al.*, 2018).

1.3. Desirable properties of an endodontic sealer

According to Grossman, (as quoted by Trope, Bunes and Debelian, 2015), an ideal root filling cement should be easy to introduce into the canal. It should have adequate flow properties to flow within the canal to seal the canal both laterally and apically. However, it should not be of too low viscosity as to flow outside the confines of the root canal space. It is desirable that the sealer should have minimal or no shrinkage after setting to prevent formation of voids. It should provide a hermetic seal. It should have a prolonged bacteriostatic and/or bactericidal activity to prevent bacterial growth. Radiopacity is another requirement. This property is to facilitate visualization of the sealer on radiographs. This is helpful in evaluating the quality of obturation. It is also desirable that it should not stain tooth structure, be biocompatible, be sterile or be amenable to being quickly and easily sterilized prior to placement. Finally, it should be easily removed from within the root when a need arises to do so (Yadav *et al.*, 2013) .

1.4. Bioceramic sealers

1.4.1. Background

Pre-mixed bioceramic based sealer cements were introduced in clinical practice in 2008 (Debelian and Trope, 2016) . Prior to this, there had been challenges encountered with the zinc-oxide eugenol based cements and epoxy-resin based sealer cements. These challenges included poor

biocompatibility, poor handling properties, hydrophobicity, shrinkage on setting and failure to form a true chemical bond with root dentine (Mickel and Wright, 1999; Zmener *et al.*, 2003).

1.4.2. Development

Bioceramics are ceramic materials developed for use in medicine and dentistry (Stefan Jitaru *et al.*, 2016). They have a widespread use in these two fields. Initially, their use in endodontics was limited to perforation repair and retrograde filling materials in apical surgical procedures since they had poor handling properties (Duarte *et al.*, 2018). Their use as endodontic sealers is as a result of improvement in the handling technology of nano-particulate matter. This improvement resulted in materials exhibiting optimal handling properties such as ease of dispensing and use. They also have inherent ability to use the moisture in dentine to drive the setting reaction within a clinically acceptable time (Stefan Jitaru *et al.*, 2016; Colombo *et al.*, 2018).

TotalFill BC sealer (FKG Dentaire SA, Switzerland) is marketed in various other regions as iRootSP, Endosequence BC sealer and BC sealer. Its components are zirconium oxide, calcium silicates, calcium phosphate, calcium hydroxide fillers and thickening agents. The last two components' ratios in the mix are varied accordingly to produce other products with higher viscosity that are used as root repair materials (FKG Dentaire, 2013).

1.4.3. Application technique

Although the obturation techniques of lateral and vertical condensation used with conventional sealers can be used with these materials, their use (specifically for TotalFill BC) involves hydraulic condensation, also known as passive or bonded obturation. Pluggers and spreaders are not used in this technique. The GP cone is the condenser and the sealer is the filler similar to bonding a post in a post-supported restoration. This takes a shorter duration, is less technique sensitive and there is minimal or no pressure exerted on the canal walls thus minimizing possibility of formation of micro-cracks within the root dentine (Trope, Bunes and Debelian, 2015). TotalFill BC is compatible with both vertical and horizontal condensation techniques as well (FKG Dentaire, 2013).

According to the manufacturer, TotalFill BC is supplied as a premixed sealer paste with intra-canal application tips that are used to express a small amount of the material into the coronal third of the canal. A small file is then used to coat the canal walls with the material. The master GP is then coated with the cement and then slowly inserted into the canal to full working length. If needed, especially for oval shaped canals, more GP points can be added without laterally compacting the master GP. The manufacturer cautions against excessive cement since the precise fit of the master GP creates a hydraulic system in which the excess cement may prevent the master GP extending all the way to the working length. Therefore, in as much as the material is lauded as being less technique sensitive, the quantity of cement used and the method of application of both the master GP and cement clearly demonstrate that it is technique sensitive.

1.4.4. Salient properties of Bioceramic Sealers

Bioceramic sealers have excellent biocompatibility. Biomaterials that are biocompatible do not trigger any adverse reactions when they contact living tissues. The possible adverse reactions are toxicity, irritation, inflammation, allergic reactions and carcinogenesis (Al-Haddad and Aziz, 2016). Biocompatibility tests done on cell cultures showed TotalFill BC sealer to be more biocompatible than the commonly used calcium-based and zinc oxide based sealer cements (Zhou *et al.*, 2015). The biocompatibility of the root repair products of the same material has been shown to be comparable and in some studies better than that of MTA-based products (AlAnezi *et al.*, 2010; Ma *et al.*, 2011; Ciasca *et al.*, 2012; Chen *et al.*, 2015; Colombo *et al.*, 2018).

Bioceramics have been shown to have anti-microbial activity. This is because of their high pH upon setting and release of calcium ions. The calcium ions also stimulate repair through the deposition of mineralized tissue (Lovato and Sedgley, 2011). Remineralization increases the success rates of endodontic therapy. iRoot SP sealer (TotalFill BC sealer) has been shown to have a higher and prolonged bactericidal activity against strains of *E.Faecalis*, an organism implicated in persistent peri-apical periodontitis after primary endodontic treatment (Zhang *et al.*, 2009; Wang, Shen and Haapasalo, 2014; Duarte *et al.*, 2018).

TotalFill BC sealer has been shown to have a long working time and a relatively short setting time which are both desirable properties of a root filling material (Zhou *et al.*, 2013). In this study, which involved an indentation technique using a Gilmore needle, TotalFill BC sealer had a setting time of 2.7 hours with a mean standard deviation of 0.3. This was comparable to that of MTA Fillapex (Angelus) which was found to have the shortest setting time of two and half hours with a mean standard deviation of 0.3 hours. In the same study, AH Plus took eleven and half hours to set with a mean standard deviation of 1.5 hours. Fast setting of a sealer cement while allowing enough time for manipulation and placement is a desirable property. This is because sealer cements which take longer time to set run a risk of reduced biocompatibility as a result of tissue irritation (Zoufan *et al.*, 2011). Separate studies have shown bioceramic sealers to have shorter setting times within the canal and less interference by the presence of residual moisture within the canal during the setting reaction (Charland *et al.*, 2013; Zhou *et al.*, 2013; Gandolfi, Siboni and Prati, 2016). It can therefore be concluded, that the shorter setting times of bioceramic sealers that allow time to apply but set early enough to avoid unnecessary irritation of the peri-apical tissues, is an advantage.

Bioceramic sealers like EndoSequence and MTA Fillapex have been shown to have favorable flow properties which meet ISO standards (Zhou *et al.*, 2013). Adequate flow facilitates entry of the sealer into inaccessible areas such as isthmi, fins and lateral canals which are inaccessible to the gutta percha core material (Al-Haddad and Aziz, 2016).

The radiopacity of TotalFill BC sealer is 3.83 units of aluminium (Candeiro *et al.*, 2012). Even though the radiopacity of TotalFill BC was found to be lower than that of AH Plus in the study of Candeiro, it is still within the acceptable set out standards of the ISO, which requires that root sealers have a minimum radiopacity of 3mm of aluminium (Al-Haddad and Aziz, 2016). Adequate radiopacity facilitates visualization and enables the operator to distinguish the sealer from the surrounding tissues. The quality of obturation can thus be evaluated. It is important that root canal sealers be sufficiently radiopaque and distinguishable from adjacent anatomical structures. However, a more radiopaque filling material should not be falsely interpreted to have a better sealing ability.

TotalFill BC sealer has been shown to have good adhesion to root dentine upon setting even in the presence of minimal residual moisture content within the root canal with or without the smear layer and in the presence of residual calcium hydroxide (Nagas *et al.*, 2012; Shokouhinejad *et al.*,

2013; Madhuri *et al.*, 2016; Ghabraei *et al.*, 2017). Adhesion is defined as the ability to bond to the canal dentin and to promote the binding of GP points to each other and to dentin.

TotalFill BC sealer has been shown to have acceptable resistance to dissolution in water despite of its hydrophilicity. Zhou *et al.*, showed that TotalFill BC has a solubility value of 2.9%. This was higher than MTA Fillapex (Angelus) which has solubility of 1.1% (Zhou *et al.*, 2013). However, these values meet ANSI/ADA recommendations of solubility not exceeding 3%. Conflicting findings were reported by Wang who reported MTA Fillapex to be highly soluble namely 14.94%, more than AH Plus, which was 0.25% (Wang, 2015). The differences in the findings may be attributed to variations in methods used to dry samples after having subjected them to solubility testing. ANSI/ADA recommend that solubility of a root canal sealer not exceed 3% by mass (Al-Haddad and Aziz, 2016).

Inadequate removal of root filling materials from within the pulp chamber carries a high risk of dentin discoloration. A root canal sealer should not stain the tooth. Ioannidis, found that EndoSequence Root Repair Material putty and EndoSequence Root Repair Material fast set paste, (both of which have the same composition as TotalFill BC sealer) have a low potential to cause dentin discoloration (Ioannidis *et al.*, 2013). This finding makes the sealer to be the material of choice where aesthetics is a high priority. These findings were confirmed in a study conducted in 2015 (Kohli *et al.*, 2015).

1.4.5. Retreatability

The main disadvantage that has been highlighted with the use of bioceramic sealers is the challenge that is involved with removal of the root filling when the need arises. Such circumstances where removal of the root filling material is needed include post placement and retreatment when primary root canal fails (Virdee and Thomas, 2017). Residual root filling materials act as a barrier which prevents access to and complete removal of necrotic debris and bacteria that cause and sustain peri-apical lesions (Ng *et al.*, 2007). Studies evaluating the various mechanical and chemical techniques of removal of different root filling materials confirm that absolute complete removal is impossible (Só *et al.*, 2008; Alves *et al.*, 2016; Silva *et al.*, 2017; Versiani *et al.*, 2018). However,

a pre-requisite to successful retreatment is that, working length and apical patency must be established. All root canal filling materials, including the sealer and the core materials have to be removed (Torabinejad, Ashraf & Walton, 2014). The bulk of residual root-filling material during retreatment is made up of the sealer (Wilcox *et al.*, 1987). Although the study cited here is an old study, its findings would hold true especially for bioceramic sealers. This is because the hydraulic condensation technique advocated for in their use, is mostly a single cone technique with most of the canal filled by the sealer cement. These root-filling materials should be removed to facilitate successful retreatment.

In a study by Hess (Hess *et al.*, 2011), where Endosequence BC sealer (similar product to TotalFill BC sealer) was used as the sealant and the obturation done to WL, apical patency was established in only 80% of the canals. When the obturation was done 2mm short of the WL, WL and apical patency was achieved in only 30% of the teeth. These findings imply that a proper obturation needing retreatment has 20% chance of failing to regain apical patency using currently available materials and techniques. Failure to establish working length and apical patency could potentially lead to failure of the retreatment as both bacteria and their products that initiate and sustain peri-apical periodontitis remain within the root canal system (Ng *et al.*, 2007).

Research findings which conflict with the above findings were reported by a different group of researchers using GP as the core material and three different sealers: AH Plus, Total Fill BC and MTA Fillapex (Agrafioti, Koursoumis and Kontakiotis, 2015). This group found that working length and patency was established in 100% of specimens in all groups. This group had also intentionally obturated one of their sample groups with the master cone GP 2mm short of the working length to allow evaluation of the effect of the sealer cement independently. They established that in the group where the master GP was placed 2mm short of the WL, although working length and apical patency were achieved, it took a longer time. This was in comparison to the groups that were sealed to length with GP and AH Plus as well as the group that was filled to length with gutta percha and TotalFill BC and/or MTA Fillapex. The difference in time was statistically significant. There are a number of other studies which have similar findings (Obeid and Nagy, 2015; Oltra *et al.*, 2017).

Therefore, there is a lack of agreement on whether apical patency and working length can be achieved when retreatment is carried out. Further research in this field is therefore justified.

1.5. Retreatment Protocols

As quoted by Bhagavaldas, the Glossary of Endodontics defines retreatment as a procedure to remove root canal filling material from the tooth, followed by cleaning, shaping and obturation of the canals (Bhagavaldas *et al.*, 2017). Hand files, rotary instruments including Gates Glidden and patented retreatment file kits by various manufacturers, endodontic ultrasonic tips, gutta percha solvents like chloroform, tetrachloroethylene, xylene, halothane and eucalyptol, turpentine and orange oils have all been proposed and used in removal of obturation material (Virdee and Thomas, 2017).

Gates Glidden drills mounted on electric handpieces to adequately control torque and speed are used to gain initial entry into the canals. Their use should be limited to the straight portion of the canal. They should be used with caution to avoid gouging out of dentine which could result in strip perforations and/or weakened roots which are prone to fracture (Hülsmann and Stotz, 1997).

The piezo-electric ultrasonic devices with special endodontic ultrasonic tips are used to safely remove the superficial layer of GP and to create a small reservoir for the solvent. The vibrations produced by the devices' tip within the root structure also is thought to weaken the adhesion of the obturation material to the canal walls facilitating its removal (Agrafioti, Koursoumis and Kontakiotis, 2015).

Both hand files and rotary retreatment kits are used initially to grossly remove the root filling material accompanied by copious irrigation with sodium hypochlorite after each instrumentation cycle. Nickel titanium (Ni-Ti) rotary instruments have come into widespread use because of their safety, efficiency and speed in removing the GP and the sealer cement residues (Ersev *et al.*, 2012; Virdee and Thomas, 2017).

Solvents are best used only after the gross removal of GP and sealer is complete. Their use during gross removal frequently leads to inconvenient residues of GP painted across the length of the canal walls (Virdee and Thomas, 2017). Traditionally, chloroform has been the solvent of choice due to its ability to rapidly dissolve GP into a thin liquid. However, there has been renewed interest to find alternatives due to its potential for misuse as well as carcinogenic properties (Chutich *et*

al., 1998). Additionally, the hepatotoxic side effect of halothane deters its use. The failure of turpentine oils to dissolve GP at room temperatures makes it impractical for chair-side application. Of the remaining solvents, tetrachloroethylene, xylene, eucalyptol, and orange oils have shown to be the most biocompatible while also possessing useful solvency properties at 37°C (Wourms *et al.*, 1990). The most recognizable may be the tetrachloroethylene solvent, which is commercially available as Endosolv (Septodont, Saint-Maur-des-Fossés, France). Initially it was formulated as Endosolv E (E in the brand name is short form for eugenol) for use in removal of obturation materials from canals sealed with eugenol-based sealers, and Endosolv R (R in the brand name is short form for resin) removal of obturation materials from canals sealed using resin-based sealers. Currently, it is formulated and available as Endosolv. According to the manufacturer, the new formulation is effective in retreatment of canals sealed with either resin-based or eugenol-based sealers. The effectiveness of this formulation in canals sealed using bioceramic sealer cements has not been established.

The solvent is delivered into the canal with the use of a side-vented 27 gauge needle. The needle should be placed into the canal using a passive technique to deliver the solvent into each root canal. It is advised that a flushing action be used. This is because repeated irrigation and aspiration creates turbulent pressures that enhance filling material removal. Further, the deposited volume should be adequate to fill up the root canal up to the floor of the pulp chamber. Agitation of the solvent with the use of hand files. The largest size of fitting paper points should then be inserted into the canal to absorb the now dissolved root filling material (Virdee and Thomas, 2017).

Following removal of root canal obturation materials, chemomechanical preparation using the preferred and appropriate techniques, instruments and irrigants should be completed and followed by obturation. An irrigation regime that includes a final rinse of 17% ethylenediaminetetraacetic acid (EDTA) followed by NaOCl has shown to improve resolution of peri-apical pathology in retreatment cases. This can possibly be explained by the fact that the irrigation protocol removes the residual smear layer. The smear layer is known to contain infected organic and inorganic matter, solvents and filling material that is created throughout retreatment. These may be the aetiology for sustained peri-apical infection and inflammation (Ng, Mann and Gulabivala, 2011).

The XP-endo Finisher R (FKG Dentaire, Switzerland), was introduced for use as a final step in improving root canal cleaning. It consists of a number 25 tip and a non-tapered rotary NiTi

instrument made of a special alloy (MaxWire; Martensite-Austenite Electropolish Flex, FKG Dentaire). According to the manufacturer, the file changes its shape according to the temperature. At room temperature, in its martensitic phase (M-phase), the file is straight. However, when submitted to body temperatures, it enters its austenitic phase (A-phase) and assumes a spoon shape of 1.5 mm depth in the final 10 mm of its length. According to the manufacturer, when the instrument is placed inside the canal in rotation mode, the A-phase shape allows the file to access and clean areas that other instruments might not be able to reach, without damaging dentine or altering the original canal shape. There is evidence that supplementary instrumentation using the XP-endo Retreatment R file helps to remove material left after retreatment (Alves *et al.*, 2016). However, another study shows that whilst the file improves removal of residual material, it does not completely rid the canal of the root filling material (Silva *et al.*, 2017). The study by Silva *et al* compared the two variants of the product, XP- endo Finisher and XP-endo Finisher R whereby the R variety is meant for retreatment cases. There was no significant difference between the two as relates to the amount of residual material remaining within the canals after retreatment. There is limited information that is published about the use of these files as they are relatively new in the market. It would be worthy to determine whether the extra cleaning offered by these files would help remove any materials from within the canal that would prevent achievement of WL and apical patency.

CHAPTER 2: METHODOLOGY

2.1 Aim and Objectives

2.1.1 Aim

The aim of the study was to determine the retreatability of root canals sealed using a bioceramic sealer TotalFill BC (FKG Dentaire SA, Switzerland). AH Plus (Dentsply Detrey GmbH Konstanz, Germany) was used as the control.

2.1.2 Objectives

1. To determine if it is possible to achieve working length in roots previously obturated with a bioceramic sealer, TotalFill BC sealer, with the master gutta percha cone at working length (WL).
2. To determine if it is possible to achieve working length in roots previously obturated with a bioceramic sealer, TotalFill BC sealer, with the master gutta percha cone placed 3mm short of the working length.
3. To determine the time (in seconds) it takes to achieve working length and apical patency, when it is possible to achieve the parameters in objectives 1-2 above.
4. To compare the results obtained in 1-3 above with those obtained with the control, AH Plus.

2.2 Null Hypothesis

There is no difference between the retreatability and time taken to treat root canals sealed with a bioceramic-based endodontic sealer cement and those sealed with a resin-based endodontic sealer cement when mechanical and chemical retreatment methods are used.

CHAPTER 3: MATERIALS AND AND METHODS

3. MATERIALS AND METHODS

3.1 Study design

The study was an experimental descriptive *in-vitro* study.

3.2 Study Population

The teeth used in the study were obtained from the University of the Western Cape Oral Health Centre. The teeth collected were those indicated for extraction by the students and staff.

3.3 Inclusion Criteria

1. Human single rooted, single canal anterior and premolar teeth
2. Teeth roots with mild curvature ($<20^{\circ}$ angulation)
3. Teeth with patent canals as confirmed by radiographic examination
4. Teeth with apical patency as confirmed using K-file size 10

3.4 Exclusion criteria

1. Teeth with moderate to severe root curvature at any point along the roots ($>20^{\circ}$)
2. Teeth with incompletely formed roots and open apices
3. Teeth with fractured roots
4. Teeth with canal bifurcation/trifurcation as confirmed by radiographic examination
5. Teeth with initial apical size of more than size 30
6. Teeth with sclerosed canals
7. Teeth with fusing/merging canals
8. Teeth with no apical patency

3.5 Sample size

One hundred and twenty human single rooted anterior and premolar teeth with single canals were used in the study.

3.6 Specimen Preparation

The anterior and premolar teeth extracted for various reasons were washed under tap water and immediately immersed in 0.5% sodium hypochlorite for thirty minutes. The 0.5% sodium hypochlorite solution was prepared by mixing equal portions of distilled water and 1% hypochlorite solution -Milton's solution- (Incolabs, Parktown, South Africa).



Figure 3.1: A sample of collected specimens after 30 minutes in 0.5% sodium hypochlorite solution before cleaning with ultrasonic tips and sorting them for inclusion and exclusion

The specimens were removed from the solution and cleaned using ultrasonic tips mounted on an ultrasonic scaler (Suprasson, Satelec Acteon, France) to remove all the adherent hard and soft tissues. They were then stored in physiological saline (B Braun Medical, Randburg, South Africa) until the start of the study. The teeth were decoronated at the cement-enamel junction using a minitome diamond disk (Struers, Randburg, South Africa) and water cooling to leave a root 12-15mm in length.



Figure 3.2: Left: Minitome machine Right: The struers diamond wheel used on the minitome machine to section the teeth at the CEJ



Figure 3.3: Measuring the root length using an endodontic mm ruler

A size 10K file (Dentsply Maillefer, Ballaigues, Switzerland) was introduced into the canal until its tip was visible at the apical foramen. The working length (WL) was determined by reducing 1mm from this length.

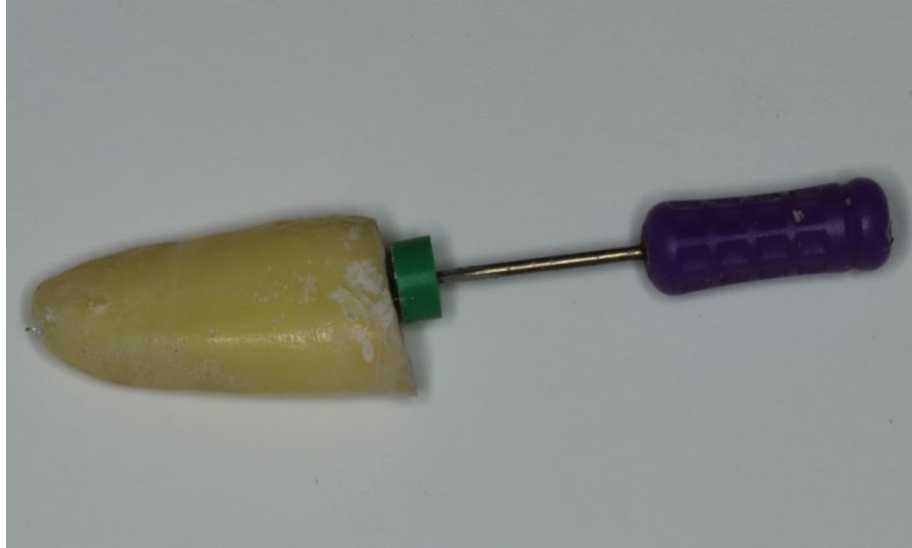


Figure 3.4: A 10k endodontic file introduced into the canal until its tip is visible at the apical foramen. This was done to confirm apical patency and working length. Working length was determined by reducing 1mm from this length and confirmed radiographically.

Radiographs were taken using an intra-oral peri-apical machine (CS 2100, Carestream Health, Onex Corporation, Toronto, Ontario, Canada) to confirm the working length.

Another set of radiographs without the files in position were done from a different angle to confirm that the teeth had single, non-furcated canals.



Figure 3. 5: Samples of specimens lined up on phosphor plates for imaging. A protective dark paper was used to over the phosphor plates to prevent scratching them.



Figure 3.6: The intra-oral radiography machine used to expose the phosphor plates.



Figure 3.7: Digora scanner system (Orange, CA) used to process the exposed plates and project the images on the screen for viewing, manipulation of quality, storage and sharing.



Figure 3.8: Some of the collected teeth divided into groups according to their established working length.

3.7. Canal preparation and obturation

The glide path was established using ScoutRace files (FKG Dentaire SA, Switzerland) which consist of three files ISO sizes of 10, 15 and 20 with a 2% taper.



Figure 3.9: The ScoutRace system.

The root canals were then prepared using iRace Ni-Ti files R1 (15/0.04), R2 (25/0.04) and R3 (30/0.04) in a Wave One (Dentsply Sirona, PA) motor with the torque 1.5Ncm and 600RPM revolution speed as recommended by the manufacturer. Additional use of R1a (20/0.02) and R1b (25/0.02) was used as required in case of difficult to negotiate canals.



Figure 3.10: Endodontic motor with the torque and speed settings as required by the manufacturer of iRace treatment files used in the study

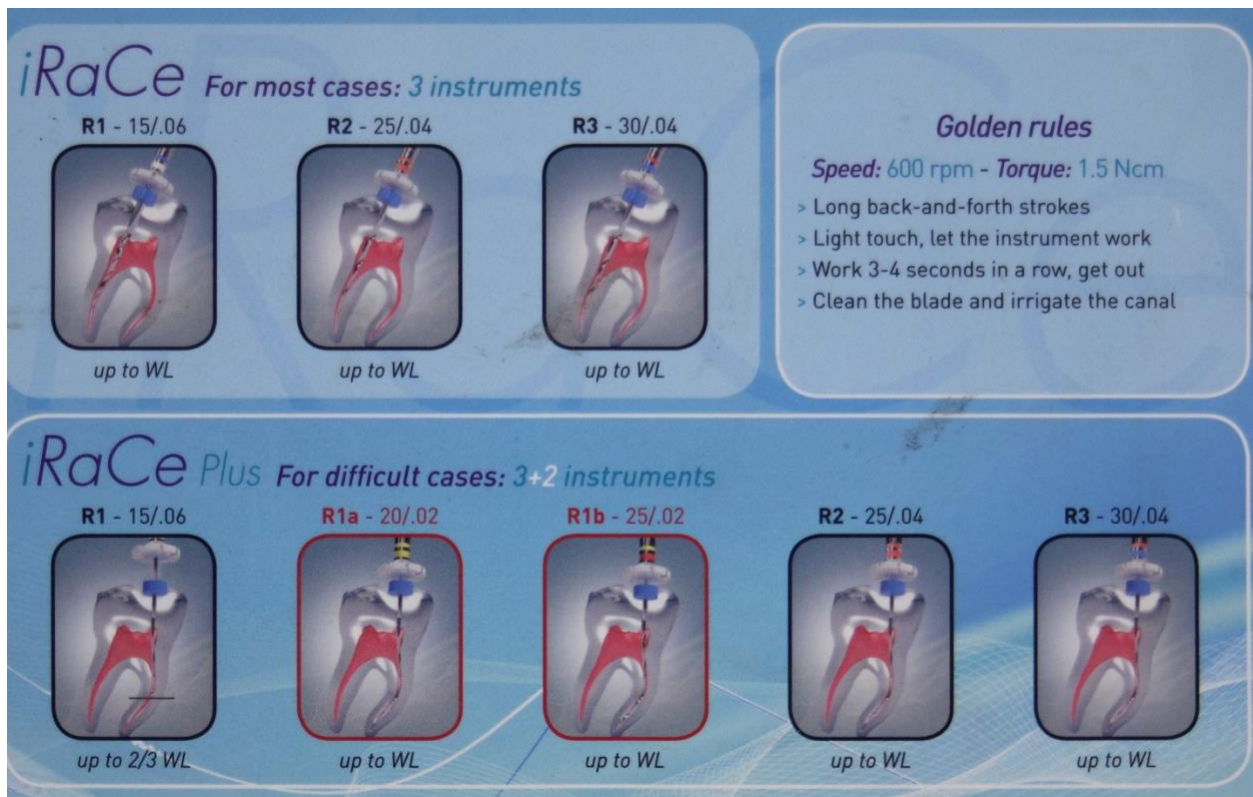


Figure 3.11: A pictorial representation of the treatment protocol as presented by the manufacturer.

RC Prep cream (Medical Products Laboratories, PA, USA) which contains 10% urea peroxide and 15% Ethylenediamine tetraacetic acid (EDTA) was used to lubricate the canals and instruments.



Figure 3.12: RC Prep cream (Medical Products Laboratories, PA, USA).

After each instrument, the canal was irrigated with 2.5 ml of 1% solution of sodium hypochlorite in a 5ml disposable plastic syringe and a 30-G irrigating tip (HenrySchein, Melville, NY). Then, the final flush to remove the smear layer was performed with 5ml of EDTA for 30 seconds followed by 5ml of 3.5% of sodium hypochlorite and then 5ml of distilled water. The root was dried with paper points (FKG Dentaire SA, Switzerland). The apical patency was reconfirmed with a #10 K-file before filling the roots.

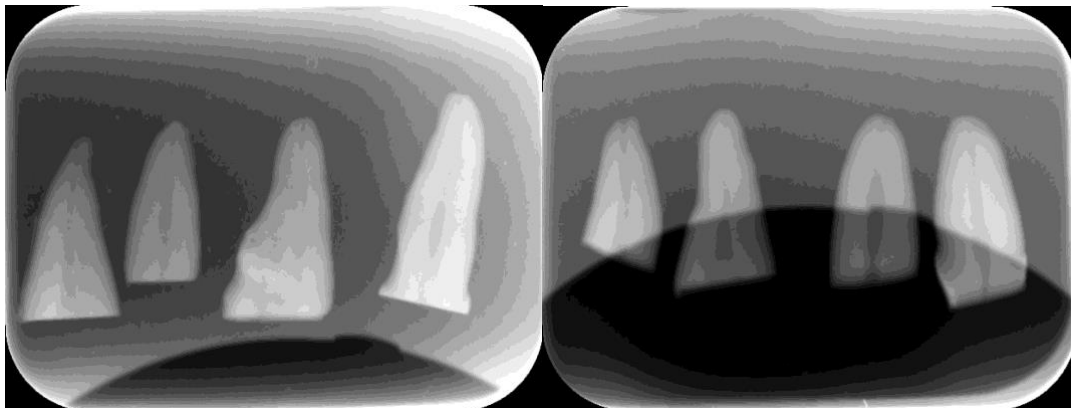


Figure 3.13: Samples of radiographs of the prepared canals before obturation.

The teeth were first stratified into groups according to their canal lengths and then randomly allocated into four groups 1, 2, 3 and 4 of 30 (n=30). Group 1 was obturated with TotalFill BC sealer and bioceramic nano particle-coated Gutta Percha (FKG Dentaire SA, Switzerland) placed at working length (Group 1). Group 2 was obturated with TotalFill BC with the bioceramic nano-particle –coated Gutta Percha placed 3mm short of the working length (Group 2). Group 3 was obturated using AH Plus and regular ISO Gutta Percha (Dentsply Detrey GmbH Konstanz, Germany) placed to working length (Group 3) and Group 4 was obturated using AH Plus and GP placed 3mm short of the working length. The sealers were introduced into the root canals using a #20 K-file (Flexofile, Dentsply Sirona SA) in order to coat the canal walls. The master GP cone was then coated with the sealer and slowly inserted to the appropriate length. The hydraulic condensation technique, as described by the manufacturer, whereby the GP is used to spread the sealer cement within the canal and accessory GPs placed only when necessary was used for groups 1 and 2. The lateral condensation technique was used for groups 3 and 4. Digital x-rays were taken and used to assess the quality of the root filling.



Figure 3.14: TotalFill BC sealer with its nano-coated GPs sizes 30/04 and 15/04.

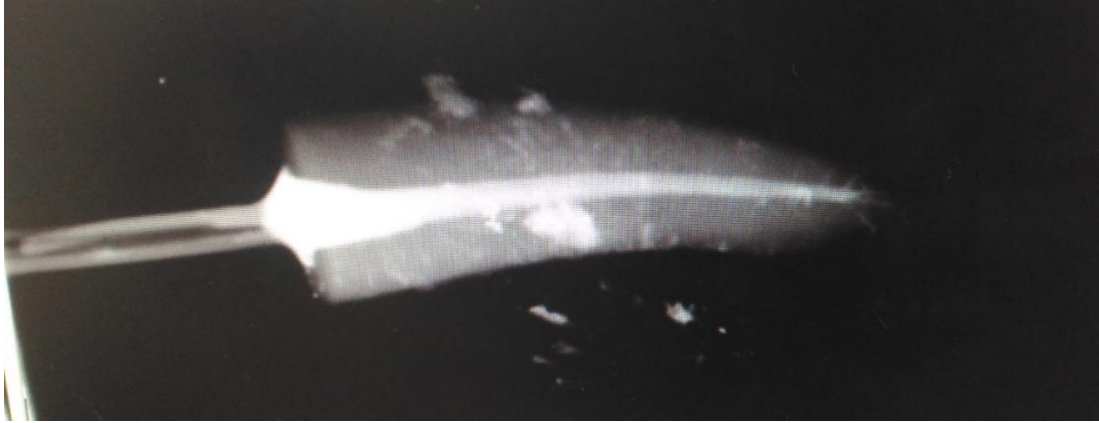


Figure 3.15: A magnified view of one of the canals obturated with Total Fill BC in which two accessory GPs were added.

The canal orifices were then sealed with a glass ionomer restorative material (GC Fuji IX GP, GC America).



Figure 3.16: Canal orifices sealed off with glass ionomer cement.

All the specimens were stored at 37⁰C in 100% humidity for three weeks in a laboratory warm water bath (Labcon Laboratory Equipment, Krugersdorp, South Africa)



Figure 3.17: Left: Samples placed in a warm water bath for 28 days. Right: The warm water bath.

The same operator performed all the endodontic procedures. All the procedures were done using a dental operating microscope (DOM) with magnification between X5-X10 (Zeiss S100 / OPMI pico, Carl Zeiss Meditec AG, Oberkochen, Germany).



Figure 3.18: Dental Operating Microscope ((Zeiss S100 / OPMI pico, Carl Zeiss Meditec AG, Oberkochen, Germany).

3.8. Retreatment procedure

A medium sized round bur (Mani, Utsunomiya, Tochigi, Japan) mounted on a high-speed handpiece (W&H, Bürmoos, Austria) was used to remove the glass ionomer cement seal.

D-Race retreatment files DR1 and DR2 (FKG Dentaire SA, Switzerland) were used for the removal of obturation material.



Figure 3.19: DRace retreatment files (FKG Dentaire SA, Switzerland)

The DR1 which has a taper of 10%, an active cutting tip of ISO size 030 and a D0-D1 length of 8mm, at 1.5Ncm torque and 1000rpm, was used to remove obturation material in the coronal third of the root. The DR2 file which has a taper of 4%, a non-cutting tip of ISO size 025 and a D0-D1 length of 16mm, at 1.5Ncm torque and 600rpm was used to remove obturation material in the apical two-thirds of the root.

The retreatment file was advanced until resistance was encountered or working length was reached. If resistance was encountered before working length was reached, two drops of Endosolv solvent for root canal sealers (Saint-Maur-des-Fossés, France) were introduced into the canal and removal re-attempted after 3 minutes. If working length was not achieved using the rotary files, a further 2 drops of endosolv was applied. 3 minutes later, small Flexofiles #s 6, 8 and 10 (Dentsply Maillefer, Ballaigues, Switzerland) and Pro-Ultra Endodontic Tips (Dentsply Tulsa Dental Specialties) numbers 6 and 7 used in a pecking motion were used in an attempt to reach WL. This was repeated if the first intervention was unsuccessful. Retreatment was abandoned and considered unsuccessful if no progress was being made at this stage or the retreatment time had gone beyond 20 minutes (1200 seconds).

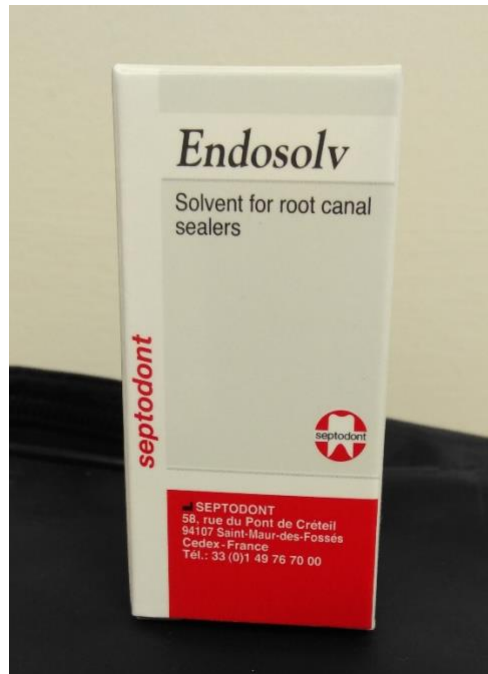


Figure 3.20: Endosolv root canal solvent for endodontic cements by Septodont that was used in the study



Figure 3.21: Ultrasonic tips used during retreatment

3.9. Data Capturing

The results on achievement of WL, apical patency and the time taken to achieve these were recorded on a pre-prepared data capturing sheet and later transferred onto an Excel Spreadsheet.

SPECIMEN/VARIABLE	WORKING LENGTH AT START OF TREATMENT	APICAL PATENCY AT START OF TREATMENT(YES/NO)	RETREATMENT STARTING TIME (SECONDS)	RETREATMENT STOPPING TIME	WORKING LENGTH AT STOPPAGE OF RETREATMENT	WORKING LENGTH REGAINED AT STOPPAGE OF RETREATMENT	TIME TAKEN FOR THE RETREATMENT PROCEDURE	APICAL PATENCY REGAINED AT THE STOPPAGE OF RETREATMENT	ANY FRACTURED INSTRUMENTS WITHIN THE CANAL DURING RETREATMENT	SUCCESS IN REGAINING WORKING LENGTH USING XP ENDO R	SUCCESS REGAINING APICAL PATENCY USING XP ENDO R	ANY SEPARATED INSTRUMENTS WITHIN THE CANAL WITH XP ENDO R USE
10081												
10291												
10934												
10665												
10915												
10403												
10209												
10485												
10744												
10466												
10096												
10421												
10480												
10820												
10614												
10275												
10498												
10833												

Figure 3.22: Data capturing sheet

CHAPTER 4: RESULTS AND STATISTICS

4.1. Descriptive Statistics

4.1.1. Summary Statistics

There were 30 canals in each of the four groups 1, 2, 3 and 4. In total there were 120 specimens that were retreated. The average lengths of the canals in each group after randomization did not vary greatly among the four groups. They mostly ranged between 13-15 mm with the average length in each group being close to 14mm. There were 2 outliers in each of the groups 1, 2 and 3 that were over 17mm. This information is depicted in the box plot below.

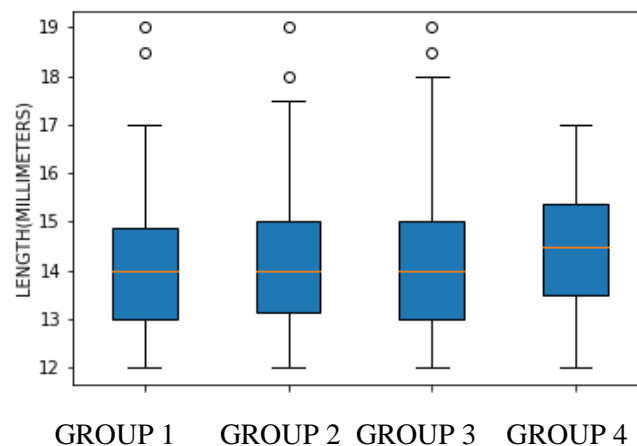


Figure 4.1: Box plot showing the distribution of canal lengths in each of the groups

In all cases where working length was regained, apical patency was also achieved. Working length was regained and apical patency achieved in all 30 teeth in groups 1 and 3. This translates to 100% successful retreatment. However, working length was regained and apical patency achieved in only 9 out of the 30 teeth (30%) in group 2 and 25 out of 30 teeth (83%) in group 4. In total 94 out of 120 teeth were successfully retreated. (See Table 4.1 overleaf)

GROUP	NO. OF SPECIMENS	NO. OF SPECIMENS SUCESSFULLY RETREATED	PERCENTAGE OF SPECIMENS SUCCESSFULLY RETREATED
1	30	30	100%
2	30	9	30%
3	30	30	100%
4	30	25	83%
TOTAL	120	94	78.3%

Table 4.1: Table showing the retreatability of canals in each group

In the samples where working length was regained and apical patency achieved, it happened much faster in Group 3 (median time = 346 seconds) followed by Group 1 (median time = 577.5 seconds). Group 4 took the second longest time (median time = 872.5 seconds) while group 2 took the longest time (median time = 1218 seconds).

GROUP	N	P50
1	30	577.5
2	30	1219
3	30	346
4	30	872.5
TOTAL	120	728

Table 4.2: Table of the median retreatment times (in seconds) for each group

When the time it took to retreat was considered, regardless of whether retreatment was successful or not, group 2 took the longest time while group 3 took the shortest time. The times it took to work on each specimen from each group is presented the table and box plots below:

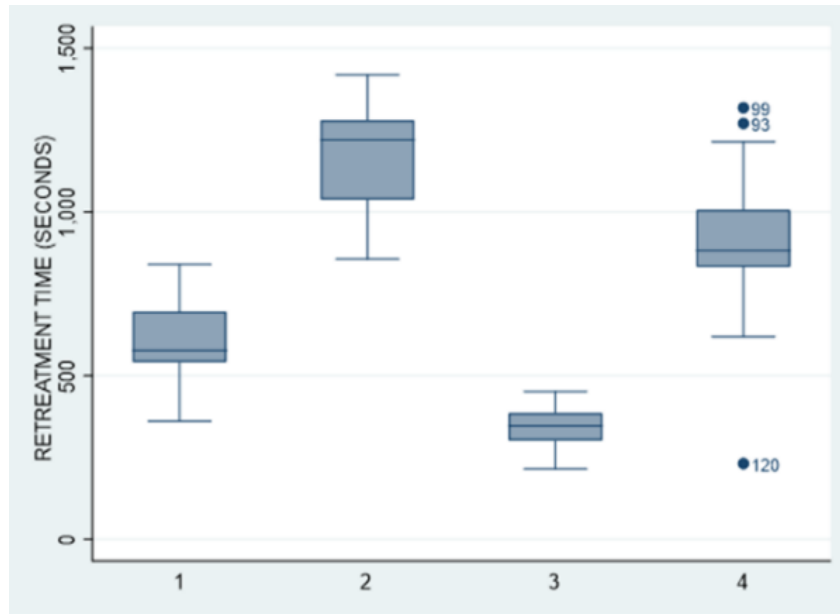


Figure 4.2: Box plot showing the retreatment times (in seconds) for each group.

4.1.2. Summary Statistics Using Survival Analysis Function

4.1.2.1. Overview

In this study, not only was the ability to regain apical patency and working length investigated, but the time it happened was also investigated. A survival analysis was therefore conducted. The events of interest were regaining of working length and apical patency. These, in the survival analysis were referred to as failure, implying that when they occurred, the obturation had failed. The intervention, over time, was the retreatment procedure.

4.1.2.2. Total Time at Risk

Overall, the total time at risk for all the specimens was 90384 seconds. This is represented overleaf.

. stsum

failure _d: APICALPATENCYREGAINED == 2
 analysis time _t: RETREATMENTTIMESECONDS

	time at risk	incidence rate	no. of subjects	Survival time		
				25%	50%	75%
total	90384	.00104	120	425	721	1016

Table 4.3: Table of time to failure

4.1.2.3. Summary of the Cumulative Hazard over Time

The teeth were tracked from the start of the retreatment process for 20 minutes. Apical patency was either gained and if not, that tooth was censored (abandoned) because apical patency could not be gained. There were 120 readings with an overall time at risk of 90384 seconds and a median survival time of 721 seconds until apical patency was gained. Apical patency was achieved in 94 of the 120 teeth. Across all four groups, the shortest time taken to reach apical patency was 216 seconds and the longest time taken to reach apical patency was 1418 seconds. The median time for reaching apical patency was 728 seconds, overall.

failure _d: APICALPATENCYREGAINED == 2
 analysis time _t: RETREATMENTTIMESECONDS

Category	total	per subject			
		mean	min	median	max
no. of subjects	120				
no. of records	120	1	1	1	1
(first) entry time		0	0	0	0
(final) exit time		753.2	216	728	1418
subjects with gap	0				
time on gap if gap	0				
time at risk	90384	753.2	216	728	1418
failures	94	.7833333	0	1	1

Table 4.4: Table of measures of central tendency per group

4.1.2.4. The P-Percentile of Survival

The p-percentile of survival time is the analysis time at which p% of subjects have failed - working length reached and apical patency regained- and (1- p) % have not. The p-percentile of survival was calculated for each group and is represented in the tables below:

```
failure _d: APICALPATENCYREGAINED == 2
analysis time _t: RETREATMENTTIMESECONDS
```

GROUP	no. of subjects	25%	Std. Err.	[95% Conf. Interval]	
1	30	541	33.10231	499	552
2	30	1076	77.40047	975	.
3	30	312	9.688481	252	325
4	30	810	50.05715	619	850
total	120	425	49.0153	361	541

Table 4.5: Table of P-percentile of survival

In the table above, 25% of teeth have failed at 541 seconds; 1076 seconds; 312 seconds and 810 seconds in Groups, 1,2,3 and 4, respectively. This shows that Group 2 has a longer survival time, which implies that it took longer to reach apical patency. Furthermore, it also indicates that 25% of teeth in Group 3 has taken the shortest time to reach apical patency.

```
failure _d: APICALPATENCYREGAINED == 2
analysis time _t: RETREATMENTTIMESECONDS
```

GROUP	no. of subjects	50%	Std. Err.	[95% Conf. Interval]	
1	30	576	38.34058	546	670
2	30	.	.	1120	.
3	30	346	19.81077	316	376
4	30	863	48.61038	833	952
total	120	721	65.27027	611	843

Table 4.6: Table of time at the 50 percentile point

Fifty percent have failed at 576 seconds; 346 seconds; 863 seconds in Groups 1, 3 and 4, respectively. Fifty percent of the teeth in Group 2 had a longer survival rate, i.e., it did not achieve apical patency. However, 50% of teeth in Group 3 once again took the shortest time to reach apical patency. Group 2 only had a 9/30 failure rate in the entire trial and thus apical patency was not reached in 50% of the teeth in this group.

```
. stci, p(75) by(GROUP)
```

```
failure _d: APICALPATENCYREGAINED == 2
analysis time _t: RETREATMENTTIMESECONDS
```

GROUP	no. of subjects	75%	Std. Err.	[95% Conf. Interval]	
1	30	696	38.61011	612	735
2	30
3	30	386	7.302967	360	425
4	30	1006	49.42094	930	.
total	120	1016	.	950	.

Table 4.7: Table of time at the 75 percentile point

Seventy-five percent have failed at 696 seconds, 386 seconds, 1006 seconds in Groups 1, 3 and 4, respectively. Therefore, 75% of teeth in Group 3 had reached apical patency in the shortest time. Teeth in Group 2 only had a 9/30 failure rate in the entire trial and thus apical patency was not reached in 75% of the teeth in this group. Seventy-five percent of teeth in Group 4 had the longest time to reach apical patency at 1006 seconds.

4.1.2.5. Survival Probability over Time

Not only did teeth in Group 2 and Group 4 take the longest time to reach apical patency, but both had teeth that did not reach apical patency. In this respect, Group 2 had the highest number of teeth that did not reach apical patency. Teeth in Group 1 and 3 all reached apical patency. And Group 3 took the shortest time to reach apical patency. This information is presented in graphical form below:

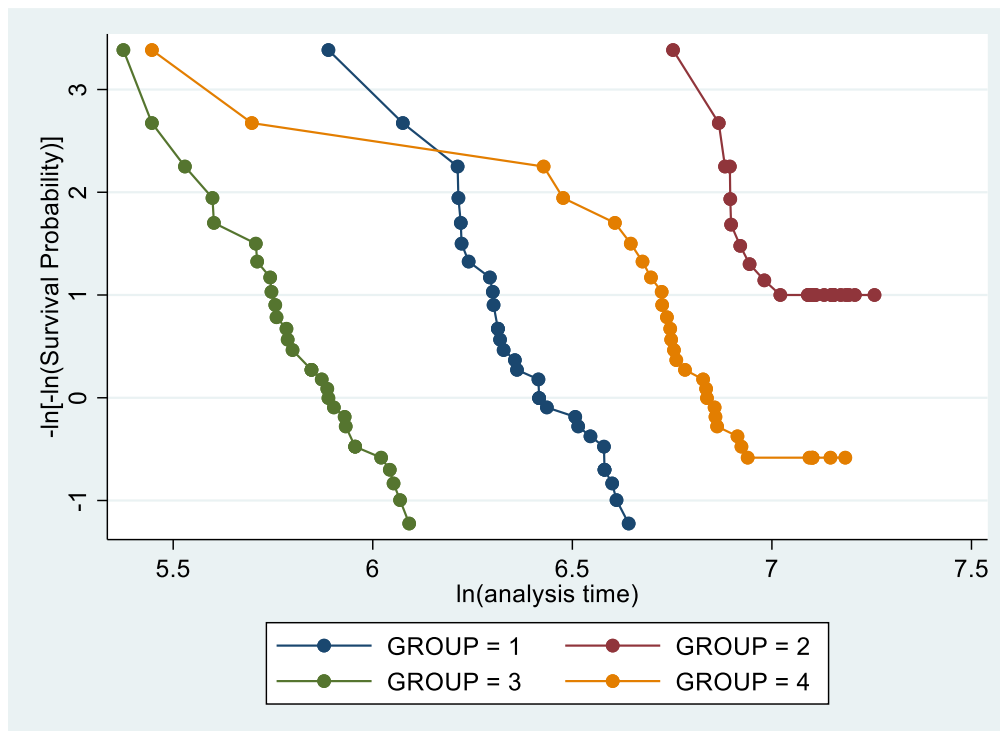


Figure 4.3: Graph of survival probability over time

4.1.2.6. The Kaplan-Meier Estimator of The Survival Functions

The Kaplan-Meier estimator of the survivor functions for the four groups are plotted below:

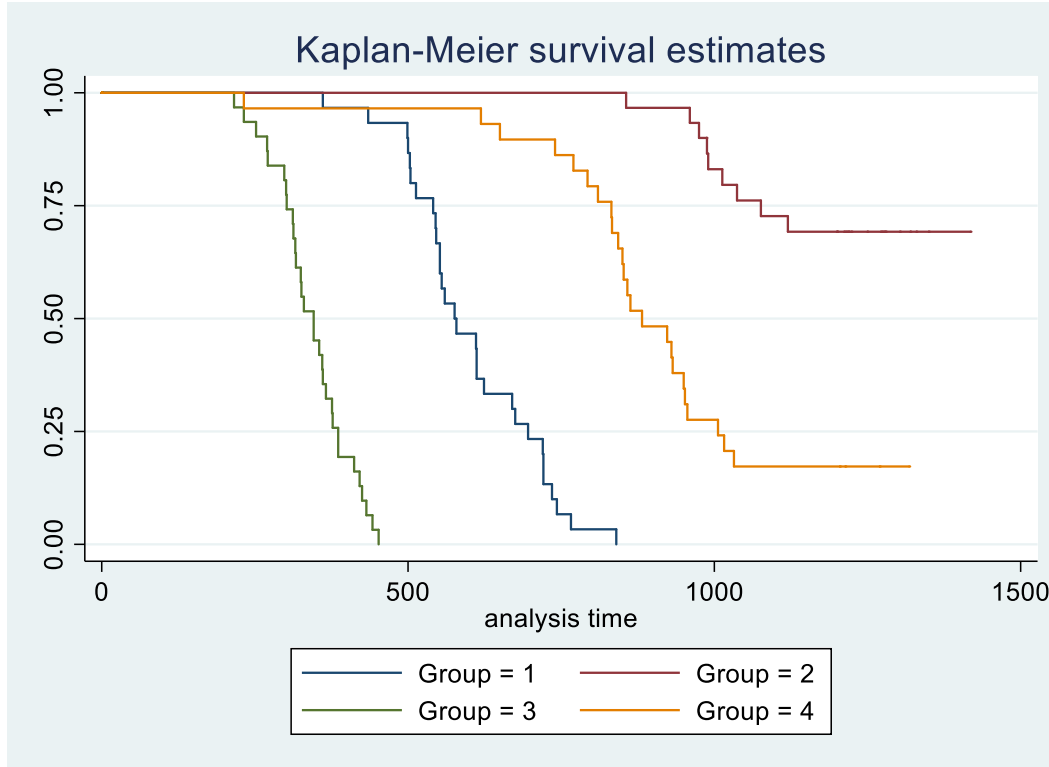


Figure 4.4: Graph of the Kaplan-Meier estimator of the survival function

All four groups show a horizontal line until the first apical patency is gained at 216 seconds. The Kaplan-Meier survival curve is shown as a step function, with a horizontal line if there are no apical patency gained and a vertical drop corresponding to the change in the survivor function after every event that occurs. It can be seen that the survival times for group 2 and 4 had a much longer horizontal line compared to groups 1 and 3. As can be seen, all four groups start at 1, but group 2 and 4 do not reach zero, because apical patency was not achieved in those groups.

As time goes on, teeth are more than likely to not reach apical patency.

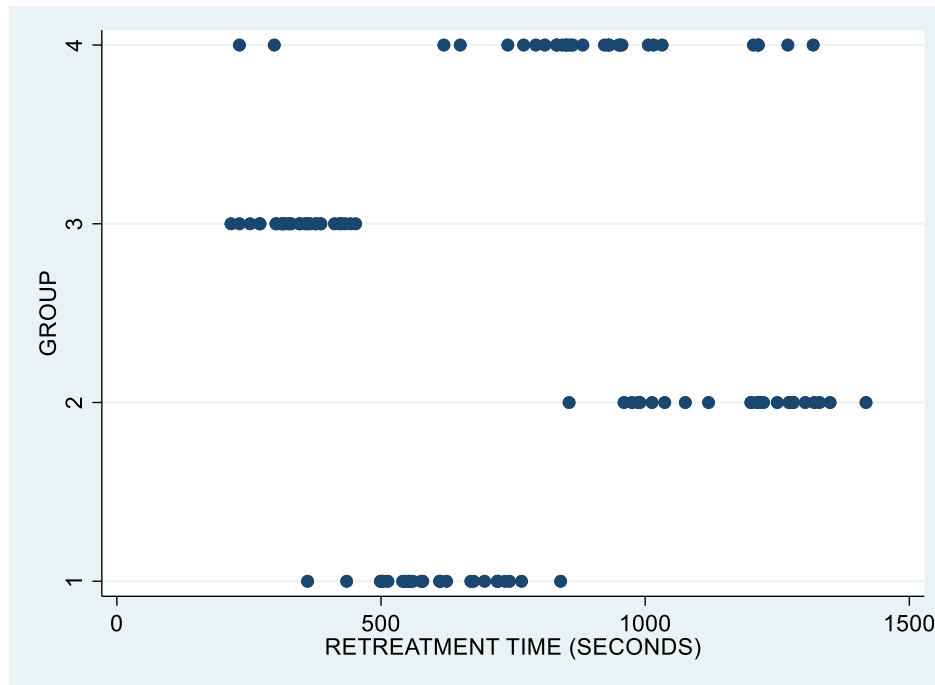


Figure 4.5: Graph of censored observations

The censoring appears different across group 1 and 3 compared to groups 2 and 4. Thus the censoring is not equal amongst the groups.

The summary statistics above, show the events observed and expected across the four groups. Apical patency was achieved in all the teeth in groups 1 and 3. Apical patency was least gained in group 2 followed by group 4. The data is right censored which means that apical patency was not gained after 20 minutes.

4.1.2.7. Nelson-Aalen Estimate Of The Cumulative Hazard Function

The proportional hazards assumption can be graphically represented by using the cumulative hazard function also known as the Nelson-Aalen estimate of the cumulative hazard function.

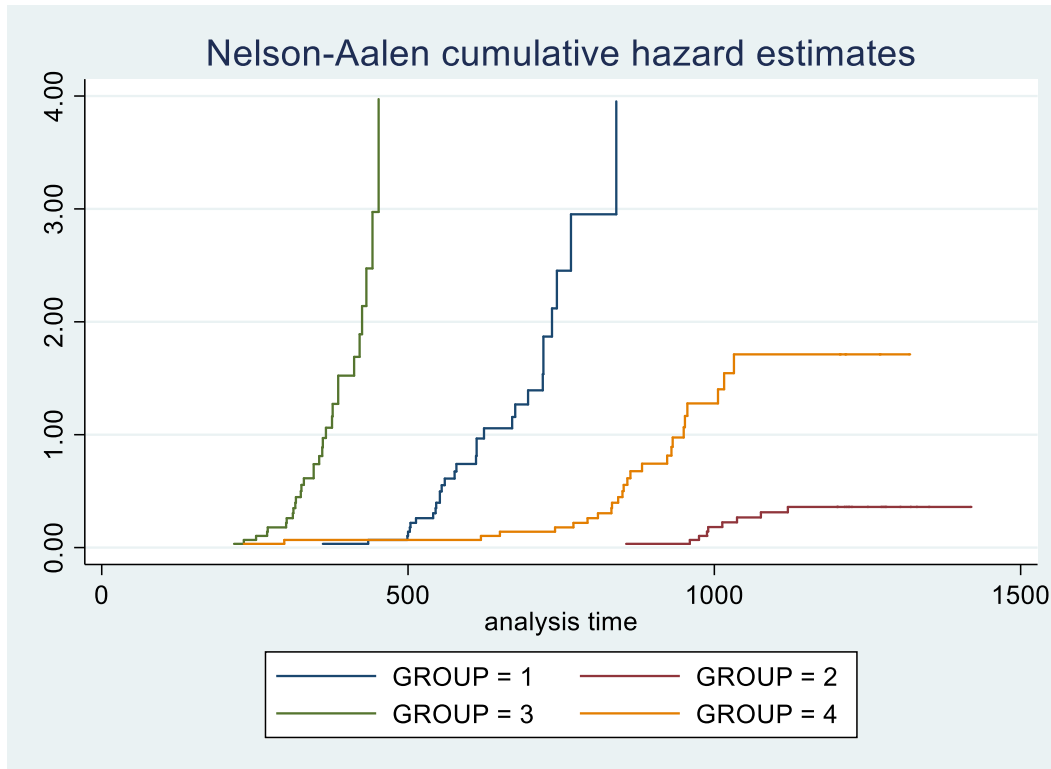


Figure 4.6: Graph of Nelson-Aalen cumulative hazard estimates

4.2. Statistical Analysis

4.2.1. Statistical Analysis using the Survival Analysis Function

The summary statistics on the previous pages, show the events observed and expected across the four groups. Apical patency was achieved in all the teeth in groups 1 and 3. Apical patency was least gained in group 2 followed by group 4. This information was statistically analysed by allowing for difference in survival time by comparing the hazards in the four groups over the duration. It was assumed that the ratio of the hazards is constant over time because it cannot be assumed that the hazards of the event of interest is constant over time. The assumption that the hazard ratio is constant over time is known as the proportional hazards assumption.

In order to statistically analyse the differences in the proportionality of the hazard over time between and among the groups, the number of specimens in each group that apical patency occurred was calculated. The minimum, maximum and median time (in seconds) taken and the full time at risk for all the specimens in each group was also calculated.

This information is shown on the next pages for each group:

```

failure _d: APICALPATENCYREGAINED == 2
analysis time _t: RETREATMENTTIMESECONDS

```

Category	total	per subject			
		mean	min	median	max
no. of subjects	30				
no. of records	30	1	1	1	1
(first) entry time		0	0	0	0
(final) exit time		602.2333	361	577.5	840
subjects with gap	0				
time on gap if gap	0				
time at risk	18067	602.2333	361	577.5	840
failures	30	1	1	1	1

Table 4.8: Table of retreatment result and time for group one

Apical patency occurred in all 30 teeth and appears to have occurred with a minimum time of 361 seconds in group 1. The maximum time taken to reach patency is 840 seconds and the median time is 577.5 seconds. The full time at risk for all 30 teeth, in group 1 combined is 18067 seconds.

-> GROUP = 2

failure _d: APICALPATENCYREGAINED == 2
analysis time _t: RETREATMENTTIMESECONDS

Category	total	per subject			
		mean	min	median	max
no. of subjects	30				
no. of records	30	1	1	1	1
(first) entry time		0	0	0	0
(final) exit time		1178.267	856	1219	1418
subjects with gap	0				
time on gap if gap	0				
time at risk	35348	1178.267	856	1219	1418
failures	9	.3	0	0	1

Table 4.9: Table of retreatment result and time for group 2

Apical patency occurred in 9 teeth and appears to have occurred with a minimum time of 856 seconds in Group 2. The maximum time taken to reach patency is 1418 seconds and the median time is 1219 seconds. The full time at risk for all 9 teeth in Group 2 combined is 35348 seconds.

-> GROUP = 3

failure _d: APICALPATENCYREGAINED == 2
analysis time _t: RETREATMENTTIMESECONDS

Category	total	per subject			
		mean	min	median	max
no. of subjects	30				
no. of records	30	1	1	1	1
(first) entry time		0	0	0	0
(final) exit time		344.2	216	346	452
subjects with gap	0				
time on gap if gap	0				
time at risk	10326	344.2	216	346	452
failures	30	1	1	1	1

Table 4.10: Table of retreatment result and time for group 3

Apical patency occurred in all 30 teeth and appears to have occurred with a minimum time of 216 seconds in Group 3. The maximum time taken to reach patency is 452 seconds and the median time is 346 seconds. The full time at risk for all 30 teeth in Group3, combined is 10326 seconds.

-> GROUP = 4

failure _d: APICALPATENCYREGAINED == 2
analysis time _t: RETREATMENTTIMESECONDS

Category	total	per subject			
		mean	min	median	max
no. of subjects	30				
no. of records	30	1	1	1	1
(first) entry time		0	0	0	0
(final) exit time		888.1	232	872.5	1318
subjects with gap	0				
time on gap if gap	0				
time at risk	26643	888.1	232	872.5	1318
failures	25	.8333333	0	1	1

Table 4.11: Table of retreatment result and time for group 4

Apical patency occurred in 25 teeth and appears to have occurred with a minimum time of 232 seconds in Group 4. The maximum time taken to reach patency is 1318 seconds and the median time is 872.5 seconds. The full time at risk for all 25 teeth in Group 4, combined is 26643 seconds.

On inspection, the cumulative hazard ratios are not proportional to each other and therefore statistical tests were performed to detect if there are differences between the four groups over time. There are three statistical tests that can be selected in STATA that test whether the survival functions are equal. These are the log rank test (Mantel, 1966), Breslow test (Breslow, 1970; Gehan, 1965) and the Tarone-Ware test (Tarone & Ware, 1977), all of which were selected as produced and are presented below:

```
. sts test RETREATMENTTIMESECONDS, logrank trend  
  
      failure _d:  APICALPATENCYREGAINED == 2  
analysis time _t:  RETREATMENTTIMESECONDS
```

Log-rank test for equality of survivor functions

```
chi2(108) =      540.27  
Pr>chi2 =      0.0000
```

Test for trend of survivor functions

```
chi2(1) =      221.05  
Pr>chi2 =      0.0000
```

Figure 4.7: Log-rank test equality of survival functions

```

. sts test RETREATMENTTIMESECONDS, tware trend

      failure _d:  APICALPATENCYREGAINED == 2
analysis time _t:  RETREATMENTTIMESECONDS

      chi2(108) =      501.21
      Pr>chi2 =      0.0000

Test for trend of survivor functions

      chi2(1) =      194.83
      Pr>chi2 =      0.0000

```

Figure 4.8: Tarone-Ware test of equality of survival functions

```

. sts test RETREATMENTTIMESECONDS, wilcoxon trend

      failure _d:  APICALPATENCYREGAINED == 2
analysis time _t:  RETREATMENTTIMESECONDS

      chi2(108) =      469.81
      Pr>chi2 =      0.0000

Test for trend of survivor functions

      chi2(1) =      171.07
      Pr>chi2 =      0.0000

```

Figure 4.9: Wilcoxon trend test of equality of survival functions

Running all the statistical tests all returned the same result (e.g., statistically significant), therefore only report the result of the log rank test as reported. Also, the log rank test weights the difference at each time point equally (i.e., all weights are equal to 1). Compared to the other two statistical tests (i.e., the Breslow and the Tarone-Ware tests), the log rank test places greater emphasis on differences at later rather than earlier time points (i.e., all other things being equal, survival functions that show differences at later time points are more likely to be determined to be different using the log rank test than the other tests).

The log rank test was used to test the null hypothesis that there is no difference in the overall survival distributions between the groups (e.g., intervention groups) in the population. To test this null hypothesis, the log rank test calculated a χ^2 -statistic (the "Chi-Square" column), which is compared to a χ^2 -distribution with two degrees of freedom (the "df" column). In order to determine whether the survival distributions are statistically significantly different, the "Sig." column which contains the p-value for this test was consulted. It can be seen that the significance level of this test is 0.000. This does not mean that $p = 0.000$, but that $p < 0.005$.

A log rank test was run to determine if there were differences in the survival distribution for the different types of groups. The survival distributions for the four groups were statistically significantly different, $\chi^2(2) = 221.05$, $p < 0.005$.

4.2.2. Statistical Analysis using the Kruskal-Wallis H Test

This analysis was derived by looking at the results of the retreatment that were presented in the box plot in the section 4.1.1. section in the descriptive statistics section (Figure 4), shown again below for convenience:

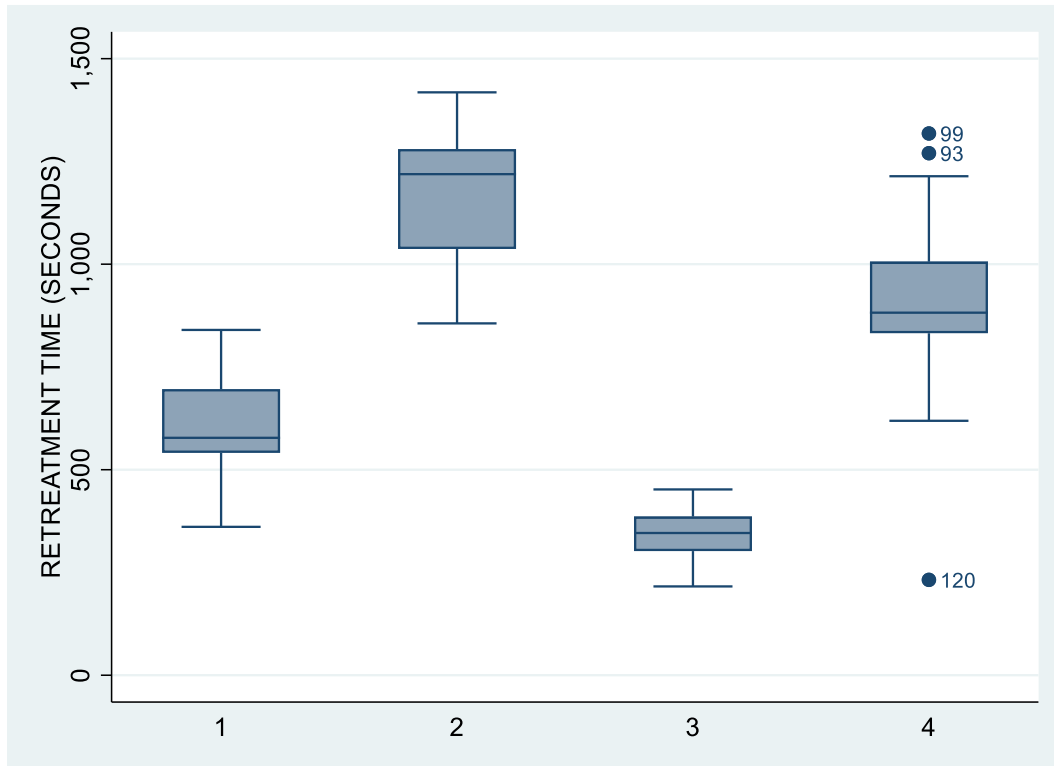


Figure 4.10: Box plot of retreatment times for each group

On inspection of the boxplot, it was determined that there were outliers that could not be removed from the analysis. Therefore, a Kruskal-Wallis H test was run to determine if there were differences in retreatment times between four groups of the two endodontic sealing materials, each with two different working lengths: Distributions of retreatment times were not similar for all groups, as assessed by visual inspection of the boxplot. The distributions of retreatment times were statistically significantly different between groups, $\chi^2(3) = 96.280$, $p = 0.001$.

A Kruskal-Wallis equality-of -groups rank test was performed. This is shown in the analysis below.

Kruskal-Wallis equality-of-populations rank test

GROUP	Obs	Rank Sum
1	30	1440.50
2	30	3053.00
3	30	532.00
4	30	2234.50

chi-squared = 96.280 with 3 d.f.
probability = 0.0001

) chi-squared with ties = 96.284 with 3 d.f.
probability = 0.0001

Figure 4.11: Kruskal-Wallis equality-of populations rank test

Pairwise comparisons were performed using Dunn's (1964) procedure with a Bonferroni correction for multiple comparisons. Adjusted p-values are presented. Values were mean ranks unless otherwise stated. This post hoc analysis revealed statistically significant differences in Retreatment times between the Group 2 (1219) and Group 3 (346) ($p < 0.0001$), and Group 3 (346) and Group 4 (872.50) ($p < 0.0001$), and Group 1(577.50) and Group 2 (1219) ($p < 0.0001$), and Group 1 (577.50) and Group 3 (346) ($p = 0.0022$, and between Group 1 (577.50) and Group 4 (872.50) ($p = 0.0096$), in that order.

Dunn's Pairwise Comparison of RETREATMENTTIMESECONDS by GROUP
(Bonferroni)

Col Mean- Row Mean	1	2	3
2	-5.984684 0.0000		
3	3.371836 0.0022	9.356520 0.0000	
4	-2.946877 0.0096	3.037807 0.0071	-6.318713 0.0000

Figure 4.12: Dunn's Pairwise Comparison of Retreatment by group with Bonferroni correction

There were 94 teeth that reached apical patency. Group 2 had the least amount of teeth that reached apical patency (9) and it also took the longest time to reach apical patency (median time 990 seconds). Group 3 took the shortest time to reach apical patency in all thirty teeth at a median time of 346 seconds.

Summary for variables: RETREATMENTTIMESECONDS
by categories of: GROUP (GROUP)

GROUP	N	p50	iqr
1	30	577.5	155
2	9	990	62
3	30	346	74
4	25	852	139
Total	94	577.5	467

Table 4.12: Table of results of retreatment, median time and interquartile range per group

CHAPTER 5: DISCUSSION

5.1. Overview

Root filling materials act as a barrier which prevents access to and complete removal of necrotic debris and bacteria that cause and sustain peri-apical lesions (Ng *et al.*, 2007). This should be removed to facilitate successful retreatment (Torabinejad, Ashraf & Walton, 2014). Studies evaluating the removal of different root filling materials confirm that absolute complete removal of these materials is impossible (Só *et al.*, 2008; Alves *et al.*, 2016; Silva *et al.*, 2017; Versiani *et al.*, 2018). However, as a pre-requisite to successful retreatment, working length and apical patency must be established. (Torabinejad, Ashraf & Walton, 2014). Opinion on if root canals sealed using a bioceramic sealer can successfully be retreated is divided. This study aimed to determine the retreatability of canals sealed using a bioceramic sealer. The sealing of canals in groups 2 and 4 with the gutta percha cone 3mm short of the working length allowed the study to independently test the effect of the experimental and control sealer cements on the retreatability of canals. This was important since in practice, situations could arise whereby an operator, using an improper technique failed to extend the master cone to the full working length, sealing the apical area with only the sealer cement.

5.2. Findings From the Study & Significance

From the results, it was observed that retreatment of canals sealed using a bioceramic sealer took longer than the control group. Sealing the canal with the master GP cone short of the WL not only made the retreatment to take longer, but it reduced the chances of successful retreatment immensely, more so in the bioceramic sealer group. On inspection of the boxplot, it was determined that there were outliers that could not be removed from the analysis and thus a Kruskal-Wallis H test was run to determine if there were differences in retreatment times between the four groups varying endodontic sealing materials, and different working lengths. Distributions of retreatment times were not similar for all groups, as assessed by visual inspection of a boxplot.

The distributions of retreatment times were statistically significantly different between groups, $\chi^2(3) = 96.280$, $p = 0.001$.

Pairwise comparisons were performed using Dunn's (1964) procedure with a Bonferroni correction for multiple comparisons. Adjusted p-values are presented in the results above. This post hoc analysis revealed statistically significant differences in retreatment times between Group 2 (1219) and Group 3 (346) ($p < 0.0001$), and Group 3 (346) and Group 4 (872.50) ($p < 0.0001$), and Group 1 (577.50) and Group 2 (1219) ($p < 0.0001$), and Group 1 (577.50) and Group 3 (346) ($p = 0.0022$), and between Group 1 (577.50) and Group 4 (872.50) ($p = 0.0096$), in that order.

5.3. Comparison with Other Studies

Since retreatment times for the four groups were statistically significantly different, ($\chi^2(2) = 221.05$, $p < 0.005$), the null hypothesis that there is no difference in the retreatment times between the groups (e.g., intervention groups) in the population and the retreatability was therefore rejected.

The findings of this study agree with those of Hess and co-workers (Hess *et al.*, 2011) who found that it was significantly more difficult to retreat canals sealed using a bioceramic sealer especially where the GP cone does not extend to the working length. They noted that GP serves as a pathway for the retreatment instruments. The findings of both the studies contrast with those of another group (Agrafioti, Koursoumis and Kontakiotis, 2015). This group found that working length and patency was established in 100% of specimens in all groups. This group had also intentionally obturated one of their sample groups with the master cone GP 2mm short of the working length to allow evaluation of the effect of the sealer cement independently. They established that in the group where the master GP was placed 2mm short of the WL, although working length and apical patency were achieved, it took a longer time. This was in comparison to the groups that were sealed to length with GP and AH Plus as well as the group that was filled to length with Gutta percha and TotalFill BC and/or MTA Fillapex. The difference in time was statistically significant. This latter finding agrees with both this study and that by Hess.

The difference in these findings could be accounted for by the duration which the cements were allowed to set before retreatment as well as when the decision to stop retreatment was set at. This study set the stoppage at either when working length and apical patency was achieved or when no progress was being made by the retreatment instruments apically beyond the 20-minute mark. In

the Agrafioti study (Agrafioti, Koursoumis and Kontakiotis, 2015), the time at which retreatment was to be stopped if progress wasn't being made was not stated. The time to stop in case of lack of progress was outlined in the present study because clinically extended attempts to retreat canals are prone to result in procedural errors like perforation and instrument separation.

5.4. Limitations

This was a laboratory study that was used to explain a clinical phenomenon. It is therefore difficult to reproduce the exact clinical scenario. However, it would be unethical to conduct such a study in human subjects in a clinical setting.

The use of straight single canals in the study is another limitation. Their use implies that the findings cannot be replicated in curved canals especially those of molars. However, it was necessary that controls of the root curvature be established so that the effects of the cement can be tested independently. Since the canals were assigned to both the control and the experimental group randomly, the findings herein can be attributed to the type of sealing material used. It would be expected that curved canals would be more difficult to treat. The findings herein can therefore only be used as a guide but not a rule.

5.5. Summary and conclusion

Since the fully extended GP will guarantee a passage for retreatment instruments to the apical area of the canal should a need to retreat arise, the sealer and GP application technique during obturation should allow for full extension of the GP within the canal. Improper use of bioceramic sealers diminishes the chances of successful retreatment. The use of bioceramic sealers to seal successfully retreated canals should be considered.

5.6. Conflict of interest

The authors declare that they have no conflict of interest

5.7. Source of funding

Self and Medical Mission Charitable Trust (MMCT), Kenya.

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ADDENDUM 2: ETHICS CLEARANCE FOR THE RESEARCH



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23 April 2018

Dr G Obaigwa
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Ethics Reference Number: BM18/2/1

Project Title: Retreatability of root canals filled using a bioceramic sealer cement and Gutta Percha.

Approval Period: 23 March 2018 – 23 March 2019

I hereby certify that the Biomedical Science Research Ethics Committee of the University of the Western Cape approved the scientific methodology and ethics of the above mentioned research project.

Any amendments, extension or other modifications to the protocol must be submitted to the Ethics Committee for approval.

Please remember to submit a progress report in good time for annual renewal.

The Committee must be informed of any serious adverse event and/or termination of the study.

A handwritten signature in black ink, appearing to read 'Josias', is placed over a white rectangular box.

*Ms Patricia Josias
Research Ethics Committee Officer
University of the Western Cape*

PROVISIONAL REC NUMBER -130416-050

ADDENDUM 3: TURNITIN SIMILARITY REPORT

Final thesis			
ORIGINALITY REPORT			
% 18	% 10	% 12	% 14
SIMILARITY INDEX	INTERNET SOURCES	PUBLICATIONS	STUDENT PAPERS
PRIMARY SOURCES			
1	www.nature.com Internet Source		% 2
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