http://dx.doi.org/10.17159/2519-0105/2022/v77no2a4

Retreatability of root canals obturated using a bioceramic sealer and gutta percha

SADJ March 2022, Vol. 77 No. 2 p77 - p84

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ABSTRACT

Introduction
The use of bioceramic sealers may, on occasion, complicate endodontic retreatment. This is due to their hard setting nature as well as adherence to root dentine which makes them more challenging to dislodge from root canals.

Aim
The aim of this *in vitro* study was to determine the retreatability of root canals sealed with a bioceramic calcium silicate-based sealer cement.

Materials and Methods
120 permanent human single rooted teeth were selected for the study. After working length and apical patency determination, the teeth were prepared using iRace™ Ni-Ti rotary files. Teeth were divided into four groups (n=30) and obturated as follows:

- Group 1: TotalFill BC™ points and TotalFill BC™ sealer with the master GP at WL using basic hydraulic technique
- Group 2: TotalFill BC™ points and TotalFill BC™ sealer with the master GP 3mm short of WL using basic hydraulic technique
- Group 3: GP and AH Plus™ with the master GP at WL using lateral condensation technique
- Group 4: GP and AH Plus™ with the master GP 3mm short of WL using lateral condensation technique
- D-Race™ retreatment files and Endosolv™ was used to remove obturation material.

Results
The Kruskal-Wallis H test, pairwise and comparison between groups showed that the type of sealer cement and the working length influenced both the retreatability of the canal and retreatment time. The differences were statistically significant ($p < 0.005$) at a 95% CI.

Conclusion
Fully extended GP will guarantee a passage for retreatment instruments to the apical area of the canal. 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.

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INTRODUCTION
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 by-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 by-products which are responsible for persistent peri-apical inflammation.[1]

Although there is considerable debate about which is more important between the root filling and the coronal seal, both the coronal and root canal seals are central in preventing bacterial re-entry and recolonization of the root canal system and the surrounding peri-apical tissues. The seal entombs any bacteria that may not have been removed during canal space preparation and irrigation; and prevents their re-entry from the oral cavity respectively.[2]

Functions of Endodontic Sealers
Conventionally, the obturation of the root canal system is done using a solid core material; mostly Gutta Percha (GP) cones together with a sealer cement which is in a paste form. The sealer flows and seals patent accessory canals, voids, apical deltas and ramifications which may be present in the root canal.[3] The sealer serves as a canal lubricant to facilitate placement of the root canal core material. The sealer also helps to create a bonded interface between the core material and the root dentine. 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.[4]

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. Vertical and lateral condensation techniques were developed to minimize the sealer interface and increase adaptation of the sealer and the GP to the root canal walls.[3]

Bioceramic sealers

Pre-mixed bioceramic based sealer cements were introduced in clinical practice in 2008.[5] 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.[6,7]

Bioceramics are ceramic materials developed for use in medicine and dentistry.[8] Initially their use in endodontics was limited to perforation repair and retrograde filling materials in apical surgical procedures due to their poor handling properties.[9] 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.[8,9]

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 viscosities that are used as root repair materials.[11]

Application technique of Bioceramic Endodontic Sealers

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. 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 micro-crack formation within the root dentine.[3] TotalFill BC is compatible with both vertical and horizontal condensation techniques as well.[11]

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.[11]

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.[12] 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.[13] 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.[10,14-17]

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.[18] 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.[9,19,20]

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.[21] In a study by Zhou *et al.*[21] 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. The setting time of a sealer cement (while allowing enough time for manipulation and placement) is a desirable property. Sealer cements that take longer time to set run the risk of reduced biocompatibility as a result of tissue irritation.[22] 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.[21,23,24] Thus, the shorter setting times of bioceramic sealers (which 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 favourable flow properties which meet ISO standards.[21] 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.[12]

The radiopacity of TotalFill BC sealer is 3.83 units of aluminium.[25] Even though the radiopacity of TotalFill BC was found to be lower than that of AH Plus in the study of Candeiro *et al.*[25] it is still within the acceptable standards of the ISO, which requires that root sealers have a minimum radiopacity of 3mm of aluminium.[12] 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.

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.[26-29] 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 root dentin.

TotalFill BC™ sealer has been shown to have acceptable resistance to dissolution in water despite its hydrophilicity. Zhou[21] *et al,* showed that TotalFill BC has a solubility value of 2.9%. This was higher than MTA Fillapex (Angelus) which has a solubility of 1.1%.[21] However, these values meet ANSI/ADA recommendations of solubility not exceeding 3%.Conflicting findings were reported by Wang[30] who reported MTA Fillapex to be highly soluble namely 14.94%, more than AH Plus, which was 0.25%.[30] 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.[12]

Inadequate removal of root filling materials from within the pulp chamber caries a high risk of dentin discoloration. A root canal sealer should not stain the tooth. Ioannidis[31] et al, 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.[31] This finding makes the sealer to be the material of choice where aesthetics is a high priority.

Retreatability of root canals

The main disadvantage 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 treatment fails.[32] 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.[33]

In order to successfully retreat the diseased tooth, it is necessary to remove all or part of the coronal restoration as well as the obturation materials from the root canal system. This allows for cleaning and shaping to be performed, so as to eliminate the micro-organisms responsible for post-treatment endodontic disease. Studies evaluating the various mechanical and chemical techniques of removal of different root filling materials confirm that absolute complete removal is impossible.[34-37] 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.[38] In a study by Hess *et al*.[39], where Endosequence BC sealer (similar product to TotalFill BC sealer) was used as the sealer and the obturation was done to working length, apical patency was established in only 80% of the canals. When the obturation was done 2mm short of the working length, 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.[33]

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.[40] The researchers 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 working length, 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.[41,42]

Retreatment Protocols

As quoted by Bhagavaldas *et al.*[43], the Glossary of Endodontics defines retreatment as a procedure to remove root canal filling material from root canals, followed by cleaning, shaping and obturation of the canals.[43] 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.[32]

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.[44]

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 is thought to weaken the adhesion of the obturation material to the canal walls facilitating its removal.[40]

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.[32,45]

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.[32] 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.[46] 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.[47] The most recognizable tetrachloroethylene solvent 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) for the removal of obturation materials from canals sealed using resin–based sealers. Currently, it is formulated and availed 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 by using 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 recommended that a flushing action be used. This is because repeated irrigation and aspiration creates turbulent pressures that enhance filling material removal. The deposited volume should be adequate to fill up the root canal up to the floor of the pulp chamber and the solvent is agitated with hand files. The largest size of fitting paper points should then be inserted into the canal to absorb the now dissolved root filling material.[32]

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 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; which may be the cause of sustained peri-apical infection and inflammation.[48]

MATERIALS AND METHODS

One hundred and twenty single rooted, single canal anterior and premolar teeth were selected for this study. The teeth were obtained from the oral surgery and service rendering clinics of the Faculty of Dentistry, University of the Western Cape. The teeth collected for the purposes of this study were extracted for reasons unrelated to the objectives of this study. Prior to commencement of this study, ethical clearance was obtained from the Research Committee of the Faculty of Dentistry, University of the Western Cape (Ethics number: BM18/2/1). Every aspect of this study was conducted in accordance with the ethical and safety guidelines for handling human tissues and conducting laboratory studies, as prescribed by South African law: The Health Professions Act 56 of 1974 (Health Professions Council of South Africa, 2008).

Inclusion Criteria

1. Human single rooted, single canal anterior and premolar teeth
2. Teeth roots with mild curvature
3. Teeth with patent canals as confirmed by radiographic examination
4. Teeth with apical patency as confirmed using K-file size 10

Exclusion criteria

1. Teeth with moderate to severe root curvature at any point along the roots
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

Specimen Preparation

The extracted teeth 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). All adherent hard and soft tissues were removed from teeth using an ultrasonic scaler (Suprasson, Satelec Acteon, France), and specimens were then stored in physiological saline (B Braun Medical, Randburg, SouthAfrica). 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.

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. 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.

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.

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. 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.

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.

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) and obturated as follows:

Group 1	TotalFill BC sealer and bioceramic nano particle–coated Gutta Percha (FKG Dentaire SA, Switzerland)	At working length
Group 2	TotalFill BC sealer and bioceramic nano particle–coated Gutta Percha (FKG Dentaire SA, Switzerland)	At working length minus 3mm
Group 3	AH Plus and regular ISO Gutta Percha (Dentsply Detrey GmbH Konstanz, Germany)	At working length
Group 4	AH Plus and regular ISO Gutta Percha (Dentsply Detrey GmbH Konstanz, Germany)	At working length minus 3mm

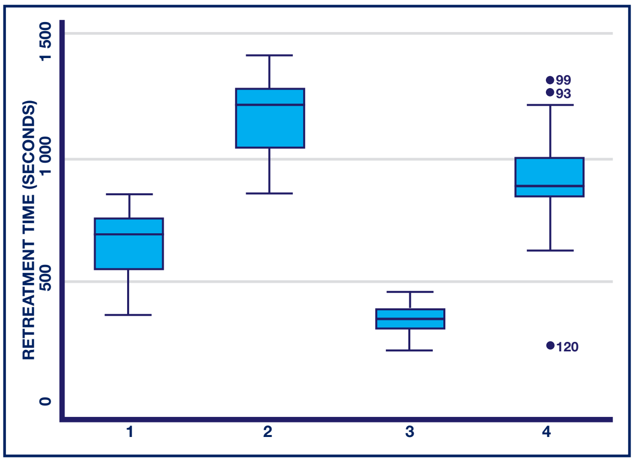
The sealers were introduced into the root canals using a #20 K-file (Flexofile, Dentsply Sirona SA) in order to coat the canal walls. The master GP cone was then coated with the sealer and slowly inserted to the appropriate length. The hydraulic condensation technique, as described by the manufacturer, where 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. All the specimens were stored at 37ºC in 100% humidity for three weeks in a laboratory warm water bath (Labcon Laboratory Equipment, Krugersdorp, South Africa)

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.

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. Three 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).

Fig 1. Box plot showing the retreatment times (in seconds) for each group.



RESULTS

Statistical analysis

There were 30 canals in each of the four groups 1, 2, 3 and 4. In total there were 120 specimens that were retreated. 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 1)

Table 1

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%**

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). (See Table II)

Table II

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

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 left.

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. (See Fig 1) 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 significant different between groups, $\chi2(3) = 96.280$, $p = 0.001$.

There were 94 teeth that reached apical patency. Group 2 had the least number 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.

DISCUSSION

The use of endodontic bioceramic based sealers have grown in popularity in recent years. The mechanism of bioceramic sealer bonding to root dentine is based on: the diffusion of the sealer particles into dentine tubules causing mechanical interlocking bonds; infiltration of the sealer mineral content into intertubular dentine causing a mineral infiltration zone; and the reaction of the phosphate with calcium silicate hydrogel and calcium hydroxide which causes the formation of hydroxyapatite along the mineral infiltration zone.[21,30] Thus; bioceramic sealers have great biocompatibility due to their similarity with biological hydroxyapatite. The biocompatibility of bioceramics aid in preventing a reaction in surrounding tissues as well as chemically bonding to tooth structure. The calcium phosphate component in bioceramic materials intensifies the setting reactions which results in a chemical configuration with a crystalline formation close to tooth and bone-apatite materials.[30]

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.[48] This should be removed to facilitate successful retreatment.[38] Endodontic retreatment is performed to remove the root filling material (Gutta Percha), after persistent infection and root canal failure. This followed by debridement, shaping and disinfection of root pulp system for a second time.

Studies evaluating the removal of different root filling materials confirm that absolute complete removal of these materials is impossible.[34-37] However, as a pre-requisite to successful retreatment, working length and apical patency must be established.[38] Opinion on whether root canals sealed using a bioceramic sealer can successfully be retreated is divided.

This study aimed to determine the retreability of canals sealed using a bioceramic sealer. The sealing of canals in groups 2 (TotalFill BC) and 4 (AH Plus) 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. Although this is not the correct or ideal manner to use these materials, this may happen in the clinical scenario.

The results indicated that retreatment of canals sealed using a bioceramic sealer took longer than the epoxy resin–amine-based 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. The additional time can be attributed to extra time needed to get patency and regaining working length due to the nature of the bioceramic material. 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, $\chi2(3) = 96.280$, $p = 0.001$. The retreatment times for the four groups were statistically significantly different, ($\chi2(2) = 221.05$, $p < 0.005$).

The findings of this study agree with those of Hess *et al.*[39] 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. Even though the bioceramic sealers have set, the GP remains the core material. Agrafioti *et al.*[40] 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 *et al*.[39]

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[40] study, 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. The difference in root anatomy of specimens could also contribute to the difference between the current study and that of Agrafioti *et al.*[40]

CONCLUSION

The present *in vitro* study suggests that the new calcium silicate-based sealers are negotiable, when the root canal anatomy is simple. However, these procedures may be time demanding. The current study submits that bioceramic sealers are navigable within certain constraints. However, it does require more time spent to complete the procedures. 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.

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