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BOSTON UNIVERSITY

HENRY M. GOLDMAN SCHOOL OF DENTAL MEDICINE

THESIS

THE EFFECT OF TEMPERATURE ON THE PHYSICAL PROPERTIES OF BIOCERAMIC SEALERS

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DEDICATION

To my wife who always supported my dreams and journeys, and my son whose determination to achieve his milestones pushed me to work harder

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I would love to thank Dr. Russell Giordano for his advice and support throughout the whole project. His help was irreplaceable.

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Without all your help I would have never completed this work.

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THE EFFECT OF TEMPERATURE ON THE PHYSICAL PROPERTIES OF BIOCERAMIC SEALERS

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Abstract

Introduction: The compatibility of EndoSequence BC Sealer (BC Sealer; Brasseler USA, Savannah, GA) for warm vertical compaction has been questioned due to changing physical properties under higher temperature. The aim was to evaluate the effect of heating on the physical properties (flowability and radiopacity) of a new calcium-based root canal sealer (EndoSequence BC Sealer HiFlow [HiFlow]) in comparison with EndoSequence BC Sealer.

Methods: The flow, and radiopacity of the 2 sealers were measured according to ISO 6786/2012 at different temperatures. Forty real printed plastic teeth (incisor) were used to evaluate the flowability of the two Standard EndoSequence BC Sealer and HiFlow EndoSequence BC Sealer into the lateral and apical accessory canals. These evaluation was done with two obturation techniques including single cone and warm vertical condensation.

Result: The mean flowability was ranging from 22.25 mm to 9.52 mm. The results indicate that there is a statistical difference between the flowability of the two calcium silicate based sealers under all three different temperatures (37˚C, 100˚C and 150˚C). Radiopacity was measured at two different temperatures including 21˚C and 100˚C. The mean gray value ranged from 213.55 to 202.25. Results showed that HiFlow is more radiopaque and there is a statistically significant difference at both temperatures. The results of single cone and warm vertical obturation techniques show that there is no significant difference between the flowability of the two calcium silicate based sealers into the lateral and apical accessory canals at 21°C and there is a significant difference at higher temperatures.

Conclusions: HiFlow BC sealer had higher flow and was more radiopaque, especially at high temperatures, which are generated by the commonly used warm vertical compaction technique.

Keywords: EndoSequence BC sealer; HiFlow; physical properties; warm vertical compaction; single cone.

Table of Contents

Table of Contents

DEDICATION .... *iii*

ACKNOWLEDGMENTS .... *iv*

Abstract .... *v*

Table of Contents .... *vii*

List of tables .... *x*

List of Figures .... *xi*

List of Abbreviation .... *xii*

Chapter 1. INTRODUCTION *1*

1.1 Anatomy and Morphology of Root Canal System **2**

1.2 Cleaning, Shaping and Obturation: **3**

1.3 Bioceramic sealers **5**

1.4 Obturation and Sealers **6**

1.4.1 Zinc Oxide and Eugenol 7

1.4.2 Calcium Silicate Sealers 8

1.4.3 Introduction of properties 9

1.4.4 Expansion and sealing ability 10

1.4.5 Compressive strength 10

1.4.6 Radiopacity....11
1.4.7 Setting Time....11
1.4.8 Calcium and ion release and alkalinizing properties....11
1.4.9 Porosity....12
1.4.10 Solubility....12
1.4.11 The “bioactivity” issue....13
1.4.12 Root- End filling materials....13
1.4.13 Pulp capping materials....14
1.4.14 Dentin hypersensitivity....14
1.4.15 Root canal sealers....14
1.4.16 Root perforation repair materials....15
1.4.17 Apicogenesis, apexification, pulp revascularization and treatment of open apex roots....15
1.4.18 Dentin remineralization....16
1.4.19 Endosequence BC Sealer....16

1.7 Statement of the problem....19

1.8 Objectives....20

Chapter 2. MATERIALS AND METHODS....21

2.1 Flowability test....22

2.2 Radiopacity Test....24

2.3 Flowability into Mid-Lateral and Apical Canals....25

2.3.1 Teeth selection, preparation, and experimental groups....26
2.3.2 Warm Vertical Compaction Technique....27
2.3.3 Single Cone technique....28
2.3.4 Evaluation of the flowability into the mid-lateral and apical canal....28

Chapter 3. RESULTS *30*

3.1 Flowability Test **30**

3.2 Radiopacity **35**

3.3 Flowability into the lateral and apical accessory canals with single cone technique .. **40**

3.4 Flowability into the lateral and accessory canals with warm vertical condensation technique **40**

Chapter 4. DISCUSSION *45*

4.1 Flowability **45**

4.2 Radiopacity **50**

4.3 Limitation of the study **51**

4.4 Conclusions **53**

References *54*

CV/Resume..**61**

List of tables

Table 1. Mean, Standard deviation and Standard of the error for two sealers under different temperatures 31

Table 2. One-way ANOVA Analysis of The Flowability by sealer showing that there is a significant difference between two sealers at two different temperatures. 33

Table 3. Results of Tukey Kramer HSD All Pairs Comparison statistical test showing the difference. Positive values show pairs of means that are significantly different. 33

Table 4. Oneway Analysis of All Temp By Groups > Means Comparisons > Comparisons for all pairs using Tukey-Kramer HSD. Levels not connected by same letter are significantly different. 34

Table 5. Mean, Standard deviation and Standard of the error for two sealers under different temperatures 36

Table 6. One-way ANOVA Analysis of The radiopacity by sealer showing that there is a significant difference between two sealers at two different temperatures. 37

Table 7. Results of Tukey Kramer HSD All Pairs Comparison statistical test showing the difference. Positive values show pairs of means that are significantly different. 38

Table 8: Oneway Analysis of Gray value Overall By Groups > Means Comparison> Comparison for all pairs using Tukey-Kramer HSD 39

Table 9. Results of Tukey Kramer HSD All Pairs Comparison statistical test showing the difference. Positive values show pairs of means that are significantly different 41

Table 10. Results of Tukey Kramer HSD All Pairs Comparison statistical test showing the difference. 44

List of Figures

Figure 1 EDX analysis 19

Figure 2 Zinc Oxide-eugenol sealer 22

Figure 3 standard Endosequence BC® sealer (Brassler USA), standard Endosequence BC® sealer HiFlow (Brassler USA) 22

Figure 4 A sample disk after unloading and digital caliper 23

Figure 5 Aluminum step wedge and poured metal mold 25

Figure 6 Radiograph of sealer and Aluminum step wedge 25

Figure 7 Files, cleaned and shaped plastic tooth 26

Figure 8 Measuring the amount of flowability of sealer into the apical and mid-lateral canal. ... 29

Figure 9 One Way Analysis of all temperatures by groups 32

Figure 10 One Way Analysis of all temperatures by groups 37

Figure 11 One Way Analysis of all temperatures by groups 43

List of Abbreviation

C3PS- Calcium Triphosphate Silicate

C2PS- Calcium Diphosphate Silicate

HCSC- Hydraulic Calcium Silicate Cements

MTA- Mineral Trioxide Aggregate

STDBC- Standard Bioceramic Sealer

Chapter 1. INTRODUCTION

There is no way to know with complete certainty, the origin of endodontics or the people who performed it. The first evidence dates to 200 B.C. Archeologists in Negev region of Israeli desert found a human skull containing a tooth that had a 2.5mm bronze wire embedded in the pulp chamber. This dates to the time of Romans, and it is believed that this practice was used to relieve dental pain at the time. In 1729 Pierre Fauchard, father of modern dentistry, published *The Surgeon Dentist.* In his book he wrote about pulp chambers and root canal spaces and the procedure of opening into the teeth to relieve pressure and drain the pus to cure dental pain. In 1838 Edwin Maynard developed the first endodontic instrument by modifying a watch spring. In 1847 Edwin Truman introduced gutta Percha to the field of dentistry as a denture base material and in 1867 G.A. Bowman used Gutta Percha as root filling material. Over a period of years many other materials have been developed for use in endodontic obturation, but none has endured the test of time like gutta percha. To this day gutta percha is the most widely accepted material for endodontic use.

In recent years, with the introduction of bio ceramic sealers into the market, new and more conservative methods of root canal therapy are being performed by some practitioners. The purpose of this study is to compare the flowability of Bio ceramic and Zinc Oxide Eugenol sealers.

1.1 Anatomy and Morphology of Root Canal System

The root canal space anatomy is complex and divides into minute portals of exit. To understand the anatomy of each tooth until recently a practitioner only had radiographs to rely on. In recent years with the introduction of CBCT, the scans provide more information about the morphology of the canals, but CT images are not always clear and as reliable as we need. Dental microscopes have also played an important role in aiding clinicians with visibility and magnification of the pulp chamber (182). The main objective of root canal therapy is adequate disinfection of the root canal system to treat or prevent apical periodontitis. A root canal system that has a complex anatomy with multiple portals of exit may not get the necessary mechanical sterilization to prevent procedural failure. Dr. Herbert Schilder, one of the pioneers of the field of endodontics extensively studied the presence of MB2 canals, apical deltas, lateral and accessory canals in the apical, middle, and coronal third of the canals (147). The furcation canals were routinely filled with his method of vertical condensation technique. Although the supplemental canals mentioned do not form a collateral circulation, their presence provides portals of exit for the micron size micro- organisms that can cause procedural failure.

The root canal anatomy is divided into two sections. The pulp chamber, located in the anatomic crown of a tooth, and the root canal space located in the root structure of a tooth. The root canal has an inverted cone shape with simple or multiple curvatures from the orifice to the apical foramen (107). Supplemental canals are minute size canals extending from the main canal to the exterior of the roots. These canals are formed by entrapment of periodontal vessels in Hertwig's epithelial root sheath during calcification phase of the tooth development. The

accessory canals in the furcation of multirooted teeth are referred to as furcation canals and are formed due to the entrapment of periodontal vessels during the fusion of the diaphragm stage of dental development (46).

1.2 Cleaning, Shaping and Obturation:

The success and predictability of root canal treatment to prevent or cure apical periodontitis is dependent on accurate diagnosis and performing each stage of treatment to a high standard. Endodontic therapy is an intricate procedure with little margin of error for success in treatment. Every step of the procedure determines the success of the next step. It requires patience, time, good visualization, magnification of the field, patient compliance, and it requires intimate knowledge of the root canal anatomy (11,158).

Apical periodontitis is caused by infection of the pulp tissue leading to pulp necrosis and bacterial colonization of the root canal space. The bacteria and bacterial byproducts eventually leave the root canal space into the surrounding structure and cause symptoms and bone necrosis. The root canal treatment is aimed at eliminating the micro-organisms from the root canal system and preventing reinfection with a three-dimensional seal of the canals and a satisfactory coronal restoration (172,418).

Herb Schilder's paper entitled Cleaning and Shaping the Root Canal, has been adopted as the ideal approach to managing the infected root canal systems. The paper refers to cleaning and shaping "as the removal of all organic substrate from the root canal system and the development

of a purposeful form within each canal for the reception of a dense and permanent root canal filling". He established the ideal objectives that are still followed today (445).

The principles of cleaning and shaping of the root canal system may not have changed in decades however the armamentarium available to the clinicians are evolving rapidly. The introduction of Nickel Titanium files (NiTi files) has allowed flexibility and creation of a glidepath in complex root canal systems. The newer systems also require fewer instruments to prepare canals and some reciprocating files may require only one file for the entire procedure. Cleaning and shaping are not independent of one another. Alteration of the shape of a canal to a continuous taper, allows direct removal of the bacteria and the pulp tissue from the root canal space, it also allows irrigation solution to penetrate deeper into the canal space. A continuous tapered preparation will also aid in obturation of the canals to produce a three dimensional seal of the root canal space. Schilder's objectives in canal preparation can be summarized as:

- Taper – a continuous tapered preparation
- Canal axis – straight line axis in the center of the root
- Foramen – the original position and size should be maintained

The irrigation delivery systems have also improved from the thick gauge needles of the decades past. The more efficient side vent nylon needles, and negative apical pressure systems, sonic and ultrasonic agitation techniques have become a norm in endodontic practices. With the philosophy of minimally invasive endodontics developing among practitioners, in which access cavities are

limited in size in order to preserve as much tooth structure as possible to prevent weakening the tooth, endodontic treatments will rely more heavily on irrigation or more advanced methods (laser radiation) of disinfection of the root canal system. Sodium hypochlorite has been the irrigation of choice for decades mainly due to its efficacy in dissolving organic tissue and effectiveness against broad range of microbial organisms. Sonic, ultrasonic and heated solutions of sodium hypochlorite have been in use for years with better efficacy but all carry risk of complication of hypochlorite extrusion. A novel irrigation technique using multisonic sound waves known as GentleWave is designed to develop a broad spectrum of sound waves within a solution to enhance cleaning of the root canal system.

1.3 Bioceramic sealers

Bioceramic sealers have been showed high level of predictability and successfully root canal treatment. Most practioners use this type of sealer because of biocompatibility and physicochemical properties (4). This sealer is composed of Calcium Phosphate, Calcium Silicate, Calcium Hydroxide, Zirconium Oxide, and filler and thickening agents. Endosequence BC® sealer (Brassler USA) has been introduced to the market. This product has many unique features including using the moisture of dentinal tubes to initiate the setting process. It is also highly radiopaque and hydrophilic.. Endosequence BC® sealer (Brassler USA) is able to form hydroxyapatite upon setting and chemically bonds to dentinal walls (5). BC sealer acts as an anti-bacterial while setting because of high alkaline PH. The other unique feature is zero shrinkage (6-7-8)

1.4 Obturation and Sealers

Three-dimensional obturation of the radicular space is essential to long-term success. The canal system should be sealed apically, coronally, and laterally. Various methods have been advocated for obturation. Unfortunately, all materials and techniques result in some degree of leakage (12).

Various endodontic materials have been advocated for obturation of the radicular space. Most techniques employ a core material and sealer. Regardless of the core material a sealer is essential to every technique and helps achieve a fluid-tight seal.

Root canal sealers are necessary to seal the space between the dentinal wall and the obturating core interface. Sealers also fill voids and irregularities in the root canal, lateral and accessory canals, and spaces between gutta-percha points used in lateral condensation. Sealers also serve as lubricants during the obturation process.

Grossman outlined the properties of an ideal sealer as one that (13)

- Exhibits tackiness when mixed to provide good adhesion between it and the canal wall when set.
- Establishes a hermetic seal.

- Radiopaque, so that it can be seen on a radiograph.
- Very fine powder, so that it can mix easily with liquid.
- No shrinkage on setting.
- No staining of tooth structure.
- Bacteriostatic, or at least does not encourage bacterial growth.
- Exhibits a slow set.
- Insoluble in tissue fluid.s
- Tissue tolerant; that is, nonirritating to periradicular tissue.
- Soluble in a common solvent if it is necessary to remove the root canal filling.

The most popular sealers are zinc oxide–eugenol formulations, calcium hydroxide sealers, glass ionomer sealers, resin-based (epoxy resin or methacrylate resin) sealers, and the recently introduced calcium silicate–based sealers. Despite claims by the manufacturers on the advantages of each class of sealers, there are no evidence-based data, based on randomized clinical trials, demonstrating the superiority of one class of sealer over another. Regardless of the sealer selected, all exhibit some degree toxicity until they have set (34).

1.4.1 Zinc Oxide and Eugenol

Zinc oxide–eugenol sealers have a history of successful use over an extended period of time. Zinc oxide–eugenol sealers will resorb if extruded into the peri radicular tissues (14).

They exhibit a slow setting time,6 shrinkage on setting,192 solubility,290 and they can stain tooth structure (15,16). An advantage to this sealer group is antimicrobial activity (17,18).

Zinc Oxide-Eugenol Liquid component is Eugenol 85% and Olive oil 15%. Formula for Powder Zinc Oxide–Eugenol Root Canal Sealer is below.

Powder	**Percentage by weight**
Zinc oxide	42 %
Staybelite resin	27 %
Bismuth subcarbonate	15 %
Barium sulfate	15 %
Sodium borate, anhydrous	1 %

1.4.2 Calcium Silicate Sealers

A new category of root canal sealers based on mineral trioxide aggregate (MTA) has recently been commercially available. This type of root canal sealer is attractive because of the bioactivity that has been reported for MTA-type materials which are also known for being hydrophilic (19).

Calcium silicate sealers include some of the same hydraulic compounds found in Portland cement, primarily tricalcium silicate and dicalcium silicate powder (19). Tricalcium silicate cements/sealers set by reaction with water and form a highly alkaline (pH of about 12) mixture consisting of a rigid matrix of calcium silicate hydrates and calcium hydroxide (89). These

hydrates form on the surface of the original calcium silicate particles and hydration gradually penetrates inward. When tricalcium silicate cement sets, the dimensional change is less than 0.1% expansion, which helps with creating a barrier, and is especially important for endodontics. For the tricalcium silicate particles to contribute to sealing, they must become hydrated in the tooth by exchange of the non-aqueous vehicle for water in the root canal. The possibility of extrusion past the apex with a bioactive material leads to the supposition that healing in the periapical area would occur more readily with a tricalcium silicate product.

The physical properties Endosequence BC Sealer (21).

Flow (mm)	23
Film thickness (µm)	22
Solubility (Mass loss)	2.9 %
Dimensional stability (Volume Change)	0.09 %
Working time (hours,minutes)	2:40
Setting time (hours)	>24

1.4.3 Introduction of properties

Hydraulic calcium silicate cements (HCSCs), well known as MTA (mineral trioxide aggregate) were developed and have been in use for more than 20 years. An important property that they which previous materials have failed to demonstrate, is that "they can set in wet environments such as in the presence of water, blood, dentinal fluid, saliva, etc., and have satisfactory/good biological properties." (33).

1.4.4 Expansion and sealing ability

HCSCs have intrinsic properties which can be affected by host molecules. HCSCs expand by 0.2-6% of their initial volume and water resorption causing expansion and contributing to the sealing capacity while proteins reduce the expansion of the material and increase the setting time (22). The absorption of water and subsequent expansion of HCSCs enhances their push-out strength as well as "increases micromechanical cement retention along the internal walls and interface adaptations" (33).

1.4.5 Compressive strength

The factors which strongly affect compressive strength of the material are the stage of hydration and the condensation pressure (23). The condensed dry powder of this material has been shown to produce adequate seal in root end fillings (33). Another factor that can affect the compressive strength of the material is acidity. According to Watt et al., higher acidity and lower pH levels affect the compressive strengths of certain cements such as white and gray MTA (35).

1.4.6 Radiopacity

HCSCs have radiopacifiers in their composition to make them suitable for clinical use (33). Unfortunately, certain materials which are added to HCSCs to improve their radiopacity, such as bismuth oxide, may reduce the "cement's biocompatibility" (33). Therefore, certain HCSCs which are used for pulp capping or apicogenesis specifically, do not contain any radiopacifiers (33).

1.4.7 Setting Time

Setting time is an important factor for HCSCs because in certain clinical applications, such as in root-end surgery, the setting time needs to be fast (3). According to Prati et Gandolfi (33), because HCSCs are hydraulic materials, they can set in the presence of water in approximately 40-120 min, with the initial setting time being around 40-50 min, while the final setting time is around 120-170 min (2015). It was further stated in the previously mentioned study that the setting time for HCSCs doped with various calcium phosphates was around 75-80 min. There are certain components which increase setting time such as NaF (24), and certain components which decrease setting time such as calcium chloride (22). As previously mentioned, the presence of proteins increases setting time of HCSCs. Other factors which also influence the setting time of HCSCs include pH as well as the force which is applied to press the powder in the tooth (23).

1.4.8 Calcium and ion release and alkalinizing properties

HCSC based materials release Ca ions for at least 28 days when exposed to saliva (33). Their calcium hydroxide release is linked to their alkalinizing activity as well as their antibacterial properties: calcium silicate materials possess up to 15-30 days of antimicrobial action (33). The antimicrobial effects of Calcium hydroxide include protein denaturation as well as DNA and cytoplasmic damage (25). Calcium hydroxide is a base which can increase the pH of its surrounding environment. According to McHugh et al. (26), the alkalinization of the pH greater than 10.5 reduces the growth of certain common endodontic pathogens such as *E. faecalis.* Therefore, alkanization of the environment by calcium hydroxide release could potentially reduce the growth of certain common endodontic pathogens.

1.4.9 Porosity

Different commercial HCSCs have different porosity values due to higher reactivity and capacity to release bioactive ions. Higher porosity HCSCs create interconnected channels and create space for leakage which could negatively affect their sealing ability and marginal adaptability. HCSCs expanding relative to their initial volumes and forming calcium phosphate precipitates which fill some of the porosities of the material (33). The porosity percentage of certain HCSCs have been investigated. The porosity percentage of tricalcium is 30.98 % (33). The porosity is interconnected in dentinal tubules. These two properties contribute to the reduction of the overall porosity of the material over time.

1.4.10 Solubility

HCSCs solubility ranges from 12-38 % depending on the material (38). HCSCs are more soluble than calcium hydroxide cements. They are responsible for calcium phosphate formation due to releasing Calcium ions, high Si-OH group exposure and fast Phosphate ion uptake (33). The solubility of HCSCs varies depending on the type of cement, with MTA-based cements generally showing less solubility compared to the Portland cement-based cements (37).

1.4.11 The "bioactivity" issue

HCSCs have been shown to have bioactivity ability due to the "nucleation of calcium phosphates and formation of an apatite layer in different SBFs" (33). Because of this, HCSC materials have the ability to support the cell differentiation and stimulate tissue repair, osteogenesis and cementogenesis (33). However, there was a study done which suggested that "tricalcium silicate cements do not induce osteogenic differentiation of human marrow-derived mesenchymal stem cells in vitro" (33). Therefore, more research needs to be done in the future to investigate this property of HCSCs.

1.4.12 Root- End filling materials

HCSCs have a long history in being clinically used as root-end filling materials. Not only do HCSCs exhibit an efficient and durable seal, but they are more biocompatible than other materials such as resin, amalgam, GICs and zinc oxide cements, IRM, and SuperEBA (27).

1.4.13 Pulp capping materials

The goal of pulp capping materials is to preserve pulp vitality and to induce a new dentin bridge to protect the dental pulpal complex. HCSCs show promising effects on dental pulp stem cells as they were able to induce new hard tissue and dentin formation in animals and third molars of humans (33). This is a manufacturer's description that one mechanism through which this is done is biodentine, a calcium silicate material, inducing secretion of TGF-B1 by pulp cells which form early mineralized foci (29). Many in vitro investigations support HCSCs as the material of choice for direct pulp capping (33).

1.4.14 Dentin hypersensitivity

Calcium silicate cements have been proposed to be used to reduce dentin permeability because of their ability to "set in wet conditions and form stable occlusion of dentinal tubules when gently applied and spread with a microbrush on the exposed dentin surface" (33).

1.4.15 Root canal sealers

There are two important factors which make calcium silicates ideal for use as root canal sealers. The first important factor is that calcium silicates are able to set in wet conditions and the

second is that they are able to induce bone formation due to their ability to upregulate mineralization related gene expression for macromolecules such as COL1 and BSP protein (33). Zhang et al. (30), further stated that Calcium silicates could allow the healing of periapical tissues as well. In fact, MTA provides a more "favorable environment for periodontal ligament fibroblast adhesion and growth than amalgam, Dyract(Densply Sirona), IRM(Densply Sirona), and Super Bond C&B(Sun Medical), by regulating cell behavior" (33).

1.4.16 Root perforation repair materials

Root perforations are the result of complex canal anatomy as well as poor instrumentation control. The materials such as amalgam, IRM, calcium hydroxide, and glass ionomer possess osteogenic, cementogenic, or antibacterial properties (28). They are also unable to ensure complete sealing (28). According to Prati et Gandolf (33), HCSCs appear as the choice material for root repairs "in the presence of perforations and other communications between the root/pulp chamber and the periodontal ligaments" due to results from various studies. MTA is also a good material to restore external root resorption as reported by Olivieri et al (31), due to the presence of cementum-like tissue within dentin defect of extracted teeth when treated with MTA.

1.4.17 Apicogenesis, apexification, pulp revascularization and treatment of open apex roots

A 10 year study of observing 17 cases with necrotic pulp and immature apices, it was reported that MTA was a suitable choice in the management of teeth with open apices and periapical lesions. The results of this study were further confirmed by Mente et al. (32).

1.4.18 Dentin remineralization

According to various studies, HCSCs could potentially boost “remineralization of previously demineralized and carious dentin lesions” (33).

1.4.19 Endosequence BC Sealer

BC Sealer is alkaline (10-12pH) before completely set and one day after setting making it highly antibacterial. A recent study showed that BC Sealer killed Enterococcus faecalis within 2 minutes of contact. A recent study proved that BC Sealer has a contact angle which is lower than all other sealers tested. This unique feature of BC Sealer improves its ability to bond to dentin and obturation materials and improves its ability to effectively kill microbes throughout all aspects of the root canal system (10).

BC Sealer is essentially a root repair material with a flowable consistency. The unique osteogenic properties of BC Sealer make it particularly effective on non-vital cases with extensive bone loss or apical periodontitis (49).

BC Sealer’s hydrophilic/hydroxyapatite producing formula and excellent flowability allow it bond readily to both dentin and to bioceramic filling materials (BC PointsTM). A recent study showed that BC Sealer has superior bond strength when compared to other popular sealers. A study varied the moisture content to determine its effect on bond strengths. BC Sealer outperformed all the other sealers at all moisture levels (11). On the other hand, another study compared the bond strength of BC sealers with resin-based sealers. It showed that Bio ceramic sealers presents significantly worse bonding strength than resin-based sealers. There is no significantly different bonding strength to root denting among bioceramic sealers themselves (50).

Composition of Endo-sequence BC Sealer

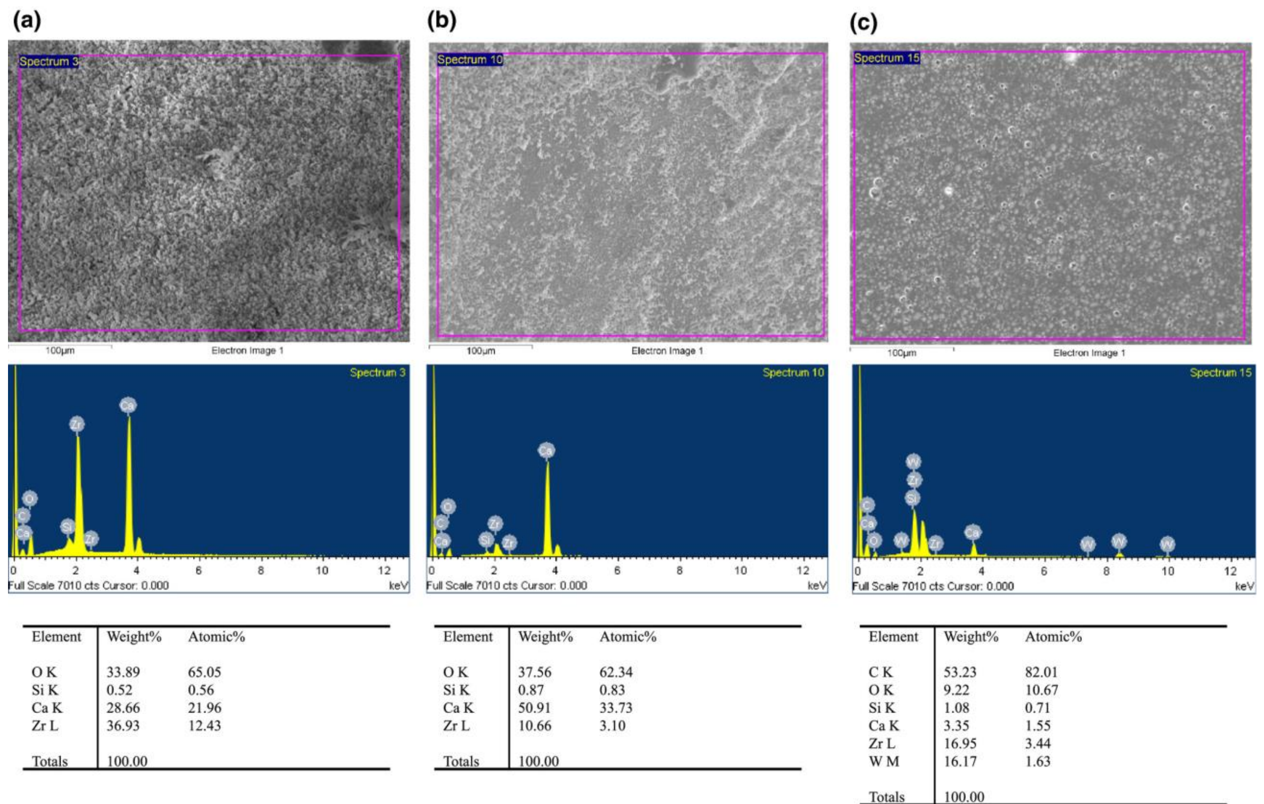
Zirconium oxide
Calcium silicates
Calcium phosphate monobasic (CaH4P2O8)
Calcium hydroxide
Filler
Thickening agents

Composition of Endo-Sequence HiFlow BC Sealer

Zirconium oxide
Tricalcium silicate
Dicalcium silicate
Calcium hydroxide
Filler

Unlike traditional points, EndoSequence® BC Points™ are subjected to a patented process of impregnating and coating each cone with bioceramic nanoparticles. The bioceramic particles found in BC Sealer bond with the bioceramic particles in BC Points™ to form a true gap-free seal. A recent study showed that BC Sealer and coated cones resulted in higher fracture resistance of the roots compared to other filling techniques (53).

SEM-EDX analysis showed the qualitative semi-quantitative elemental composition of the surface of each material. BCS and BCHiF showed the similar elemental composition. C, O and Si were the same % in both sealers, as for the amount of Ca^{+2} and Zr a variation was found. BCHiF showed higher % of Zr than BCS. On the other hand, the % of Ca^{+2} in BC Sealer was significantly higher when compared with the amount of Zr ($P < 0.05$) (48).



Element	Weight%	Atomic%
O K	33.89	65.05
Si K	0.52	0.56
Ca K	28.66	21.96
Zr L	36.93	12.43
Totals	100.00	

Element	Weight%	Atomic%
O K	37.56	62.34
Si K	0.87	0.83
Ca K	50.91	33.73
Zr L	10.66	3.10
Totals	100.00	

Element	Weight%	Atomic%
C K	53.23	82.01
O K	9.22	10.67
Si K	1.08	0.71
Ca K	3.35	1.55
Zr L	16.95	3.44
W M	16.17	1.63
Totals	100.00	

Figure 1 EDX analysis

Evaluation of the chemical composition (spectra) and the element distribution (elemental mapping) of BCHiF (Column a), BCS (Column b) and AHP (Column c) conducted with energy-dispersive X-ray spectroscopy. BCHiF contains higher % of Zr than BC Sealer. The % of Ca+2 in BCS is higher when compared with the amount of Zr (48).

1.7 Statement of the problem

The standard BC sealer has been recommended to be used for single cone obturation techniques. Some clinicians are concerned about this simple technique because of a lack of enough condensation and possible leaking of bacteria into the canal. Warm compaction obturation

technique is one of the most reliable techniques used by many clinicians because of its high amount of gutt-percha/ sealer ratio and condensation which prevents any bacterial leakage into the canal. The warm vertical compaction technique is a technique in which warm softened gutta percha is packed tightly using various plugger sizes to fill the canal and apex or apices of a tooth. Physicochemical properties of sealers are different under different temperatures and obturation techniques. The main function of a sealer is to flow into all of the spaces in the main and accessories canals and to prevent bacteria from getting into the canal. Flowability of the sealer can affect the success of root canal therapy.

Physical properties of Standard BC sealer may be affected by high temperatures in the warm vertical compaction technique. Flowability of Standard BC sealer will be decreased using the warm vertical compaction technique. Therefore, this raises concerns regarding the effectiveness of sealing when using Standard BC Sealer in the warm vertical technique.

A new product, BC HiFlow, has been introduced into the market that is compatible with warm vertical compaction technique. There are few studies that have tested the physicochemical properties of BC HiFlow sealer under high temperature and warm vertical compaction (34, 36)

1.8 Objectives

Three sealers including the standard Endosequence BC® sealer (Brassler USA), standard Endosequence BC® sealer HiFlow (Brassler USA), and zinc oxide–eugenol sealer (Pulp Canal Sealer; Kerr, Orange, CA) were used in this research project. Warm vertical compaction and single cone techniques were used in this investigation. The flowability of sealers into root canals with

two different obturation techniques and flowability of sealers under two different temperatures in the laboratory were evaluated. The radiopacity of two sealers was evaluated at two different temperatures.

Chapter 2. MATERIALS AND METHODS

Three sealers were evaluated in this research project including the standard Endosequence BC® sealer (Brassler USA), standard Endosequence BC® sealer HiFlow (Brassler USA), zinc oxide–eugenol sealer (Pulp Canal Sealer; Kerr, Orange, CA). This research project was conducted in two parts. In the first part, the flowability as well as the radiopacity of Standard BC Sealer and BC sealer HiFlow were tested. In the second part, the flowability of three sealers, including two experimental groups (Standard BC Sealer and BC Sealer HiFlow) and one control group (Zinc Oxide Eugenol), with two different obturation techniques (Warm vertical compaction and Single cone technique) were evaluated.

Figure 2 Zinc Oxide-eugenol sealer

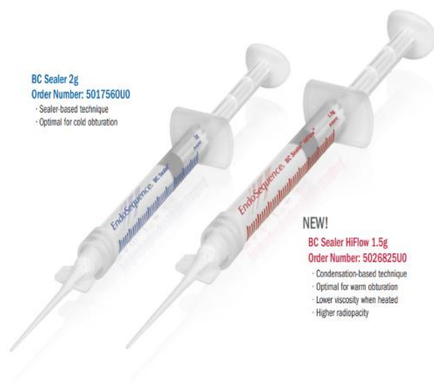


Figure 3 standard Endosequence BC® sealer (Brassler USA), standard Endosequence BC® sealer HiFlow (Brassler USA)

2.1 Flowability test

Two groups were tested in this part of the research project including;

1. Standard BC sealer
2. BC sealer HiFlow

The flowability test was performed at three different temperatures including 37˚C, 100˚C and 150˚C for two types of sealers (standard Endosequence BC® sealer (Brassler USA), standard Endosequence BC® sealer HiFlow (Brassler USA). A volume of 0.05 ± 0.005 mL was placed on the center of a glass plate (40 mm * 40 mm * 5 mm) with a graduated syringe (BD Luer-Lok 1 mL Syringe; Becton Dickinson & Co, Franklin Lakes, NJ) for all temperatures. A second glass plate (weighed 20 gr) and a 100-gr weight were placed on top of the sealer 3 minutes later. The glass plate was unloaded after 10 minutes. The minimum and maximum diameters of the sample disks were measured by a digital caliper (Husky 6 in. 3-Mode Digital Fractional Caliper). A box was made with an adjustable heater to keep the temperature at 37˚C and the test was done within the box. The sealer was placed on the center of the glass plate and then it was stored in the oven under two temperatures (100˚C and 150˚C) for 1 minute before loading with 100 grams. The rest of the tests were performed as described above. Each specimen was tested five times. The mean value was used for the flowability of each sealer.

The flowability of the ZOE was tested exactly as described above under three different temperatures.

Figure 4 A sample disk after unloading and digital caliper

2.2 Radiopacity Test

Two groups were tested in this part of research project including;

1. Standard BC sealer
2. BC sealer HiFlow

Two sealers were tested under two different temperatures including 21˚C and 120˚C. The sealers were poured into the metal mold (diameter of 5 mm and a thickness of 5 mm) and placed in the center of the X-ray sensor(RVG 6200, Carestream) close to the aluminum step wedge (purity of 99.99%) with a thickness from 1 to 10 mm in equally sized steps of 1 mm. The sensor was secured on the table before exposure. The sealer, step wedge and X-ray sensor were exposed with an X-ray machine (Toshiba 30-A1027) using an exposure time of 0.064S at 70 kV, 6mA, and at a target-film distance of 300 mm. Heated sealers were stored at 120˚C before exposure and the rest of the test was done as above. Five exposures were done for each sealer. The density (gray value) of radiographs and each step of aluminum step wedge with different thickness were evaluated by using ImageJ software (Wayne Rasband) The density of the image of the sealers was compared to the aluminum step wedge, and the radiopacity of the sealer was expressed in the millimeters of step wedge.

Figure 5 Aluminum step wedge and poured metal mold

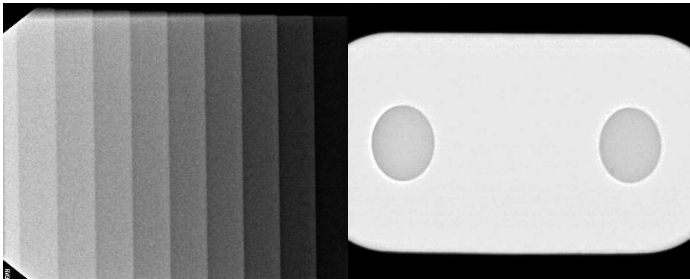


Figure 6 Radiograph of sealer and Aluminum step wedge

2.3 Flowability into Mid-Lateral and Apical Canals

The second part of this study was designed to evaluate the flowability of three sealers into mid-lateral and apical canals with two different techniques and temperatures.

2.3.1 Teeth selection, preparation, and experimental groups

Fifty teeth,#9- accessed (TRUETOOTH #9 – ACCESSED, Delabs) that are identical to a true tooth #9 with 0.14mm exiting diameter of the lateral and apical canals were provided. A #10 K-File Stainless Steel (Endoflex®) was used to pass 1mm from the anatomical apex for patency of each canal. A step down technique was used for cleaning and shaping with Pro Taper gold rotary files (Dentsply Tulsa Dental®). 500 revolutions per minute (rpm) was used to achieve a size of #30, with a 06 taper as a master apical file. 5mL 6% Sodium Hypochlorite (3D Dental Plasmid®) was used with a graduated syringe (BD Syringe with Luer-Lok® Tip – 10 ml) to remove all of the wax in the canal. After drying the canal with a paper point, a #10 K-File Stainless Steel (Endoflex®) was used to pass to 1mm of the anatomical apex for patency of each canal.

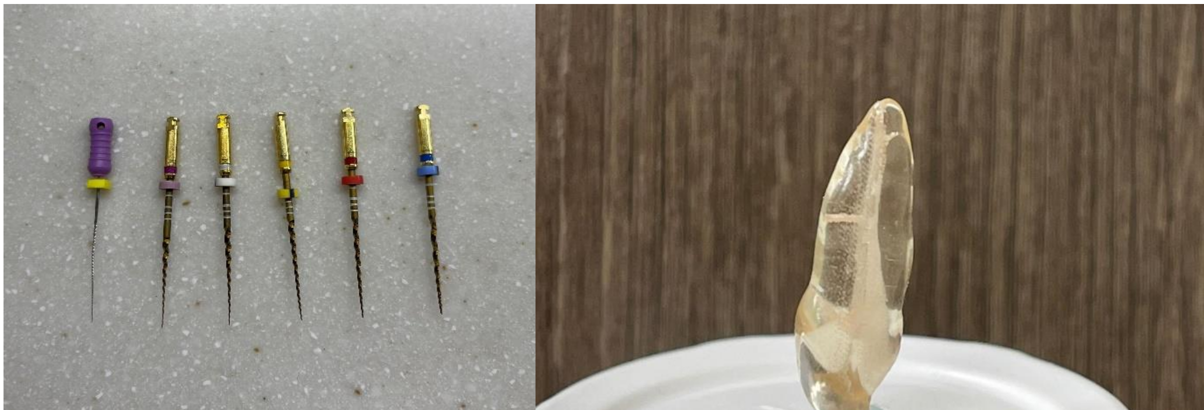


Figure 7 Files, cleaned and shaped plastic tooth

2.3.2 Warm Vertical Compaction Technique

Warm vertical compaction of gutta-percha as a method of obturating was used after preparing the canal with a continuously tapering funnel shape. Three sealers were tested with this obturation technique including standard BC Sealer, BC sealer HiFlow as experimental groups and Zinc oxide eugenol as a control group. A #30 master cone (ProTaper Gold, Dentsplay Sirona®) was fitted 0.5-1mm from the anatomical apex and replicated the exact taper of the canal. 0.05mL of sealer was applied into the canal and then the master cone was placed into the canal. The coronal portion of master cone was cut, 5-6mm from the apex, with a heated instrument (The Touch 'n Heat unit, SybronEndo®, Orange, Calif). The temperature of the tip was recorded with inferared camera. The average temperature of the tip was 175 ˚C and 170 ˚C in associated with sealer and gutta percha. This temperature was recorded three times after two second burst. This apical portion was removed in four successive increments. A plugger was inserted into the canal to compact the plasticized Gutta-percha apically until the down pack was completed. The rest of canal was back-filled with warm Gutta-percha with four gutta-percha segments. Obtura III Max System (Kerr®, Orange, CA) with Obtura Max backfill GP pellet and Obtura Needles 20 gauge were used for the back-fill process.

2.3.3 Single Cone technique

A #30 master cone (ProTaper Gold, Dentsplay Sirona®) was fitted right at the anatomical apex and then was removed. 0.05mL sealer was applied into the canal and then the master cone was placed into the canal. The Touch 'n Heat unit (SybronEndo®, Orange, Calif) was used to cut the Gutta-percha at the level of canal's orifice. 0.05 mL sealer was placed into the canal and then the tooth was placed in the oven at 120˚C for one minute. The master cone was placed into the canal immediately after the heating process.

2.3.4 Evaluation of the flowability into the mid-lateral and apical canal

The mid-lateral and apical canal were measured with a digital caliper. The length of the mid-lateral canal was 2mm and apical canal was 1mm. All measurements were performed using an endodontic microscope (©Global surgical corporation). All specimens were stabilized with wax and then the level of flowability was measured for each specimen with a digital caliper at a magnification of 12.8x with the microscope. All measurements were performed immediately after finishing the obturation.

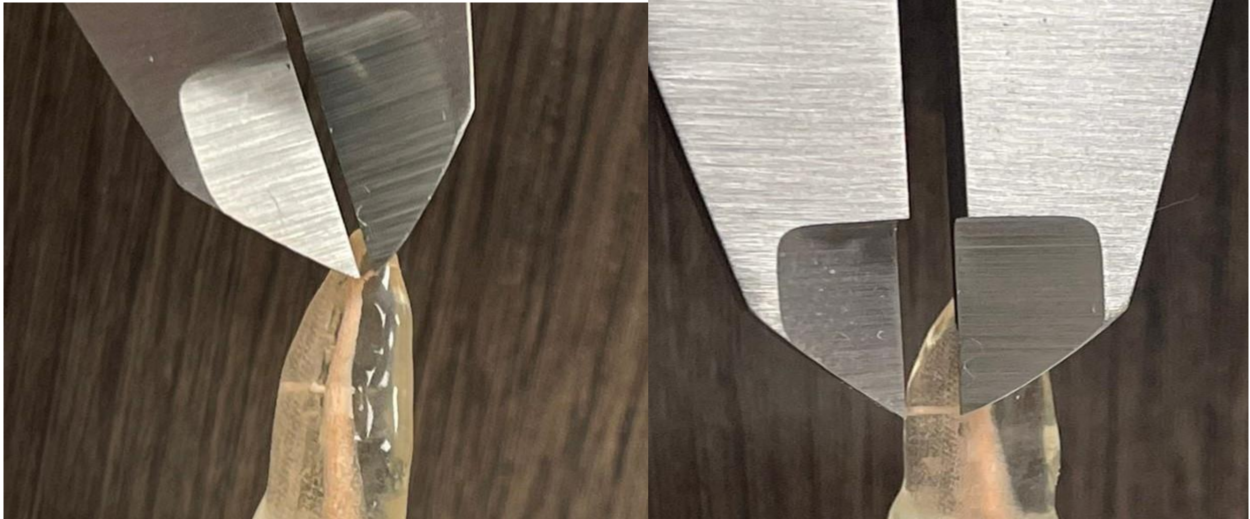


Figure 8 Measuring the amount of flowability of sealer into the apical and mid-lateral canal.

Chapter 3. RESULTS

3.1 Flowability Test

The flowability test for two calcium silicate-based sealers under different temperatures was determined based on the previously stated protocol. The JMP Pro 15 statistical program was used to analyze the results. The obtained results are presented in the Table 1 and figure 8.

Table 1. Mean, Standard deviation and Standard of the error for two sealers under different temperatures

Level	Number	Mean	Std Dev	Std Err Mean
HIBIO37	5	22.258	0.246	0.110
HIBIO100	5	21.068	0.365	0.163
HIBIO150	5	17.084	0.105	0.047
STDBIO37	5	20.018	0.622	0.278
STDBIO100	5	19.162	0.515	0.230
STDBIO150	5	9.52	0.358	0.160

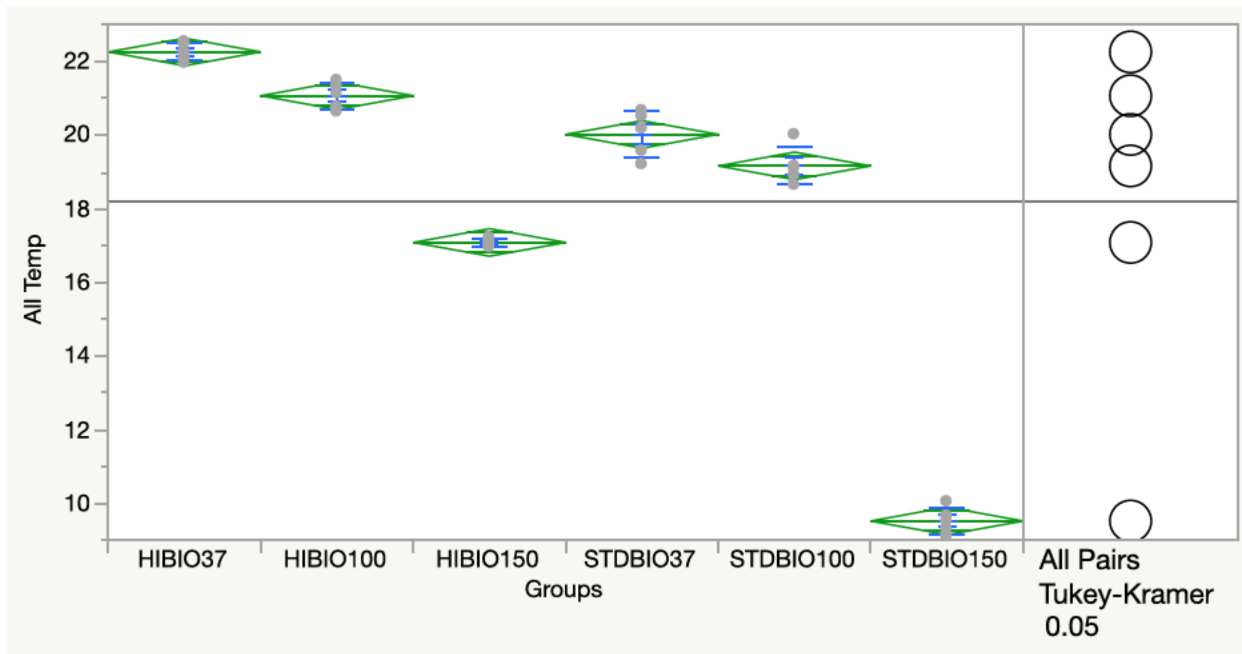


Figure 9 One Way Analysis of all temperatures by groups

The mean flowability ranged from 22.25 mm to 9.52 mm, statistical analysis using one-way ANOVA was used to determine the difference in the obtained group means. The mean flowability of ZOE was 22.31mm, 23.56mm and 23.98 under 37˚C, 100˚C and 150˚C respectively. The null hypothesis is that there is no statistically significant difference between the flowability of the two-calcium silicate-based sealers regardless of the method used. With alpha set as 0.05 and p-value of <.0001, we rejected the null hypothesis. The results are presented in the Table 2.

Table 2. One-way ANOVA Analysis of The Flowability by sealer showing that there is a significant difference between two sealers at two different temperatures.

Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Groups	5	527.54931	105.510	643.0195	<.0001*
Error	24	3.93804	0.164		
C. Total	29	531.48735			

The results are indicating that there is a statistical difference between that flowability of the two calcium silicate based sealers under all three different temperatures. The Tukey Kramer HSD test was used to determine the significant difference. The results are presented in the Table 3.

Table 3. Results of Tukey Kramer HSD All Pairs Comparison statistical test showing the difference. Positive values show pairs of means that are significantly different.

	HIBIO37	HIBIO100	STDBIO37	STDBIO100	HIBIO150	STDBIO150
HIBIO37	-0.792	0.398	1.448	2.304	4.382	11.946

HIBIO100	0.398	-0.792	0.258	1.114	3.192	10.756
STDBIO37	1.448	0.258	-0.792	0.064	2.142	9.706
STDBIO100	2.304	1.114	0.064	-0.792	1.286	8.850
HIBIO150	4.382	3.192	2.142	1.286	-0.792	6.772
STDBIO150	11.946	10.756	9.706	8.850	6.772	-0.792

Based on p-values obtained in Tukey Kramer HSD test <.0001 for HIBIO and STDBIO under all three different temperatures, the null hypothesis has been rejected since p-value are less than alpha value of 0.05. Therefore, we concluded that there is a statistically significant difference between the flowability of the HIBIO and STDBIO under all three different temperatures. The outcome of the study supports the manufacture claims that the materials presented by them are comparable to each other at least when it comes to flowability. The connecting letters report shows the difference between each group, Table 4.

Table 4. Oneway Analysis of All Temp By Groups > Means Comparisons > Comparisons for all pairs using Tukey-Kramer HSD. Levels not connected by same letter are significantly different.

Level							**Mean**

HIBIO37	A						22.25mm
HIBIO100		B					21.06mm
STDBIO37			C				20.01mm
STDBIO100				D			19.16mm
HIBIO150					E		17.08mm
STDBIO150						F	9.52mm

3.2 Radiopacity

The Radiopacity test for two sealers under different temperatures was determined based on the previously stated protocol. The JMP Pro statistical program was used to analyze the results. The obtained results are presented in the Table 4 and figure 2.

Table 5. Mean, Standard deviation and Standard of the error for two sealers under different temperatures

Level	Number	Mean	Std Dev	Std Err Mean	Lower 95%	Upper 95%
BCHF	5	212.563	0.765	0.342	211.613	213.514
BCHF120	5	213.556	0.554	0.248	212.869	214.244
BCSTAND	5	202.253	0.619	0.277	201.485	203.022
BCSTAND120	5	202.368	0.846	0.378	201.318	203.418

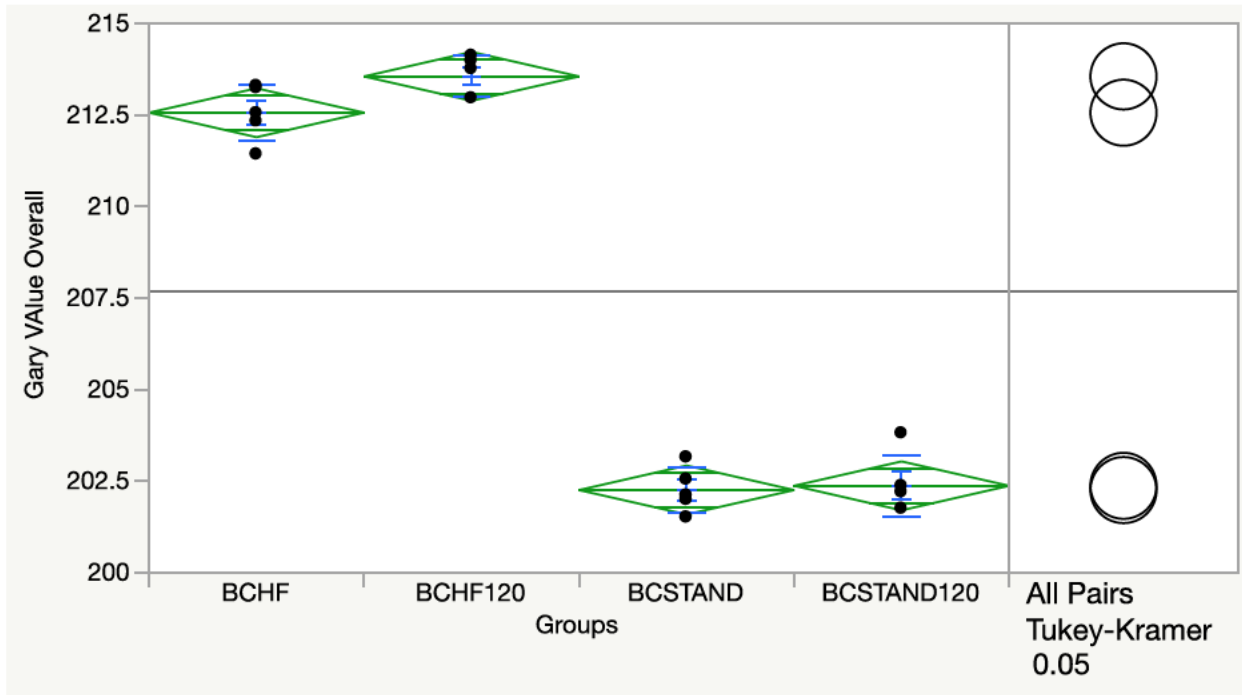


Figure 10 One Way Analysis of all temperatures by groups

The mean gray value ranged from 213.55 to 202.25. Statistical analysis using one-way ANOVA was used to determine the existence of difference in the obtained group means. The null hypothesis is that there is no statistically significant difference between the radiopacity of the two-calcium silicate based sealers regardless of the method used. With alpha set as 0.05 and p-value of $<.0001$, we rejected the null hypothesis. The results are presented in the Table 5.

Table 6. One-way ANOVA Analysis of The radiopacity by sealer showing that there is a significant difference between two sealers at two different temperatures.

Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Groups	3	580.22358	193.408	388.6519	<.0001*
Error	16	7.96220	0.498		
C. Total	19	588.18579			

The results indicate that there is a statistical difference between that radiopacity of the two calcium silicate based sealers under both two different temperatures. The Tukey Kramer HSD test was used to determine the significant difference. The results are presented in the Table 6.

Table 7. Results of Tukey Kramer HSD All Pairs Comparison statistical test showing the difference. Positive values show pairs of means that are significantly different.

	BCHF120	BCHF	BCSTAND120	BCSTAND
BCHF120	-1.276	-0.284	9.912	10.027

BCHF	-0.284	-1.276	8.919	9.034
BCSTAND120	9.912	8.919	-1.276	-1.162
BCSTAND	10.027	9.034	-1.162	-1.276

Based on p-values obtained in Tukey Kramer HSD test <.0001 for HIBIO and STDBIO under both two different temperatures, the null hypothesis has been rejected since p-value are less than alpha value of 0.05. Therefore, we concluded that there is a statistically significant difference between the radiopacity of the HIBIO and STDBIO under both two different temperatures. The outcome of the study supports the manufacture claims that the materials presented by them are comparable to each other at least when it comes to radiopacity.

Table 8: Oneway Analysis of Gray value Overall By Groups > Means Comparison> Comparison for all pairs using Tukey-Kramer HSD

Level			Mean
BCHF120	A		213.556 GV
BCHF	A		212.563 GV

BCSTAND120		B	202.368 GV
BCSTAND		B	202.253 GV

3.3 Flowability into the lateral and apical accessory canals with single cone technique

One of the main functions of endodontics sealer is to flow and seal the lateral canals to prevent reinfection of the root canal system after root canal treatment. As mentioned previously sealing capability and flowability can be measured in many ways. The flowability of the two-calcium silicate-based sealers were evaluated. The JMP Pro statistical program was used to analyze the results. The mean flowability into the lateral canals with single cone technique under two different temperature was ranging from 1.69mm and 0.122 mm. The mean flowability into the accessory canal with single cone technique under two different temperature was ranging from 0.89mm and 0.121 mm. Statistical analysis using one-way ANOVA was used to determine the existence of difference in the obtained group means. The results of single cone obturation technique are indicating that there is not a statistical difference between that flowability of the two Calcium Silicate based sealers into the lateral and apical accessory canals under 21C and there is a statistical difference between that flowability into the lateral and apical accessory canal under 120˚C. The ability to flow of both standard BC sealer and HiFlow BC sealer were decreased by placing the injected sealer at 120˚C for 1 minute before single cone obturation but HiFlow BC sealer showed a better performance compared to the Standard BC sealer.

3.4 Flowability into the lateral and accessory canals with warm vertical condensation technique

The flowability of the two-calcium silicate-based sealers as an experimental groups and ZOE as a control group was evaluated. The JMP Pro statistical program was used to analyze the results. The mean flowability into the lateral canals with warm vertical condensation technique was ranging from 1.96mm and 0.69 mm. The mean flowability into the accessory canal with warm vertical condensation technique was ranging from 0.97mm and 0.18 mm. Statistical analysis using one-way ANOVA was used to determine the existence of difference in the obtained group means. The results of the warm vertical condensation technique are indicating that both standard and HiFlow BC sealers showed statistically significant differences into the mid-lateral and apical accessory canals in comparison with zinc oxide eugenol ($P<0.05$). HiFlow BC sealer showed better ability to flow into the mid-lateral and apical accessory canal as compared to standard BC sealer using the warm vertical compaction technique. The results showed that there is a significant difference of flowability into the lateral canal between HiFlow and Standard BC sealers but there is no statistically significant difference of flowability into the apical accessory canals between HiFlow and Standard BC sealers.

The obtained results are presented in the Table 7 and figure 3.

Table 9. Results of Tukey Kramer HSD All Pairs Comparison statistical test showing the difference. Positive values show pairs of means that are significantly different.

Level	Number	Mean	Std Error	Lower 95%	Upper 95%
BCHIFLOW21	8	1.69000	0.05984	1.5713	1.8087
BCHIFLOW21A	8	0.89750	0.05984	0.7788	1.0162

BCHIFLOWHEATED	8	0.51125	0.05984	0.3925	0.6300
BCHIFLOWHEATEDA	8	0.27625	0.05984	0.1575	0.3950
BCHIFLOWWV	8	1.66250	0.05984	1.5438	1.7812
BCHIFLOWWVA	8	0.18250	0.05984	0.0638	0.3012
BCSTAND21	8	1.57500	0.05984	1.4563	1.6937
BCSTAND21A	8	0.89250	0.05984	0.7738	1.0112
BCSTANDARDWV	8	0.69375	0.05984	0.5750	0.8125
BCSTANDARDWVA	8	0.18250	0.05984	0.0638	0.3012
BCSTANDHEATED	8	0.12250	0.05984	0.0038	0.2412
BCSTANDHEATEDA	8	0.12125	0.05984	0.0025	0.2400
ZOEWV	8	1.96500	0.05984	1.8463	2.0837
ZOEWVA	8	0.97875	0.05984	0.8600	1.0975

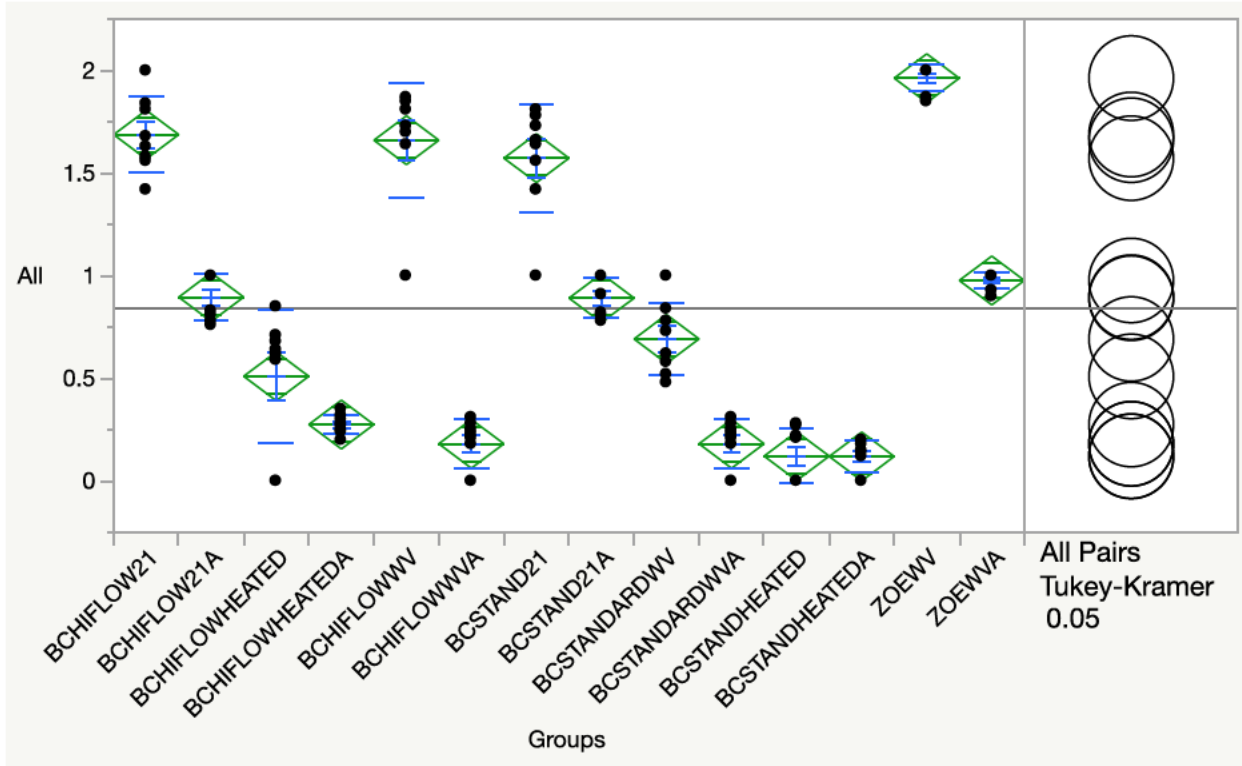


Figure 11 One Way Analysis of all temperatures by groups

The Tukey Kramer HSD test was used to determine the significant difference. The results are presented in the Table 8.

Table 10. Results of Tukey Kramer HSD All Pairs Comparison statistical test showing the difference.

Level							Mean
ZOEWV	A						1.9650000
BCHIFLOW21	A	B					1.6900000
BCHIFLOWWV		B					1.6625000
BCSTAND21		B					1.5750000
ZOEWVA			C				0.9787500
BCHIFLOW21A			C				0.8975000
BCSTAND21A			C				0.8925000
BCSTANDARDWV			C	D			0.6937500
BCHIFLOWHEATED				D	E		0.5112500

BCHIFLOWHEATEDA					E	F	0.2762500
BCHIFLOWWVA						F	0.1825000
BCSTANDARDWVA						F	0.1825000
BCSTANDHEATED						F	0.1225000
BCSTANDHEATEDA						F	0.1212500

Chapter 4. DISCUSSION

4.1 Flowability

Recent developments in the dental material science has lead to improvement in dental materials. In endodontics, a proper seal of the canal is a key step in successful root canal therapy. The idea of creating a monoblock filling, where the sealer adheres to both root canal dentin and the core material is very appealing since it would prevent bacterial movement, deter microleakage, and increase the success rate of endodontic treatment. A proper seal does not depend only on the adhesion, but also on other properties such as flow of the material. However,

flowing the sealer into the root canal system still seems to be an essential component required to obtain a hermetic seal and according to the studies it is correlated with decreased microleakage (42). As mentioned previously in the introduction, Physical properties of the sealers can be evaluated with different methods.

This study evaluated the flowability, radiopacity and flowability of the sealer into the root canal system including lateral canal and apical accessory canal. It was previously suggested that physical properties of the sealers can be varied under different temperatures. A study by Mann et al (39) showed that the application of heat affected the flow of HiFlow and STD BC sealers. Both sealers met or exceeded the minimum value of 17 mm under 21°C required by ISO standards. Their results showed an increase in HiFlow BC sealers along with the temperature increase, whereas a decrease was found for STD BC sealer. Temperature may affect sealer flow, likely due to changes in their setting reaction, chemical structure, and weight loss by losing moisture due to heat. Contrary to that, Chen et al (34) found that the flow of STD BC Sealer and HiFlow was reduced by heating to 100 C for 1 minute, whereas HiFlow still maintained a higher flow than BC Sealer and complied with the requirements of ISO 6876 specification for all tested sealers.

Lacey et al (40) and Zhou et al (41) investigated the temperature effect on the viscosity of sealers at room temperature and body temperature. The viscosity of both sealers showed temperature dependence over the temperature range studied. Interestingly, the viscosity of both sealers decreased (indicating increased flow) from 21° C to 100° C and increased to the highest at 150° C. The conflicting results of flow and viscosity between room temperature and 100° C could be caused by differences in methodologies because the continuous movement of the material in the rheometer may interfere unduly with the initiation of setting or a dried portion of

the material. Thus, the decreasing viscosity from 21° C to 100° C was a result of a reduced cohesive force between molecules and increased rates of molecular interchange by the increasing temperature.

Comparing multiple studies, it was concluded that physical properties of both STD BC and HiFlow sealers might be affected by higher temperature. In our study we evaluated the flowability of the STD and HiFlow BC sealers while applying heat. Our results regarding the flowability were the same as the results obtained from Chen at al (34). These results showed that the flowability of both sealers decreased under higher temperatures but the HiFlow BC sealer complied with the requirement of ISO 6876 specification under all temperatures. Our result showed that flowability of ZOE under three different temperatures is acceptable and meet the criteria of ISO 6876:2012. Neda showed that the mean diameter of ZOE flowability is 22.17mm under room temperature (51). Wei Qu et all (52) evaluated the flowability of the ZOE under higher temperature. He showed that the flow of ZOE sealer was unaffected by the high temperature from 25 °C to 140°C.

Yamauchi et al (44) studied the effects of heating on the physical properties of premixed calcium silicate-based root canal sealers. Their evaluation method was the same as us in this research but their result was different. According to ISO 6876:2012, the requirement for flow is at least 17 mm. They showed that both STD and HiFlow BC sealers met this criterion at room temperature. However, when the sealers were placed at 100°C for an initial 1 min, flow was below the standard value for both sealers, and was significantly reduced ($P < 0.05$). Our results showed that the HiFlow BC sealer still met the ISO 6876:2012 criteria under higher temperatures. The performance of HiFlow BC sealer after applying heat was a common result

between our result and their results. The poor performance of bioceramic sealers in this flowabilty test can be also explained by the fact that after applying heat, an amount of water was evaporated. This causes less followability of these sealers under higher temperatures. On the other hand, as mentioned before, applying heat up to certain degree might decrease the viscosity and increase the followability due to decreasing the cohesive force between molecules (40,41). As mentioned by Chen et al (34) existing studies are often difficult to compare, because of the different methodologies and study focus.

In order to account better for the clinical situation, this study tested the flowability of the STD BC and HiFlow BC into the lateral and accessory canals under different obturation techniques and temperatures.

Our study tried to best mimic the clinical situation and a printed plastic tooth was selected having both lateral and accessory canals. A literature search revealed that there is no published study that has compared the flowability of the STD BC and HiFlow BC inside lateral and apical accessory canals. There are some studies that evaluate the penetration of the BC sealers into the dentinal tubules on different part of the canals.

Reynolds et al (43) compared dentinal tubule penetration of STD and HiFlow BC sealers with resin-based sealer. They compared these sealers under single cone obturation technique and warm vertical condensation technique. Results showed that there is no statistically significant difference in sealer type or obturation technique at the examined levels ($P > 0.05$). In conclusion, dentinal tubule penetration was similar comparing STD BC Sealer, HiFlow BC Sealer and resin-based sealers using single cone and warm vertical condensation techniques.

A part of these results was the same as our results. Our study showed that there is no significant difference of flowability between two STD and HiFlow BC sealers with single cone technique under room temperature. Although the flowability of the STD BC sealer was lower than HiFlow into the lateral and apical accessory canals under higher temperature with single cone obturation technique.

Contrary, McMichaeal et al (44), compared the dentinal tubule penetration of STD BC sealer under two different obturation techniques including a single cone technique and a warm vertical condensation technique. He showed that both obturation techniques provided similar dentinal tubule penetration at both a 1mm and a 5mm level from the apex. Our study showed that the ability to flow of STD BC sealer was affected in warm vertical condensation due to increasing the temperature.

This study considered ZOE sealer as a control group with the warm vertical condensation technique. ZOE sealer had the best flowability into the lateral and apical accessory canals and there was a significant difference compared with both STD and Hiflow BC sealer. According to Sweetman et al., the temperature is higher in the middle of the canal compare to the apical third of the canal in the warm vertical condensation obturation technique. This explained our result regarding the flowability of the both STD and HiFlow BC sealers into the lateral and accessory apical canals. Sweetman et al (45), showed that the highest mean temperature change on the internal root surface was 74.19 C with the system B at the 6 mm level (6 mm coronal to working length) and the lowest mean temperature change on the internal root surface was 2.09C at the 0 mm level from the apex. We found a significant difference between STD and HiFlow BC sealers regarding to flowability into the lateral canal due to increasing the temperature. Although there

was no significant difference of flowability of the STD and HiFlow BC sealer into the apical accessory canal due to a lower temperature. It showed both sealers could maintain their ability to seal the apical accessory canals in the warm vertical condensation technique.

4.2 Radiopacity

Both BC Sealer and HiFlow are premixed calcium silicate–based sealers, which have major inorganic components including tricalcium silicate, dicalcium silicate and calcium phosphates. Therefore, they were used in the present study to evaluate the effect of heating on the physicochemical properties. Radiopacity of the sealers is important because it shows the location, consistency and the flowability of the sealers on the radiograph. Root canal sealers vary in radiopacity (46,47). These Bio-ceramic based sealers contain significant amounts of barium sulfate to enhance their radiopacity. Although these components may enhance visualization of anatomic structures such as lateral canals, it is important to realize they do not increase the sealing ability of the sealer and the quality of the obturation. It is erroneous to claim that obturations with highly radiopaque sealers are better than those made with less radiopaque materials. This type of comparison and claim to superiority are both unfounded and unwarranted. The radiographic appearance or aesthetic appearance of the obturated canal system should be secondary to meticulous cleaning and shaping. Although assessment of the root canal obturation is based on radiographic findings, root canal sealers do not have to be highly radiopaque to be effective.

We compared the radiopacity of these two BC sealers under different temperatures to determine if a higher temperature might change their radiopacity. Chen et al (34) compared the

radiopacity of the STD and HiFlow BC sealers at room temperature. He showed that HiFlow BC sealers is more radiopaque compared to STD BC sealer and there is a statistically significant difference. Our study showed the same results as the previous study regarding a higher radiopacity of the HiFlow BC sealer at room temperature. Our results showed that all tested sealers met or exceeded the minimum 3 mm Al radiopacity values determined by ISO standards. Mann et al (1) showed that there is no significant difference beween these two BC sealers under room temperature, although HiFlow is more radiopaque than STD BC sealer. Our study compared the radiopacity of each sealer after applying heat. It showed that the amount of radiopacity was not changed at higher temperature and there are no significant differences. More studies are needed to evaluate the radiopacity under different temperatures with different methodologies.

4.3 Limitation of the study

This study was limited by the type of the printed plastic teeth. For the flowability test printed plastic teeth were used (incisors). The size, diameter, and length of the lateral and apical accessory canals might be different compared to natural teeth. There are different factors inside the natural teeth that might affect and prevent of flowing sealers into these canals including the remaining organic and inorganic materials like dentinal debris and pulp that might block these canals if there is not enough irrigation. There is currently no study which used these printed plastic teeth for evaluating the flowability of sealers.

Future studies should take that into account and try to make printed plastic teeth similar as much as possible to natural teeth.

Our study also was limited by the technique sensitivity of the warm vertical condensation technique. There is no guarantee to have the same pressure during the down pack for all cases. The flowability of the sealer might be affected with different down pack pressure with pluggers and the result might be affected. We tried to obturate all printed plastic teeth under the same condition and pressure. A future study should try to reduce these variables during the warm vertical condensation obturation technique.

Another limitation of the study was the exact temperature of the sealer inside the tooth. We heated the tooth and sealer together and it was not possible to have the sealer temperature inside of the tooth.

This study was also limited to the number of tested materials. There are different companies that produce calcium silicate-based sealer in the market. They claim that flowability of these sealers are not affected with higher temperatures with warm vertical condensation technique. Also, when considering future directions for the studies, it seems viable to mention new bioactive materials, currently marketed for restorative use. Although they are not yet adapted to be used as sealers in the canals, if proven successful they could be modified for intracanal use. Among those new hybrid materials ACTIVA BioACTIVE products (Pulpdent, Watertown, MA, USA) and Surefill one (Dentsply Sirona, York, PA) seem to be the most promising.

Lastly, our study is an in vitro study, where the conditions were adjusted to mimic clinical situation, due to the fact that in vivo evaluating physical properties of the sealers under higher temperatures is not possible. Further in vivo performance evaluation of the Calcium-Silicate based sealers is needed to conclude their usefulness in root canal therapy.

4.4 Conclusions

1. With the limitation of this study, it is concluded that HiFlow BC sealer compared to STD BC sealer was more radiopaque.

2. HiFlow BC sealer compared to STD BC sealer had a higher flow especially at high temperatures, which are generated by the commonly used warm vertical compaction technique.

3. HiFlow BC sealer compared to STD BC sealer and ZOE: Thus, it has better ability to flow into canals than STD BC sealer but it is still lower than ZOE

References

1. West, J. D. (1975). *The relationship between three-dimensional endodontic seal and endodontic failures* (Doctoral dissertation, Boston University).

2. Wu, M. K., van Der Sluis, L. W., & Wesselink, P. R. (2004). Fluid transport along gutta-percha backfills with and without sealer. *Oral Surgery, Oral Medicine, Oral Pathology, Oral Radiology, and Endodontology*, *97*(2), 257-262.

3. Torabinejad, M., Kettering, J. D., & Bakland, L. K. (1979). Evaluation of systemic immunological reactions to AH-26 root canal sealer. *Journal of endodontics*, *5*(7), 196-200.

4. Koch K, Brave D. The increased use of bioceramics in endodontics. Dentaltown. 2009;10:39-43.

5. Zhang, W., Li, Z., & Peng, B. (2010). Ex vivo cytotoxicity of a new calcium silicate–based canal filling material. *International endodontic journal*, *43*(9), 769-774.

6. Ma, J., Shen, Y., Stojicic, S., & Haapasalo, M. (2011). Biocompatibility of two novel root repair materials. *Journal of Endodontics*, *37*(6), 793-798.

7. Elshamy, F. M., Singh, G., Elraih, H., Gupta, I., & Idris, F. A. (2016). Antibacterial Effect of New Bioceramic Pulp Capping Material on the Main Cariogenic Bacteria. *The journal of contemporary dental practice*, *17*(5), 349-353.

8. Tran, D., He, J., Glickman, G. N., & Woodmansey, K. F. (2016). Comparative analysis of calcium silicate–based root filling materials using an open apex model. *Journal of endodontics*, *42*(4), 654-658.

9. Tabassum S, Khan FR. Failure of endodontic treatment: The usual suspects. Eur J Dent. 2016;10(1):144-147. doi:10.4103/1305-7456.17568

10. Zhang H, Shen Y, Ruse ND, Haapasalo M. Antibacterial activity of endodontic sealers by modified direct contact test against enterooccus faecalis. JOE. 2009; 35(7): 1051-5

11. Nagas E, Uyanik MO, Eymirli A, Cehreli ZC,Vallittu PK, Lassila LVJ, Durmaz V. Dentin moisture conditions affect the adhesion of root canal sealers. JOE. 2011; 38

12. Wu MK, Wesselink PR. Endodontic leakage studies reconsidered. I. Methodology, application and relevance. Int Endod J. 1993;26:37.

13. Grossman L. Endodontics. ed 11. Lea & Febiger: Philadelphia; 1988.

14. Augsburger RA, Peters DD. Radiographic evaluation of extruded obturation materials. J Endod. 1990;16:492.

15. Davis MC, Walton RE, Rivera EM. Sealer distribution in coronal dentin. J Endod. 2002;28:464.

16. Krastl G, Allgayer N, Lenherr P, et al. Tooth discoloration induced by endodontic materials: a literature review. Dent Traumatol. 2013;29:2.

17. al-Khatib ZZ, Baum RH, Morse DR, et al. The antimicrobial effect of various endodontic sealers. Oral Surg Oral Med Oral Pathol. 1990;70:784

18. Barkhordar RA. Evaluation of antimicrobial activity in vitro of ten root canal sealers on Streptococcus sanguis and Streptococcus mutans. Oral Surg Oral Med Oral Pathol. 1989;68:770.

19. Camilleri J, Pitt Ford TR. Mineral trioxide aggregate: a review of the constituents and biological properties of the material. Int Endod J. 2006;39:747.

20. Darvell BW, Wu RC. “MTA”—a hydraulic silicate cement: review update and setting reaction. Dent Mater. 2011;27:407.

21. Nagas E, Uyanik MO, Eymirli A, et al. Dentin moisture conditions affect the adhesion of root canal sealers. J Endod. 2012;38:240.

22. Gandolfi MG, Iacono F, Agee K, Siboni F, Tay F, Pashley DH, et al. Setting time and expansion in different soaking media of experimental accelerated calcium–silicate cements and ProRoot MTA. Oral Surg, Oral Med, Oral Pathol, Oral Rad Endod 2009;108:e39–45.

23. Nekofaar MH, Adusei G, Sheykhrezae MS, Hayes SJ, Bryan ST, Dummer PMH. The effect of condensation pressure on selected physical properties of mineral trioxide aggregate. Int Endod J 2007;40:453–61.

24. Abdullah D, Ford TR, Papaioannou S, Nicholson J, McDonald F. An evaluation of accelerated Portland cement as a restorative material. Biomaterials 2002;23: 4001–10.

25. Siqueira Jr JF, Lopes HP. Mechanisms of antimicrobial activity of calcium hydroxide: a critical review. Int Endod J 1999;32:361–9.

26. McHugh CP, Zhang P, Michalek S, Eleazer PD. pH required to kill *Enterococcus faecalis* in vitro. J Endod 2004;30:218–9.

27. Katsamakis S, Slot DE, Van der Sluis LWM, Van der Weijden F. Histological response of the periodontium to MTA: a systematic review. J Clin Periodontol 2013;40:334–44.

28. Holland R, Ferreira LB, de Souza V, Otoboni Fihlo JA, Murata SS, Dezan Jr E. Reaction of the lateral periodontium of dog's teeth contaminated and noncontaminated perforations filled with mineral trioxide aggregate. J Endod 2007;33:1192–7.

29. Laurent P, Camps J, About I. Biodentine induced TGF-B1 release from human pulp cells and early dental pulp mineralization. Int Endod J 2012;45:439–48.

30. Zhang W, Li Z, Peng B. Effect of iRoot SP on mineralization-related genes expression in MG63 cells. J Endod 2010;36:1978–82.

31. Olivieri JG, Duran-Sindreu F, Mercadè M, Perez N, Roig M. Treatment of a perforating external root resorption with mineral trioxide aggregate and histologic examination after extraction. J Periodontol 2012;38:1007–10.

32. Mente J, Leo M, Panagidis D, Ohle M, Schneider S, Bermejo JL, et al. Treatment outcome of mineral trioxide aggregate in open apex teeth. J Endod 2013;39:20–6.

33. Prati, Carlo, and Maria Giovanna Gandolfi. "Calcium silicate bioactive cements: Biological perspectives and clinical applications." *Dental materials : official publication of the Academy of Dental Materials* vol. 31,4 (2015): 351-70. doi:10.1016/j.dental.2015.01.004

34. Chen, B., Haapasalo, M., Mobuchon, C., Li, X., Ma, J., & Shen, Y. (2020). Cytotoxicity and the effect of temperature on physical properties and chemical composition of a new calcium silicate–based root canal sealer. *Journal of endodontics*, *46*(4), 531-538.

35. Watts JD, Holt DM, Beeson TJ, Kirkpatrick TC, Rutledge RE. Effects of pH and mixing agents on the temporal setting of tooth-colored and gray mineral trioxide aggregate. J Endod 2007;33:970–3.

36. Yamauchi S, Watanabe S, Okiji T. Effects of heating on the physical properties of premixed calcium silicate-based root canal sealers. J Oral Sci. 2020 Dec 23;63(1):65-69. doi: 10.2334/josnusd.20-0325. Epub 2020 Dec 10. PMID: 33298628.

37. Shokouhinejad, N et al. "Bioactivity of EndoSequence root repair material and bioaggregate." *International endodontic journal* vol. 45,12 (2012): 1127-34. doi:10.1111/j.1365-2591.2012.02083.x

38. Gandolfi MG, Siboni F, Botero T, Bossù M, Riccitiello F, Prati C. Calcium silicate and calcium hydroxide materials for pulp capping: biointeractivity, porosity, solubility and bioactivity of current formulations. J Appl Biomater Funct Mater 2014

39. Mann, A., Zeng, Y., Kirkpatrick, T., van der Hoeven, R., Silva, R., Letra, A., & de Souza, L. C. (2022). Evaluation of the physicochemical and biological properties of EndoSequence BC Sealer HiFlow. *Journal of Endodontics*, *48*(1), 123-131.

40. Lacey, S., Pitt Ford, T. R., Yuan, X. F., Sherriff, M., & Watson, T. (2006). The effect of temperature on viscosity of root canal sealers. *International endodontic journal*, *39*(11), 860-866.

41. Zhou, H. M., Shen, Y., Zheng, W., Li, L. I., Zheng, Y. F., & Haapasalo, M. (2013). Physical properties of 5 root canal sealers. *Journal of endodontics*, *39*(10), 1281-1286.

42. Carvalho CN, Grazziotin-Soares R, de Miranda Candeiro GT, et al. Micro Push-out Bond Strength and Bioactivity Analysis of a Bioceramic Root Canal Sealer. *Iranian Endodontic Journal.* 2017;12(3):343-348. doi:10.22037/iej.v12i3.16091

43. Reynolds, J. Z., Augsburger, R. A., Svoboda, K. K., & Jalali, P. (2020). Comparing dentinal tubule penetration of conventional and 'HiFlow'bioceramic sealers with resin-based sealer: An in vitro study. *Australian Endodontic Journal*, *46*(3), 387-393.

44. McMichael, G. E., Primus, C. M., & Opperman, L. A. (2016). Dentinal tubule penetration of tricalcium silicate sealers. *Journal of endodontics*, *42*(4), 632-636.

45. Sweatman, T. L., Baumgartner, J. C., & Sakaguchi, R. L. (2001). Radicular temperatures associated with thermoplasticized gutta-percha. *Journal of Endodontics*, *27*(8), 512-515.

46. Rasimick BJ, Shah RP, Musikant BL, et al. Radiopacity of endodontic materials on film and a digital sensor. J Endod. 2007;33:1098.

47. Ozkocak I, Sonat B. Evaluation of Effects on the Adhesion of Various Root Canal Sealers after Er:YAG Laser and Irrigants Are Used on the Dentin Surface *Journal of Endodontics*. 2015;41(8):1331-1336. doi:10.1016/j.joen.2015.03.004

48. Rodríguez-Lozano, F. J., López-García, S., García-Bernal, D., Tomás-Catalá, C. J., Santos, J. M., Llena, C., ... & Forner, L. (2020). Chemical composition and bioactivity potential of the new Endosequence BC Sealer formulation HiFlow. International Endodontic Journal, 53(9), 1216-1228.

49. Giacomino, C. M., Wealleans, J. A., Kuhn, N., & Diogenes, A. (2019). Comparative biocompatibility and osteogenic potential of two bioceramic sealers. *Journal of endodontics*, *45*(1), 51-56.

50. Tomaszewska, M. A. (2023). *Bond strength of calcium silicate based bioceramic sealers to dentin* (Doctoral dissertation, Boston University).

51. Hifeda, N. (2016). *Comparison of the physical properties for five different commercial root canal sealers* (Doctoral dissertation).

52. Qu, W., Bai, W., Liang, Y. H., & Gao, X. J. (2016). Influence of warm vertical compaction technique on physical properties of root canal sealers. *Journal of Endodontics*, *42*(12), 1829-1833.

53. Ghoneim, A. G., Lutfy, R. A., Sabet, N. E., & Fayyad, D. M. (2011). Resistance to fracture of roots obturated with novel canal-filling systems. *Journal of endodontics*, *37*(11), 1590-1592.