Influence of Endodontic Sealers on Dentin Strength in Endodontically Treated Teeth

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Recommended Citation
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Influence of Endodontic Sealers on Dentin Strength in Endodontically Treated Teeth

Andrew C. Fossum
D.D.S., University of Texas, 2008

A Thesis
Submitted in Partial Fulfillment of the Requirements for the Degree of Master of Dental Science at the University of Connecticut 2019
Influence of Endodontic Sealers on Dentin Strength in Endodontically Treated Teeth

Presented by

Andrew C. Fossum, D.D.S.
Acknowledgments

I would like to extend my gratefulness to my major advisor Dr. John R. Kelly. Without his support and direction throughout this process, this project would not have been possible. His knowledge and expertise in his field is immeasurable. Dr. Kelly always pushed me to do the best I could and made me confident in what I was doing. I am so appreciative of him to take on this endeavor with me and to be my major advisor.

I also would like to extend my esteemed admiration to my program director and associate advisor Dr. Kamran Safavi. It is futile to put into words what his mentorship and guidance has done and will continue to do for me throughout my career and life. Dr. Safavi is an icon not only in the field of endodontics but as a person who is caring, generous and will always be considered part of the family.

Additionally, I would like to express gratitude to another of my associate advisors Dr. Blythe Kaufman. When it comes to someone who is competent and a has a knowledge in the field of endodontics, in which it is hard to find an equal, is Dr. Kaufman. Her dedication to provide a sound foundation of scientific knowledge will forever support my career and understanding of endodontics.

The authors have no financial affiliation or involvement with any commercial organization with direct financial interest in the subject or materials discussed in this manuscript, nor have any such arrangements existed in the past three years.

Andrew C. Fossum, D.D.S.
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Abstract

Influence of Endodontic Sealers on Dentin Strength in Endodontically Treated Teeth
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Introduction: Gutta-percha is not compressible and tooth fracture can be initiated when force is applied to the gutta-percha. The aim of this study was to apply a hoop stress to roots which have been obturated with either gutta-percha and no sealer, gutta-percha and AH Plus sealer, gutta-percha and EndoSequence Bioceramic Sealer (BC Sealer), gutta-percha and Tetranite®, or Tetranite® and no gutta-percha until fracture occurred and then compared the failure stresses. Methods: Teeth were divided into five groups based on the sealer type used, no sealer used or only sealer used. The teeth were then sectioned into 2mm thickness discs and load was applied using a piston until fracture took place. The stress generated by the gutta-percha on the tooth wall was then calculated using a hoop stress formula. One – way ANOVA with a 95% multiple range test was used to compare hoop stresses at failure for all groups (SPSS, TBM). Linear regression was used to examine failure load versus dentin wall thickness (SigmaPlot 13.0, Systa Software). Results: With respect to the amount of stress exerted by the gutta-percha on the internal tooth wall with or without sealer types showed there were significant differences between the Tetranite®/no gutta-percha group and all the groups (p < 0.05). Multiple comparisons showed no significant difference between the gutta-percha/no sealer group and gutta-percha/AH Plus sealer group (p < 0.928), gutta-percha/no sealer group and gutta-percha/BC sealer group (p < 0.927), gutta-percha/no sealer group and gutta-percha/Tetranite® group (p < 1.000), gutta-percha/AH Plus sealer group and gutta-percha/BC sealer group (p < 0.479), gutta-percha/AH Plus sealer group and gutta-percha/Tetranite® group (p < 0.845) and the gutta-percha/BC sealer group and gutta-percha/Tetranite® group (p < 0.973). Conclusions: Application of a hoop stress provides the field of endodontics a method to test whether sealers enhance dentin strength. Currently there is a knowledge gap in endodontics where there is no method to test whether endodontic sealers enhance dentin strength, and this shows it is possible. The Tetranite®/no gutta-percha group enhanced dentin strength in this study.
I. Introduction

Root canal therapy is primarily completed by shaping, cleaning, and filling the root canal space with endodontic files, irrigants, gutta-percha, and endodontic sealers respectively. The variety of available instruments today for shaping a root canal consists mainly of endodontic hand files and rotary file instruments. Endodontic hand files are manually operated endodontic instruments used for cleaning and shaping of root canals. Hand filing is very time consuming and this preparation technique can lead to iatrogenic errors (i.e. ledging, zipping, canal transportation and apical blockage) (Walton et al., 2002), much consideration has been directed toward root canal preparation techniques with rotary instruments.

Endodontic Rotary Files

Rotary endodontic instruments are primarily used to obtain most of the shaping and are mechanically driven with a handpiece. NiTi alloy was developed by the Naval Ordnance Laboratory (White Oak, MD, USA). It was named Nitinol; an acronym for nickel (ni), titanium (ti) and Naval Ordnance Laboratory (Buehler et al., 1963). In the late 1980s nickel-titanium (NiTi) rotary files were introduced to endodontics. Rotary NiTi instruments have become popular as they can clean and shape root canals with fewer procedural errors and more predictability than stainless steel hand files (Hargreaves et al., 2011).

Many designs of NiTi instruments are available. Most resemble a basic file, with flutes along the length and a latching or attaching system to affix the file to a handpiece. Some are available in different tapers and with noncutting tips. NiTi rotary instruments
are used to flare either with the step-back or the crown-down methods. NiTi rotary instrumentation has advantages as well as disadvantages compared with stainless steel hand instrumentation. Because of their flexibility, the files have less tendency to transport curved canals. Finger fatigue is less because the handpiece is doing much of the work. Somewhat less time is required to prepare the canal. Debridement effectiveness is comparable to that with hand instrumentation. There are also disadvantages. Expense is greater if one of the special motor systems is purchased; in addition, the files are costly. Files are prone to breakage, without warning, particularly if overused. Overall, no difference is seen with NiTi rotary instruments for either quality of debridement or prognosis; there are no substantive data on either. (Walton et al., 2002)

In the past decade, several proprietary processing procedures for nickel titanium (NiTi) alloy were developed to improve the mechanical properties of NiTi endodontic instruments. Thermomechanically treated NiTi alloys have been reported to be more flexible with improved cyclic fatigue resistance and greater angle of deflection at failure when compared to conventional NiTi (Zupanc et al., 2018). Thermomechanically-treated NiTi instruments are the latest advancement of rotary files of which many brands exist on the market today.

**Gutta-Percha**

Gutta-percha is the main component used to fill the root canal space. The early history of gutta-percha is obscure. The Malays and Chinese are said to have used it in a remote and undetermined epoch long before Western civilization had any knowledge of its existence (Obach 1898; Seelingmann et al., 1910). Gutta-percha, as formerly prepared by the natives of Asia, had a yellowish-brown color and showed a decidedly
fibrous texture. Gutta-percha occupied an unrivaled position as the most desirable insulator of electric cables until its replacement by vulcanized rubber late in the nineteenth century. Gutta-percha was employed for the manufacture of corks, cements, thread, surgical instruments, garments, pipes, and sheathing for ships. Even boats were made wholly of gutta-percha, one as early as 1850. Maps and globes were made of the material, and, because of the thin sheets into which it could be rolled, gutta-percha seemed destined to replace paper. The variety of manufactured articles became bewildering. Musical instruments, candelabra, gaiters, garters, suspenders, window shades, carpets, gloves, mattresses, pillows, tents, umbrellas, and a host of other articles were fabricated of gutta-percha. Gutta-percha golf balls were introduced by the later part of the nineteenth century, and until 1920 “gutties” was the term used for golf balls on links in this country and abroad. Gutta-percha, the naturally occurring polymer of isoprene, has been known to dentistry for approximately 170 years (Prinz 1945; Payne 1884).

In 1942, C. M. Bunn reported an interesting complication in the molecular chemistry of gutta-percha. He found that the polymer could exist in two distinctly different crystalline forms, which he termed alpha” and “beta” modifications. Most commercial gutta-percha exists as the “beta” crystalline structure (Fisher 1953). The “alpha” form occurs in the tree. It is in this form that most commercial gutta-percha, including dental gutta-percha, exists (Goodman et al., 1974). Gutta-percha undergoes phase transitions when heated from beta to alpha phase at around 115° F (46° C). At a range between 130° to 140° F (54° to 60° C) an amorphous phase is reached. When cooled at an extremely slow rate the material will recrystallize to the alpha phase.
However, this is difficult to achieve and under normal conditions the material returns to
the beta phase. The softening point of gutta-percha was found to be 147°F (64°C). The
phase transformation is important in thermoplastic obturation techniques (Goodman et
al., 1981).

Gutta-percha is derived from dried sap from trees of the family Sapotaceae
(Spångberg et al., 1982). It is composed of 20% gutta-percha, 80% zinc oxide, dye and
metal salts added for color and radiographic contrast. In addition, some manufacturers
add calcium hydroxide, chlorexidine, or iodoform as an antimicrobial to impart some
disinfectant properties to the material (Ørstavik et al., 2005). The variations in content
are because of different manufacturers and distributors desiring different handling
properties. Some formulations are softer than others. Some clinicians choose the
brand of gutta-percha depending on the technique being used. Compaction with
spreaders, condensers or carriers is usually the means used to attempt to compensate
for the shrinkage of the core material (McElroy 1955). An important characteristic of
gutta-percha and of clinical importance is the fact that when it is exposed to air and light
over time it becomes more brittle. Storage of gutta-percha in a refrigerator extends the
shelf life of the material (Wong et al., 1982).

Gutta-percha tends to be used for many reasons. It is impervious to moisture, is
radiopaque, is not an irritant to tissue beyond the apex, is bacteriostatic, is sterile and
easily sterilized, and easy to remove from the root canal space (Ørstavik et al., 2005).
Gutta-percha is not compressible and is sensitive to temperature changes, it will tend to
become brittle and fracture before ductile yield occurs (Friedman et al., 1977). The
delivery of gutta-percha to the root canal can be accomplished in a variety of ways.
Obturation Techniques

The operator may choose one of many obturation techniques to deliver the gutta-percha including: lateral compaction, vertical compaction, continuous wave, warm lateral, injection techniques, thermomechanical, carrier-based, chemoplasticized, custom cone/solvents, pastes, and apical barrier. The lateral compaction technique uses a master cone corresponding to the final instrumentation size and length of the canal is coated with sealer, inserted into the canal, laterally compacted with spreaders and filled with additional accessory cones.

Vertical compaction is where a master cone corresponding to the final instrumentation size and length of the canal is fitted, coated with sealer, heated and compacted vertically with pluggers until the apical 3-4mm segment of the canal is filled. Then the remaining root canal is back filled using warm pieces of core material.

Continuous wave is essentially a vertical compaction (down-packing) of core material and sealer in the apical portion of the root canal using commercially available heating devices such as System B (SybronEndo, Orange, Calif.) and Elements Obturation Unit™ (SybronEndo, Orange, Calif.), and then back filling the remaining portion of the root canal with thermoplasticized core material using injection devices such as the Obtura (Obtura Spartan, Earth City, Mo.), Elements Obturation Unit™ (SybronEndo, Orange, Calif.), and HotShot (Discus Dental, Culver City, Calif.).

Warm lateral uses a master cone corresponding to the final instrumentation size of the canal is coated with sealer, inserted into the canal, heated with a warm spreader,
laterally compacted with spreaders and filled with additional accessory cones. Some devices use vibration in addition to the warm spreader.

Two types of injection techniques are:

1. A preheated, thermoplasticized, injectable core material is injected directly into the root canal. A master cone is not used but sealer is placed in the canal before injection, with either the Obtura (Obtura Spartan, Earth City, Mo.), or Ultrafil (Coltene Whaledent, Cuyahoga Falls, Ohio) or Calamus® (DENTSPLY Tulsa Dental Specialties, Tulsa, Okla.) filling systems.

2. A cold, flowable matrix that is triturated, GuttaFlow® (Coltene Whaledent, Cuyahoga Falls, Ohio), consists of gutta-percha added to a resin sealer, RoekoSeal. The material is provided in capsules for trituration. The technique involves injection of the material into the canal and placing a single master cone.

Thermomechanical is a technique where a cone coated with sealer is placed in the root canal, engaged with a rotary instrument that frictionally warms, plasticizes and compacts it into the root canal.

Carrier-based systems include two types:

1. Carrier-Based Thermoplasticized: Warm gutta-percha on a plastic carrier, is delivered directly into the canal as a root canal filling. Examples are: ThermaFil® (Dentsply Tulsa Dental Specialties, Tulsa, Okla.), Realseal 1™ (Sybron, Orange, Calif.), Densfil™ (DENTSPLY Maillefer, Tulsa, Okla.) and Soft-Core® (Axis Dental, Coppell, Texas).
2. **Carrier-Based Sectional:** A sized and fitted section of gutta-percha with sealer is inserted into the apical 4mm of the root canal. The remaining portion of the root canal is filled with injectable, thermoplastized gutta-percha using an injection gun. An example is SimpliFill (Discus Dental, Culver City, Calif.).

Chemoplasticized technique uses Chemically softened gutta-percha, using solvents such as chloroform or eucalyptol, is placed on already fitted gutta-percha cones, inserted into the canal, laterally compacted with spreaders and the canal filled with additional accessory cones.

Custom cone and solvents such as chloroform, eucalyptol or halothane are used to soften the outer surface of the cone as if making an impression of the apical portion of the canal. However, since shrinkage occurs, it is then removed and reinserted into the canal with sealer, laterally condensed with spreaders and accessory cones.

Pastes fills have been used in a variety of applications. When used as the definitive filling material without a core, they are generally considered to be less successful and not ideal. Lastly, apical barriers are important for the obturation of canals with immature roots with open apices. Mineral trioxide aggregate is generally considered the material of choice at this time (American Association of Endodontists. Colleagues for Excellence 2009). Gutta-percha cannot be used as the sole filling material; it lacks the adherent properties necessary to seal the root canal space. Therefore, a sealer (cement) is always needed for the final seal (Hargreaves et al., 2011).
Endodontic Sealers

Sealers are used between dentin surfaces and core materials to fill spaces that are created due to the physical inability of the core materials to fill all areas of the canal. Traditionally desirable characteristics were to adhere to dentin and the core material as well as to have adequate cohesive strength. Newer generation sealers are being engineered to improve their ability to penetrate dentinal tubules and bond to, instead of just adhering to, both the dentin and core material surfaces. Various types of delivery systems such as auto-mix syringes have improved not only the efficiency of mixing, but also the quality of the mix and ultimately the properties of the set material. Various types of sealers include zinc oxide-eugenol, as well as polymer resins, glass ionomer, bio-glass and silicon-based materials (American Association of Endodontists. Colleagues for Excellence 2009). Endodontic sealers are used to achieve a satisfactory seal between the gutta-percha and dentin (Pascon et al., 1990). Sealers must show cohesive strength to keep the obturation material together. The ideal root canal sealer properties were described by Grossman (Grossman et al., 1982):

1. It should be tacky when mixed to provide good adhesion between it and the canal wall when set.
2. It should make a hermetic seal.
3. It should be radiopaque so that it can be visualized on the radiograph.
4. The particles of powder should be very fine so that they can mix easily with liquid.
5. It should not shrink upon setting.
6. It should not discolor tooth structure.
(7) It should be bacteriostatic or at least not encourage bacterial growth.

(8) It should set slowly.

(9) It should be insoluble in tissue fluids.

(10) It should be well tolerated by the periapical tissue.

(11) It should be soluble in common solvents if it is necessary to remove the root canal filling.

Some of the most widely used sealers used today include epoxy-resin based sealers and bioceramic filled sealers. Epoxy resin-based sealers were introduced in endodontics by Schroeder (Grossman et al., 1982), and with modifications of the original formula are commonly used for root canal filling procedures (Torabinejad et al., 1979; Wennberg et al., 1980). Resin sealers have a long history of use, provide adhesion, and do not contain eugenol. Epoxy-resin based sealers are used for root canal fillings due to their dimensional stability and resorption resistance (Garrido et al., 2010; Wolf et al., 2014).

AH-26 is an epoxy-resin based sealer that was initially developed as a single obturation material. AH-26 derives its name from, A- Aethoxylinharz (German) for ethoxyline base, H- Hexamethylene tetramine and 26- was the test number. Because of its positive handling characteristics, it has been extensively used as a sealer. It has good flow, seals well to dentin walls, antibacterial, contracts slightly while hardening, low toxicity and well tolerated by periapical tissue and has sufficient working time (Limkangwalmongkol et al., 1991). AH-26 is a slow-setting epoxy resin that was found to release formaldehyde when setting. The setting time is 36 to 48 hours at body
temperature and 5–7 days at room temperature. AH Plus (Dentsply DeTrey GmbH, Konstanz, Germany) is a modified formulation of AH-26 in which formaldehyde is not released. The sealing abilities of AH-26 and AH Plus appear comparable (De Moor et al., 2004). It is more radiopaque and has a shorter setting time of approximately 8 hours, lower solubility, and a better flow compared with AH-26. AH Plus and like others of its type has been commonly used for many years owing to its adequate radiopacity, flow, dimensional stability, low solubility and low concentration, and high resistance (Pinheiro et al., 2009).

Within the past thirty years bioceramic filled sealers have been available for procedures in endodontics. Their use corresponded to the increased presence of bioceramic technology in the fields of medicine and dentistry. Bioceramics are ceramic materials designed for medical and dental use specifically. They include bioactive glass, alumina, glass ceramics, zirconia, hydroxyapatite, and calcium phosphates (Hench et al., 1991). The arrangement of bioceramic materials into bioactive or bioinert materials is a role of their interaction with the surrounding tissue (Best et al., 2008). Bioactive materials interact with the adjacent tissues to encourage the growth of more durable ones (Koch et al., 2009). Zirconia and alumina, which are bioinert materials, produce an insignificant response from the surrounding tissues, effectively having no biological or physiological effect (Best et al., 2008). Further classification of bioactive materials according to their stability as degradable or nondegradable. Commonly used for orthopedic procedures, bioceramics can be used as joint or tissue replacements, and for coating metal implants to improve biocompatibility. Moreover, bone graft
substitutes, such as calcium phosphate-based materials, have been used which are porous ceramics (Saikia et al., 2008).

EndoSequence Bioceramic Sealer (BC Sealer; Brasseler USA, Savannah, GA) is a calcium silicate–based sealer and is composed of zirconium oxide, calcium silicates, calcium phosphate monobasic, calcium hydroxide, filler, and thickening agents (Al-Haddad et al., 2016). BC sealer is a premixed ready-to-use injectable bioceramic cement paste. Setting time is 4 hours. However, in very dry root canals, the setting time can be more than 10 hours. The setting time is dependent upon the presence of moisture in the dentinal tubules. The amount of moisture required for the setting reaction to occur reaches the root canal by means of the dentinal tubules. Therefore, it is not necessary to add moisture in the root canal prior to performing the obturation (BC; Brasseler USA, Savannah, GA).

Tetranite® (LaunchPad Medical Inc.) is a novel bone adhesive that is currently under development. Tetranite® is presently being researched as a bone cement, used with implants and also evaluated as a possible endodontic sealer/obturation material. Tetranite® is a synthetic, self-setting, injectable, cohesive, mineral–organic biomaterial, which can be used as a wet-field bioresorbable bone adhesive. Once cured, a strong, adhesive, load-bearing bond to wet bone tissue, metals, and other materials is maintained. Tetranite® powder is mixed with water in a liquid-to-powder ratio of 0.21 mL g–1 for 20 s. Upon mixing with water, a cohesive, viscous liquid is formed, which maintains its tacky character until set. One of the primary advantages of the present biomaterial is its inherent ability to set and maintain its adhesive character even in
aqueous environments. Final setting of the bone adhesive occurs within 10 min from the start of mixing. Tetranite® stems from a class of calcium phosphate bone cements. Its composition comprises tetracalcium phosphate and phosphoserine powders, which are mixed with water to produce the mineral–organic bioresorbable bone adhesive (Kirillova et al., 2018).

**Fractures and Cracks in Teeth**

Fractures present a challenging diagnostic issue to the practitioner. There is a high occurrence of fractures and cracks in teeth (Cameron et al., 1964). With the wide variety of different types of cracks in teeth it becomes essential to distinguish amongst the types of cracks. Longitudinal fractures occur in the long axis of the crown and/or the root. Five types of longitudinal tooth fractures can be described. These fractures may be as innocent as a superficial enamel craze line, or they may be as prominent as a fractured cusp. The remaining fractures include the split tooth, cracked tooth and vertical root fracture (Hargreaves et al., 2011).

Craze lines affect only the enamel, while fractured cusps, cracked teeth and split teeth begin on the occlusal surface and extend apically, affecting enamel, dentin, and possibly, the pulp. Craze lines are frequently confused with cracks but can be distinguished by transillumination (Hargreaves et al., 2011). If the tooth is cracked, the light will be blocked, allowing only a segment of the tooth structure to light up; if the tooth only has a craze line, the entire tooth structure will light up. In posterior teeth, craze lines are usually evident crossing marginal ridges and extending along buccal and lingual surfaces. Long vertical craze lines commonly appear on anterior teeth. As they
only affect the enamel, they cause no pain and are of no concern beyond the aesthetic (Colleagues Excellence - American Association of Endodontists, 2017).

Fractured cusps are defined as a complete or incomplete fracture starting from the crown of the tooth and extending subgingivally, usually directed both mesiodistally and buccolingually (Hargreaves et al., 2011). The fracture usually involves at least two aspects of the cusp by crossing the marginal ridge and extending down a buccal or lingual groove. The fracture will extend to the cervical third of the crown or root. Depending upon the amount of remaining tooth structure, the tooth is treated by removing the affected cusp and restoring with a direct or a cuspal-reinforced restoration (Colleagues Excellence - American Association of Endodontists, 2017).

Cracked tooth is an incomplete fracture originating from the crown and spreading subgingivally, usually focused mesiodistally. The fracture may extend through either or both marginal ridges and through the proximal surfaces. The fracture is in the crown portion of the tooth only or may extend from the crown to the proximal root (Hargreaves et al., 2011). Cracked teeth are described as incomplete (greenstick) fractures, which also describes their form. Occlusally, the crack is more centered and apical than a fractured cusp and, therefore, more likely to cause pulpal and periapical pathosis as it extends apically (Colleagues Excellence - American Association of Endodontists, 2017).

Split tooth is defined as a complete fracture initiated from the crown and extending subgingivally, usually directed mesiodistally through both marginal ridges and the proximal surfaces. The fracture is located coronally and extends from the crown to the proximal root (Hargreaves et al., 2011). A crack that is more centered on the
occlusion will tend to extend more apically. A split tooth is the evolution of a cracked tooth; the fracture is now complete and extends to a surface in all areas. The root surface involved is in the middle or apical third, usually extending toward the lingual. There are no dentin connections; tooth segments are now entirely separate (Colleagues Excellence - American Association of Endodontists, 2017).

Vertical root fractures begin in the root. The crack may progress into the root system to involve the pulp. Vertical fractures are located midtooth, usually running in a bucco-lingual direction (Ailor et al., 2000). Vertical root fracture is a crack that extends longitudinally down the long axis of the root. Often it extends through the pulp and to the periodontium. It tends to be more centrally located within the tooth, as opposed to being more oblique. These fractures may be present before endodontic treatment, secondary to endodontic treatment, or they may develop after endodontic treatment has been completed (Hargreaves et al., 2011). When such fractures occur with endodontically treated teeth the prognosis is poor whether the fracture is detected or not (Saw et al., 1995). The vertical root fracture creates a stress that occurs in a bucco-lingual direction through the thickest part of the dentin (Lertchirakarn et al., 2003). Typically, these cracks lead to a split root, leaving the tooth with a poor prognosis (Hargreaves et al., 2011). Several factors can contribute to these fractures such as occlusal forces, pin and post placement, or stress produced in the root during obturation of the canal which is the main cause for vertical root fracture (Saw et al., 1995). Stress on the canal surface may enhance pre-existing surface defects that were caused by apical force applied to gutta-percha and the resulting circumferential tensile stress (Chai et al., 2012).
Hoop Stress and Thick-Walled Cylinders

When tooth roots are sectioned and the root is circular, the resulting section of the root can be considered a thick-walled cylinder. Hoop stress, i.e., the circumferential stress, acts through the entire thickness of a cylindrically shaped part because of the difference between internal and external pressure (Nave et al., 2011). Hoop stress is mechanical stress defined for rotationally symmetric objects such as pipe or tubing. The real-world view of hoop stress is the tension applied to the iron bands, or hoops, of a wooden barrel. It is the result of forces acting circumferentially (Engineering ToolBox, 2005).

Stress in Axial Direction

The stress in axial direction at a point in the tube or cylinder wall can be expressed as:

\[ \sigma_a = \frac{(p_i r_i^2 - p_o r_o^2)}{(r_o^2 - r_i^2)} \]

where

- \( \sigma_a \) = stress in axial direction (MPa, psi)
- \( p_i \) = internal pressure in the tube or cylinder (MPa, psi)
- \( p_o \) = external pressure in the tube or cylinder (MPa, psi)
- \( r_i \) = internal radius of tube or cylinder (mm, in)
- \( r_o \) = external radius of tube or cylinder (mm, in)

Stress in Circumferential Direction - Hoop Stress

Lame’s theorem gives the solution to thick cylinder problem.
The stress in circumferential direction - hoop stress - at a point in the tube or cylinder wall can be expressed as:

\[ \sigma_c = \frac{[(p_i r_i^2 - p_o r_o^2) / (r_o^2 - r_i^2)] - [r_i^2 r_o^2 (p_o - p_i) / (r_o^2 - r_i^2)]}{r_i^2 r_o^2 (p_o - p_i) / (r_o^2 - r_i^2)} \]

where

\( \sigma_c = \text{stress in circumferential direction (MPa, psi)} \)
\( r = \text{radius to point in tube or cylinder wall (mm, in) } (r_i < r < r_o) \)
\( \text{maximum stress when } r = r_i \text{ (inside pipe or cylinder)} \)

(Engineering ToolBox, 2005).

![Figure 1: A thick cylinder with both external and internal pressure. (Module - NPTEL. 2017)](image)

When a thick-walled tube or cylinder is subjected to internal and external pressure a hoop and longitudinal stress are produced in the wall (Figure 1) (Engineering ToolBox, 2005). Hoop stress is of critical importance in engineering applications involving thick walled cylinders in the form of boilers, gun barrels, and high-pressure containers, which are essential structural members for many industries including power, chemical, armament, and food processing industries (Prime 2011). Because cylinders are prone to cyclic stress during their normal operation and large internal pressures
produce high tension along the inner surface of the cylinder, cracks can become a major concern and they may cause rupture. It is necessary to analyze the crack propagation to ensure the integrity of the cylinder against the fatigue failure (Salam et al., 2014).

Knowledge Gap

The ideal root canal sealer properties described by Grossman do not include enhancing the strength of dentin. It is unknown if a hoop stress can be applied in tooth roots as can be with thick-walled cylinders. Currently, there is a knowledge gap where there is no method to test whether endodontic sealers enhance dentin strength. It is therefore unknown if endodontic sealers can enhance the strength of dentin.

II. Research Aim

Aim: The purpose of this study was to induce a hoop stress in roots that have been obturated with either gutta-percha and no sealer, gutta-percha and AH Plus Sealer, gutta-percha and EndoSequence Bioceramic Sealer, gutta-percha and Tetranite, or Tetranite and no gutta-percha until fracture occurs and then comparing the failure stresses.

Hypothesis

The null hypothesis is that results will show there is no difference in failure stresses among the groups.
III. Materials and Methods

Collection of Teeth

To determine the fracture loads, human extracted single-rooted premolars with fully developed apices were collected by the Division of Oral and Maxillofacial Surgery and the Division of General Dentistry at the UConn School of Dental Medicine. No IRB protocol was required since samples were anonymous and were considered medical waste. Teeth with apices not fully formed, fractured roots, calcified root canals, internal or external root resorption and curvature beyond 20 degrees were excluded. The teeth were stored in 0.5% Sodium Azide solution. The teeth were randomly divided into groups based on the sealer type used.

The groups were as follows:

Group 1: No Sealer and gutta-percha (n=8)
Group 2: AH Plus Sealer and gutta-percha (n=7)
Group 3: EndoSequence Bioceramic Sealer and gutta-percha (n=12)
Group 4: Tetranite® and gutta-percha (n=9)
Group 5: Tetranite® (n=5)

Teeth Preparation

The crowns of the samples were removed at or below the cemento-enamel-junction (CEJ) by using a low speed and a disc to a standardized root length of about 15 mm. Working length was established using a #10 K-file into the canal until the tip is visualized at the apex and then 1 mm was subtracted for the final measurement. Cleaning and shaping were completed using Protaper Gold rotary files (Dentsply
Maillefer, Ballaigues, Switzerland) compatible with the manufacturer’s recommended rpm and torque settings for each file.

All the samples were prepared using a sequence of SX, S1, S2, F1, F2, and F3 as a final apical file. After the use of each instrument, irrigation was achieved by 0.5% sodium hypochlorite (NaOCl) and 17% ethylenediaminetetraacetic acid (EDTA) as a final irrigant for 1 minute. The canal was then rinsed off with sterile distilled water to remove residues of the solutions. The root canals were properly dried with sterile paper points (Dentsply Maillefer, Ballaigues, Switzerland).

**Teeth Obturation**

Teeth in group 1 (gutta-percha and no sealer) were obturated by the using the System B fine plugger as a heat source and thermo-plasticized injectable technique by Calamus Flow Delivery System (Dentsply-Tulsa Dental, Tulsa, OK, USA). A master gutta-percha cone (size 30 06) was inserted into the canal at working length and seared off to a level of 5 mm of working length. Vertical condensation of the gutta-percha in the apical portion of the canal was completed using a Buchannan plugger (0.7 mm diameter). The rest of the canal was obturated by the backfilling of thermo-softened gutta-percha heated at 180°C to optimally fill the canal. This was achieved by injecting warm gutta-percha, using the electric gutta-percha cartridge 20 G (0.8 mm diameter). The warm gutta-percha was then condensed vertically with a plugger (size 8) leaving 2mm between the gutta-percha and the orifice. Cavit was placed over the orifice and apex at a thickness of 2mm.

Teeth in group 2 (AH Plus sealer and gutta-percha) were obturated by using the thermo-plasticized injectable technique with AH Plus sealer. A master gutta-percha
cone (size 30 06) was coated with AH Plus sealer and inserted into the canal at working length. Vertical condensation of the gutta-percha in the apical portion of the canal was completed using a Buchannan plugger (0.7 mm diameter). The canals were then coated with another layer of AH Plus sealer using a lentulo spiral (Mani Paste Carriers, Tochigi, Japan). The rest of the canal was obturated by the backfilling of thermo-softened gutta-percha heated at 180°C to optimally fill the canal. This was achieved by injecting warm gutta-percha, using the electric gutta-percha cartridge 20 G (0.8 mm diameter). The warm gutta-percha was then condensed vertically with a plugger (size 8) leaving 1mm between the gutta-percha and the orifice. Cavit was placed over the orifice and apex to seal tooth.

Teeth in group 3 and 4 (BC Sealer/gutta-percha and Tetranite®/gutta-percha) were obturated in the same manner as in group 2 with the use of BC Sealer or Tetranite® instead of AH Plus respectively. Teeth in group 5 (Tetranite®/no gutta-percha) were obturated in the same manner as group 2 with no gutta-percha and only with Tetranite® with the use of a lentulo spiral.

After obturation each group was placed in 0.5% Sodium Azide to allow the sealer/cement to set for a period of 7 days. All teeth were prepared and obturated by a single operator, the primary investigator.

**Load Applying**

Teeth in all groups were sectioned serially into 2mm thickness discs. After the teeth were sectioned the load was applied using an MTS 858 Mini Bionix® II Biomaterials Testing System (Figure 2). One of four custom-made stainless-steel pistons with diameters of 0.68mm, 0.74mm, 0.81mm and 0.87mm, were used to apply the load with
the MTS 858 Mini Bionix® II at a constant crosshead speed of 1mm/min directly on the gutta-percha until fracture of the section occurred (Figure 3).

The software running the MTS 858 Mini Bionix® II, TestWorks® 4, automatically stopped the load when fracture occurred giving the force in Newtons (Figure 4). Photographs of the fractured discs were taken (Appendix II, Figure 7 - 11).
Figure 3: Custom-made stainless-steel pistons were used to apply the load with the MTS 858 Mini Bionix® II at a constant crosshead speed of 1mm/min directly on the gutta-percha until fracture of the section occurred.

Figure 4: TestWorks® 4 Software running during load.
The stress generated by the gutta-percha on the internal canal wall (Figure 5) was calculated by using the hoop stress formula for thick-walled cylinders (Lame’s Theorem):

\[
\sigma_h = \frac{p_i r_i^2 - p_o r_o^2}{r_o^2 - r_i^2} - \frac{(p_o - p_i) r_0^2 r_i^2}{(r_o^2 - r_i^2) r^2}
\]

Where

\(\sigma_h\) = hoop stress, i.e. stress in circumferential direction (MPa)
\(P_i\) = internal pressure
\(P_o\) = external pressure
\(r_i\) = internal radius
\(r_o\) = external radius
\(r\) = radius at point of interest (usually \(r_i\))

**Statistical Analysis**

One – way ANOVA with a 95% multiple range test was used to compare hoop stresses at failure for all groups (SPSS, TBM). Linear regression was used to examine failure load versus dentin wall thickness (SigmaPlot 13.0, Systa Software).
IV. Results

The raw data with respect to the amount of stress exerted by the gutta-percha on the internal tooth wall with or without sealer types is attached in the Appendix I, Table 4. Table 1 shows the One – way ANOVA analysis, where there were significant differences among the groups (p < 0.05). Table 2 shows when multiple comparisons were made, results showed no significant difference between groups 1 and 2 (p < 0.928), groups 1 and 3 (p < 0.927), groups 1 and 4 (p < 1.000), groups 2 and 3 (p < 0.479), groups 2 and 4 (p < 0.845) and groups 3 and 4 (p < 0.973). Group 5 showed a significant difference between all the groups (p < 0.05).

Mean failure stresses and standard deviations are presented in table 3 and figure 6. The Tetranite® group had the highest mean failure stress value, which was statistically significant. The BC Sealer and gutta-percha group had the lowest mean failure stress value, but this was not significant.

Table 1. One - way ANOVA analysis.

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Table 2. Multiple Comparisons

Dependent Variable: stress
Tukey HSD

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<th>Std. Error</th>
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<th>95% Confidence Interval</th>
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</tbody>
</table>

* The mean difference is significant at the 0.05 level.

Group 1: No Sealer and gutta-percha
Group 2: AH Plus Sealer and gutta-percha
Group 3: BC Sealer and gutta-percha
Group 4: Tetranite® and gutta-percha
Group 5: Tetranite®
### Table 3. Mean Failure Stress (MPa) and Standard Deviations

**Tukey HSD\textsuperscript{a,b}**

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*a. Uses Harmonic Mean Sample Size = 7.549.*

*b. The group sizes are unequal. The harmonic mean of the group sizes is used. Type I error levels are not guaranteed.*

**Means for groups in homogeneous subsets are displayed.**

**Figure 6: Failure Stress of Each Group**
V. Discussion

Endodontic treatment is completed by instrumenting, disinfecting, and obturating the root canal space. Today with the use of the most advanced rotary file instruments the goal of instrumentation can be accomplished with fewer procedural errors and more predictability than with the stainless-steel hand files (Hargreaves et al., 2011). With the introduction of NiTi rotary files in the 1980s and the now thermomechanically-treated NiTi instruments, endodontics is advancing with each given day.

An increasing number of rotary nickel-titanium (NiTi) file systems have been marketed by various manufacturers. These systems differ from one another in the design of the cutting blades, body taper, and tip configuration. Despite the obvious clinical advantages of these techniques over hand instrumentation, the influence of the design of the cutting blades is still controversial (Peters et al., 2004; Bergmans et al., 2002) and could generate increased friction and stresses within the root canal (Blum et al., 2003). Rotary instrumentation requires less time to prepare canals as compared with hand instrumentation but result in significantly more rotations of the instruments inside the canal (Pasqualini et al., 2008). This may cause more friction between the files and the canal walls.

With using NiTi instruments, a variable degree of rotational force is applied to root canal walls which can lead to the creation of microcracks or craze lines in root dentin. The extent of a defect may be related to various contributing factors such as the tip design, cross-sectional geometry, taper, pitch, and flute form (Yoldas et al., 2012). The complexity of root canal anatomy, remaining dentinal wall thickness and canal
diameter after preparation (Rundquist et al., 2006), may also influence the stress concentration. In addition, the age-related change in microstructure of dentin leading to progressive dentinal sclerosis may correspond to lower resistance to damage initiation and propagation (Mireku et al., 2010). The more dentin removed the more chance for a fracture. The craze lines these could later propagate into vertical root fracture if the tooth is subjected to repeated stresses from endodontic or restorative procedures (Bier et al., 2009). It has been shown that the use of nickel–titanium rotary instrument systems were associated with inducing microcracks in root dentin (Saha et al., 2017). These microcracks are secondary to endodontic treatment which may eventually propagate through the remaining dentin and lead to a vertical root fracture.

It is well known that endodontic sealers are used to achieve a satisfactory seal between the gutta-percha and dentin (Pascon et al., 1990). Having a sealer that enhances dentin strength would be advantageous. Currently there is a knowledge gap in endodontics where there is no method to test whether endodontic sealers enhance dentin strength, which in turn could possibly lessen the propagation of these microcracks.

In this study we prepared tooth discs obturated with either gutta-percha and no sealer, AH Plus Sealer and gutta-percha, EndoSequence Bioceramic Sealer and gutta-percha, Tetranite® and gutta-percha, or Tetranite® and no gutta-percha. These discs were essentially thick-walled cylinders. Hoop stress was applied to these cylinders until fracture occurred. A comparison was then made between the fracture loads of each group. The results of our study do not support the original hypothesis that there was no difference in fracture loads among the groups (Table 1). Tetranite®/gutta-percha group
showed to have the highest mean failure stress and the difference was statistically significant (Table 3). BC Sealer/gutta-percha had the lowest mean failure stress, but this was not significant compared to groups 1, 2 or 4 (Table 3).

In this study we used 0.5% Sodium Azide solution to store our extracted teeth. Human teeth used for research and teaching purposes are a potential source of bloodborne pathogens, according to the Bloodborne Pathogens Standard of the Occupational Safety and Health Administration (OSHA) (Recommended infection-control practices for dentistry, 1993). Therefore, sterilization or disinfection of extracted teeth before their in vitro use is recommended. The optimal storage conditions for dentin are controversial (Mitchem et al., 1986). Researchers have addressed different methods for tooth storage such as freezing (Tonami et al., 1996), refrigerating, or storing at an ambient temperature. Others have described storage of teeth in distilled water, a physiologic solution, chloramine, formalin, or thymol (Lee et al., 2007; Tosun et al., 2007; Goodis et al., 1993; Ziskind et al., 2003).

Sodium hypochlorite (NaOCl) was not used a storage medium because storage in NaOCl results in significantly lower bond strength than that of the other treatment specimens (Mobarak et al., 2010). Chloramine is a close analogue to sodium hypochlorite, but unlike bleach, it does not affect collagen (O’Brien et al., 1998). It has been used by several investigators for disinfecting teeth (O'Brien et al., 1998; Haller et al., 1993; Jörgensen et al., 1985; Munksgaard et al., 1988; Oilo et al., 1990). Various types of media and methods have been used to keep extracted teeth moist and kill the bacteria in them. Studies have also been performed to investigate the effect of autoclaving, boiling, (Tosun et al., 2007) and gamma irradiation (Brauer et al., 2008;
Pashley et al., 1993) on the integrity of dentin. No significant difference was found in bond strengths to the enamel of disinfected or sterilized teeth (Shaffer et al., 1985) or to those stored wet for up to 5 years (Williams et al., 1985).

Dentin moisture in extracted human teeth lacks dentinal fluid. Dentin surfaces that are moist improve bond strengths when using adhesive systems (Tay et al., 1998; Van Meerbeek et al., 1998). As a storage medium, Sodium Azide inhibits bacterial growth in teeth due to a mechanism involving metal ion complexation and displacement from enzymes (Komabayashi et al., 2009). Sodium Azide increases dentin moisture within 24 hours. Soaking root dentin in Sodium Azide solution beyond 1 day does not further increase dentin moisture (Komabayashi et al., 2009). Cross-linking of collagen when using Sodium Azide is less expected because it is not a fixative.

During preparation of the root canal it is known that a smear layer is created during cleaning and shaping that covers the instrumented root canal walls (Torabinejad et al., 2002). This smear layer contains inorganic and organic substances as well as fragments of odontoblastic processes, microorganisms and necrotic debris. Intracanal irrigants and medications are used during root canal treatment to reach the natural complexities and remove the smear layer. Intracanal irrigants exert their effects mechanically and chemically. Mechanical effects of irrigants are generated by the back and forth flow of the irrigation solution during cleaning and shaping of the infected root canals, significantly reducing the bacterial load. Studies show that irrigants that possess antibacterial properties have clearly superior effectiveness in bacterial reduction and elimination when compared with saline solution (Byström et al., 1981; Siqueira et al., 1997). When this layer is removed, the surface area is improved due to
the increased number of exposed dentinal tubules resulting in better adaptation of the sealer to dentin by forming sealer tags (Sayin et al., 2007).

AH Plus sealer generated a stronger bond to dentin after removal of the smear layer (Eldeniz et al., 2005). The smear layer contains moisture. When the smear layer is not removed, several other sealers demonstrate better bonding to the dentin because of the remaining moisture, and it might possibly act as a coupling agent by helping the adaptation quality of hydrophilic materials to the root canal walls (Lalh et al., 1999; Yildirim et al., 2008). Endosequence BC Sealer is one such hydrophilic material. BC sealer uses the moisture in the smear layer and creates a hydroxyapatite-like precipitation while setting, which adheres to dentin chemically (Dawood et al., 2017). Removal of the smear layer could therefore create a reduction of the BC sealer adaptation to the canal walls.

In this study, we removed the smear layer for each group, which may have affected the BC sealer group due to the missing moisture in the smear layer. McComb was the first to demonstrate the removal of the smear layer with EDTA and showed canals rinsed with EDTA were free of a smeared layer and superficial debris. (McComb et al., 1975). Acid exposes surface collagen and removes peritubular dentin from the top of the tubules (Pashley et al., 1984). Canals rinsed with EDTA creates a zone of demineralized collagen matrices in eroded dentin and around the dentinal tubules. Demineralized dentin zones create the opportunity for dentin hybridization by infiltration of hydrophilic adhesives/sealers. Collapse leads to adhesion/bonding issues (Tay et al., 2006). Coronal and middle sections are more eroded with EDTA than the apical erosion of the root canal (Torabinejad et al., 2003).
Our smear layer was removed with sequential use of 0.5% NaOCl and 17% aqueous EDTA, with EDTA being the final irrigant which was left in the canal for 1 minute and a final rinse with sterile distilled water to remove residues of the solutions. To effectively clean and disinfect the root canal system, an irrigant should be able to disinfect and penetrate dentin and its tubules, offer long-term antibacterial effect, remove the smear layer, and be nonantigenic, nontoxic and noncarcinogenic. In addition, it should have no adverse effects on dentin or the sealing ability of filling materials (Torabinejad et al., 2002). Sodium hypochlorite is the most commonly used root canal irrigant. Advantages of NaOCl include its ability to dissolve organic substances present in the root canal system and its affordability. The major disadvantages of this irrigant are its cytotoxicity when injected into periradicular tissues, foul smell and taste, ability to bleach clothes and ability to cause corrosion of metal objects (Gomes et al., 2001). In addition, it does not kill all bacteria, (Sigueira et al., 1997; Sjogren et al., 1997; Shuping et al., 2000; Shabahang et al., 2003), nor does it remove all of the smear layer (McCome et al., 1975). It also alters the properties of dentin (Sim et al., 2001; Grigoratos et al., 2001).

Chelating agents such as ethylenediaminetetraacetic acid (EDTA), citric acid and tetracycline are used for removal of the inorganic portion of the smear layer (Torabinejad et al., 2002). NaOCl is an adjunct solution for removal of the remaining organic components. Irrigation with 17% EDTA for one minute followed by a final rinse with NaOCl is the most commonly recommended method to remove the smear layer (Johnson et al., 2009). Longer exposures can cause excessive removal of both
peritubular and intratubular dentin (Calt et al., 2000). EDTA has little or no antibacterial effect (Torabinejad et al., 2003).

One limitation of this study was not keeping track of whether the tooth sections came from the apical, middle or coronal thirds. The dentin in the apical third has fewer number of dentinal tubules and they have a reduced diameter, which in affect has a reduced sealer area, then the coronal part. The coronal part of the root canal system has a more intricate tubular structure. The coronal third has a higher number of dentinal tubules and the diameter of the tubules is larger and produces better infiltration of sealer compared to the apical counterpart (Carneiro et al., 2012; Nagas et al., 2011). Our seemingly large standard deviations would be consistent with this.

**Future Studies**

Incorporation of all the sealers on the market could be used or upcoming sealers which have not been released for future studies. Keeping track of the location of the tooth sections, apical third, middle third, or coronal third may change the outcome. Tooth selection with more circular shape should be used. Increasing the numbers of samples and obturating canals with sealer types only could influence results.

**VI. Conclusion**

Application of a hoop stress provides the field of endodontics a method to test whether sealers enhance dentin strength. Currently there is a knowledge gap in endodontics where there is no method to test whether endodontic sealers enhance dentin strength, and this shows it is possible to do so. Tetranite® enhanced dentin strength in this study. The hypothesis was not confirmed, and the results showed there was a significant difference in fracture stress among the groups and Tetranite®.
### VII. Appendix

**Appendix I: Raw data**

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Table: Data collected.
Appendix II: Photographs of Fractures in Groups 1 through 5.

Figure 7: Group 1: No Sealer and gutta-percha
Figure 8: Group 2: AH Plus Sealer and gutta-percha
Figure 9: Group 3: BC Sealer and gutta-percha
Figure 10: Group 4: Tetranite® and gutta-percha
Figure 11: Group 5: Tetranite® alone
Appendix II: Software utilized for calculations.
Appendix III: Photograph of workstation used for preparing teeth.

Figure 13: Workstation for preparing teeth with surgical operating microscope (M320, Leica Microsystems).
VIII. References


Sim TP, Knowles JC, Ng YL, Shelton J, Gulabivala K. Effect of sodium hypochlorite on mechanical properties of dentine and tooth surface strain. Int Endod J (2001);34:120-32.


Thick Walled Cylinders - University of Washington. courses.washington.edu/me354a/Thick Walled Cylinders.pdf.


