AN *IN-VITRO* SEM STUDY COMPARING THE DEBRIDEMENT EFFICACY OF THE ENDOACTIVATOR™ SYSTEM VERSUS THE ULTRASONIC BYPASS™ SYSTEM FOLLOWING HAND-ROTARY INSTRUMENTATION

by

Steven Wayne Binkley

Submitted to the Graduate Faculty of the School of Dentistry in partial fulfillment of the requirements for the degree of Master of Science in Dentistry, Indiana University School of Dentistry, 2010.

Thesis accepted by the faculty of the Department of Endodontics, Indiana University School of Dentistry, in partial fulfillment of the requirements for the degree of Master of Science in Dentisty.

____

Joseph Legan

____

Mychel Vail
Chairman of Research Committee

____

B. Keith Moore

____

Susan Zunt

____

Kenneth Spolnik
Program Director

Date ____________________________

ACKNOWLEDGMENTS

I would first like to thank my loving wife, Angela Franklin Binkley, for your patience and understanding not only during these last two years, but also during our nine-plus years of marriage. Your love and support have always helped me through the many struggles during my education, and I will never be able to truly show you how much you mean to me. I would also like to thank my brother- and sister-in-law, Loren and Andrea Renfrow, and my mother-in-law, Edie Franklin Grant, for their support during these two years. The sacrifices you made and the love you have shown me are humbling.

I am extremely grateful to my mentors, Dr. Vail, Dr. Spolnik, and Dr. Legan for their sincere dedication to education. The sacrifices you guys make on a daily basis to the Department of Endodontics at Indiana University are immeasurable. You are always so giving with your time and wisdom. I would also like to thank Dr. Adams, Dr. Deardorf, Dr. Hine, Dr. Steffel, Dr. Leddy, Dr. Higgins, and Dr. Pfotenhauer for their tireless dedication. This program would not be what it is today without your support. I would like to extend a special thank-you to Dr. Paul Sahni for his sincere friendship and constant challenges to become a better clinician. Your energy and excitement for our specialty is contagious. I would also like to thank Diane, Elaine, Steve, Linda, Jenny, Amy, Renee, Sabrina, and the rest of the department staff for tolerating me and making our clinic the best graduate department in the entire school. You guys rock!

Lastly, I would like to thank Dr. Cecil Brown for the opportunity to train at Indiana University. Though we no longer get to see you on a daily basis, your presence is still felt and many of your traditions continue in our department.

TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

INTRODUCTION

The removal of all tissue, vital or necrotic, microorganisms, and microbial by-products from the root canal system is the goal of endodontic therapy. Effective debridement of all of the areas of the root canal system can be extremely difficult to achieve. The intricate nature of canal anatomy, made up of root irregularities, isthmuses, webs, fins and anastomoses, can lead to residual tissue and debris present in the canals after chemo-mechanical instrumentation.[1-9] Removal of debris and microorganisms is further facilitated by the flushing action of irrigation solution.[1-8, 10-12] However, the effectiveness of syringe irrigation is influenced by the aforementioned canal irregularities.

Research conducted *in vivo* has failed to demonstrate total elimination of the microbial population after traditional instrumentation and irrigation procedures in infected canals.[13-19] Dalton et al.[13] showed that only 28 percent of all canals could be rendered bacteria-free after rotary instrumentation and irrigation with sterile saline. After nickel-titanium rotary instrumentation and irrigation with 1.25-percent sodium hypochlorite, Shuping et al.[15] were only able to achieve negative cultures in 62 percent of teeth. These percentages can be attributed to the complexity of canal anatomy. Therefore, improving the antibacterial efficacy of our current endodontic instrumentation techniques and procedures is essential.

A possible solution to the problem of effective debridement and disinfection of the root canal system is through the use of ultrasonics.[20] As an adjunct to chemo-mechanical cleaning and shaping of the root canal system, ultrasonic activation of irrigation solutions and instruments have become very popular.[1-8, 21, 22] Studies have shown that ultrasonic activation of irrigation solutions in the root canal system can increase canal and isthmus cleanliness.[23-28] The theory behind the mechanism of action is that of acoustic streaming.[23] When placed passively in a canal, acoustic streaming via ultrasonic activation has been shown to produce enough shear force to dislodge debris from canal walls.[23] Residual canal debris is more effectively removed via ultrasonic instrumentation when compared with conventional instrumentation techniques. Clinically, removal of the smear layer and disruption of bacteria biofilms should be a goal with any practitioner's disinfection protocol.

Recently, two new devices have been introduced that aim to improve clinical outcomes and increase endodontic success via activation of canal irrigation solution. The manufacturer of the EndoActivator system (Dentsply Tulsa Dental, Tulsa, OK) claims, "a significant advancement in disinfection and improves debridement and the disruption of the smear layer and biofilm." The Ultrasonic Bypass system (Vista Dental, Racine, WI) "allows for the controlled delivery of sodium hypochlorite which…. significantly increases cleanliness and improves the ability to clean and debride fins and isthmuses." A review of the literature revealed no studies that have compared the effectiveness of these two devices. Therefore, the purpose of this investigation is to compare the debridement efficacy of the EndoActivator system versus the Ultrasonic Bypass system following hand-rotary instrumentation via scanning electron microscopy.

REVIEW OF LITERATURE

Dr. Harry Johnston of Atlanta, Georgia, is credited with coining the term endodontics in 1928. He combined the Greek words "en" meaning in or within, and the "odous" meaning tooth, to describe the process of working within the tooth. Dr. Johnston also has been identified as the first clinician to limit his practice to endodontics.[29] However, the "practice" of working within the tooth dates back more than 2000 years to the finding of a bronze wire inside a lateral incisor of a Nabatean warrior skull.[30]

Dental disease was first theorized by the Chinese in 1400 BC. The Chinese proposed that dental worms were present in the tooth destroying tooth structure, which led to pain. The prescription of removing the affected tooth and restoring the tooth with amalgam was initiated to relieve the pain.[31]

The toothache has plagued man since the beginning of time. Remedies have been as varied as the cultures from which they originate. Writings from as early as 1500 BC contain recipes for "curing the gnawing of the blood in the tooth."[31] From gall nut extract to roasted earthworms, to candle wax with Henbane seeds, to a mixture of camphor, sulfur, and myrrh, the treatments for odontalgia were based on the assumption of the tooth worms that caused decay.

Abulcasis, in 11th-century Persia, utilized cautery to treat toothaches by inserting a red-hot needle into the pulp. In the late 1500s, French anatomist Ambrose Paire also advocated the use of cauterization to "burn(s) the nerve, thus rendering it incapable of again feeling or causing pain." In an attempt to kill the tooth worms, Johann Stephan

Strabelberger utilized vitriol oil and a frog cooked in vinegar as remedies. In 1728 Pierre Fauchard, the founder of modern dentistry, advocated a twice-daily rinse with one's own urine to relieve the symptoms of a toothache.[31] Fauchard also described a technique that included placing lead foil into the pulp chamber after establishing drainage.[32]

Longbotham recommended filling the roots of teeth that were to be extracted in 1802. However, Edward Hudson in 1809 was the first to actually perform this procedure via gold foil as an obturating material. Clinicians now venturing into the canals of teeth led to the development of new instruments. Made from a filed down watch spring, Edwin Maynard created the first root canal broach in 1838.[33] The first known form of isolation of the offending tooth to be treated can be traced back to S.C. Barnum in 1864. For improved asepsis, he recommended the use of a thin rubber sheet over the tooth. This technique of isolation was advanced in 1873 with the advent of the rubber dam clamp by Bowman.[34] These early innovations led to the adoption of rubber dam isolation as the standard of care in endodontics both to control contamination and for the increased patient safety.

The first known use of gutta-percha as a filling material dates back to Edwin Truman in 1847. In this same year, Hill also advocated filling the root canal system with a concoction of feldspar, lime, powdered glass, gutta-percha, and metal knows as "Hill's Stopping."[32, 34] Bowman also popularized the use of gutta-percha as the sole obturating material, and in 1883 introduced a solution of chloroform and gutta percha.[31]

The last two decades of the 19th century witnessed many advances in diagnosis and pain control in dentistry. The development of the ability to record radiographs in 1895 by Wilhelm Roentgen and local anesthetics to provide painless dentistry were two monumental advancements.[32] By the early 20th century, the first commercially available x-ray machines were introduced enabling clinicians to visualize the root canal system before, during, and after the procedure. Kells in 1899 was a pioneer in using radiographs for their diagnostic value and to assess root canal obturation.[31, 32]

The advancement and acceptance of endodontic therapy encountered many challenges during the first decades of the 20th century. The most daunting challenge came from the theory of focal infection as described by E.C. Rosenow in 1909. This theory stated that a localized or generalized infection could result due to bacteria traveling through the blood stream from a distant site of infection.[31] Dr. Rosenow used earlier case reports from his mentor, F. Billings, in which many different types of afflictions were cured by dental extractions. A severe blow to the legitimacy of endodontic therapy was dealt in 1910 when Sir William Hunter, a British physician, presented a lecture on sepsis and antisepsis to the faculty at McGill University. His condemnation of American dentistry's emphasis on tooth restoration over extraction culminated in his famous quote those restorations were "a veritable mausoleum of gold over a mass of sepsis." This led to the needless extraction of thousands of endodontically treated teeth during the first three decades of the 1900s. Other concepts such as "elective localization" where bacteria have an affinity for a specific body part, and "transmutation" where by bacteria spontaneously mutate into another species, were also used to support the removal of any diseased teeth. It was not until the late 1930s that the focal infection theory began to be disproven.[31] Cecil and Angeuine published one of the earliest research papers that began to erode the focal infection theory. They reported on 200 cases of rheumatoid arthritis that did not improve with tonsillectomy and dental extraction. In

1940 Reinmann[29] published a critical report raising several issues against the validity of the theory of focal infection. During the 1940s, many additional research papers and editorials by leading scientists continually refuted the theory of focal infection and advocated a return to constructive dental treatment. In 1939 Fish published a paper that theorized by removing the nidus of infection, the infection would resolve. This theory, along with later research, formed the basis of successful root canal treatment.[31]

ENDODONTIC THEORY

In 1936 Blayney[35] was able to illustrate histological specimens that were free of bacteria in properly root canal treated teeth. His statement that "the finding of a pulpless tooth in the mouth of a patient who complains of systemic disease is not prima facie evidence that the tooth is the causative factor" effectively helped to refute the focal infection theory. Throughout the 1940s and 1950s, multiple studies demonstrated the safety of endodontic procedures, and the subsequent retention of these teeth.[36]

Healey[37] in 1956, was one of the first to emphasize the importance of accurate diagnosis and judicious case selection in order to increase the success of endodontic therapy. He recommended not only adequate treatment procedures, but also the significance of the patient's systemic condition, the local conditions of the oral cavity, the skill and ability of the operator, as well as the necessity of the tooth in the arch. Sterilization of the root canal and adequate obturation of the entire root canal system were also stressed by Healey.

In 1955 Stewart[38] described three specific phases of endodontic therapy: chemo-mechanical preparation, microbial control, and obturation of the root canal. He discussed the importance of these and how each plays an important role in the healing of the supporting periodontal tissues of the tooth. Stewart was the first to illustrate how increasing the size of the canal not only removes more microbes, but also allows for an increased volume of irrigation solutions to penetrate further into the root canal system. Of the three, Stewart stressed that chemo-mechanical preparation was of the utmost significance for endodontic success.

Coolidge[39] discussed past and present concepts in endodontics. Two concepts radically changed the perspective on treating vital pulps and pulpless teeth with infected root canals. The first was living tissue can be destroyed by infection, chemical and mechanical injury. The second was that the basis for treatment must be based on sound biological principles. When mechanically cleaned teeth were shown to be free of bacteria cultures without the use of medication, the necessity of mechanical debridement was illustrated.

PULP BIOLOGY

In 1965 Kakehashi et al.[40] cemented the finding that bacteria are the causative factor in the development of pulpal pathosis. They demonstrated that surgically exposing the dental pulps in rats in a germ-free environment only led to mild pulpal inflammation and no abscess formation. These same exposures in a conventional laboratory setting exhibited abscess formation and the development of purulence in less than 10 days in all cases. Therefore, the goal of endodontic therapy should be to eliminate the source of infection and inflammation in the root canal system.

Sundquist et al.[41] in 1977 reinforced the concept that pulpal pathosis can only occur in the presence of bacteria. He found that apical periodontitis could only be demonstrated in teeth with bacteria present in canal systems, where as periapical pathosis was not present in any necrotic tooth with intact crowns in a sterile environment.

While elimination of the causative factor (bacteria) through chemo-mechanical preparation of the canal system is of the utmost importance for successful endodontic therapy, Kuttler[42] contends that proper obturation can be just as, if not more, important. He describes three properties of the ideal obturation: thoroughly filling the dentinal section of the canals, sealing the canal system at the cemento-dentinal junction, and facilitate the development of new cementum. His contention is that a hermetic seal will create an environment leading to the formation of a healthy periodontium, normal osseous structures, and an intact lamina dura that surrounds the periapical area of the tooth.

Schilder[43] stated that the goal of endodontics is the elimination of the root canal system as a source of inflammation and infection for the periapical tissues. He advocated doing this by cleaning, shaping, and finally sealing the root canal system with a three-dimensional obturation. This hermetic seal will then act as an impediment to separate the root canal system and the periapical tissues. With the root canal system now sealed from the periodontium, endodontic pathogens cannot gain access to the supporting tissues, which leads to successful endodontic therapy.

In 1967 Grossman[44] outlined 13 principles that were to be followed in every root canal procedure to achieve the highest rate of success. Grossman's tenets, as they are known, are as follows:

1) Aseptic technique and using a rubber dam for all procedures.
2) Instruments are to remain in the canal.

3) Instruments are to be placed into the canal without force.
4) The canal space should be enlarged to properly remove debris.
5) The root canal system should be continuously irrigated with an appropriate antiseptic solution.
6) All solutions should remain within the canal.
7) Fistulas do not require special treatment.
8) A negative culture should be obtained prior to obturation.
9) The canal must be hermetically sealed during obturation.
10) The obturation material should not irritate the periapical tissue.
11) Proper drainage must be established.
12) Avoid injecting directly into an area of infection.
13) Apical surgery may be required if non-surgical therapy does not result in healing.

Though there is debate among investigators regarding which aspect of endodontic therapy is most important for success; cleaning and shaping or the creation of a hermetic seal, there is little disagreement on the necessity for a good coronal seal. In 1994 Ray and Trope[45] examined over one-thousand endodontically treated teeth and correlated the quality of the endodontic therapy and the coronal restoration and how this translated into a successful endodontic outcome. They concluded that the quality of the coronal restoration was more important than the quality of the endodontic treatment when examining these teeth for the absence of apical periodontitis (API).

Yamauchi et al.[19] examined the effect of orifice plugs on the formation of apical periodontitis *in vivo*. After endodontic therapy was completed, the coronal 2 mm of gutta-percha was replaced with a dentin bonded composite resin, IRM, or left untreated. After being open to the oral environment for eight months, the authors found 89 percent of canals left untreated developed periapical inflammation. However, only 39 percent of the canals restored with an orifice plug developed apical periodontitis. These findings underscore the clinical importance of providing the most efficient coronal seal possible to prevent micro leakage. Gutta-percha and sealer alone lack the ability to do this independently.

SUCCESS OF ENDODONTIC THERAPY

Imperative to the practice of endodontics is the clinician's ability to speak intelligently concerning the potential outcomes of initial treatment, retreatment, and surgical endodontic therapy. Many studies exist that examine success and failure rates among these different treatment modalities. Outcomes have classically been studied using clinical signs and symptoms, radiographic interpretation, and evaluation of excised tissue histopathologically.[46] The definition of success should be correlated with the goals of the prescribed therapy, such as healing of or prevention of apical periodontitis, and/or retention of a functional, asymptomatic tooth.

In 1987 Matsumoto[47] investigated factors affecting the successful prognosis of root canal treatment. He found no differences in the healing potential of teeth obturated with positive cultures at the time of obturation versus those with negative canal cultures at the same time. He did find the following factors led to an increase in the incidence of failure: periapical rarefactions, occlusal trauma, lone standing or teeth with only one adjacent tooth.

In 1990 Sjogren[48] further examined factors affecting long-term results of endodontic treatment. He evaluated 356 teeth eight to ten years after the completion of root canal therapy. His findings suggested that the preoperative status of the pulp is a direct determinant of success. Teeth with vital or non-vital pulps and no periapical radiolucency were successful over 96 percent of the time, where as teeth with necrotic pulps and periapical radiolucencies healed only 86 percent of the time. The lowest success rates were witnessed in previously treated teeth with periapical lesions. These teeth healed only 62 percent of the time after retreatment. The overall success rate for non-surgical endodontic therapy was 91 percent.

Krekis and Tronstad[49] evaluated endodontic treatment performed by dental students using a standardized technique. Five-hundred one roots were examined at post-operative intervals ranging from six months to five years and found an adequate coronal seal was present 97 percent of the time. Interestingly, the overall success rate was also 97 percent. This reinforces the earlier claim from Trope[45] that the coronal seal may be the most significant determining factor in success rates for non-surgical endodontic therapy.

Lazarski[46] conducted an epidemiological evaluation of the outcome of over 110,000 non-surgically treated teeth. These were cases completed by endodontists and their referring general dentists. He found that 94.44 percent remained functional for at least 3.5 years. Teeth that were not restored after root canal therapy had a statistically significant higher incidence of undergoing extraction when compared with restored teeth.

The Washington study[29] is the earliest and one of the most extensive studies examining success rates with endodontic therapy. This study, conducted at the University of Washington, evaluated success and failure based on radiographic interpretation when comparing preoperative and follow-up radiographs. Treatment was deemed successful if there was an absence of a periapical lesion or a decrease in size of an existing lesion upon follow-up. Failures were diagnosed when a lesion was present at recall but was absent previously, or if there was no change in size of the lesion. Of the 3678 total patients, two-year recalls were available for 1229 patients and five-year recalls for 302 patients. The overall success rate was 93 percent at the five-year follow-up. The study showed that the mandibular second molar had the highest success rates, and the most commonly treated tooth was the mandibular first molar. When surgical therapy was necessary, the two-year success rate was 88 percent.

Friedman et al.[50] examined 510 teeth with follow-up periods ranging from four to six years as part of the Toronto study. He found that 86 percent of all teeth to be classified as healed. Statistical analysis identified two specific preoperative outcome predictors that had a significantly negative influence on success. These were the presence of a preoperative periapical radiolucency and the presence of multiple roots. Teeth without preoperative radiolucencies were classified as healed 93 percent of the time compared to 82 percent when a preoperative lesion was present. Single rooted teeth were categorized as healed 93 percent of the time, but multi-rooted teeth only had an 84-percent healed rate. A better outcome is expected for teeth without radiolucencies, with single roots, and without mid-treatment complications.

Salehrabi and Rotstein[51] conducted one of the largest epidemiological studies concerning outcome assessment of endodontic treatment. The authors assessed 1,462,936 teeth in 1,126,288 patients from all 50 states across the US over an eight-year period. Both general practitioners and endodontists provided treatment. Eight years after initial non-surgical endodontic therapy, 97 percent of all teeth were still present in the oral cavity. The combined incidence of these teeth needing retreatments, apical surgeries, and extractions was only 3 percent, and most often occurred within the first three years after initial therapy. Eighty-five percent of the teeth requiring extraction did not have a full coverage coronal restoration present.

ROOT CANAL ANATOMY

A thorough knowledge of tooth morphology and root canal anatomy is paramount to providing successful endodontic therapy.[52] Variability in the canal anatomy of the adult human dentition is quite common. Many factors can influence this variability, but are not limited to the following: ethnic background, age of patient, gender, and systemic medical conditions.[53] For each tooth in the permanent dentition, there exists a broad range of variation reported in the endodontic literature addressing the number of roots, number of canals in a root, shape of these canals, and the incidence of fused roots.[54-60]

Three dimensional models of the adult human dentition, like those produced by Brown and Herbranson,[61] detail the extremely complex and highly variable root canal anatomy that exists in permanent teeth. Understanding this variability and recognizing the specific patterns that are common to particular roots can aid the clinician in providing more successful endodontic therapy. Much clinical and laboratory research has been carried out detailing these complexities.

Hess[62] was the first to detail the complex anatomy present within the human root canal system. This research clearly illustrated the complexity of canals and gave evidence to disprove, previous claims about the simplicity of canal anatomy. Additional studies by Pineda[52] and Skidmore[63] revealed the presence of roots containing multiple canals, fins, deltas, anastomoses, deltas, webs, inter-canal communications, lateral canals, accessory canals, and "C" shaped configurations. Understanding that this type of anatomy is more often the rule rather than the exception and developing fundamentally sound techniques for preparation and obturation.[64] Application of this knowledge and understanding to clinical care is fundamental to providing the highest quality endodontic treatment.

Weine et al.[65] in 1969 provided the first classification system for a single root having more than one canal. He utilized the mesiobuccal root of a maxillary first molar for his discussion. After sectioning the mesiobuccal roots of 208 maxillary first molars, he found the following results: one hundred one (48.5 percent) had one canal; 78 (37.5 percent) showed two canals that merged toward a single apical portal of exit, and 29 (14.0 percent) showed evidence of two separate canals from the orifice to the apical foramen.

A component of this complex apical anatomy relates to the true anatomic terminus of the canal in relation to the radiographic apex of the tooth. Levy and Glatt[66] investigated how often these two characteristics differ in 122 specimens. They found that nearly 65 percent of the time the clinical terminus of the canal did not coincide with the radiographic apex of the tooth. Thirty-three percent of the time the samples exhibited mesial or distal deviations when viewed from the buccal or lingual. These findings illustrate the significant deviations that occur, and are why they recommended obturating the canal slightly shy of the radiographic apex, due to the curvature in the buccolingual direction that cannot be appreciated on radiographs.

Pineda and Kuttler[52] studied over 7200 root canals and found nearly 97 percent were not in fact straight when viewed from the buccolingual and mesiodistal. The foramen of the main canal systems was located to one side of the true clinical apex of the root in 83 percent of the cases. This distance could range from tenths of a millimeter to as much as 3 millimeters. They also noted that the terminal one-third of the canal was often smaller in the mesiodistal dimension when compared to the buccolingual dimension.

Vertucci[67] in 1984 studied 2400 permanent extracted teeth and developed a classification system detailing the number of root canals and their different types, the ramifications off of the main canal, approximate location of the apical foramina and anastomoses, and the incidence of apical deltas. This classification system has provided the framework from which other systems have developed detailing the complexities of the root canal system (#10 and #60 from Ingle chapter 6). An appreciation for the morphology of the pulp cavity and canal are paramount to providing successful endodontic therapy. Being aware of the possible existence and frequency of complex anatomy (bifurcations, trifurcation, double canals, etc.) can aid the clinician in determining etiology should a case unexpectedly fail. This knowledge will prove valuable during initial endodontic treatment, endodontic retreatment, and surgical endodontic treatment.

In 2005 Nair et al.[68] examined the *in-vivo* microbial status of the apical root canal system of human mandibular first molars with primary apical periodontitis. In this study, the mesial roots of mandibular first molars were treated with non-surgical endodontic therapy, then immediately had the apical portion of this root of each tooth removed via apical surgery. These specimens were evaluated for residual intracanal infection after instrumentation, antimicrobial irrigation, and obturation. In fourteen of the 16 samples examined, residual microbes were located in inaccessible areas of the canal system. These microbes existed as mostly biofilms in these fins, deltas, isthmuses, and accessory canals. This reinforces the complexity of the apical anatomy that can exist in the human dentition, and the need for a modality to attempt to clean these areas that are inaccessible with our traditional instrumentation procedures.

INSTRUMENTATION

Instruments utilized in root canal preparation are extremely varied. Both hand and rotary instruments are available to the clinician for use. Stainless steel and nickel-titanium are the materials that comprise the overwhelming majority of endodontic instruments, and a thorough understanding of how these instruments function, the risks/benefits in utilizing each type of instrument, and when to replace these instruments is paramount to successful non-surgical endodontic therapy.[69]

Preparation techniques utilizing endodontic instruments include the following:

1. Manual preparation – The use of broaches, files, and reamers by hand.

2. Automated preparation with stainless steel instruments – Use of an engine-driven slow-speed handpiece with Peeso reamers and Gates Glidden drills

3. Automated preparation with nickel-titanium instruments – The use of an electronic handpiece that rotates these files at a programmed torque and speed setting.

4. Ultrasonic preparation – The use of endodontic ultrasonic instruments to remove canal blockages, obstructions, and debris.

In 1974, Schilder[70] recommended five components that each endodontic instrument should be able to create inside a canal. They are as follows:

1) The root canal should have continuous taper.
2) The cross-sectional diameter of the canal should be smaller at every point as you progress apically.
3) The root canal preparation should follow the shape of the original canal.
4) The apical foramen should remain in its original position.
5) The apical foramen should be kept as small as practical.

Achieving these goals through thorough instrumentation is an extremely vital aspect of endodontic therapy. Schilder also concluded that shaping should be carried out in relation to the obturation technique, as well as with respect to the unique anatomy of each canal.[69] Schilder also stated instrumentation should allow for complete removal of all tissue from the canal space, not force debris beyond the apex, stay inside the canal, and create sufficient space for intra-canal medicaments.[70]

The ISO (International Standards Organization) began standardizing endodontic instruments and obturation materials in 1959.[53] This system defined specific formulas for diameter and taper, standardized the increase in size from one instrument to the next, and developed a numbering system based on metric diameters. Today, ISO instruments are now universal in these areas, therefore eliminating any confusion or variability across different instruments.

K-type files[71] and Hedstrom (H-type) files[55, 72] are the most commonly used hand files during endodontic therapy. K-type files have been utilized the longest in endodontic therapy. These instruments were historically created by grinding round stainless steel wire of various sizes into different shapes (circular, square, rhomboid, or triangular). Then these instruments are ground to their proper taper, and then twisted counterclockwise a specific number of times based on the specific file type. These files are very good when used to locate and enlarge canals. They can be used in either a filing or reaming motion, and will tend to stay centered in the canal. However, due to the standardized .02 taper, these files, when used alone, will tend to create narrow preparations, thus decreasing the efficacy of irrigation protocols.[71] Hedstrom files are created from circular stainless steel wire. Its design allows this file to be very efficient when used in a "pull" or translational motion on the outstroke out of the canal. This allows for the planning of the dentinal walls, removing any overhangs or other canal irregularities that may impede effective cleaning and shaping. These files are much more aggressive in the amount of dentin removal when compared to the K-files, and special attention should be paid when using these files so as not to remove excess dentin. This could result in thin radicular walls and possible strip perforation.[55, 72]

Gates Glidden drills, introduced over 100 years ago, are engine driven instruments that allow for very efficient coronal to mid-root enlargement. They are manufactured in different numbered sizes, from one to six, with corresponding diameters ranging from 0.5 mm to 1.5 mm. These instruments have long, thin parallel shafts with a small cutting head. They can be used in a "crown-down" or "step-back" technique, and cut on the outstroke when removed from the canal. These instruments are very efficient and can lead to excessive dentin removal and strip perforation. Care must be taken not to exert excessive pressure on these instruments, or insertion them into a canal at an incorrect angle. When used properly, they are a very safe, effective, and beneficial addition to the endodontic armamentarium.[29, 72]

Endodontic instruments constructed from nickel-titanium have undoubtedly changed the practice of endodontics over the last 15+ years. Endodontic files constructed of nickel-titanium are more flexible, can more efficiently negotiate canal curvatures, wear less, and resist fracture better when compared to stainless steel files because of the metal's super elasticity. This property allows the metal to return to its original shape after significant deformation during use.[69]

Himel[73] in 1995 compared instrumentation of curved canals in plastic blocks with stainless steel instruments and nickel-titanium hand files. He found that apical transportation occurred less often with ni-ti files. Ni-Ti files produced no apical ledging as compared to nearly 31-percent ledging when stainless steel files were used. Also, working length was more accurately maintained in the ni-ti groups, and canal wall stripping was almost non-existent as well.

In 1995 Esposito and Cunningham[74] examined the ability of K-flex stainless steel files, ni-ti hand and rotary files to maintain the original shape of the canal during instrumentation. Ni-Ti hand and rotary files were found to maintain the original canal path significantly more often than stainless steel hand files. As stainless steel files increased in size, the amount of deviation from the original canal path increased. In curved canals enlarged beyond a size 30 file, ni-ti files were significantly more effecting in maintaining the original canal path as well.

IRRIGATION

Utilizing irrigation solutions is an integral component in achieving successful non-surgical root canal therapy via chemo-mechanical preparation.[75] Irrigating solutions allow for more efficient removal of pulpal tissue and dentin debris during endodontic therapy, as well as the elimination of bacteria. Also, the packing of infected tissue into the apical extent of the canal, or out into the periapical areas, can be prevented by utilizing irrigation solutions.

Many different irrigation solutions have been utilized during the history of endodontic treatment. Until World War II, the most commonly used solution was water. It was readily available, very inexpensive, and provided the canal with lubrication. Chelating agents and weak acids have also been utilized as irrigating solutions due to their capacity to make canal instrumentation more efficient and soften dentin. Other solutions utilized in modern endodontic therapy include sodium hypochlorite (NaOCl), ethylenediaminetetraacetic acid (EDTA), chlorhexidine (CHX), and (MTAD) Mixture of tetracycline, acid, and detergent. Each of these solutions have proven effective at decreasing the microbiota when utilized in different phases of nonsurgical therapy.[76]

For nearly seventy years, NaOCl has been utilized as an irrigating solution and is considered the standard for modern endodontic therapy. It is antimicrobial, helps to lubricate the canals, is relatively inexpensive, has an extended shelf life, dissolves organic tissue, increases dentin tubule permeability, and can whiten discolored teeth. The most common concentration used today is 6 percent, and the solution has shown increased effectiveness when heated, activated with sonic and ultrasonic instruments, or when utilized with a high volume final flush.[76] When NaOCl is introduced into the canal, it begins to ionize and produce hypochlorous (HOCl). It is this component of NaOCl that is responsible for bacterial inactivation. Hypochloric acid has been found to dissolve human tissue, disrupt oxidative phosphorylation, destroy cell membranes, and halt DNA synthesis.[77-79]

Varying concentrations of NaOCl have been utilized in endodontic therapy, ranging from 0.5 percent to 6.0 percent. It is most widely recognized for its antimicrobial properties. Long known as a strong antibacterial agent, NaOCl has also shown to be effective in killing resistant organisms, such as *Candida Albicans*.[80] Radcliffe et al.[81] demonstrated the high susceptibility of *C. Albicans* to NaOCl.

Higher concentrations of NaOCl have proven to be more efficient and effective at killing microorganisms. Vianna et al.[82] in their study demonstrated that a concentration of 0.5-percent NaOCl required 30 minutes to kill *C. Albicans*, whereas a concentration of 5.25 percent killed all yeast cells in less than 20 seconds. He also showed the effectiveness of NaOCl against three Gram-negative anaerobic rods typically isolated in cases of apical periodontitis: *Porphyromonas gingivalis, P. endodontalis, and Provotella intermedia*. All were highly susceptible to NaOCl, with all three species being killed within 15 seconds.

There are some microorganisms proving to be somewhat resistant to NaOCl irrigation alone. Gomes et al.[83] performed an *in-vitro* test to evaluate NaOCl's ability to kill *Enterococcus faecalis*. Over 30 seconds was required for 5.25-percent NaOCl to kill *E. faecalis*, while it took over 10 and 30 minutes to completely kill the bacteria with concentrations of 2.5 percent and 0.5 percent respectively. Radcliffe[81] also confirmed this higher resistance of *E. faecalis* to NaOCl.

Correlating the results of *in-vitro* studies that prove to be similar to *in vivo* can be challenging, due to the inherent disadvantages that accompany *in-vitro* testing. These include the following: high volume of the irrigation solution available to kill microbes, direct access to all microorganisms, and the absence of any other material that could provide protection for the bacteria.[14] Many authors have examined if this increase in the concentration of NaOCl leads to more efficient microbial elimination *in vivo*. Both Bystrom and Sundquist[84, 85] examined the effects of varying concentrations of NaOCl compared to saline in eradicating a mixed anaerobic bacterial flora. Although both found that a concentration as low as 0.5-percent NaOCl improved the antibacterial effectiveness of canal preparation, total elimination of bacteria could not be achieved, even after multiple appointments.

Siqueira et al.[18] also examined the difference in bacterial elimination of NaOCl compared to saline. Their results were similar to Bystrom and Sundquist in that NaOCl performed better than saline; however, no difference in efficacy could be detected when comparing 0.5-percent, 2.5-percent, and 5-percent NaOCl.

While killing bacteria and dissolving tissue quite effectively, NaOCl has been criticized for several negative side effects that it does possess. NaOCl is extremely caustic, has an unpleasant taste, does not remove the smear layer, and can prove toxic when it comes into contact with tissue outside the root canal system.[3, 86, 87] NaOCl's lack of effectiveness *in vivo* when compared to *in-vitro* studies is most likely due to the complexity of root canal anatomy, especially in the apical region of a canal. NaOCl's effectiveness can also be affected by other substances found in a canal. Haapasalo[88] examined the effect that dentin powder would have on NaOCl's property to kill *E.*

faecalis. He found that the presence of dentin delayed the ability of NaOCl to effectively kill *E. faecalis*, regardless of the concentration. Marcinkiewicz et al.[89] also found that nitrites prevented effective killing of bacteria by NaOCl.

Luebke[90] in 1967 provided a detailed summation on the processes of disinfection and debridement in the root canal system. Ideal conditions exist for proliferation of microbiota inside a necrotic root canal system. He showed that these sources of sustenance and protection are removed from the bacteria when the bulk of the tissue is removed during chemo-mechanical preparation. Though complete sterilization of the root canal system is not possible, proper debridement of the canal can lead to success.

The use of chlorhexidine glaciate has increased in popularity due to its outstanding antimicrobial activity and substantivity.[91-93] When compared to NaOCl, its use as an irrigation solution and intra-canal medicament can be attributed to the following characteristics: 1) It is not as irritating to the periapical tissues; 2) It does not have a bad smell; 3) It does not cause spotting on patient's clothes. However, chlorhexidine gluconate lacks any tissue dissolving properties, which is an important rationale for the use of NaOCl.

Chlorhexidine has proven effective against Gram-positive and Gram-negative bacteria, as well as yeasts and fungi. It is most effective against Gram-positive bacteria, however its efficacy is dependent upon the pH and is greatly diminished in the presence of organic material.[92] Chlorhexidine can cross the peptidoglycan layer in both Gram-positive and Gram-negative bacteria. Once inside the microbe, it invades the bacteria cytoplasm. In yeasts, chlorhexidine is able to penetrate the inner plasma membrane. Chlorhexidine will cause coagulation of the intracellular components of the microorganism and lead to their death.[78] Another attractive property of chlorhexidine is in its substantivity (long-term effectiveness) even after the irrigation solution has been removed from the canal.

Many studies have described the differences in the property of chlorhexidine to kill certain microorganisms that have proven more resistant to NaOCl. Of particular interest is its property to kill *E. faecalis*. This Gram-negative bacterium has been found to exist in many cases of refractory apical periodontitis.[18] Gomes[83] in 2001 demonstrated that a solution of chlorhexidine ranging from 0.12 percent to 2.0 percent killed *E. faecalis* in 30 seconds or less, where as a solution of NaOCl (4 percent or less) took up to 30 minutes for complete killing of the bacteria. These same findings were supported by Vianna[82] and Oncag.[82, 94]

Waltimo[95] in 1999, illustrated the antifungal effectiveness of chlorhexidine. The property of chlorhexidine to attack the inner membrane of the yeast plasma membrane has also been demonstrated by other studies ([50, 95-97] from Ingle).[80, 96-98] Chlorhexidine, when used alone and not mixed, was also found to be more effective at killing other fungi when compared to combining other disinfectants.

Combining chlorhexidine and NaOCl has been proposed as a method to simplify the clinical work required and reap the benefits of both solutions. Unfortunately, chlorhexidine and NaOCl are not soluble in each other and an orange-brown precipitate forms, known as PCA (para-chloroanaline).[99] Basrani[99] in 2007 showed that PCA is toxic to human tissues. The primary consequence of PCA is met hemoglobin formation, resulting in cyanosis. Other possible side effects include, but are not limited to, hemolytic anemia, extra-medullary hematopoiesis, splenomegaly, erythrocyte toxicity, and regenerative anemia. PCA has also shown to have carcinogenic properties, potentially increasing the incidence of conditions such as hepatocellular carcinomas and hemangiosarcomas of the spleen. Because of these findings, it is advisable to wash away any remaining NaOCl with alcohol or EDTA prior to using chlorhexidine.

Chlorhexidine has additional disadvantages when compared to NaOCl. It is unable to dissolve organic debris, including pulpal tissue and actually has its efficacy decreased in the presence of organic matter.[92] Clegg[100] in 2006, demonstrated that chlorhexidine was unable to affect the structure of biofilms, while NaOCl was shown to completely remove them. Although chlorhexidine was shown to kill all bacteria, this biofilm structure can still express antigenic properties, causing an immune response in the periapical tissues.

Despite these limitations, this is significant evidence that a 2-percent chlorhexidine gluconate solution is a good adjunct to use during non-surgical root canal therapy, however it cannot replace the use of NaOCl. Additional research is needed to verify the optimal sequence of irrigation solutions for different case types. This will aid clinicians in providing the most effective treatment in eliminating endodontic infections.

Iodine containing compounds are among the most commonly used and oldest disinfectants available. They are most commonly utilized as surface and skin disinfectants, as well as prior to surgery. Iodine has proven to be much less caustic to human tissue; however, it rapidly kills bacteria, viruses, fungi, and spores.[101] I_2 is the active antimicrobial component in iodine and rapidly penetrates into the microorganisms attacking proteins and nucleotides leading to cell death.

Peciuliene[102] in 2001 evaluated the overall effectiveness of irrigation with iodine in 20 teeth that had a diagnosis of previous treatment with apical periodontitis. After removing the previous obturation material, samples were taken of the canal and bacterial culturing was performed. The results indicated that the use of iodine potassium iodide (IPI) produced an increased number of negative canal cultures after normal chemo-mechanical preparation.

Molande[103] in 1999 investigated the antimicrobial effect of calcium hydroxide in root canals pretreated with 5-percent IPI. The hypothesis was that IPI would allow for an increase in the antimicrobial effect of calcium hydroxide. He found that IPI had no effect on the overall power of calcium hydroxide. However, the possibility does exist that IPI could reduce the number of strains of *E. faecalis.*

Unfortunately, several studies have indicated that iodine compounds are rendered ineffective when they come in contact with dentin. Haapasalo[88] in 2000, studied the interaction of IPI with the physical and chemical environment of necrotic root canals. He found that IPI is completely inactivated by the dentin matrix, which is predominately collagen. This same finding was also supported by Portenier[104] in 2001, which achieved similar results. These findings illustrate the ineffectiveness of IPI to be utilized as an irrigating solution in non-surgical endodontic therapy.

MTAD (a mixture of tetracycline, acid, and detergent) is a combination irrigation solution that has recently been introduced for endodontic. Torabinejad[105, 106] in 2003 described the potential benefits of utilizing MTAD. Because it has a low pH (2.15) MTAD is able to remove the smear layer and also has bactericidal effects against endodontic pathogens. MTAD also has been touted as being “gentler” on dentin when compared to EDTA, and less catatonic than 5.25-percent NaOCl.[107] Irrigating with MTAD is used as a final step prior to obturation after cleaning and shaping has been accomplished with sodium hypochlorite in the canals.

Due to the high concentration of tetracycline, the antibacterial activity of MTAD has been researched thoroughly. Shabahang[108] in 2003, examined the *in-vitro* antimicrobial efficacy of MTAD. In this study, extracted teeth were contaminated with *E. faecalis* or whole saliva, and the antibacterial effects of MTAD were measured. MTAD was shown to have very good antimicrobial effects. Another study by Shaba hang and Torabinejad[109] revealed MTAD exhibited a greater antimicrobial effect when compared to 5.25-percent NaOCl. Portended in 2006 investigated *in-vitro* Mad's property to kill *E. faecalis* and found in less than five minutes all of the bacteria were killed by MTAD.

Conversely, several studies have shown either no difference in the antibacterial efficacy of MTAD when compared with NaOCl, or they have shown MTAD to be less effective. Cho and Baumgartner[110] performed an *in-vitro* comparison of the antimicrobial effectiveness of NaOCl/EDTA and NaOCl/MTAD. Extracted roots were infected for with *E. faecalis* for four weeks, chemo mechanically prepared and irrigated, and examined for viable bacteria. They found no difference between the two irrigation regimens.

An additional study by Baumgartner[111] et al. in 2007, examined 26 matched pairs of teeth comparing the same irrigation protocols. In this study, the regimen of NaOCl/EDTA produced 0/20 positive bacterial cultures, while the NaOCl/MTAD mixture produced 8/20 and 10/20 positive culture samples when sampled directly after irrigation, and after incrementing the canals two instrument sizes wider. Johla[111] in 2007 also compared the antimicrobial efficacy of NaOCl/MTAD to NaOCl/EDTA and found the NaOCl/EDTA regimen significantly reduced the levels of microbes inside the canals of extracted molars. Zero samples exhibited bacterial growth in this group, while 40 percent of the samples from the NaOCl/MTAD group exhibited positive bacterial growth.

ULTRASONIC ACTIVATION OF IRRIGATION SOLUTIONS

Ultrasonic's have been utilized for over one hundred years in dentistry. The utilization of ultrasonic energy to facilitate canal cleanliness and disinfection has a long history in endodontic. Richman[112] in 1957 was the first to introduce ultrasonic's into root canal therapy. Since then, many studies have compared the property of ultrasonic's to remove debris, decrease the microbiota present inside an infected canal, remove smear layer, and allow for more efficient penetration of irrigation solutions into dentinal tubules.

Two different mechanisms of ultrasonic irrigation have been described in endodontic literature. The first entails a combination of ultrasonic irrigation and instrumentation occurring simultaneously. This is known as ultrasonic irrigation (UI). UI occurs when the canal walls are intentionally contacted with the file while irrigation solution is concurrently delivered into the canal. The second method operates without the concurrent active instrumentation of the canal walls and is known as passive ultrasonic irrigation (PUI). This occurs when an activated instrument is allowed to oscillate freely inside a canal, with no attempts to contact, plane, or file the canal walls.[22]

Many early studies compared the effectiveness of hand instrumentation alone and with the addition of ultrasonics. Weller[9] in 1980, studied this by comparing the debridement efficacy in resin blocks containing simulated root canal spaces. The canal spaces were filled with a gelatin laced with a radioisotope, prepared using hand instruments and ultrasonics alone, and then measured for loss of radioactivity. No significant difference in canal debridement was noted between these two techniques. However, when ultrasonication followed hand instrumentation, the canal spaces had significantly less radioactivity, illustrating increased canal debridement.

In 1985 Goodman et al.[1] compared the efficacy of a step-back technique versus a step-back/ultrasonic technique in human mandibular molars. This *in-vitro* study examined 60 extracted human mandibular molars for canal and isthmus cleanliness. The authors found that the step-back/ultrasound preparation yielded significantly cleaner canal isthmuses at 1 mm and 3 mm from the apex when compared to the step-back technique alone and the control.

These initial studies on UI focused on the use of an ultrasonic unit designed by Martin[113] that became commercially available for use in 1980. Martin and Cunningham[114-118] completed several *in-vitro* studies utilizing this device. Each study continually showed that teeth prepared ultrasonically with this device produced significantly cleaner canals and more efficient removal of the smear layer was also found.

Cameron[119] in 1983, also examined the removal of smear layer using ultrasonics. Thirty-five extracted human instrumented with traditional endodontic cleaning and shaping techniques, then subjected to ultrasonic activation of 3-percent sodium hypochlorite for intervals of 1, 3, and 5 minutes were compared. These teeth were examined under a scanning electron microscope (SEM) for smear layer removal. The results showed that each increasing time interval removed more of the smear layer until it was virtually non-existent after 5 minutes of UI.

Nevertheless, other studies have failed to confirm the observations of earlier studies supporting the superiority of UI as a primary debridement technique. Reynolds et al.[120] examined the effectiveness of the step-back, sonic, and ultrasonic instrumentation techniques in small, curved root canals. Eighty canals were examined histologically for remaining dentin and predentin after the different canal preparation techniques were employed. When the coronal, middle, and apical regions were examined, no statistically significant differences were found.

Walker and del Rio[121] in 1989, performed a histological evaluation of 50 extracted human first and second lower molars. After routine endodontic access and length determination were accomplished, half of the mesial canals were treated with sonic or ultrasonic instrumentation techniques, and the other mesial canals were prepared with traditional instrumentation techniques. When examined histologically, there was no statistically significant difference among the groups when comparing dentin removal and soft tissue debridement.

In 1987 Ahmad[122] provided an insight into the mechanisms of action involved with ultrasonic debridement of root canals, and to explore the inconsistent results of these techniques. He explored two distinct processes, cavitation and acoustic streaming, and how they impact and influence canal debridement. Cavitation is the growth and collapse of small, gas-filled bubbles. Acoustic streaming is defined as the rapid movement of particles of a fluid in a vortex-like motion around a vibrating object. The results of this study suggested that minimal if any cavitation occurred during UI, thereby minimizing the significance of cavitation in canal debridement. Acoustic streaming, however, was shown to actually occur and this mechanism was presumed to be more relevant to the production of canal cleanliness associated with UI.

Several studies have also reported on significant canal alternations that can occur when utilizing ultrasonically activated K-type files.[69] These unsatisfactory results include frequent canal zipping, canal straightening, and strip perforation. Because of this, clinicians should take care not to allow the ultrasonic instrument to touch the canal walls upon introduction into and activation of the instrument into the canal.[22, 121]

More contemporary research has focused on the efficacy of PUI in the role of canal cleanliness and debridement. Gutarts et al.[11] in 2005 histologically compared the *in-vivo* debridement efficacy of hand/rotary canal preparation versus a hand/rotary/ultrasound technique in mesial root canals of vital mandibular molars. For the ultrasound technique, an ultrasonic needle in a mini-endo unit was activated for one minute in the canals. When examined histologically at every 0.2 mm from 1 mm to 3 mm from the apex, the canal walls and isthmuses were statistically significantly cleaner at all levels in the ultrasound group when compared to hand/rotary instrumentation alone.

In 2007 Carver et al.[123] examined the antibacterial efficacy of ultrasound after hand rotary instrumentation in necrotic mandibular molars. Canals were sampled for bacteria before and after hand/rotary instrumentation, and after 1 minute of ultrasonic irrigation per canal. Samples were incubated for seven days and evaluated for the number of colony forming units (CFUs). A significant reduction in positive cultures and CFUs were noted with the addition of the ultrasonic activation of the irrigation solution.

Statistical analysis revealed that the addition of the ultrasonic activation resulted in a seven-fold decrease in the number of positive cultures when compared to hand/rotary instrumentation alone.

Burleson et al.[124] in 2007 examined histologically necrotic mandibular molars after hand/rotary and hand/rotary/ultrasound instrumentation. These teeth were treated *in vivo*, extracted, and then sectioned in 0.2-mm segments from 1 mm to 3 mm from the apex. They were then examined for canal cleanliness. The results of this study revealed canal and isthmus cleanliness to be statistically significantly higher for hand/rotary/ultrasound instrumentation at all levels.

SONIC ACTIVATION OF IRRIGATION SOLUTIONS

Tronstad et al.[125] in 1985 were the first to detail the use of sonic instrumentation for endodontics. Three main differences exist between sonic and ultrasonic irrigation. The first is the frequency of operation of these two distinct patterns of activation. Sonic irrigation functions at frequencies lower then 20,000 cycles per minute (CPM), whereas ultrasonic activation occurs above 20,000 cycles per minute. The second difference is that sonic activation produces smaller shear stresses when compared to ultrasonic activation.[23] Finally, sonic energy produces significantly higher amplitudes resulting in greater back-and-forth movement of the tip of the instrument. This type of vibration has proven very efficient for root canal debridement[27] and has shown to be unaffected when the movement of the file is constrained.

Initially, sonic irrigation was performed utilizing a Ripisonic file attached to a sonic handpiece after final cleaning and shaping. These files had a non-uniform taper and were barbed, thereby increasing unintentional damage to canal walls and altering the final preparation of the canal.[126] Recently, a device called the EndoActivator System (Dentsply Tulsa Dental Specialties, Tulsa, OK) was introduced. This device sonically activates irrigation solutions inside canals. This device utilizes disposable polymer tips attached to a battery powered portable handpiece. The handpiece has three adjustable frequencies, 2000, 4000, and 10,000 cycles per minute, and the tips are available in 3 different sizes (15/.02, 25/.04, 35/.04). The manufacturer claims these disposable polymer tips are strong and flexible, thereby decreasing the incidence of breakage. The tips are smooth, so they do not cut dentin, and this also eliminates the disadvantages of the Ripisonic system. The manufacturer also recommends utilizing the tip in an up and down motion while vibrating the tip at the highest speed setting (10,000 cycles per minute).

Several studies have compared the cleaning efficacy of passive sonic and passive ultrasonic activation. Jensen et al.[22] in 1999 evaluated this *in vitro* in molar root canals after hand instrumentation. In this study, curved molar canals were instrumented to a size 35 hand file, and then treated for three minutes with passive sonic and ultrasonic activation. A debris score was then calculated for each specimen based on the amount of debris remaining on canal walls after treatment. No statistically significant difference was found between the two types of activation, both were shown to yield significantly lower debris scores when compared to hand instrumentation alone.

These findings have been supported in other studies. Cunningham and Martin and Stamos[115, 127] detailed the impressions of clinicians utilizing an endosonic unit (Cavi-Endo) for nearly one year at Marquette University. During this time, the Endosonic unit was used primarily for preflaring canals, canal preparation, pathfinding, and the removal of foreign obstructions, silver points, and posts. The general consensus among the clinicians utilizing the device was that sonic activation is a valuable endodontic tool and has a myriad of uses.

Sabins[128] in 2003, compared the cleaning efficacy of short-term sonic and ultrasonic passive irrigation after hand instrumentation in curved canals of molar root canals. This *in-vitro* study was similar in design to the Jensen[22] study; however, activation of irrigation solutions occurred for as little as 30 seconds compared to three minutes. Debris scores were tabulated for the apical 3 mm and 6 mm and the results indicate that passive sonic and ultrasonic activation, for as little as 30 seconds, yielded debris scores significantly lower than hand instrumentation alone.

The EndoActivator system has been touted as a device that can effectively and efficiently remove the smear layer, clean debris from lateral canals, and dislodge clumps of simulated biofilm in curved molar canals.[129] This device has also been shown to produce a powerful hydrodynamic phenomenon when used in an up-and-down motion with the tip of the file vibrating.[130] A significant cloud of debris can be observed within a solution filled chamber during its use. Utilizing the tip at 10,000 cpm has been shown to disrupt smear layer, remove biofilm, and optimize debridement inside canals.[129, 130]

In 2009 de Gregorio et al.[131] examined the effects of EDTA, sonic, and ultrasonic activation on the penetration of sodium hypochlorite into lateral canals. Four-hundred eighty simulated lateral canals were created in eighty teeth at differing levels in the apical 6 mm of each root. The teeth were treated with sonic and ultrasonic activation, and evaluated for sodium hypochlorite penetration using a contrast solution. Both sonic and ultrasonic activation provided better irrigation of lateral canals at 4.5 mm and 2 mm from working length when compared to traditional needle irrigation alone. This difference was not statistically significant; however, sonic activation did allow for sodium hypochlorite to successfully penetrate more lateral canals than ultrasonic activation.

Shen et al.[132] examined the antimicrobial effect of ultrasonics and sonic activation of two distance chlorhexidine preparations on biofilm bacteria. Established, multi-species biofilms on collagen coated hydroxyapatite disks were subjected for 1 minute and 3 minutes to 2-percent chlorhexidine with and without ultrasonic and sonic activation. After treatment, the samples were examined for the amount of dead bacteria. The results of this study showed that ultrasonic or sonic activation of 2-percent chlorhexidine did not disrupt or disperse the biofilm structure; however, sonic activation did produce more dead bacteria upon analysis when compared to ultrasonic activation.

Reducing the risk of expressing sodium hypochlorite into the periapical tissues is the goal of any root canal irrigation delivery protocol. Several *in-vitro* studies have demonstrated the routine extrusion of irrigation solutions through patent canal terminations. In 2009 Desai and Van Himel[133] examined the safety of various intracanal irrigating systems. This was assessed by measuring the volume of solution extruded while using each system. Their results showed that the EndoActivator extruded statistically significantly less solution when compared to manual irrigation with a side-ported needle, passive ultrasonic activation, and the Rinse Endo (RE) system (Air Techniques Inc, New York, NY), thus decreasing the chances of an untoward sodium hypochlorite accident during clinical treatment.

SEM EVALUATION OF POST-OPERATIVE ROOT CANAL CLEANLINESS

Investigating root canal segments under a scanning electron microscope (SEM) is the standard protocol for evaluating post-operative cleanliness of root canals. Several different protocols have been utilized when evaluating results in past studies. Scoring systems evaluating the cleanliness of canals used in SEM studies range from three scores,[129, 134-137] to four scores,[23, 125, 138-140] five scores, [27, 141-144] and even up to seven scores.[145] When reviewing these previous studies, it is apparent that in a majority of cases the specimens have not been coded nor have the examiners been blinded prior to SEM evaluation. By coding the specimens and blinding the examiners, this helps to prevent the identification of the preparation technique or the instrument used.

Certain biases can occur when evaluating specimens under SEM. Magnifications utilized in previous studies are either not detailed or samples are evaluated under differing levels of magnification. When evaluating samples under higher magnifications, smaller and smaller segments of the canal walls are visible. Most SEM operators have a tendency to select the cleanest areas in a canal with open dentinal tubules, rather than recording and scoring areas with large amounts of debris present. Also, operators may adjust the magnification or change the area observed in order to obtain a cleaner image.

Specimens of extracted teeth can be sectioned horizontally and longitudinally for examination under SEM. When sectioning specimens horizontally, pulp tissue, predentin, and remaining debris can be readily evaluated and quantified. Sectioning and evaluating specimens horizontally allows for accurate investigation of canal isthmuses, fins, webs, and recesses. However, loose debris inside the canal can be lost, or excessive debris can be introduced during the sectioning process. This can lead to contamination of the specimen and inaccurate data. Evaluating root canals sectioned longitudinally allows for complete inspection of both halves of the entire root canal system. Longitudinal sectioning greatly decreases the possibility of contamination; however, lateral canals, isthmuses, and other accessory anatomy can prove difficult to identify.

MATERIALS AND METHODS

Sixty human, single-rooted, maxillary anterior teeth were collected from the Oral Health Department under IUPUI/Clarian IRB study number 0308-74. All teeth were evaluated radiographically to ensure canal curvature of less than 30˚ using Schneider's[25] method, no gross pulpal calcifications, and ensure normal anatomy. Teeth were then sterilized in 6.0-percent sodium hypochlorite for a period of two weeks prior to initiating the experimental procedures

.

ROOT CANAL PREPARATION OF GROUPS 1, 2, AND 3

Following sterilization, each tooth received an ideal access preparation (Figure 1). Working length was determined by ensuring that a new #15 stainless steel K-flex file (Dentsply Maillefer, Tulsa, OK) would pass to the apical foramen, and then subtracting 1mm from this measurement. The incisal edge of the tooth was used as the point of reference for the working length determination (Figure 2). K-flex hand files were utilized to achieve initial canal preparation. An electric motor with 1:8 reduction contra-angle handpiece at 600 rpm (AEU-20 Endodontic System, Dentsply-Tulsa Dental, Johnson City, TN) was used with the Endosequence .06 taper (Figure 3) nickel titanium rotary instruments (Brasseler, Savannah, GA). Rc Prep™ (Premier Dental Products, King of Prussia, PA) and 6-percent sodium hypochlorite was utilized for file lubrication and irrigation (Figure 4). A crown-up technique of instrumentation was used beginning with a 15/.06 EndoSequence file and all canals were finished to a size 40/.06 at working length (Figure 5) hypochlorite was utilized as the irrigation solution during instrumentation phase of each canal with 2 ml being used between each instrument. At the completion of the instrumentation phase of the experiment, smear layer removal from the canals was accomplished by irrigating each canal with 2 ml of 17-percent EDTA (ethylenediaminetetraacetic acid) for a period of 1 minute (Figure 6). Following smear layer removal, each canal was then irrigated with 6 ml of sodium hypochlorite for 2 minutes. Canals were then dried with coarse and medium sterile paper points (Figure 7).

Group 1: Control Group

The control group will consist of 20 teeth that will receive no additional treatment after hand/rotary instrumentation and irrigation with sodium hypochlorite using a slotted needle.

Group 2: Canal Preparation plus EndoActivator

Six-percent sodium hypochlorite was expressed into the canal spaces of the 20 teeth in this group with a 27-gauge slotted needle (Monojet, Sherwood Medical, St. Louis, MO) to within 1 mm to 2 mm of the working length. The EndoActivator (Figure 8) with a size large (35/.04 taper) tip was then placed to within 1 mm to 2 mm of the working length and activated for 1 minute following the manufacturers' directions. Excess irrigation solution was collected via high-speed evacuation.

Group 3: Canal Preparation plus Ultrasonic Bypass System

After instrumentation, the Ultrasonic Bypass System (Figure 9) was introduced into the canals to within 1 mm to 2 mm of the working length. This system allowed for the controlled delivery of sodium hypochlorite directly through a 30- gauge irrigating tip (Figure 10) at a rate of 5ml/min (Figure 11). Excess irrigation solution was collected via high-speed evacuation.

CANAL SECTIONING

Teeth were grooved longitudinally (Figure 12) along the buccal and lingual surfaces with a carborundum disc at medium speed. Teeth were then cleaned and dried in a dessicator (Figure13) before being split with a micro-blade and mallet (Figure 14). A scanning electron microscope was utilized to view the half with the most visible part of the apex present. Division of each sample into 3 equal parts (Figure 15) was accomplished by making small indentation grooves into the side of the root with a #15 scalpel blade. Samples were thoroughly dried and mountings made utilizing metallic stubs.

MICROSCOPIC EVALUATION

Each canal wall was evaluated in the coronal, middle, and apical thirds of the root. Each of these sections was examined using the JSM-5310 High Vacuum Scanning Electron Microscope (Figure 16). To ensure standardization of the area examined for each sample, the central beam of the SEM was directed to the center of each third of the canal space being analyzed. This distance was 9 mm (location A), 6 mm (location B), and 3 mm (location C) from the apex (Figure 17). The SEM operator did this under X50 magnification. Magnification was then increased to X1000 and the area of the canal was photographed and used for scoring. As outlined by the American Association of Endodontists in, "Contemporary Terminology for Endodontics," smear layer was defined as the following: A surface film of debris retained on dentin or other surfaces after instrumentation with either rotary instruments or endodontic files; consists of dentin particles, remnants of vital or necrotic pulp tissue, bacterial components, and retained irrigation solution. Scores for all samples were recorded according to the following system as described by Al-Hadlaq et al.[146] (Figure 18).

Score 1: Clean root canal, only few small debris particles.

Score 2: Few small isles of debris covering less than 25 percent of the root canal wall.

Score 3: Many accumulations of debris covering more than 25 percent but less than 50 percent of the root canal wall.

Score 4: More than 50 percent of the root canal wall covered by debris.

Two blinded examiners independently scored the samples. Examiners were calibrated on 20 independent specimens taken from a different study to increase both inter-examiner and intra-examiner reliability. When there was a discrepancy in the scoring of a sample, a forced consensus was reached by the two examiners. The mean scores of smear layer present in the canal spaces of the samples that receive the EndoActivator were compared with the smear layer scores recorded for the samples that received the Ultrasonic Bypass system.

STATISTICAL METHODS

Intra-examiner repeatability and inter-examiner agreement of the debris removal scores were assessed using two-way contingency tables, percent agreement, and weighted kappa statistics. Using the consensus scores separately for each of the three locations, the three methods were compared for differences in debris removal scores using a Kruskal-Wallis test, which determines if there are any differences among the three groups. If the overall test were significant, Wilcoxon Rank Sum tests were used to compare each pair of groups.

SAMPLE SIZE

With a sample size of 20 teeth per group, this study possessed 80-percent power to detect a difference of 0.7 between any two groups, assuming two-sided tests with a nonparametric adjustment at a 5-percent significance level. Sample size calculations were performed using PASS (NCSS, Kaysville, UT).

RESULTS

Intra-examiner repeatability: Intra-examiner repeatability was acceptable for Examiner 1 (weighted kappa = 0.83), with disagreements usually due to a lower score on the repeat evaluation. Intra-examiner repeatability was also acceptable for Examiner 2 (weighted kappa = 0.84), again with disagreements usually due to a lower score on the repeat evaluation (Table 1).

Inter-examiner agreement: The inter-examiner agreement analysis showed that disagreements were usually caused by higher scores given by Examiner 2 than by Examiner 1 (weighted kappa = 0.79), with the weighted kappa slightly lower when compared with the intra-examiner kappas as expected (Table 2).

Group comparisons (Figure 19): For location A (coronal third) there were significant differences in debris scores among groups ($p = 0.0019$), with significantly lower scores for the Ultrasonic Bypass System than the Controls ($p = 0.0013$), and no significant difference between the EndoActivator and Control groups ($p = 0.090$) or between the EndoActivator and the Ultrasonic Bypass System ($p = 0.065$). For location B (middle third) there were significant differences in debris scores among groups ($p = 0.0030$), with significantly lower scores for the Ultrasonic Bypass System than the Control ($p = 0.0030$) and EndoActivator ($p = 0.0361$), and no significant difference between the EndoActivator and Control groups ($p = 0.098$). For location C (apical third) there was no group effect on debris score ($p = 0.056$) (Table 3).

FIGURES AND TABLES

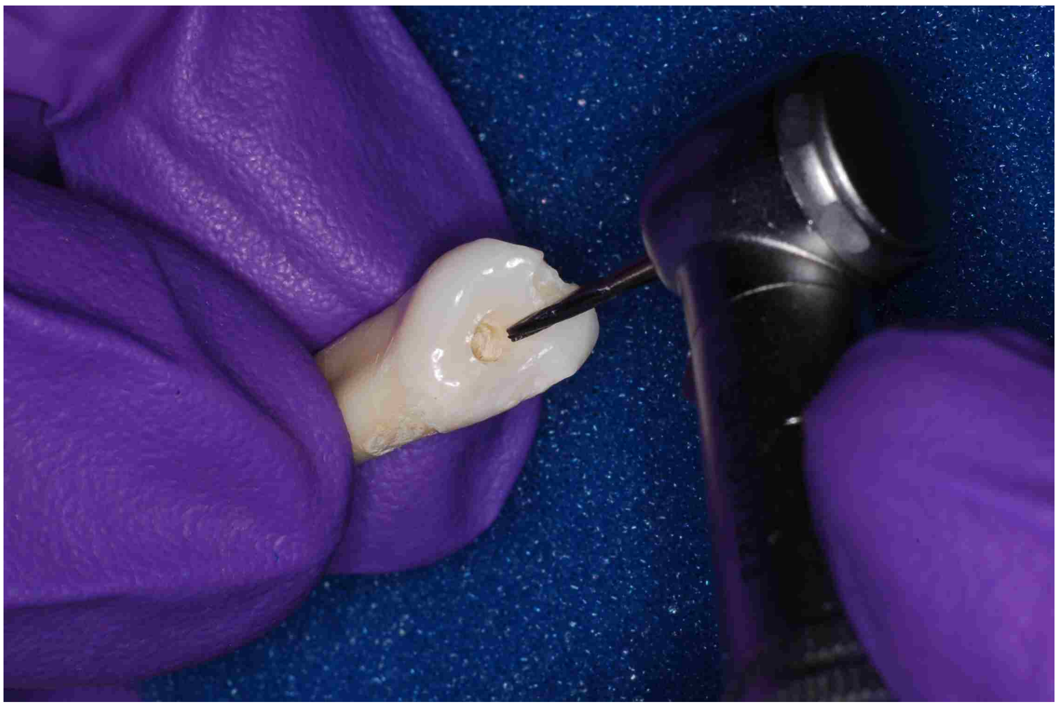

FIGURE 1. Ideal access preparation.

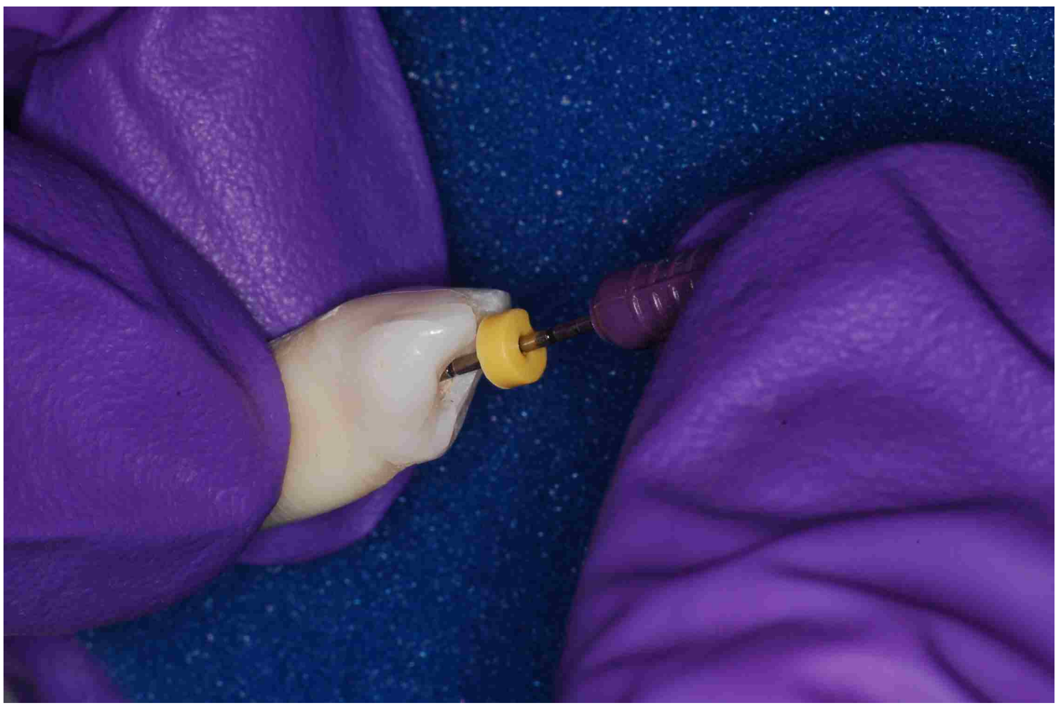

FIGURE 2. Determining working length.

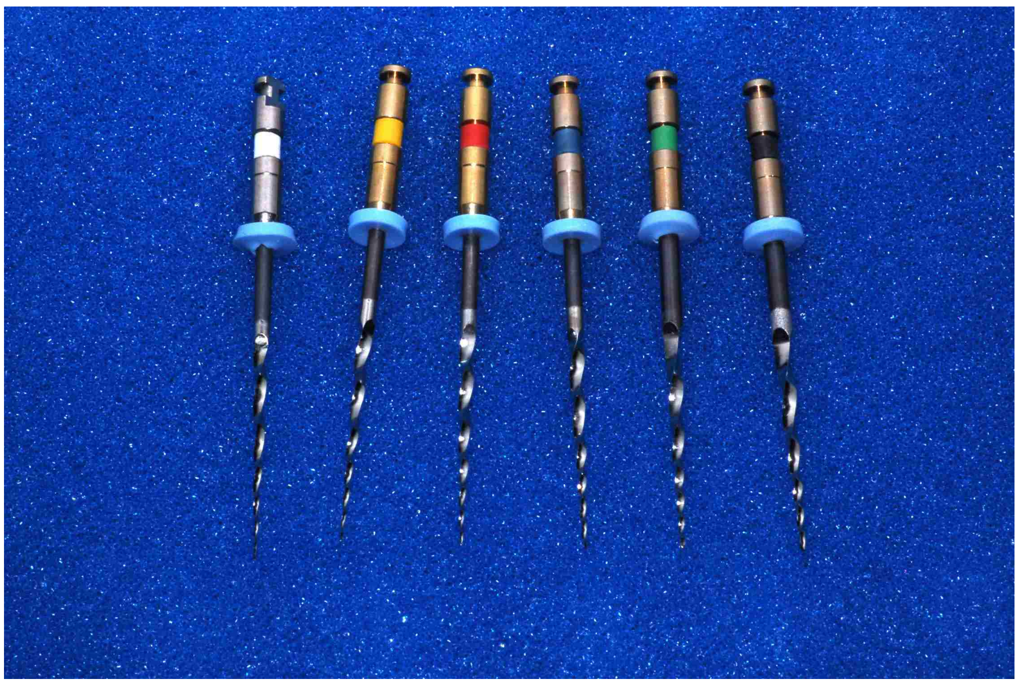

FIGURE 3. EndoSequence nickel titanium rotary instruments.

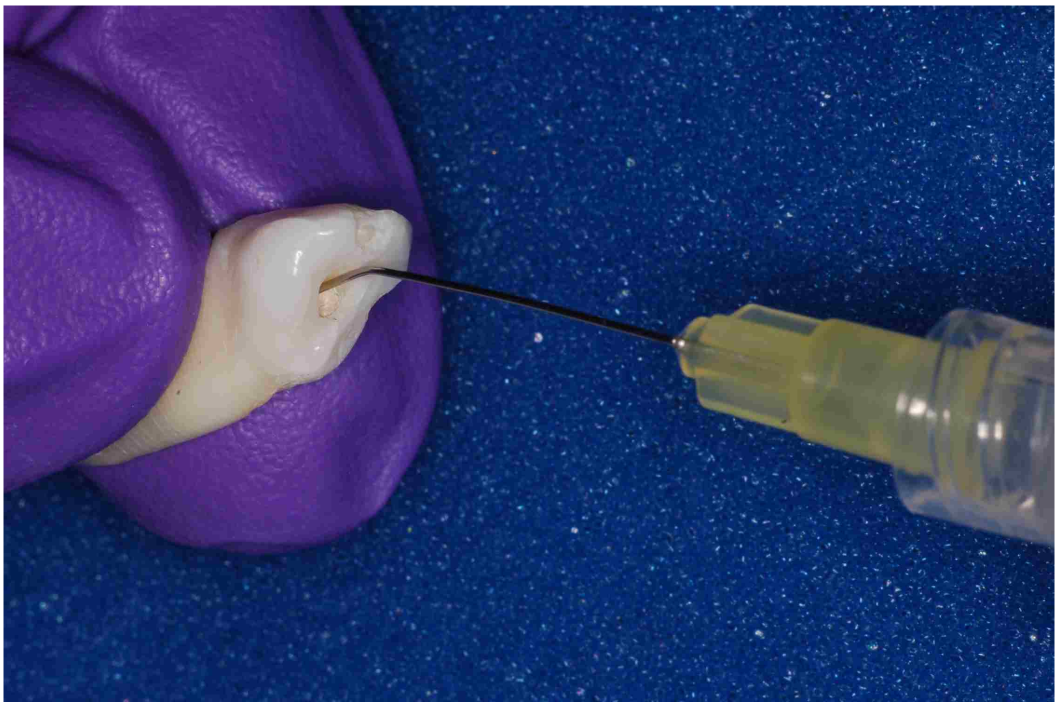

FIGURE 4. Irrigation with sodium hypochlorite during instrumentation.

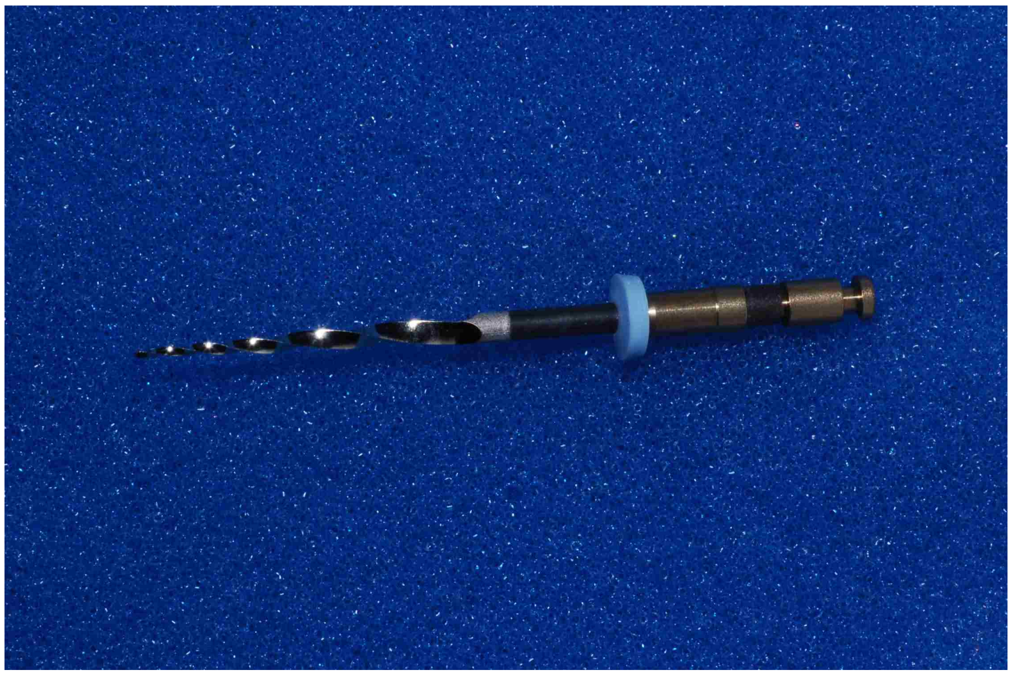

FIGURE 5. Master apical file size 40/.06.

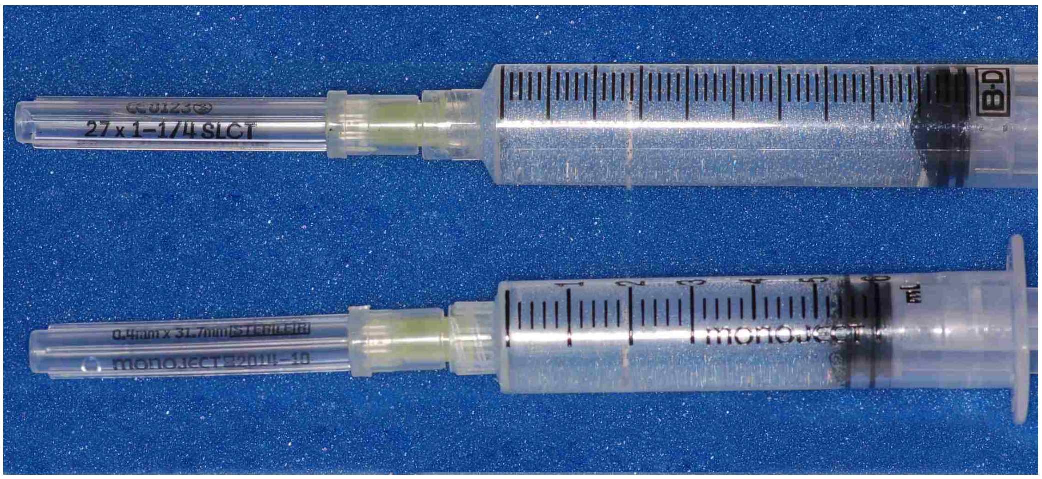

FIGURE 6. Irrigation with 6.0-percent sodium hypochlorite and 17-percent EDTA.

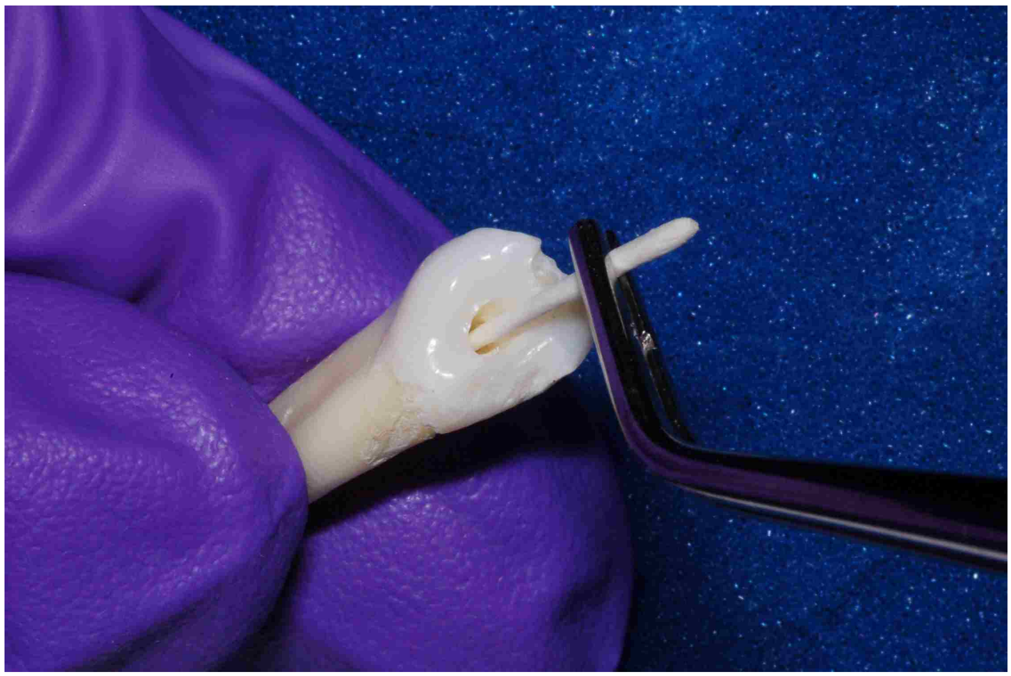

FIGURE 7. Drying the canal with paper points.

FIGURE 8. EndoActivator™ with 35/.04 tip.

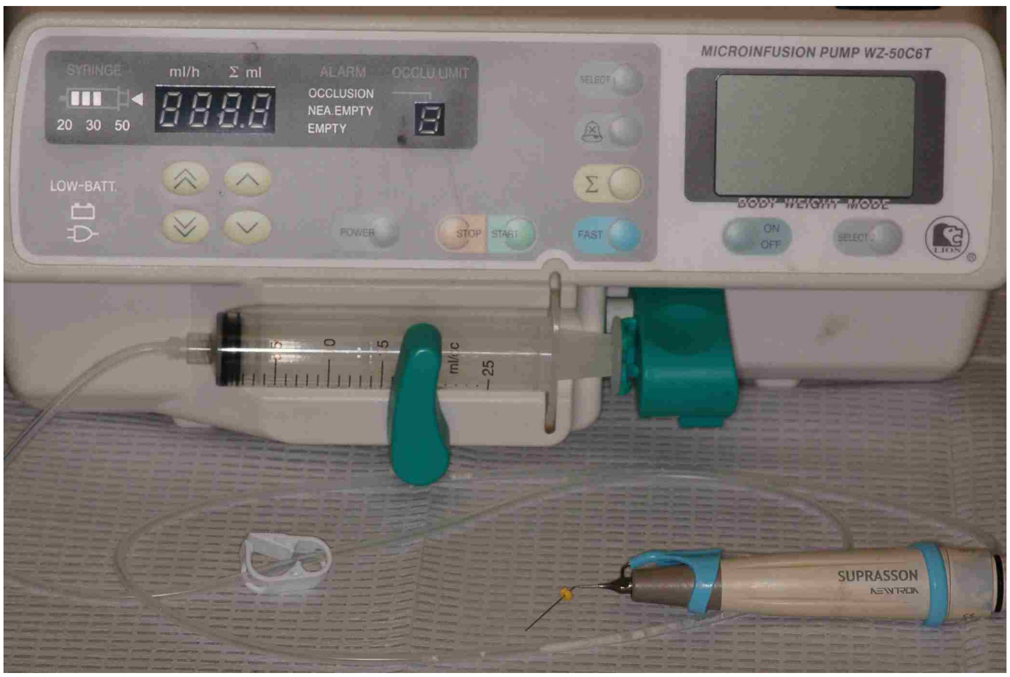

FIGURE 9. Ultrasonic Bypass™ System.

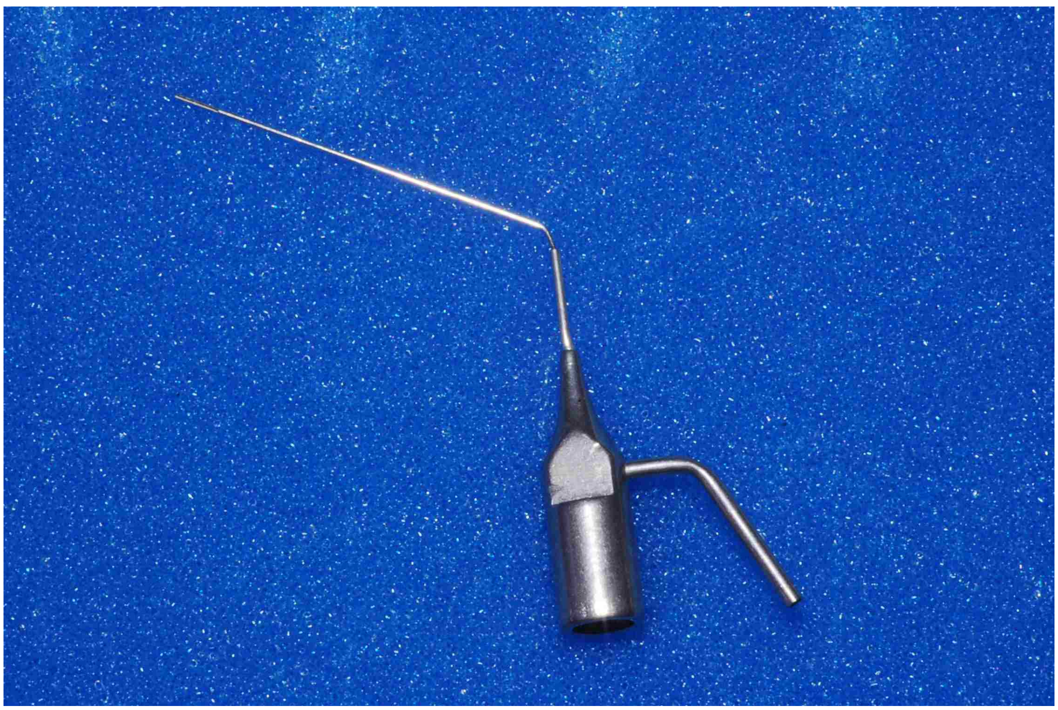

FIGURE 10. Ultrasonic Bypass System™ tip.

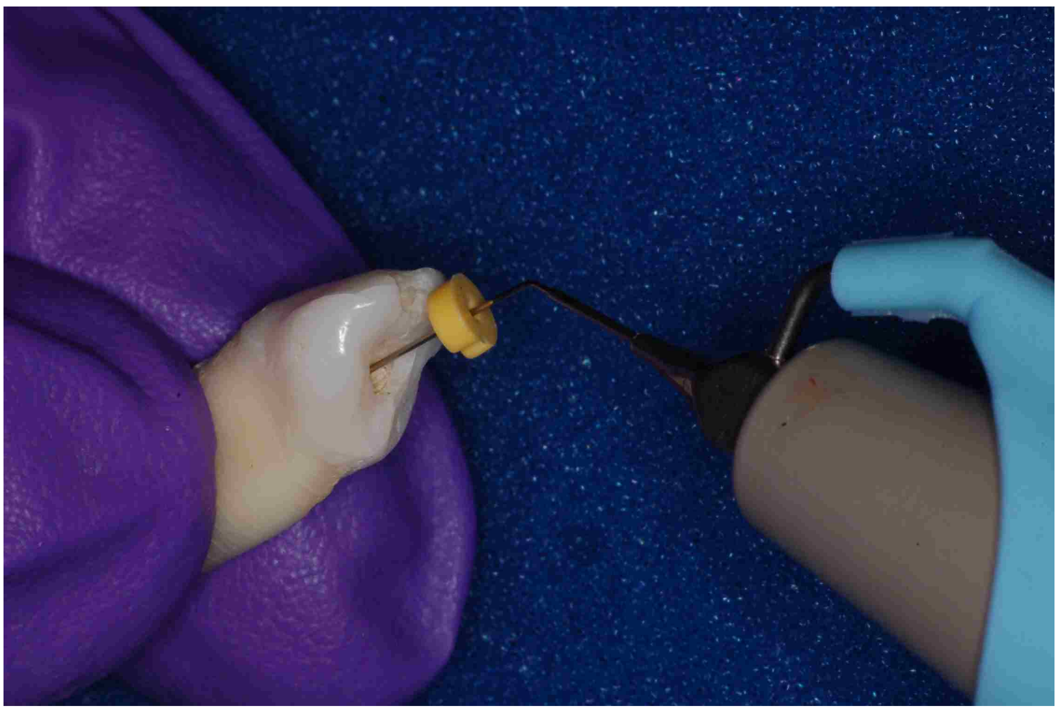

FIGURE 11. Activation with the Ultrasonic Bypass™ System.

FIGURE 12. Tooth grooved vertically with a carborundum disc.

FIGURE 13. Drying in the dessicator for two weeks.

FIGURE 14. Separation of tooth with a scalpel blade and rubber mallet.

FIGURE 15. Sectioned tooth used for evaluation.

FIGURE 16. High-vacuum scanning electron microscope.

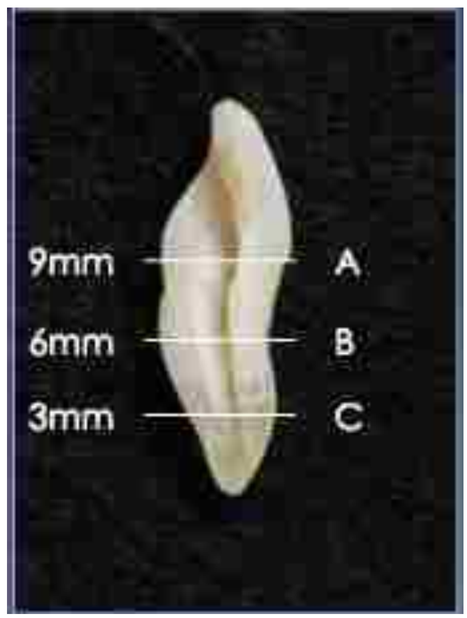

FIGURE 17. Roots divided into 3-mm segments.

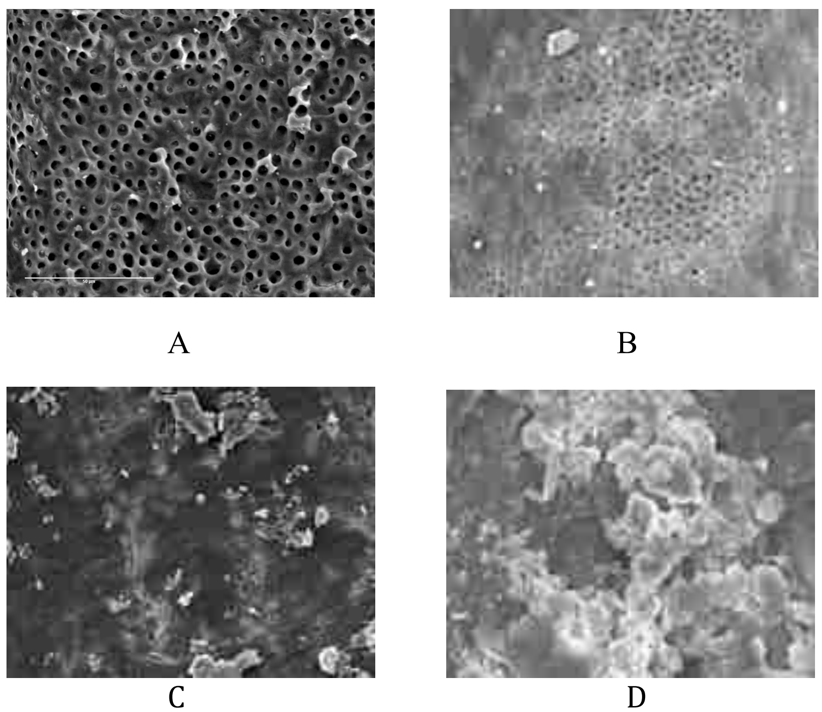

FIGURE 18. Representative SEM photomicrographs. Specimens with (A) smear/debris score 1, (B) smear/debris score 2, (C) smear/debris score 3, and (D) smear/debris score 4.

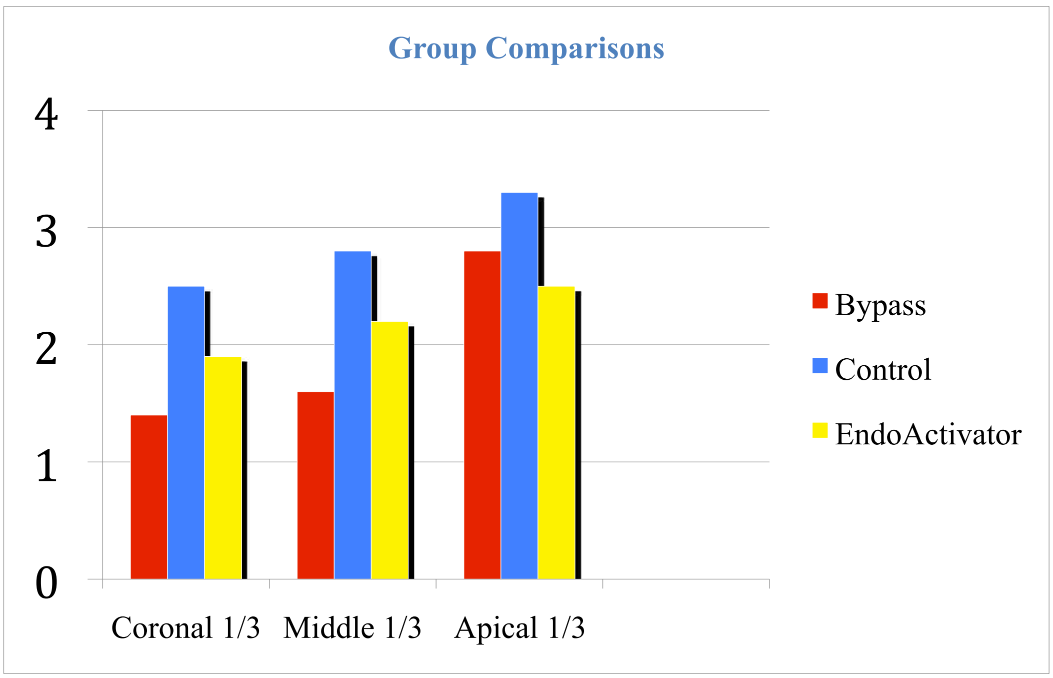

FIGURE 19. Comparison of mean scores among the control, the Ultrasonic Bypass™ System, and EndoActivator™.

TABLE I

Intra-examiner repeatability of Examiners #1 and #2

Examiner	First	Second 1	2	3	4	Kappa	Wt. Kappa
JB	1	70	1	0	0	0.71	0.83
	2	11	25	3	0		
	3	0	8	26	1		
	4	0	0	13	22		
MV	1	48	5	0	0	0.74	0.84
	2	11	38	3	0		
	3	1	7	28	4		
	4	0	0	4	31		

TABLE II

Inter-examiner repeatability between Examiners #1 and #2

	MV					
JB	1	2	3	4	Kappa	Wt. Kappa
1	52	19	0	0	0.65	0.79
2	0	27	12	0		
3	1	6	24	4		
4	0	0	4	31		

TABLE III

Summary statistics of average score by group and location

Location	Group	N	Mean	SD	SE
A	Bypass	20	1.4	0.7	0.2
	Control	20	2.5	1.1	0.2
	EndoActivator	20	1.9	1.1	0.2
B	Bypass	20	1.6	0.8	0.2
	Control	20	2.8	1.1	0.3
	EndoActivator	20	2.2	0.9	0.2
C	Bypass	20	2.8	1.2	0.3
	Control	20	3.3	0.9	0.2
	EndoActivator	20	2.5	1.1	0.3

DISCUSSION

The objective of this study was to evaluate and compare the debridement *in-vitro* efficacy of the EndoActivator System versus the Ultrasonic Bypass System following hand-rotary instrumentation. Based on the results of this research, the addition of one minute of sonic or ultrasonic activation of 6-percent NaOCl and 17-percent EDTA significantly improves the removal of debris and smear layer from inside the canals of single-rooted anterior teeth.

Many different factors may play a role in influencing the debridement efficacy of these two devices. The increase in the amount of sodium hypochlorite cycled through the canals during the usage of these two devices (less than 1 ml for the EndoActivator compared to 5 ml for the Ultrasonic Bypass System) could have had a significant effect on the debridement efficacy of these two devices. The additional NaOCl may have helped to produce the statistical significance found in the coronal and middle thirds in the canals treated with the Ultrasonic Bypass System.

The difference in the size of the tips utilized by these two devices could very well affect debridement efficacy inside canals. The size of the tip used in the EndoActivator corresponded to a size 35/.04. This is the largest tip available for use with this device. This size tip was able to fit passively to within 1 mm of working length. This size was used based on the manufacturer’s recommendation to maximize acoustic streaming inside the canals. Two other size tips are available for use with this device (15/.02 and 25/.04); however, they were not used in this study. The manufacturer recommends using the largest size tip that will fit passively into the canal to within 2 mm of working length.

Because the canals were all prepared to a size 40/06 at working length, the 35/.04 tip was chosen and was examined prior to use to ensure that it did not bind within the length of the canal. Using the largest tip available is theorized to increase the "hydrodynamic" debridement that occurs, according to the manufacturer. This larger size at the apical extent of the tip could explain the finding of cleaner canal walls of the apical 3 mm of the treated canals when compared with the bypass system and the controls. The size of the tip utilized by the Ultrasonic Bypass System was equivalent to a 30-gauge needle internally. This was the only size tip available for this system at the time of this study. There is no taper associated with this tip, therefore the distance between the tip and the canal walls increased from the apical one-third to the coronal one-third. This could allow for a more efficient exchange and activation of the irrigation solutions used in this study and could explain the increased debridement efficacy in the coronal and middle thirds of the canals.

The material used in the construction of the tips for these two devices could also influence each device's efficiency. The EndoActivator tip is constructed of a flexible, smooth, radiolucent polymer. The flexibility of this material may allow for continual acoustic streaming even when the tip comes in contact with canal walls during its use.[129] This could explain the increased debridement efficacy found in the apical 1/3 of the treated canals. The bypass tips are made of stainless steel. The acoustic streaming that occurs from occurs from an ultrasonically activated rigid tip is all but eliminated as soon as that tip contacts a solid surface (such as a canal wall).[115] This could result in gauging or cavitation at the point of contact, resulting in an altered canal shape and decreased debridement efficiency.

The size of the tip in comparison to the size of the canal preparation can also affect the effectiveness of these two devices. Utilizing a smaller tip allows for more area between the tip and the canal wall, which could allow for more efficient exchange of the activated irrigation solution in these areas. This could create more acoustic streaming, therefore possibly resulting in a cleaner canal. By this rationale, a smaller size tip utilized in these devices may actually result in increased debridement efficacy, and a cleaner canal.

The EndoActivator utilized the same volume of solution placed into the canal during its use. It was not refreshed during the 1 minute of activation. This additional volume of sodium hypochlorite amounted to less than 1 milliliter. The Ultrasonic Bypass System provided a continuous flow of fresh sodium hypochlorite into the canal during its use. This constant exchange of fresh sodium hypochlorite also allowed for an additional 5 ml of solution to be processed through the tooth. This additional volume of fluid could explain the statistically significantly cleaner samples that were present in the coronal and middle thirds of roots treated with this system, and not the actual effects of the ultrasonic activation.

Increasing the time of the activation of the irrigation solutions may also impact the debridement efficacy of these devices. In this study, one minute of activation was chosen due to its ease of application and efficiency in transferring this to an *in-vivo* setting. Previous research has shown that increasing the time of activation may lead to increased canal cleanliness. Perhaps increasing the time that these devices are utilized could lead to less debris present inside canals.[128, 147]

Microbial loads have also been shown to be reduced utilizing similar type devices. Though this was not measured in this particular study, when examining previous research, ultrasonic activation of irrigation solutions has proven to provide as much as a seven-fold decrease in the bacterial colony forming units present inside canals treated *in vivo*.[123, 148]

Approximately 30 percent to 35 percent of the internal canal anatomy is never addressed with instruments alone.[149] Utilizing these devices to activate irrigation solutions may allow for deeper, more efficient penetration into the fins, webs, deltas, lateral canals, and other anatomic complexities inside canals of human teeth. This would allow for more efficient debridement and cleaning which, in theory, should lead to higher success rates for non-surgical endodontic therapy. Increases in success rates would directly increase retention rates of endodontically treated teeth for longer periods of time.

Increasing the temperature of the sodium hypochlorite inside canals has been shown to provide increased debridement efficacy and killing of microbes.[150] In this study, all irrigation solutions were utilized at a room temperature of approximately 72°F. Increasing the temperature of the irrigation solutions prior to their use may have impacted their debridement efficacy. Also, an interesting variable to monitor would have been how much the temperature of these solutions increased during the use of these devices inside the canals, and if this increase would prove significant. We would suspect the increase to be greater during the use of the EndoActivator because the solution is not constantly being replenished as it is with the Ultrasonic Bypass System.

An additional factor to consider is if the use of these devices causes an increase in the outer root surface temperature. Research has shown that increasing the outer root surface temperature by more than just a few degrees can lead to irreparable harm to the periodontal ligament and surrounding bone. This trauma can cause necrosis of the bone and even propagate tooth loss. As of yet, no research has been conducted to measure this when utilizing these two specific devices.

When measuring debris removal, it is very difficult to ensure that excess debris is not introduced into the canals during sectioning of the roots prior to SEM observation. In this study, roots were sectioned longitudinally using a carborundum disc along the buccal and lingual surfaces, and then split using a scalpel blade and a rubber mallet. During this process, it is possible that debris not native to the canal space could have been introduced into the canal, thereby skewing the evaluator's scores. A more reliable method of sectioning teeth to decrease the possibility of introducing outside debris into the canal would involve the use of a microtome.

An additional method, as described by Jiang et al.[151] could also have been used. In this study, roots were sectioned longitudinally, cleaned of internal debris with sand paper resulting in a smooth surface with very little of the original canal remaining. The two segments were then reassembled, secured, and new canal spaces were prepared prior to testing sonic and ultrasonic devices for debris and smear layer removal. This model would have provided a more standardized canal space and ensured equivalent amounts of dentin debris present in the root canal prior to the irrigation procedure. This method may have produced more accurate dentin debris removal scores.

SUMMARY AND CONCLUSION

The purpose of this study was to evaluate the debridement efficacy of the EndoActivator System versus the Ultrasonic Bypass System following hand-rotary instrumentation in maxillary anterior teeth. Sixty extracted maxillary anterior teeth were divided into three groups. Teeth were instrumented using ISO k-flex hand files and the EndoSequence rotary nickel-titanium instrument system in a crown-down fashion and subjected to different final irrigation protocols. Group 1 (control) was irrigated with 6.0 percent sodium hypochlorite without activation. Group 2 received 1 minute of activation of 6.0-percent sodium hypochlorite via the EndoActivator system. Group 3 received 1 minute of activation via the Ultrasonic Bypass System and a 30-gauge ultrasonic tip. Teeth were then sectioned longitudinally and each segment was divided into three equal parts representing the coronal, middle, and apical thirds of the canal. SEM evaluation was performed on the section with the most visible part of the apex present. SEM photographs were made of each segment of root for analysis. A scoring system was then utilized to assess debris and smear layer removal.

Intra-examiner repeatability and inter-examiner agreement of the debris removal scores was assessed using two-way contingency tables, percent agreement, and weighted kappa statistics. Using the consensus scores separately for each of the three locations, the three methods were compared for differences in debris removal scores using a Kruskal-Wallis test, which determined if there were any differences among the three groups. A Wilcoxon Rank Sum test was then used to compare each pair of groups if the overall test was significant.

The results of this study indicate that both the EndoActivator and Ultrasonic Bypass groups had a smaller percentage of canal space occupied by smear layer and debris when compared to the control group at all three levels. This difference was statistically significant for the Ultrasonic Bypass System when compared with the control at both the coronal and middle thirds of the samples evaluated. This difference was not statistically significant in the apical third. When compared to the EndoActivator, the Ultrasonic Bypass System produced cleaner canals in the coronal and middle thirds, with the difference being statistically significant in the middle third only (Figure 20).

These results of this research support the use of either of these two devices when compared with the controls. Smear layer removal and debridement efficacy was greatly increased when using either sonic or ultrasonic activation of sodium hypochlorite. More research is warranted concerning these two devices. Examining the antimicrobial efficacy with the use of these two devices could lend additional validation to their use in non-surgical endodontic therapy.

REFERENCES

1. Goodman A, Reader A, Beck M, Melfi R, Meyers W. An in vitro comparison of the efficacy of the step-back technique versus a step-back/ultrasonic technique in human mandibular molars. J Endod 1985;11(6):249-56.

2. Haidet J, Reader A, Beck M, Meyers W. An in vivo comparison of the step-back technique versus a step-back/ultrasonic technique in human mandibular molars. J Endod 1989;15(5):195-9.

3. Hulsmann M, Hahn W. Complications during root canal irrigation--literature review and case reports. Int Endod J 2000;33(3):186-93.

4. Lev R, Reader A, Beck M, Meyers W. An in vitro comparison of the step-back technique versus a step-back/ultrasonic technique for 1 and 3 minutes. J Endod 1987;13(11):523-30.

5. Mayer BE, Peters OA, Barbakow F. Effects of rotary instruments and ultrasonic irrigation on debris and smear layer scores: a scanning electron microscopic study. Int Endod J 2002;35(7):582-9.

6. Metzler RS, Montgomery S. Effectiveness of ultrasonics and calcium hydroxide for the debridement of human mandibular molars. J Endod 1989;15(8):373-8.

7. Schafer E, Zapke K. A comparative scanning electron microscopic investigation of the efficacy of manual and automated instrumentation of root canals. J Endod 2000;26(11):660-4.

8. Tan BT, Messer HH. The quality of apical canal preparation using hand and rotary instruments with specific criteria for enlargement based on initial apical file size. J Endod 2002;28(9):658-64.

9. Weller RN, Brady JM, Bernier WE. Efficacy of ultrasonic cleaning. J Endod 1980;6(9):740-3.

10. Archer R, Reader A, Nist R, Beck M, Meyers WJ. An in vivo evaluation of the efficacy of ultrasound after step-back preparation in mandibular molars. J Endod 1992;18(11):549-52.

11. Gutarts R, Nusstein J, Reader A, Beck M. In vivo debridement efficacy of ultrasonic irrigation following hand-rotary instrumentation in human mandibular molars. J Endod 2005;31(3):166-70.

12. Versumer J, Hulsmann M, Schafers F. A comparative study of root canal preparation using Profile .04 and Lightspeed rotary Ni-Ti instruments. Int Endod J 2002;35(1):37-46.

13. Dalton BC, Orstavik D, Phillips C, Pettiette M, Trope M. Bacterial reduction with nickel-titanium rotary instrumentation. J Endod 1998;24(11):763-7.

14. Peters LB, Wesselink PR. Periapical healing of endodontically treated teeth in one and two visits obturated in the presence or absence of detectable microorganisms. Int Endod J 2002;35(8):660-7.

15. Shuping GB, Orstavik D, Sigurdsson A, Trope M. Reduction of intracanal bacteria using nickel-titanium rotary instrumentation and various medications. J Endod 2000;26(12):751-5.

16. Siqueira JF, Jr., Lima KC, Magalhaes FA, Lopes HP, de Uzeda M. Mechanical reduction of the bacterial population in the root canal by three instrumentation techniques. J Endod 1999;25(5):332-5.

17. Siqueira JF, Jr., Rocas IN, Favieri A, Lima KC. Chemomechanical reduction of the bacterial population in the root canal after instrumentation and irrigation with 1%, 2.5%, and 5.25% sodium hypochlorite. J Endod 2000;26(6):331-4.

18. Siqueira JF, Jr., Rocas IN, Santos SR, Lima KC, Magalhaes FA, de Uzeda M. Efficacy of instrumentation techniques and irrigation regimens in reducing the bacterial population within root canals. J Endod 2002;28(3):181-4.

19. Yamauchi S, Shipper G, Buttke T, Yamauchi M, Trope M. Effect of orifice plugs on periapical inflammation in dogs. J Endod 2006;32(6):524-6.

20. Spoleti P, Siragusa M, Spoleti MJ. Bacteriological evaluation of passive ultrasonic activation. J Endod 2003;29(1):12-4.

21. Briseno Marroquin B, Sobarzo-Navarro V, Devens S. The influence of different engine-driven, sound ultrasound systems and the Canal Master on root canal preparation: an in vitro study. Int Endod J 1993;26(3):190-7.

22. Jensen SA, Walker TL, Hutter JW, Nicoll BK. Comparison of the cleaning efficacy of passive sonic activation and passive ultrasonic activation after hand instrumentation in molar root canals. J Endod 1999;25(11):735-8.

23. Ahmad A, Siddiqui AA, Ali B. Ultrasonic propagation in tissues of the bird Corvus splendens Vieillot. Indian J Exp Biol 1987;25(7):483-4.

24. Lumley PJ, Walmsley AD, Laird WR. Streaming patterns produced around endosonic files. Int Endod J 1991;24(6):290-7.

25. Schneider SW. A comparison of canal preparations in straight and curved root canals. Oral Surg Oral Med Oral Pathol 1971;32(2):271-5.

26. Walmsley AD. Ultrasound and root canal treatment: the need for scientific evaluation. Int Endod J 1987;20(3):105-11.

27. Walmsley AD, Lumley PJ, Laird WR. Oscillatory pattern of sonically powered endodontic files. Int Endod J 1989;22(3):125-32.

28. Walmsley AD, Williams AR. Effects of constraint on the oscillatory pattern of endosonic files. J Endod 1989;15(5):189-94.

29. Ingle JI, Bakland LK. Endodontics. 4th ed. Baltimore: Williams & Wilkins; 1994.

30. Grossman H. Root canal therapy. Philadelphia: Lea & Febiger; 1940.

31. Ingle JI, Taintor JF. Endodontics. 3rd ed. Philadelphia: Lea & Febiger; 1985.

32. Cruse WP, Bellizzi R. A historic review of endodontics, 1689-1963, part 1. J Endod 1980;6(3):495-9.

33. Ostrander FD. The practice of endodontics: past, present, and future. J Dent Educ 1967;31(3):386-8.

34. Grossman LI. Endodontics 1776-1976: a bicentennial history against the background of general dentistry. J Am Dent Assoc 1976;93(1):78-87.

35. Blayney JR. Present-day evaluation of the pulpless tooth. J Am Dent Assoc 1936:533-44.

36. Vail MM SC. Temporary placements for access openings, a survey from board certified endodontists. Unpublished 2003.

37. Healey E. Selection of cases and treatment procedures. J Am Dent Assoc 1956(53):434.

38. Stweart G. The importance of chemomechanical preparation of the root canal. J Oral Surg 1955;8:993-7.

39. Coolidge ED. Past and present concepts in endodontics. J Am Dent Assoc 1960;61:676-88.

40. Kakehashi S, Stanley HR, Fitzgerald RJ. The effects of surgical exposures of dental pulps in germ-free and conventional laboratory rats. Oral Surg Oral Med Oral Pathol 1965;20:340-9.

41. Carlsson J, Frolander F, Sundquist G. Oxygen tolerance of anaerobic bacteria isolated from necrotic dental pulps. Acta Odontol Scand 1977;35(3):139-45.

42. Kuttler Y. A precision and biologic root canal filling technic. J Am Dent Assoc 1958;56(1):38-50.

43. Schilder H. Filling root canals in three dimensions. Dent Clin North Am 1967:723-44.

44. Grossman LI. Endodontics: then and now. Oral Surg Oral Med Oral Pathol 1971;32(2):254-9.

45. Ray HA, Trope M. Periapical status of endodontically treated teeth in relation to the technical quality of the root filling and the coronal restoration. Int Endod J 1995;28(1):12-8.

46. Lazarski MP, Walker WA, 3rd, Flores CM, Schindler WG, Hargreaves KM. Epidemiological evaluation of the outcomes of nonsurgical root canal treatment in a large cohort of insured dental patients. J Endod 2001;27(12):791-6.

47. Matsumoto T, Nagai T, Ida K, Ito M, Kawai Y, Horiba N, et al. Factors affecting successful prognosis of root canal treatment. J Endod 1987;13(5):239-42.

48. Sjogren U, Hagglund B, Sundqvist G, Wing K. Factors affecting the long-term results of endodontic treatment. J Endod 1990;16(10):498-504.

49. Kerekes K, Tronstad L. Long-term results of endodontic treatment performed with a standardized technique. J Endod 1979;5(3):83-90.

50. de Chevigny C, Dao TT, Basrani BR, Marquis V, Farzaneh M, Abitbol S, et al. Treatment outcome in endodontics: the Toronto study--phase 4: initial treatment. J Endod 2008;34(3):258-63.

51. Salehrabi R, Rotstein I. Endodontic treatment outcomes in a large patient population in the USA: an epidemiological study. J Endod 2004;30(12):846-50.

52. Pineda F, Kuttler Y. Mesiodistal and buccolingual roentgenographic investigation of 7,275 root canals. Oral Surg Oral Med Oral Pathol 1972;33(1):101-10.

53. Walton RE, Torabinejad M. Principles and practice of endodontics. 2nd ed. Philadelphia: W.B. Saunders; 1996.

54. al Shalabi RM, Omer OE, Glennon J, Jennings M, Claffey NM. Root canal anatomy of maxillary first and second permanent molars. Int Endod J 2000;33(5):405-14.

55. Gray R. The maxillary first molar: anatomy and morphology of permanent Teeth. Iowa City: University of Iowa College of Dentistry; 1983.

56. Pecora JD, Woelfel JB, Sousa Neto MD. Morphologic study of the maxillary molars. (Part 1). External anatomy. Braz Dent J 1991;2(1):45-50.

57. Ross IF, Evanchik PA. Root fusion in molars: incidence and sex linkage. J Periodontol 1981;52(11):663-7.

58. Sabala CL, Benenati FW, Neas BR. Bilateral root or root canal aberrations in a dental school patient population. J Endod 1994;20(1):38-42.

59. Thomas RP, Moule AJ, Bryant R. Root canal morphology of maxillary permanent first molar teeth at various ages. Int Endod J 1993;26(5):257-67.

60. Yang ZP, Yang SF, Lee G. The root and root canal anatomy of maxillary molars in a Chinese population. Endod Dent Traumatol 1988;4(5):215-8.

61. Brown P HE. Dental anatomy and 3D tooth atlas. 2nd ed. Illinois: Quintessence; 2005.

62. Hess W, Zürcher E, Dolamore WH. The anatomy of the root-canals of the teeth of the permanent dentition. London: J. Bale, Sons & Danielsson, ltd.; 1925.

63. Skidmore AE, Bjorndal AM. Root canal morphology of the human mandibular first molar. Oral Surg Oral Med Oral Pathol 1971;32(5):778-84.

64. Morfis A, Sylaras SN, Georgopoulou M, Kernani M, Prountzos F. Study of the apices of human permanent teeth with the use of a scanning electron microscope. Oral Surg Oral Med Oral Pathol 1994;77(2):172-6.

65. Weine FS, Healey HJ, Gerstein H, Evanson L. Canal configuration in the mesiobuccal root of the maxillary first molar and its endodontic significance. Oral Surg Oral Med Oral Pathol 1969;28(3):419-25.

66. Levy AB, Glatt L. Deviation of the apical foramen from the radiographic apex. J N J State Dent Soc 1970;41(8):12-3.

67. Vertucci FJ. Root canal anatomy of the human permanent teeth. Oral Surg Oral Med Oral Pathol 1984;58(5):589-99.

68. Nair PN, Henry S, Cano V, Vera J. Microbial status of apical root canal system of human mandibular first molars with primary apical periodontitis after "one-visit" endodontic treatment. Oral Surg Oral Med Oral Pathol Oral Radiol Endod 2005;99(2):231-52.

69. Hulsmann M PO, Dummer P. Mechanical preparation of root canals: shaping goals, techniques and means. Endod Topics 2005;10:30-76.

70. Schilder H. Cleaning and shaping the root canal. Dent Clin North Am 1974;18(2):269-96.

71. Ørstavik D, Pitt Ford TR. Essential endodontology : prevention and treatment of apical periodontitis. 2nd ed. Oxford, UK ; Ames, Iowa: Blackwell Munksgaard; 2008.

72. Cohen S, Burns RC. Pathways of the pulp. 8th ed. St. Louis: Mosby; 2002.

73. Himel VT, Ahmed KM, Wood DM, Alhadainy HA. An evaluation of nitinol and stainless steel files used by dental students during a laboratory proficiency exam. Oral Surg Oral Med Oral Pathol Oral Radiol Endod 1995;79(2):232-7.

74. Esposito PT, Cunningham CJ. A comparison of canal preparation with nickel-titanium and stainless steel instruments. J Endod 1995;21(4):173-6.

75. Haapasalo M, Endal U, Zandi H, Coil JM. Eradication of endodontic infection by instrumentation and irrigation solutions. Endodontic Topics 2005;10(1):77-102.

76. Harrison JW. Irrigation of the root canal system. Dent Clin North Am 1984;28(4):797-808.

77. Barrette WC, Jr., Hannum DM, Wheeler WD, Hurst JK. General mechanism for the bacterial toxicity of hypochlorous acid: abolition of ATP production. Biochemistry 1989;28(23):9172-8.

78. McDonnell G, Russell AD. Antiseptics and disinfectants: activity, action, and resistance. Clin Microbiol Rev 1999;12(1):147-79.

79. McKenna SM, Davies KJ. The inhibition of bacterial growth by hypochlorous acid. Possible role in the bactericidal activity of phagocytes. Biochem J 1988;254(3):685-92.

80. Waltimo TM, Orstavik D, Siren EK, Haapasalo MP. In vitro susceptibility of Candida albicans to four disinfectants and their combinations. Int Endod J 1999;32(6):421-9.

81. Radcliffe CE, Potouridou L, Qureshi R, Habahbeh N, Qualtrough A, Worthington H, Drucker DB. Antimicrobial activity of varying concentrations of sodium hypochlorite on the endodontic microorganisms Actinomyces israelii, A. naeslundii, Candida albicans and Enterococcus faecalis. Int Endod J 2004;37(7):438-46.

82. Vianna ME, Gomes BP, Berber VB, Zaia AA, Ferraz CC, de Souza-Filho FJ. In-vitro evaluation of the antimicrobial activity of chlorhexidine and sodium

hypochlorite. Oral Surg Oral Med Oral Pathol Oral Radiol Endod 2004;97(1):79-84.

83. Gomes BP, Ferraz CC, Vianna ME, Berber VB, Teixeira FB, Souza-Filho FJ. In vitro antimicrobial activity of several concentrations of sodium hypochlorite and chlorhexidine gluconate in the elimination of Enterococcus faecalis. Int Endod J 2001;34(6):424-8.

84. Bystrom A, Sundqvist G. Bacteriologic evaluation of the effect of 0.5 percent sodium hypochlorite in endodontic therapy. Oral Surg Oral Med Oral Pathol 1983;55(3):307-12.

85. Bystrom A, Sundqvist G. The antibacterial action of sodium hypochlorite and EDTA in 60 cases of endodontic therapy. Int Endod J 1985;18(1):35-40.

86. McComb D, Smith DC, Beagrie GS. The results of in-vivo endodontic chemomechanical instrumentation--a scanning electron microscopic study. J Br Endod Soc 1976;9(1):11-8.

87. Spangberg L, Engstrom B, Langeland K. Biologic effects of dental materials: toxicity and antimicrobial effect of endodontic antiseptics in-vitro. Oral Surg Oral Med Oral Pathol 1973;36(6):856-71.

88. Haapasalo HK, Siren EK, Waltimo TM, Orstavik D, Haapasalo MP. Inactivation of local root canal medicaments by dentine: an in-vitro study. Int Endod J 2000;33(2):126-31.

89. Marcinkiewicz J, Chain B, Nowak B, Grabowska A, Bryniarski K, Baran J. Antimicrobial and cytotoxic activity of hypochlorous acid: interactions with taurine and nitrite. Inflamm Res 2000;49(6):280-9.

90. Luebke RG. Pulp cavity debridement and disinfection. Dent Clin North Am 1967:603-13.

91. Russell AD. Activity of biocides against mycobacteria. Soc Appl Bacteriol Symp Ser 1996;25:87S-101S.

92. Russell AD, Day MJ. Antibacterial activity of chlorhexidine. J Hosp Infect 1993;25(4):229-38.

93. Shaker LA, Furr JR, Russell AD. Mechanism of resistance of Bacillus subtilis spores to chlorhexidine. J Appl Bacteriol 1988;64(6):531-9.

94. Oncag O, Hosgor M, Hilmioglu S, Zekioglu O, Eronat C, Burhanoglu D. Comparison of antibacterial and toxic effects of various root canal irrigants. Int Endod J 2003;36(6):423-32.

95. Waltimo TM, Siren EK, Orstavik D, Haapasalo MP. Susceptibility of oral Candida species to calcium hydroxide in-vitro. Int Endod J 1999;32(2):94-8.

96. Barkvoll P, Attramadal A. Effect of nystatin and chlorhexidine digluconate on Candida albicans. Oral Surg Oral Med Oral Pathol 1989;67(3):279-81.

97. Hamers AD, Shay K, Hahn BL, Sohnle PG. Use of a microtiter plate assay to detect the rate of killing of adherent Candida albicans by antifungal agents. Oral Surg Oral Med Oral Pathol Oral Radiol Endod 1996;81(1):44-9.

98. Hiom SJ, Furr JR, Russell AD, Dickinson JR. Effects of chlorhexidine diacetate on Candida albicans, C. glabrata and Saccharomyces cerevisiae. J Appl Bacteriol 1992;72(4):335-40.

99. Basrani BR, Manek S, Sodhi RN, Fillery E, Manzur A. Interaction between sodium hypochlorite and chlorhexidine gluconate. J Endod 2007;33(8):966-9.

100. Clegg MS, Vertucci FJ, Walker C, Belanger M, Britto LR. The effect of exposure to irrigant solutions on apical dentin biofilms in vitro. J Endod 2006;32(5):434-7.

101. Hoefs JC. Serum protein concentration and portal pressure determine the ascitic fluid protein concentration in patients with chronic liver disease. J Lab Clin Med 1983;102(2):260-73.

102. Peciuliene V, Reynaud AH, Balciuniene I, Haapasalo M. Isolation of yeasts and enteric bacteria in root-filled teeth with chronic apical periodontitis. Int Endod J 2001;34(6):429-34.

103. Molander A, Reit C, Dahlen G. The antimicrobial effect of calcium hydroxide in root canals pretreated with 5% iodine potassium iodide. Endod Dent Traumatol 1999;15(5):205-9.

104. Portenier I, Haapasalo H, Orstavik D, Yamauchi M, Haapasalo M. Inactivation of the antibacterial activity of iodine potassium iodide and chlorhexidine digluconate against Enterococcus faecalis by dentin, dentin matrix, type-I collagen, and heat-killed microbial whole cells. J Endod 2002;28(9):634-7.

105. Torabinejad M, Cho Y, Khademi AA, Bakland LK, Shabahang S. The effect of various concentrations of sodium hypochlorite on the ability of MTAD to remove the smear layer. J Endod 2003;29(4):233-9.

106. Torabinejad M, Khademi AA, Babagoli J, Cho Y, Johnson WB, Bozhilov K, et al. A new solution for the removal of the smear layer. J Endod 2003;29(3):170-5.

107. Zhang W, Torabinejad M, Li Y. Evaluation of cytotoxicity of MTAD using the MTT-tetrazolium method. J Endod 2003;29(10):654-7.

108. Shabahang S, Pouresmail M, Torabinejad M. In-vitro antimicrobial efficacy of MTAD and sodium hypochlorite. J Endod 2003;29(7):450-2.

109. Shabahang S, Torabinejad M. Effect of MTAD on Enterococcus faecalis-contaminated root canals of extracted human teeth. J Endod 2003;29(9):576-9.

110. Kho P, Baumgartner JC. A comparison of the antimicrobial efficacy of NaOCl/Biopure MTAD versus NaOCl/EDTA against Enterococcus faecalis. J Endod 2006;32(7):652-5.

111. Johal S, Baumgartner JC, Marshall JG. Comparison of the antimicrobial efficacy of 1.3% NaOCl/BioPure MTAD to 5.25% NaOCl/15% EDTA for root canal irrigation. J Endod 2007;33(1):48-51.

112. Richman R. The use of ultrasonics in root canal therapy and root resection. Med Dent J 1957;12:12-8.

113. Martin H, Cunningham WT, Norris JP, Cotton WR. Ultrasonic versus hand filing of dentin: a quantitative study. Oral Surg Oral Med Oral Pathol 1980;49(1):79-81.

114. Cunningham WT, Martin H. A scanning electron microscope evaluation of root canal debridement with the endosonic ultrasonic synergistic system. Oral Surg Oral Med Oral Pathol 1982;53(5):527-31.

115. Cunningham WT, Martin H, Forrest WR. Evaluation of root canal debridement by the endosonic ultrasonic synergistic system. Oral Surg Oral Med Oral Pathol 1982;53(4):401-4.

116. Cunningham WT, Martin H, Pelleu GB, Jr., Stoops DE. A comparison of antimicrobial effectiveness of endosonic and hand root canal therapy. Oral Surg Oral Med Oral Pathol 1982;54(2):238-41.

117. Martin H, Cunningham WT. An evaluation of postoperative pain incidence following endosonic and conventional root canal therapy. Oral Surg Oral Med Oral Pathol 1982;54(1):74-6.

118. Martin H, Cunningham WT. The effect of endosonic and hand manipulation on the amount of root canal material extruded. Oral Surg Oral Med Oral Pathol 1982;53(6):611-3.

119. Cameron JA. The use of ultrasonics in the removal of the smear layer: a scanning electron microscope study. J Endod 1983;9(7):289-92.

120. Reynolds MA, Madison S, Walton RE, Krell KV, Rittman BR. An in-vitro histological comparison of the step-back, sonic, and ultrasonic instrumentation techniques in small, curved root canals. J Endod 1987;13(7):307-14.

121. Walker TL, del Rio CE. Histological evaluation of ultrasonic and sonic instrumentation of curved root canals. J Endod 1989;15(2):49-59.

122. Ahmad M, Pitt Ford TJ, Crum LA. Ultrasonic debridement of root canals: acoustic streaming and its possible role. J Endod 1987;13(10):490-9.

123. Carver K, Nusstein J, Reader A, Beck M. In-vivo antibacterial efficacy of ultrasound after hand and rotary instrumentation in human mandibular molars. J Endod 2007;33(9):1038-43.

124. Burleson A, Nusstein J, Reader A, Beck M. The in-vivo evaluation of hand/rotary/ultrasound instrumentation in necrotic, human mandibular molars. J Endod 2007;33(7):782-7.

125. Tronstad L, Barnett F, Schwartzben L, Frasca P. Effectiveness and safety of a sonic vibratory endodontic instrument. Endod Dent Traumatol 1985;1(2):69-76.

126. Gu LS, Kim JR, Ling J, Choi KK, Pashley DH, Tay FR. Review of contemporary irrigant agitation techniques and devices. J Endod 2009;35(6):791-804.

127. Stamos DG, Haasch GC, Chenail B, Gerstein H. Endosonics: clinical impressions. J Endod 1985;11(4):181-7.

128. Sabins RA, Johnson JD, Hellstein JW. A comparison of the cleaning efficacy of short-term sonic and ultrasonic passive irrigation after hand instrumentation in molar root canals. J Endod 2003;29(10):674-8.

129. Caron G. Cleaning efficacy of the apical millimeters of curved canals using three different modalities of irrigant activation: an SEM study. Paris, France: Paris VII University; 2007.

130. Ruddle CJ. Cleaning and shaping the root canal system. In: Pathways of the pulp. St. Louis: Mosby; 2008. p. 231-91.

131. de Gregorio C, Estevez R, Cisneros R, Heilborn C, Cohenca N. Effect of EDTA, sonic, and ultrasonic activation on the penetration of sodium hypochlorite into simulated lateral canals: an in-vitro study. J Endod 2009;35(6):891-5.

132. Shen Y, Stojicic S, Qian W, Olsen I, Haapasalo M. The synergistic antimicrobial effect by mechanical agitation and two chlorhexidine preparations on biofilm bacteria. J Endod;36(1):100-4.

133. Desai P, Himel V. Comparative safety of various intracanal irrigation systems. J Endod 2009;35(4):545-9.

134. Huang TY, Gulabivala K, Ng YL. A bio-molecular film ex-vivo model to evaluate the influence of canal dimensions and irrigation variables on the efficacy of irrigation. Int Endod J 2008;41(1):60-71.

135. McGill S, Gulabivala K, Mordan N, Ng YL. The efficacy of dynamic irrigation using a commercially available system (RinsEndo) determined by removal of a collagen 'bio-molecular film' from an ex vivo model. Int Endod J 2008;41(7):602-8.

136. Ruddle CJ, inventor. Microbrush for endodontic use. 2001.

137. Wiggins S, Ottino JM. Foundations of chaotic mixing. Philos Transact A Math Phys Eng Sci 2004;362(1818):937-70.

138. Setlock J, Fayad MI, BeGole E, Bruzick M. Evaluation of canal cleanliness and smear layer removal after the use of the Quantec-E irrigation system and syringe: a comparative scanning electron microscope study. Oral Surg Oral Med Oral Pathol Oral Radiol Endod 2003;96(5):614-7.

139. Walters MJ, Baumgartner JC, Marshall JG. Efficacy of irrigation with rotary instrumentation. J Endod 2002;28(12):837-9.

140. Weise M RM, Ebert J, Petschelt A, Frankenberger R. Four methods for cleaning simulated lateral extensions of curved root canals: a SEM evaluation. Int Endod J 2007;40:991-2.

141. Barnett F, Godick B, Tronstad L. Clinical suitability of a sonic vibratory endodontic instrument. Endod Dent Traumatol 1985;1(2):77-81.

142. Card SJ, Sigurdsson A, Orstavik D, Trope M. The effectiveness of increased apical enlargement in reducing intracanal bacteria. J Endod 2002;28(11):779-83.

143. Pitt WG. Removal of oral biofilm by sonic phenomena. Am J Dent 2005;18(5):345-52.

144. Sedgley C, Applegate B, Nagel A, Hall D. Real-time imaging and quantification of bioluminescent bacteria in root canals in vitro. J Endod 2004;30(12):893-8.

145. Stamos DE, Sadeghi EM, Haasch GC, Gerstein H. An in-vitro comparison study to quantitate the debridement ability of hand, sonic, and ultrasonic instrumentation. J Endod 1987;13(9):434-40.

146. Al-Hadlaq SM, Al-Turaiki SA, Al-Sulami U, Saad AY. Efficacy of a new brush-covered irrigation needle in removing root canal debris: a scanning electron microscopic study. J Endod 2006;32(12):1181-4.

147. Abou-Rass M, Oglesby SW. The effects of temperature, concentration, and tissue type on the solvent ability of sodium hypochlorite. J Endod 1981;7(8):376-7.

148. Plotino G, Pameijer CH, Grande NM, Somma F. Ultrasonics in endodontics: a review of the literature. J Endod 2007;33(2):81-95.

149. Gutierrez JH, Garcia J. Microscopic and macroscopic investigation on results of mechanical preparation of root canals. Oral Surg Oral Med Oral Pathol 1968;25(1):108-16.

150. Cunningham WT, Joseph SW. Effect of temperature on the bactericidal action of sodium hypochlorite endodontic irrigant. Oral Surg Oral Med Oral Pathol 1980;50(6):569-71.

151. Jiang LM, Verhaagen B, Versluis M, van der Sluis LW. Evaluation of a sonic device designed to activate irrigant in the root canal. J Endod;36(1):143-6.

APPENDIX

APPENDIX I

Debris and smear layer scores from Group 1 (Control group) at each location by two examiners

Specimen	Tooth	Location	Examiner 1 score	Examiner 2 score	Examiner 1 repeat	Examiner 2 repeat
1	1	A	2	2	2	2
2		B	1	1	1	1
3		C	1	1	1	1
4	2	A	2	3	2	1
5		B	4	4	4	4
6		C	4	4	4	4
7	3	A	1	2	1	1
8		B	3	4	2	3
9		C	3	3	3	3
10	4	A	4	4	4	4
11		B	3	3	3	3
12		C	3	3	3	4
13	5	A	4	4	4	4
14		B	4	4	4	4
15		C	4	4	4	4
16	6	A	3	4	3	4
17		B	4	4	4	3
18		C	3	3	3	3
19	7	A	2	2	3	3
20		B	4	4	4	4
21		C	3	3	2	3
22	8	A	2	3	2	3
23		B	2	3	2	4
24		C	3	4	3	4
25	9	A	1	1	1	1
26		B	1	1	1	1
27		C	2	3	1	2
28	10	A	3	3	2	3

(continued)

APPENDIX I (continued)

29		B	3	3	3	3
30		C	4	4	4	4
31	11	A	4	4	4	4
32		B	4	4	4	4
33		C	4	4	4	4
34	12	A	1	1	1	2
35		B	1	2	1	2
36		C	4	4	4	3
37	13	A	4	4	4	4
38		B	3	3	3	3
39		C	4	4	4	4
40	14	A	2	2	2	2
41		B	2	3	2	2
42		C	3	3	4	3
43	15	A	3	1	2	1
44		B	2	2	2	2
45		C	4	4	4	4
46	16	A	3	3	3	3
47		B	4	4	4	4
48		C	4	4	4	4
49	17	A	1	1	1	1
50		B	1	1	1	1
51		C	2	2	2	2
52	18	A	1	2	1	1
53		B	2	2	1	1
54		C	3	3	3	3
55	19	A	1	1	1	1
56		B	2	3	2	3
57		C	4	4	3	3
58	20	A	1	2	1	2
59		B	2	2	1	2
60		C	3	3	3	3

APPENDIX II

Debris and smear layer scores for Group 2 (EndoActivator) at each location by two examiners

Specimen	Tooth	Location	Examiner 1	Examiner 2	Examiner 1 repeat	Examiner 2 repeat
1	1	A	2	2	2	2
2		B	3	3	2	3
3		C	1	1	1	1
4	2	A	1	1	1	1
5		B	1	2	1	3
6		C	4	4	3	4
7	3	A	4	4	3	4
8		B	1	1	1	2
9		C	1	2	1	2
10	4	A	3	3	2	3
11		B	4	4	4	4
12		C	1	1	1	1
13	5	A	2	3	3	2
14		B	3	3	3	3
15		C	4	3	3	3
16	6	A	1	1	1	1
17		B	2	2	1	2
18		C	1	2	1	1
19	7	A	1	1	1	1
20		B	1	2	1	1
21		C	1	1	1	1
22	8	A	1	1	1	1
23		B	1	1	1	1
24		C	1	1	1	1
25	9	A	1	2	1	2
26		B	2	2	2	2
27		C	3	3	3	3
28	10	A	2	2	1	2
29		B	1	2	2	2
30		C	2	2	1	2
31	11	A	2	3	2	2

(continued)

APPENDIX II (continued)

32		B	1	1	1	1
33		C	1	2	1	2
34	12	A	1	1	1	1
35		B	1	1	1	1
36		C	2	3	2	3
37	13	A	1	1	1	1
38		B	2	2	2	2
39		C	2	3	2	2
40	14	A	1	1	1	1
41		B	3	3	3	3
42		C	4	4	3	4
43	15	A	3	4	3	4
44		B	4	4	3	4
45		C	4	3	3	4
46	16	A	4	4	4	4
47		B	2	2	3	2
48		C	4	4	4	4
49	17	A	1	1	1	1
50		B	2	3	2	3
51		C	3	2	3	2
52	18	A	2	2	2	2
53		B	2	2	2	1
54		C	3	3	3	3
55	19	A	2	2	1	2
56		B	1	2	1	2
57		C	2	2	2	2
58	20	A	2	2	1	2
59		B	2	2	1	2
60		C	3	3	2	2

APPENDIX III

Debris and smear layer score for Group 3 (Ultrasonic Bypass System) at each location by two examiners

Specimen	Tooth	Location	Examiner 1 score	Examiner 2 score	Examiner 1 repeat	Examiner 2 repeat
1	1	A	1	1	1	1
2		B	2	2	2	2
3		C	2	2	1	2
4	2	A	1	2	1	1
5		B	1	1	1	1
6		C	4	4	4	4
7	3	A	2	3	2	2
8		B	2	2	2	2
9		C	4	4	3	4
10	4	A	2	2	2	2
11		B	1	1	1	1
12		C	1	1	1	1
13	5	A	1	1	1	1
14		B	1	2	1	1
15		C	3	3	3	3
16	6	A	2	2	1	1
17		B	3	3	3	3
18		C	4	3	3	4
19	7	A	1	1	1	1
20		B	1	1	1	1
21		C	1	2	1	2
22	8	A	1	1	1	1
23		B	1	1	1	1
24		C	1	1	1	1
25	9	A	1	1	1	1
26		B	1	1	1	1
27		C	2	2	2	2
28	10	A	1	2	1	2
29		B	3	2	3	2

(continued)

APPENDIX III (continued)

30		C	1	2	1	1
31	11	A	1	1	1	1
32		B	1	1	1	1
33		C	1	1	1	1
34	12	A	1	1	1	2
35		B	1	1	1	1
36		C	1	2	1	2
37	13	A	3	2	2	2
38		B	3	2	3	3
39		C	3	2	3	2
40	14	A	1	1	1	1
41		B	3	2	3	2
42		C	4	4	3	4
43	15	A	1	1	1	1
44		B	2	2	2	2
45		C	3	3	3	3
46	16	A	1	1	1	1
47		B	1	1	1	1
48		C	4	4	3	4
49	17	A	1	1	1	2
50		B	1	1	1	1
51		C	3	3	3	3
52	18	A	1	1	1	1
53		B	1	2	1	1
54		C	4	3	3	3
55	19	A	1	1	1	1
56		B	1	1	1	1
57		C	4	4	3	4
58	20	A	1	1	1	2
59		B	1	1	1	1
60		C	3	3	3	3

ABSTRACT

AN *IN-VITRO* SEM STUDY COMPARING THE DEBRIDEMENT EFFICACY OF THE ENDOACTIVATOR™ SYSTEM VERSUS THE ULTRASONIC BYPASS™ SYSTEM FOLLOWING HAND-ROTARY INSTRUMENTATION

by

Steven Wayne Binkley

Indiana University School of Dentistry
Indianapolis, Indiana

The purpose of this study was to evaluate and compare the debridement efficacy of the EndoActivator (Dentsply Tulsa Dental, Tulsa, OK) versus the Ultrasonic Bypass system (Vista Dental) following hand-rotary instrumentation in anterior teeth. Sixty extracted human, maxillary anterior teeth were randomly assigned to three groups. Teeth were instrumented using (ISO k-flex) hand files and EndoSequence nickel-titanium rotary files (Brasseler, Savannah, GA) to a size 40/.06 taper. Group 1 served as the control group and had no additional treatment performed. Groups 2 and 3 were subjected to a final irrigating regimen that consisted of 6-percent sodium hypochlorite for a 1-minute duration. For group 2 the irrigation solution was activated for 1 minute using the

EndoActivator system (DENTSPLY). For group 3, the irrigation solution was activated for 1 minute using the Ultrasonic Bypass System (Vista Dental). The teeth were then sectioned longitudinally and each half was divided into three equal parts 3 mm from the anatomic apex. The sample with the most visibly identifiable section of the apex was used for SEM evaluation. A scoring system to measure the efficacy of debris removal was utilized to quantify the results. Statistical analysis was performed using the Kruskal-Wallis test. If the overall test is significant, a Wilcoxon Rank Sum tests was used to compare each pair of groups.

The results of this study indicate that both the EndoActivator and Ultrasonic Bypass groups had a smaller percentage of canal space occupied by smear layer and debris when compared with the control group at all three levels. This difference was statistically significant for the Ultrasonic Bypass System when compared with the control at both the coronal and middle thirds of the samples evaluated. This difference was not statistically significant in the apical third. When compared with the EndoActivator, the Ultrasonic Bypass System produced cleaner canals in the coronal and middle thirds, with the difference being statistically significant in the middle third only (Figure 20).

These results of this research support the use of either of these two devices when compared with the controls. Smear layer removal and debridement efficacy was greatly increased when using either sonic or ultrasonic activation of sodium hypochlorite. More research is warranted concerning these two devices. Examining the antimicrobial efficacy with the use of these two devices could lend additional validation to their use in non-surgical endodontic therapy.

CURRICULUM VITAE

Steven W. Binkley

April 14, 1975	Born in Nashville, Tennessee
August 1994 to May 1997	BS in Psychology Vanderbilt University Nashville, Tennessee
July 1997 to May 2001	DMD University of Louisville School of Dentistry Louisville, Kentucky
June 2001 to June 2002	Certificate, Advanced Education in General Dentistry Residency, Pensacola Naval Air Station, Pensacola, Florida
June 2002 to June 2004	General Dentist Marine Corps Recruit Depot Parris Island, South Carolina
June 2004 to June 2008	Private practice general dentist Louisville, Kentucky
July 2008 to June 2010	Certificate, Endodontics Indiana University School of Dentistry Indianapolis, Indiana
July 2008 to June 2010	MSD Indiana University School of Dentistry, Indianapolis, Indiana

Professional Organizations and Licensure

American Dental Association
Kentucky Dental Association
American Association of Endodontists
Pankey Institute Alumni
Kentucky State Dental License