Micro-Computed Tomography of Tooth Volume Changes Following Post Removal

BY

Jiyeon J. Kim
D.M.D., Harvard University, Boston, 2011
B.A., Johns Hopkins University, Baltimore 2007

THESIS

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Defense Committee:
Kent Knoernschild, Committee Chair and Advisor, Prosthodontics
Satish Alapati, Advisor, Endodontics
Damian Lee, Advisor, Ohio State University

This thesis is dedicated to my father, Dr. Yul Kim.

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

CT	Computed Tomography
FRC	Fiber-reinforced Composite Post
GI	Glass Ionomer
RC	Resin Cement
SS	Stainless Steel

SUMMARY

Retreatment of previously root canal treated teeth results in higher long-term success rate than that of periapical surgery. Understanding how much tooth structure is removed based on type of post and cement will help in selecting future therapy for a root canal treated tooth and determine which combination of prefabricated post materials and cement materials should be used in selected cases.

The purpose of our study was to measure tooth volume change before and after post removal using micro-CT and compare the difference amongst different post and cement systems. The posts were removed using ultrasonic vibration technique. Significantly more tooth structure loss was observed in removal of serrated parallel-sided SS posts cemented with GI than other post and cement combinations.

Within the limitations of our study, we recommend the use of serrated parallel-sided SS post and GI cement for primary endodontically treated tooth with low risk for future retreatment. The mechanical retention, in addition to adhesive retention of GI cement to the root dentinal surface, play a major role in post retention of serrated parallel-sided SS posts.

The ease of post removal need to be evaluated before choosing future therapy for a patient who presents with failed primary endodontic therapy. Due to variations in retention of posts cemented with resin cement, its retention cannot be generalized.

1. INTRODUCTION

A. Background

Failures of initial root canal treatment may occur due to complex root canal systems, lack of healing from persistent intraradicular infection or extraradicular causes such as foreign objects (Torbinejad et al., 2009). Previously root canal treated teeth with persistent periapical lesions may be treated with nonsurgical retreatment or endodontic surgery. Studies showed that non-surgical retreatment of previously root canal treated teeth results in higher long-term success rate than that of periapical surgery (Torbinejad et al., 2009). The treatment decision is complicated when a post is present. Posts are used to retain the core when extensive tooth structure is missing. Posts can be drilled, pulled and/or vibrated out. Although, the most critical factor for long term success of a tooth is the amount of remaining tooth structure, the process of post removal inevitably involve tooth structure removal.

B. Statement of Problem

There is a lack of data available on exactly how much tooth structure is removed based on the type of post material and cement used. Some studies find posts cemented with resin cement had more retention that those cemented with other cements and other studies find the opposite to be true. Some studies find better retention involved with fiber posts and others find metal posts to be more retentive. We predict that more tooth structure is lost when removing a post that has more retention.

C. Purpose and Significance of Study

The purpose of this study is 1) to objectively calculate the volumetric change of previously endodontically treated teeth before and after prefabricated post removal and 2) to illustrate a micro-CT method for accurate dentin volume comparison among teeth specimens by measuring the change in tooth volume. The change in tooth volume is measured by the use of micro-CT. Conventional radiography is limited to a two-dimensional image. CT collects images from multiple viewing angles to reconstruct a three-dimensional image. The results of this study will help with the selection of future therapy of a root canal treated tooth—retreatment, apical surgery or implant therapy—and also aide clinicians in selecting which combination of prefabricated post materials and cement materials should be used after primary endodontic therapy is complete.

We tested the null hypothesis that there is no statistically significant difference in tooth volume changes following post removal for different prefabricated post and cement combinations.

II. Literature Review

A. Root Canal Therapy and Failures

The purpose of root canal therapy is to clean, shape and seal the root canal system to prevent re-infection of the tooth while maintaining normal function of the tooth. Root canal therapy has been proven to be a predictable procedure with a high success rate. (Torbinejad et al., 2009) The goal of the Toronto study project established in 1993 was to evaluate the prospective 4-year and 6-year outcome of root canal therapy provided by endodontic residents. 86% of the 510 treated teeth were free of disease and 94% remained asymptomatic after 4-6 years (de Chivigny et al., 2008). These results are consistent to the results of the systematic review of success and survival rate of root canal treatment, published by Torabinejad et al in 2009. In this study, the mean 1-6+ year success and survival rate of twenty-five studies was high, ranging 84-97%.

1) Cause of Endodontic Failure

Primary endodontic therapy can fail for many reasons. The most common reason for failure is inadequate apical seal, persistent intraradicular infections residing in insufficiently cleaned canals/previously uninstrumented canals/dentinal tubules/complex irregular root canal systems, and/or coronal leakage from exposure to the oral environment. Extraradicular causes of primary endodontic failure include periapical actinomycosis, extruded endodontic materials, an accumulated endogenous cholesterol crystals or unresolved cystic lesions. (Torabinejad et al., 2009; Paik S et al., 2004)

Coronal leakage of oral flora results from the loss of temporary or permanent restoration, or restorations with inadequate marginal seal. Swanson and Madison (1987[1]) evaluated the time dependent extent of coronal microleakage in endodontically treated teeth by measuring the dye penetration of extracted singled rooted human teeth. The extent of contamination of the entire root canals was similar in teeth exposed to saliva 3 days and 8 weeks. Therefore, the authors emphasized the importance of placing a permanent restoration or temporary material with good coronal seal as soon as possible after primary endodontic therapy is performed. When a post is involved, the retention of post without debonding is crucial to minimize the amount of coronal leakage for a long-term success of an endodontically treated tooth.

2) Treatment of Failed Root Canal Therapy

Assuming the tooth is restorable, a failed root canal treated teeth can be preserved with nonsurgical retreatment or endodontic surgery. This treatment selection may be challenging to the clinician and patient. The general consensus, however, selects nonsurgical retreatment as the preferred treatment option unless specific cases where a retreatment or post removal may be difficult and would result in higher complications such as root fractures. The outcome of retreatment is more predictable and successful than that for retrograde/surgical therapy and therefore, is a preferred treatment to previously root canal treated tooth for many practitioners (Allen et al., 1989; Molven et al., 1991). A systematic review by Torabinejad in 2009 included 34 studies published up to 38 years before and most of which were low level studies due to lack of high level endodontic studies regarding endodontic surgery and nonsurgical retreatment. This is due to the difficulty of conducting high level endodontic retreatment studies such as randomized double-blinded studies (Paik S et al., 2004). In light of these limitations, the Torabinejad systematic review concluded increased long-term 4-6 year success rate involved with nonsurgical retreatment at 83% (72% for apical surgery), although higher 2-4 year initial success is observed with endodontic surgery at 78%, compared to 71% of retreatment success. Majority of included studies agreed that the presence of apical periodontitis as an indication for retreatment. Larger lesions were related less favorable outcome. The quality of previously treatment directly correlated to the success of retreatment procedures. The authors of the Toronto study (de Chivigny et al., 2008) suggested a failure of well-obturated tooth may be due to extraradicular factors and therefore, may not respond favorably to retreatment. Preexisting procedural accidents such as transportations, ledging and perforation resulted in 31-40% drop in success rates.

B. Restorative Components of Root Canal Treated Tooth

1) Post and Core Systems

Majority of endodontically treated teeth have increase loss of tooth structure and require core build-up and/or posts to retain the core. Prefabricated posts are metal (titanium and stainless steel) or ceramic (zirconia) or reinforced-fiber/composite materials. Metal prefabricated posts, such as titanium and stainless steel, have been traditionally used successfully due to their high strength and affordability. However, the high elastic modulus of metal compared to dentin could induce stress in the radicular dentin, resulting in root fractures. Fiber posts, on the other hand, have an elastic modulus similar to dentin and can absorb forces concentrated along the root, decreasing the serious complication of root fracture. However, its flexibility could result in more frequent debonding inside root canals.

Teeth with severe loss of tooth structure require cast posts-and-cores. Although cast posts-and cores eliminate the risk of separation between the post and core, the apical portion of the post may produce a wedge effect that can result in a root fracture. Despite their limitations, prefabricated metal and fiber posts and cast posts-and-cores have shown high success and survival rates (Balkenhol et al., 2007; Fokkinga et al., 2007; Gomez-Polo et al., 2010). Studies that compare the survival rate of endodontically treated teeth restored with prefabricated posts versus cast metal posts-and-cores, generally conclude no significant differences between both groups. The retrospective study by Gomez-Polo et al. compared the 10-year cumulative survival rate of teeth restored with prefabricated posts and those with cobalt-chrome cast post-cores. The study concluded no statistically significant difference between both groups with a survival rate of 84.6% for prefabricated posts and 82.6% for cast posts and cores (Gomez-Polo et al., 2010). Similarily, a 10-year retrospective study by Balkenhol found the average survival time of cast post-and-cores to be 7.3 years (Fokkinga et al., 2007). The retention of posts, however, may be improved in cast post and cores due to intimate fit with the prepared post space.

Although there are many reasons for failures of post and core systems, studies generally agreed that the loss of retention of posts was the most common reason (Goodacre and Spolnik, 1994). According to Turner (1982), out of 10 post and core failures, 59% were caused by post loosening. Apical lesions and caries were the following most common reasons. Another study found, 13 out of 26 failures to be caused by post debonding (Sorenson and Martinoff,1984), followed by tooth fractures and post operations.

Although threaded posts are most retentive, these posts resulted in higher rates of severe complications such as tooth fractures. The threaded posts are wedged into the prepared post space, creating micro-cracks and undesirable stress onto the root dentinal walls. Tapered posts resulted in significantly less retention and higher chance of root fractures. The combination of tapered and threaded post design significantly increased the chance of root fracture even more. Therefore, the use of threaded posts had been replaced with the use of cemented parallel posts.

Serrations on parallel posts increased the mechanical retention of the post as well. (Goodacre and Spolnik, 1994)

Post length is a major factor that determines the retention of a post—longer the post length, the better the retention. There are various recommendations on the ideal post length. Goodacre 1995 reviewed current literature and studies, recommending the post to be ¾ of the root length as long as it does not compromise the apical seal. Conservation of tooth structure is the most important factor to long-term success. The post diameter should require minimal canal instrumentation and should be no more than 1/3 of the width of the root at any location and the post tip should be 1mm or less. Following these recommendations may prevent post perforations and root fracture. (Goodacre and Spolink, 1995; Mclean 1998)

2) Cements

Although, post retention is primarily influenced by post length, cement plays a significant role as well. Generally used cements for post cementation include zinc-phosphate, glass-ionomer (GI), resin-modified glass ionomer and resin cements (RC). There are conflicting literatures on what kind of cement provides the best retention. Chapman in 1985 tested the retention of prefabricated para post using different cements—zinc phosphate, zinc polycarboxylate, GI and two composite resin materials—by axial tensile testing. He found no difference in retention with zinc phosphate, zinc polycarboxylate, GI and one composite resin (Dent-Mat core paste). However, the other composite resin (P-10) had significantly less retention value than the other four materials. (Chapman et al., 1985). The retentive strength of GI cement has been linked to be comparable to zinc phosphate (Chapman et al., 1985; Tjan et al., 1987; Mendoza and Eakle, 1994). In addition to its mechanical retention, GI chemically bonds to calcium ions on the dentin surface. In addition, GI cement also has higher compressive strength and is easier to use than zinc phosphate (Mendoza and Eakle ,1994). Therefore, the use of zinc phosphate has decreased and the use of GI has increased over the years.

3) Sealers

Sealers are used to seal the space between gutta-percha fillings during the obturation process. Some of the endodontic sealers used include eugenol containing sealers, resin sealer, or calcium hydroxide sealer. Most of these sealers dissolve with time, leaving voids that potentially promote leakage (Wu et al., 2000). The study evaluated the long-term seal of gutta-percha without sealer and with sealer in extracted endodontically treated maxillary central incisors by measuring the leakage at 48 hours and 6 months. Significantly more leakage was observed when the sealer was not used at 48 hours. After 6 months, however, the amount of leakage decreased to a similar value to when a sealer was used. The authors contributed this improvement in seal to the volumetric increase of gutta-percha by water absorption. The findings of this study confirmed the necessity and importance of using sealer to reduce leakage, especially short term.

The primary reason of restorative failure of a primary endodontically treated tooth is post dislodgement (Goodacre and Spolnik, 1994, Turner et al.,1982). The use of RC has been suggested to improve the retention of the post with the adhesion of composite resin to dentin, especially with the use of dentin adhesives on the radicular dentin. Many of these studies, however, failed to include the clinically relevant step of obturating the canal space (Hagge et al., 2002). Eugenol is thought to inhibit composite polymerization by interacting with the free radical. This interaction with free radicals will lead to decrease in the rate of initiation or an increase in the rate of termination of the polymerization process (al-Waazan et al., 1997).

There are conflicting literatures on whether this interaction is clinically significant. Several studies have shown decreased bond strength of resin cement from eugenol containing products. Al-Waazan observed significantly less bond strength of two resin composite core materials to dentin when eugenol-containing temporary cements were used compared to when non-eugenol containing temporary cements or no cements were used. Tjan and Nemetz (1992) found residual eugenol from sealer to substantially reduce the retention of prefabricated posts luted with Panavia composite resin cement. The teeth specimens from this study, however, were not obturated and eugenol-containing endodontic sealer liquid was dropped into the canals and stored in humidor before the posts were cemented. Therefore, the clinical relevance is questionable but the authors recommended irrigation with ethyl alcohol (ethanol) or etching with 37% phosphoric acid gel to effectively restore the retention of posts. Interestingly, the use of citric acid and acetone adversely affected the retention of posts. Despite these issues, eugenol-containing sealers have been and are still preferentially used by clinicians due to its long history of clinical success.

A study by Schwartz et al (1998) compared the effect of eugenol containing sealer and resin-based sealer on the retention of posts cemented with zinc phosphate and composite cements. Post spaces were cleaned with EDTA, as previously recommended by Goldman et al. They found no significant differences of retention strength of posts between the use of both sealers and authors recommend the use of zinc phosphate due to its ease of use and economics. However, this may be due to the fact that the specimens were stored in water for a week and eugenol is soluble in water. Hagge et al (2002) compared the retention of posts in three major classes of sealers—eugenol containing, resin and calcium hydroxide—with that of unobturated controls. Although they found that unobturated controls had significantly higher retention strength than obturated canals with eugenol-containing sealer, there was no significant difference among the other groups. Therefore, the clinical relevance of polymerization inhibition from eugenol was not significant according to this study.

C. Procedures for Retreatment

1) Root Fracture from Post Removal

Many dentists and endodontists, believing post removal can lead to root fractures, avoid non-surgical retreatment of previously root canal treated tooth with a post. According to a survey of American endodontists (Stamos and Gutmann, 1993), many endodontists believe that post removal devices were dangerous and could not be used or did not work. Having a post was a common reason to recommend periapical surgery rather than attempting to remove the post for retreatment of root canal therapy. Among the reasons were intact post and crowns (63%), to avoid root fracture (57%), a large/long/threaded posts (28%), and when one could not remove the post after reasonable effort (88%).

In contrast to US trained endodontists, Australia and New Zealand trained endodontists reported that post removal was a common procedure and related root fractures were rare (Castrisos and Abbott, 2002). Abbott believed these differences in attitude towards post removal may be related to the individuals' dental training rather than being related to scientific evidence. Abott's retrospective study aimed to determine the success of various post removal techniques and the incidence of root fractures during post removal in a group of patients at an endodontic practice. Out of 1600 teeth, only one root (0.06%) fractured during post removal. The study concluded that root fracture is a rare occurrence and post removal is a predictable procedure with good case selection and proper technique. (Abbott 2002)

Clinical studies reported the occurrence of root fractures ranging from 2.6-10% of post and core failures (Turner et al., 1982; Hatzikyriakos et al., 1992). Surgical therapy is recommended in certain cases where teeth are identified as being predisposed to root fracture—when a wide post is present in a thin root—or when a crown was recently delivered, and due to financial reasons. The Toronto study observed a 36% decrease in success rate of nonsurgical retreatment of teeth that previously had adequate filling according to length and density of obturation. The authors suggested that his may be due to the fact that the etiology of failure in well-obturated teeth may be extraradicular and involve conditions that may not respond favorable to retreatment. Several studies found preexisting procedural accidents, such as ledging, transportations, and perforations, to have a negative effect on success of nonsurgical retreatment. (de Chivigny et al., 2008; Abbott, 2002)

2) Removal of Posts

The removal of post and cores without weakening, perforating, or fracturing the remaining root structure for nonsurgical retreatment of previous root canal treated tooth can be difficult. The level of difficulty of post removal varies according to the post type (cast or prefabricated), post material (cast metal, zirconia, titanium, aluminum), design (conical, parallel, flat or serrated), post length and cementing agent (zinc phosphate, zinc polycarboxylate, GI or RC) (Gomes et al., 2001). Conical and threaded posts have been known to concentrate unfavorable forces resulting in higher rates of root fracture than parallel posts.

Abbott identified 31.8% of 1600 cases where the cast posts/cores were removed with the crown. This incidence supported the leakage of restorative margins between the luting cement and post and cores, reinforcing the need of retreatment of the root canal to remove the etiologic factor that is causing the infection within the canal. (Abbott 2002).

Posts can be removed by many techniques such as grinding with burs or trephine, using special removal devices that allow grasping and pulling of the posts, and the application of ultrasonic vibrations. Grinding results in increased loss of tooth structure and consequently weakens the already weakened tooth. It is difficult to control a high-speed bur within a small confined space and the uses of end-cutting burs have a tendency to slip off the surfaces. Ultrasonic vibration technique involves the initial removal of tooth structure and luting cement from around the post to place the ultrasonic tip and applying the ultrasonic vibrations to transmit mechanical energy through the post to disrupt the cement bond between the post and wall of root canal system. This technique has been advocated for minimal loss of tooth structure, decreased risk for root fracture and ease of use.

It is assumed that positioning the ultrasound tip at the incisal surface maximizes the energy transferred to the post. An in vitro study by Braga et al compared different ultrasonic vibrations modes for removing intraradicular cast posts. Cast posts were cemented with zinc phosphate in 24 extracted maxillary canines. The specimens were randomly divided to three groups—no ultrasonic vibration, ultrasonic tip placed perpendicularly to the incisal core and tip placed perpendicularly to the cervical core. The study found the mean tensile strength to dislodge the posts were significantly lower when the ultrasonic vibration tip was placed at the cervical area and concludes this technique is the most effective way to reduce of the retention of the cast post to the root canal system. (Braga et al., 2012)

Studies concur on the effectiveness of ultrasonic vibration in reducing the retention of posts cemented with zinc phosphate or GI. Gomes found ultrasound technique significantly decreased the retention force of posts cemented with zinc phosphate and GI but not those with RC. (Gomes et al., 2001) Johnson found that 16 minute application of ultrasonic vibration significant decreased the tensile force to dislodge Para post cemented with zinc phosphate to a depth of 9mm in extracted human premolars (Johnson et al., 1996).

The effects of ultrasound on removal of posts cemented with resin cements, however, show conflicting results. Some studies showed vibrations had little or no effect on the retention of posts (Gomes et al., 2001; Hauman et al., 2003). Hauman's study aimed to determine whether metal type (titanium and stainless steel), cement type (zinc phosphate, glass ionomer, composite resin cement) and the use of ultrasonic vibration, influences the retention of the post system by comparing the tensile force required to remove parallel prefabricated metal posts from tooth roots. He found that 16 minutes of ultrasonic vibration was not enough to loosen the posts and found no statistically significant differences between any of the groups. The study concluded that metal type, cement type and ultrasonic vibration did not affect the retention of posts. (Hauman et al., 2003)

Other studies found effective reduction of retention of posts cemented with resin cements. An in-vitro study by Soares et al found significantly higher ultrasound application time was necessary to remove posts that were cemented with resin cement (C &B; Nisco) than those cemented with glass ionomer or zinc phosphate cement (Soares et al., 2009)

D. Micro-Computed Tomography

1) History

CT was first clinically introduced in the early 1970's. The three dimensional data generated by the CT scan offered a real life view or slices of the entire field of view from all angles of the patient. The first bench-top micro-CT was used to visualize bone microarchitecture via cone beam geometry in the 1980s. Currently the micro-CT has developed to screen small animals for drug discovery, cancer detection and monitoring and genomic research. (Ritman, 2004) In dentistry, mineralized specimens such as teeth, bone, materials such as ceramics, polymers, biomaterial scaffolds can be examined directly using micro CT (Swain and Xue, 2009). All micro CT scanners have an x-ray source, specimen and x-ray imaging device. The three main approaches in micro-CT include the cone beam, optical magnification and Bragg diffraction. The cone beam magnification approach is preferred where speed is an important factor as in treating dental patients. (Ritman 2004)

2) Advantages of Micro-CT

Micro-CT provides a much better spatial resolution with 1,000,000 times smaller voxels than clinical CT with 1 cubic mm voxels. The use of micro-CT is increasing in various areas of dental research, including dental anatomy, craniofacial and skeletal anatomy, tissue engineering, implant dentistry and endodontics. Micro-CT is used to measure the mineral concentration of bones and teeth, providing a nondestructive and precise method by avoiding irregularities from physical cutting of specimen. The enamel thickness is studied in anthropological studies in human evolution. The enamel thickness had been measured in the past by physical crosssectional method that destroys the specimen. The application of micro-CT has become an effective and nondestructive technique to measure the enamel thickness of variety of archaeological specimens. High-resolution micro-CT system is also used in nondestructive analysis of trabecular bone and in the research of craniofacial skeletal development, structure and investigation of bone growth and repair. Micro-CT enables a precise finite element of both teeth and bones to study the distribution of stress when a load is applied. In tissue engineering research, micro-CT has been used to characterize scaffold architecture, in-vitro scaffold degradation and bone growth into polymeric and calcium phosphate scaffolds. The success of dental implant therapy is determined by the osseointegration of the interface of bone and implant. The use of Micro-CT as a nondestructive and precise method in studying implant and peri-implant bone has been increasing in recent years. (Swain and Xue, 2009)

3) Micro-CT and Endodontics

Micro-CT system is widely used in the field of endodontics to improve quality of care for patients. In endodontic treatment, it is critical to understand the three dimensional root canal morphology and changes associated with root canal therapy to provide successful treatment. In-vitro methods of studying root morphology such as tooth sections and dye preparation are destructive and result in irreversible changes in the specimen. As mentioned earlier, micro-CT system undoubtedly provides a noninvasive and accurate method to study complex root canal systems. Bjorndal in 1999, reconstructed a 3D image of both external and internal morphology of a tooth and analyzed the relationship between these systems. Micro CT also provided valuable information in understanding the anatomic variations of C-shaped canal, one of the most complex anatomic variations of the canal system (Cheung et al., 2007). In addition to understanding root canal anatomy, micro-CT allows us to study the changes associated with root canal therapy. Ikram in 2009 compared tooth tissue volume changes following endodontic procedures with micro-CT and concluded that access cavity and post space preparation are the steps, which result in the largest loss of hard tissue structure and should be performed with caution. He also found that cast post space preparation caused a larger loss of tooth structure than prefabricated post space preparation. Therefore, this should be taken into account when selecting restorative treatment for root canal treated teeth. Canal preparation is the most important step for successful endodontic therapy but is adversely influenced by canal anatomy and the visualization of the operator. The efficacy of different instruments performance can be fully evaluated with the micro-CT systems. Numerous studies have evaluated and compared different root canal instruments with micro-CT. The changes in surface area and volume of root canal, amount of dentin removed, canal thickness, prepared surface and prepared canal anatomy can be measured with the data from micro-CT scans. (Swain and Xue, 2009) According to these studies, it is believed that variations in canal anatomy before preparation have more influence on the changes during preparation than techniques or instruments themselves (Peters et al., 2001). Micro-CT was also used to evaluate the effectiveness of instrumentation for retreatment of canals by Hammad in 2008. The results concluded that the filling material could not be completely removed during retreatment by using hand or rotary files. However, Gutta-percha was most efficiently removed by hand K-files.

4) Micro-CT and Research

The Micro-CT has certainly improved the quality of patient care in diagnosis and treatment. However, it has also proven useful in wide areas of dental research by efficiently providing high resolution images for qualitative and quantitative analysis of tooth, bone and implants. Results of these imaging dental researches can provide valuable information in understanding and treating patients. The future development of micro-CT systems with better resolution with a lower cost will certainly increased its use in both in vitro and in vivo dental research studies and in patient care.

III. Material and Methods

A. Specimen Collection

Forty-eight (48) extracted virgin maxillary central incisors, canines and mandibular canines were collected without any identifiers from the Oral Surgery department at University of Illinois-Chicago, College of Dentistry. These teeth were mechanically cleaned with manual scalers to remove all external debris and soaked in formaldehyde. They were maintained in Hanks balanced saline solution in room temperature during the duration of the study.

Specimens were randomly assigned and coded for two groups, 24 teeth for each group as shown in Table 1. First group received a serrated parallel-sided SS post (Para post, Coltene/Whaledent Inc.) and the second group received a glass-fiber reinforced composite (FRC) post (FRC Postec Plus, Ivoclar Vivadent). Half of the specimens were cemented with GI cement (Ketac-Cem, 3M ESPE) and the other half with self-adhesive RC (SpeedCem, Ivoclar Vivadent).

TABLE 1. SPECIMEN GROUPS

Group (#)	Post System	Luting agent
1 (12)	Serrated Parallel-sided Stainless Steel Para Post (Coltene/Whaledent Inc.)	Ketac Cem Glass Ionomer Cement (3MESPE)
2 (10)		SpeedCem Self-Adhesive Dual-curing Resin Cement (Ivoclar Vivadent)
3 (11)	Glass-fiber reinforced Composite Post (Ivoclar Vivadent)	Ketac Cem Glass Ionomer Cement (3MESPE)
4 (12)		SpeedCem Self-Adhesive Dual-curing Resin Cement (Ivoclar Vivadent)

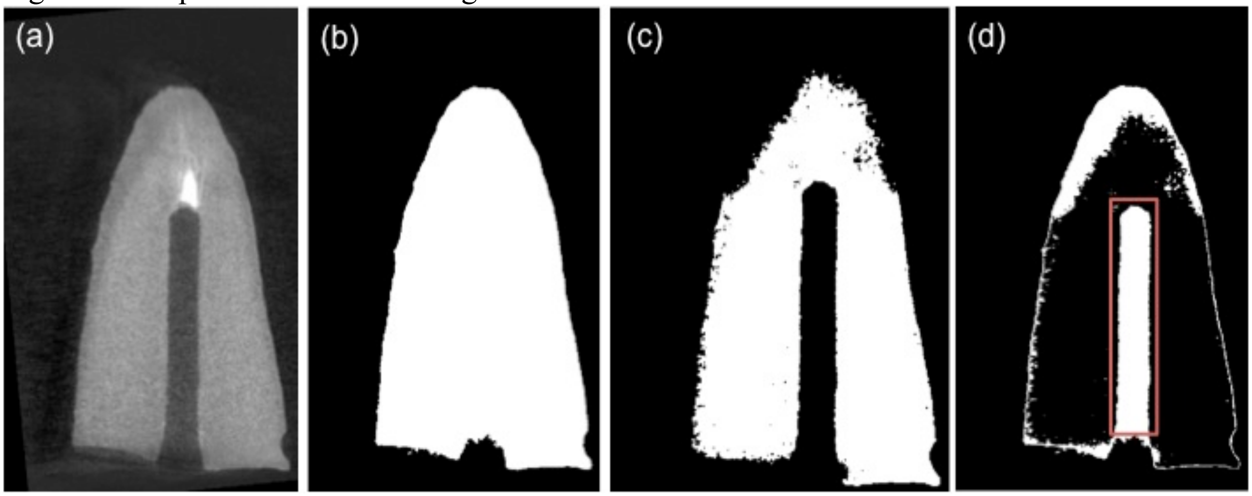
B. Tooth Root Preparation

All teeth were marked 13mm from the apex and sectioned with a high-speed carbide bur with copious water irrigation. The 13mm working length of root canal was measured using a size 10 K-file. The working length was determined when the file was moved backwards from apical foramen until it was no longer visible. The working length was prepared up to a size 45 K-file and step up flaring technique at 1mm increments was performed in preparing the root canal. RC prep was used for lubrication and water was used for irrigation during the cleaning and shaping process. Master file was used between the different size files in order to recapitulate the working length space as well. Prepared root canal spaces were cleaned with alcohol, rinsed with saline solution and completely dried with paper points. The spaces were filled with gutta-percha points covered with a thin layer of Roth's 801 Elite Grade cement (Roth International) via lateral condensation technique using a finger spreader.

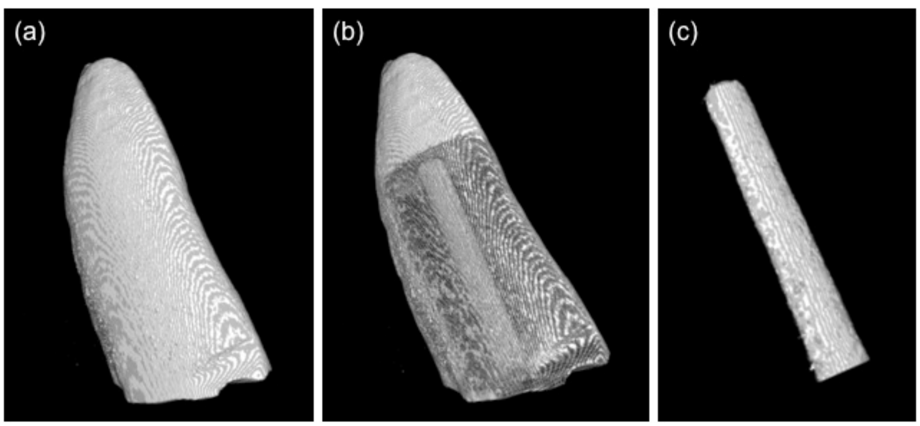
C. Post Space Preparation and Removal

8mm of gutta-percha from the coronal root was removed with the touch and heat device, leaving 5mm of gutta-percha from the apex of the root to reflect adequate apical seal in clinical situations. Size 3 Parapost drill (Coltene/Whaledent) and size 1 reamer (Ivoclar Vivadent) were used on a low-speed hand piece to prepare the post spaces for an intimate fit with their assigned post system. The post space of 8mm was checked for all specimens with a periodontal probe. Specimens were scanned with Skyscan 1172 Micro-CT to establish objective baseline volume of post space (Figure 1). Specimens were stored in Hanks balanced saline solution at room temperature for two weeks.

Figure 1. Pre-post Cementation Image



(a) Original image, (b) Binary image with filled root, (c) Threshold image, (d) Subtraction of image c from image b

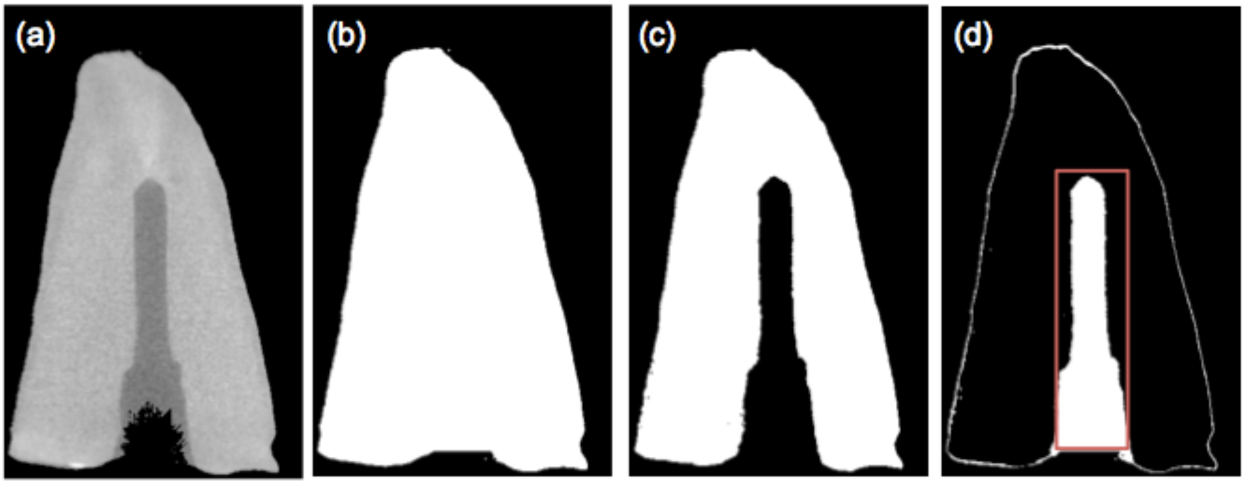


(b) Binary image with filled root, (c) Subtracted image, (d) Isolated post space

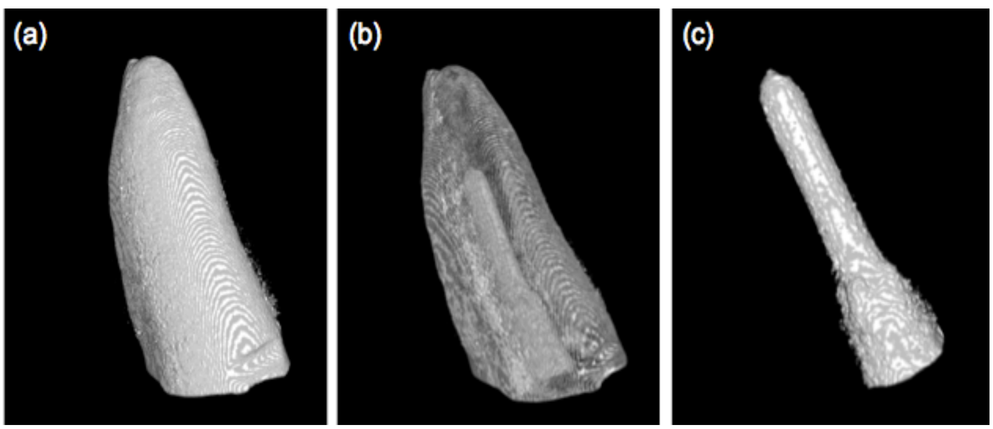
Post spaces were rinsed with water and thoroughly dried with large paper points. The glass-reinforced composite posts were cleaned with phosphoric acid etching gel (Total Etch) for 60 seconds, thoroughly rinsed with water and dried. They were silanated (Monobond-S, Ivoclar Vivadent) for 60 seconds and dried with an air syringe, as recommended by the manufacture. A thin layer of designated cement, according to assigned groups, was coated all around the posts. The posts were seated in pumping motion to allow for full seating without voids. The curing of the self-curing RC was accelerated with 20 seconds of light activation and excess cement was removed. The specimens were stored in Hanks balanced saline solution for two weeks at room temperature.

The posts were removed under an endodontic operating microscope. The posts were removed by making a small trough around the post with a ¼ round bur to allow for a purchase point for the ultrasonic tip. The posts were vibrated using an ultrasonic device without irrigation, until the posts became visibly loose. A deeper trough was created when the post was not loose after 15 minutes of ultrasonic vibration. Once loose, the posts were pulls out with a hemostat. This post removal technique was chosen because it is commonly performed by endodontists. All residual cements in post space were removed with the ultrasonic vibrating device. The post spaces were cleaned with water and paper points before being inspected with an endodontic operating microscope. Specimens were scanned using micro-CT again to determine new post space (Figure 2).

Figure 2. After Post Removal Image



(a) Original image; (b) Binary image with filled root; (c) Threshold image; (d) Subtraction of image c from image b



(b) Binary image with filled root; (c) Subtracted image; and (d) Isolated post space

D. Micro-computed Tomography and Data Collection

Three tooth root specimens were mounted on a 2.5cm diameter circular styrofoam block as far away from each other as possible to minimize diffraction of radiographic beams during scanning. The specimens were scanned by a micro-CTscanner (SkyScan 1172-D, Kontich, Belgium) with the scanning and reconstruction voxel sizes set at 27×27×27 μm^3. The same scanning conditions (70kV, 141μA, 0.4° rotation per projection, 8 frames averaged per projection, and 120ms exposure time) were maintained for scanning of all specimens. The isolated post space for each tooth root was calculated by subtracting the scanned image from a binary image with a filled root. Based on a calibration curve of known density phantoms scanned under the same conditions, the acquired tooth voxel was converted to the tissue mineral density of the tooth. Non-tooth voxel outside the tooth root were cleaned using a heuristic algorithm as described by Kim et al., 2004. All masking and compartmentalizing steps were performed using the J software (NIH) to isolate the region of the root canal. Threshold value was confirmed with comparing between original scanned image [Fig. 1(a)] and the segmented threshold image [Fig 1. (c)].

The volume change was calculated by comparing the before and after post removal radiographic data for each tooth (Table II). Specimen data that had a negative difference were removed from calculations, leaving the number of specimens for group 2, 3 to be 10 and 11. The percentage changes of mean volume for group 1,2,3,4 were 81.3%, 42.2%, 25.4% and 35.0% in order. The volume change was be calculated by comparing the before and after post removal radiographic data for each tooth.

TABLE II. TOOTH VOLUME CHANGE

Group	**Before (mm^3)**	**After (mm^3)**	**% change**
1	5.77+/- .56	10.47+/-2.18	81.3%
2	5.21+/-1.47	7.41+/-.82	42.2%
3	5.78+/- 1.04	7.25 +/- .90	25.4%
4	4.21+/-1.36	5.69+/-1.00	35.0%

IV. Results

Statistical analysis of the data was carried out using SPSS package (release 11.0, SPSS Inc., Chicago, IL). The statistical difference of tooth root volume change between the different groups was measured using Kruskal-Wallis analysis of variance (ANOVA) test (Figure 3,4), revealing a statistically significant difference ($p<0.001$). The null hypothesis that a difference does not exist among various post and cement systems in the volumetric radicular dentin loss after a post is removed from an endodontically tooth was rejected. Based on these results, each group was evaluated separately using post-hoc Tukey examination (pairwise multiple comparison) to determine which groups resulted in the significant difference. The post-hoc exam revealed a statistically significant difference in tooth volume change between group 1 (stainless steel para post cemented with GI cement) and the other groups ($p<0.0002$). There was no significant difference in tooth volume changes among groups 2,3, and 4 after post removal.

Figure 3. Percentage Tooth Volume Change (%)

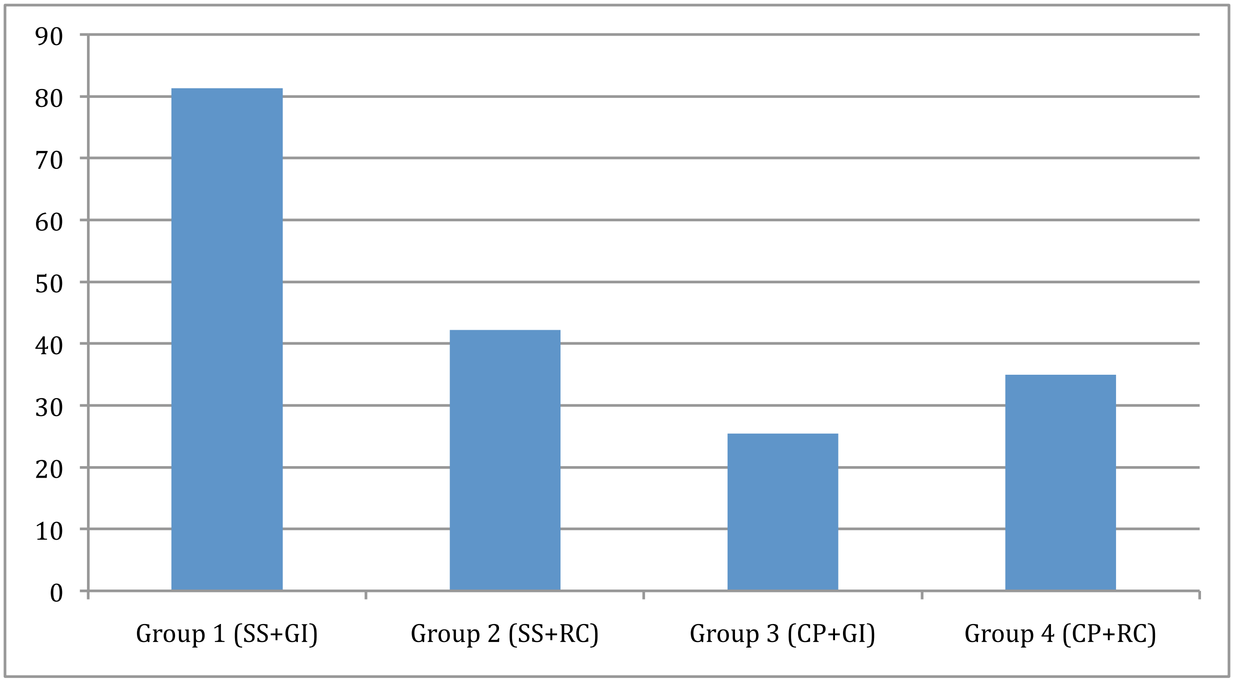
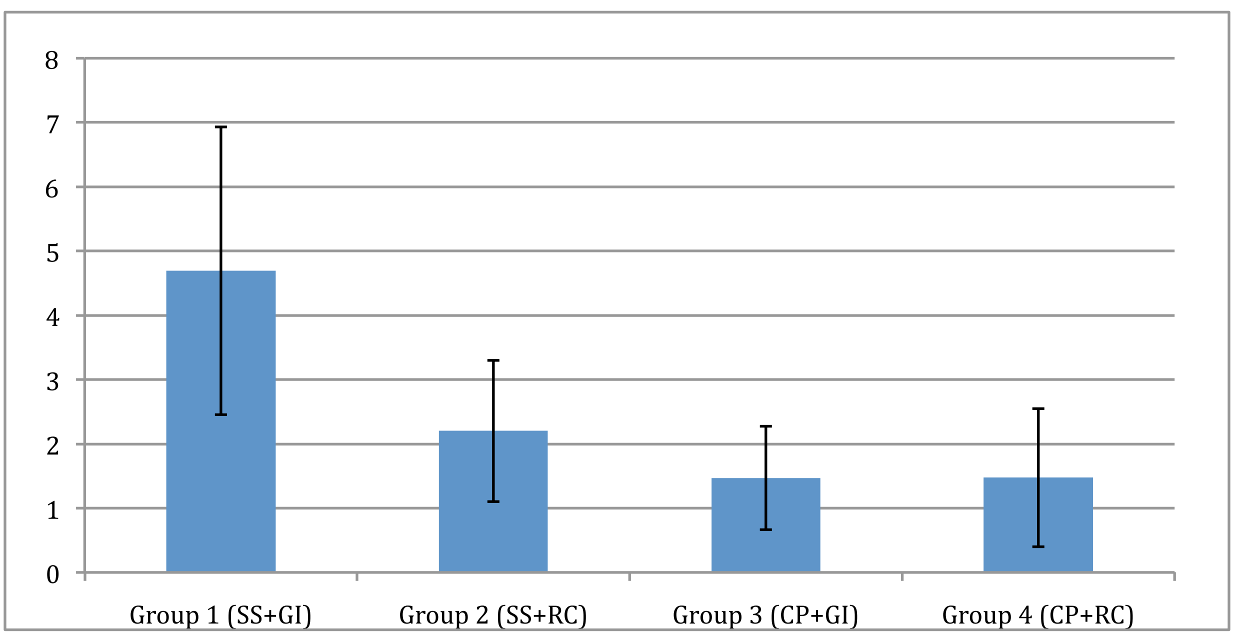


Figure 4. Post Space Volume Change (mm^3)



V. Discussion

A. Comparison of Our Study Results and Previous Studies

The results of this study did not agree with previous studies that demonstrated that resin cements provided greater retention than non-resin cements, such as GI cement (Utter et al., 1997). However, these studies have been criticized for not including the clinically relevant step of root canal obturation. When obturation step is ignored, resin cement does result in greater retention than other cements (Hagge et al., 2002)

A study by Mendoza and Eakle in 1994 had observed that Ketac-Cem (GI cement) provided retention similar to Panavia and was greater than that of All-bond 2 resin cements. The authors also found that resin cements required a greater amount of technique sensitivity than GI cement due to the fact that it can set prematurely, preventing complete seating of posts, also needing the exclusion of air and additional steps for proper cementation. The study also sheds light to the fact that resin cements are not all the same and each cement should be carefully evaluated before use. (Mendoza and Eakle 1994)

Another study observed difference in retention strength among five luting cements on prefabricated posts in root canals obturated with gutta-percha and zinc-oxide eugenol (ZOE) sealer. The five groups were Panavia 21, Ketac-Cem glass ionomer, Fleck's zinc phosphate, Parapost composite cement, and C&B Metabond 4-Meta. The control group with Panavia 21 without obturation, had significantly greater retention than all other groups. GI had significantly greater retention than zinc phosphate or Parapost composite cement. Panavia 21 had greater retention than zinc phosphate and parapost cement. Interestingly, GI and Panavia had similar retention strength despite the use of ZOE sealer. (Hagge et al., 2002).

A few studies that investigated the effect of luting cements on post retention on obturated root canals consistently find that different resin cements have different retention values; therefore, the retention of RC cannot be generalized. (Hagge et al., 2002; Mendoza and Eakle 1994) In this study, SpeedCem (self-adhesive dual-curing RC) did not provide the same amount of retention as GI cement. However, this character cannot be generalized to other resin cements. The base of SpeedCem cements has a filler content of 75% weight. Having high content of filler certainly improves the mechanical properties but not necessarily the adhesion of the post to root dentin.

The percentage of tooth volume reduction observed in the different groups in this study was consistent with the expected post retention values related to post design. Studies agreed that serrated parallel posts have higher retention values than smooth tapered posts. The serrated parallel-sided SS posts (Group 1,2) resulted in more tooth structure loss, therefore, higher retention with either cements compared to that observed in smooth tapered FRC posts (Group 3,4). The purposed mechanism of bonding is mechanical for the serrated post design. The higher percentage tooth loss observed in group 4 compared to group 3, may be due to the improved adhesive bonding observed between the FRC post and resin cement. This was not present in group 3, between the FRC post and GI cement. Group 1 resulted in significantly more tooth structure loss than the other group possibly due higher post retention from the mechanical bonding of serrated parallel-sided SS posts, in addition to the bonding between the GI and root dentin.

B. Affect of Sealer

Roth's sealer, a eugenol-containing cement, was used in our study due to the fact that it is widely used by clinicians. Although eugenol is thought to inhibit the polymerization of composite by interacting with the free radicals, the use of eugenol-containing cement as a sealer may or may not have played a role in decreased retention of resin cemented posts in our study. After obturation and imaging, the posts were stored in water. Eugenol is soluble in water, therefore, it most likely played a limited role in the reduction of retention observed in posts cemented with RC in this study.

C. Affect of Cement

Ideal restorative materials should have good adhesion to tooth structure and an ability to withstand the occlusal forces. Dentinal bonding of RC is questionable. GI, however, adhere to both enamel and dentine through an ion exchange mechanism. (Choi et al., 2011) The adhesion results as the phosphate ions from the tooth structure are displaced by carboxyl groups of polyalkenoic acid, which is the liquid part of the GI. The displaced phosphate ion takes with it a calcium ion to maintain electrolytic balance (Mount et al., 1998). This layer of covalent adhesion is permanent (Mickenautsch et al., 2011).

The use of self-adhesive dual curing RC, Speed-Cem, may be the reason for the ease of removing the posts in our study. A study compared the shear bond strength of self-adhesive resins and convention resin cements that required etch and rinse adhesive to enamel and dentin in vitro. The study found the shear bond strength to be lower in dentin and also concludes self adhesive resin cements have inferior bond strength than conventional composite resin cements. (Luhrs et al., 2010) Although we used the appointed RC to the FRC posts and followed all the necessary steps to post cementation recommended by the manufacturer, we found it easy to remove the post and less tooth structure was removed than the other groups tested.

D. Heat and Technique of Ultrasonic Vibration

The ultrasonic vibration was applied to the specimens for a significantly long time to loosen the post system, especially for group 1, and therefore the times were not recorded and compared. The long time required to loosen the post from its tooth root may be due to the fact that the posts were cemented in optimal settings and were only cemented for short time period without function. The smallest diameter para posts were cemented at 8mm, leaving 5mm of apical gutta-percha in a dry environment. Many times in clinical settings, we are encountered with short and/or wide posts and an already weakened cement bond to the tooth root due to chronic coronal leakage and function. Thus, posts are easier to remove in clinical settings than laboratory studies. Another concern would be the potential periodontal injury due to the heat generated from the ultrasonic applications, even with water irrigation and frequent breaks between ultrasonic applications. Further research in this area should be pursued for standardized procedural recommendations in clinical situations.

The use of ultrasound without water spray cooling on removing the posts may have played a significant role to the results of our study. An in-vitro study evaluated the efficacy of ultrasonic vibration with and without water spray cooling on reducing the amount of force to dislodge cast posts cemented with resin and GI cement. The study tested sixty samples in six groups: groups 1,2,3 posts cemented with GI cement; group 4,5,6, posts cemented with resin; groups 1,4 controls with no ultrasound; groups 2,5 ultrasound without water spray; and groups3,6 ultrasound with water spray. Ultrasound was applied for a total of 30 seconds at buccal, lingual and proximal surfaces with breaks in between. The tensile force necessary to dislodge the posts were recorded. The ultrasonic vibration with water spray reduced the force necessary to dislodge the GI cemented post by 53.3% of that required in the control group and that without water spray reduced the force by 59.5% for posts cemented with resin cement. Therefore, authors concluded that ultrasound with water is more effective in removing posts cemented with GI cement and ultrasound without water is more effective in removing posts cemented with resin cement. (Adarsha and Lata., 2010) In our study, we used ultrasonic vibration without water spray, which may have contributed to easy removal of the posts that were cemented with RC.

E. Post system

The two major requirements for a root canal post are sufficient rigidity and retention. Rigidity is important so minimal flexing occurs under functional loads. Dental cements will fail under tensile forces in a flexing system. This may be the reason debonding is the most frequent failure observed in carbon fiber posts. Retention of post is important since a post is used to retain a core. Parallel metal posts are more retentive than tapered posts (Schwartz and Robbins, 2004; Mclean, 1998). Purton and Love (1996) found that SS posts were significantly more rigid than carbon fiber posts under three-point loading. They also found higher retention of SS post with resin cement then that of carbon fiber post with resin cement. This result correlates to more tooth structure loss observed in group 2 than group 4 in out study. The authors predict these results are due to the mechanical retention from the serration of the parallel sided stainless steel post as suggested earlier in our discussion about this study.

Prefabricated metal posts include titanium alloys, nickel chromium alloy, brass and stainless steel. Titanium is not as strong and rigid as other metals and may break upon attempting removal. It also has similar radiopacity as gutta percha, making it difficult to identify in radiographs. (Schwartz and Robbins, 2004) Therefore, the use of titanium and other corrosive metals as a post is not recommended. The use of SS posts has been recommended for a long time due to its high strength, biocompatibility and affordability. However, its high stiffness may result in detrimental complications such as root fractures and is not esthetic. To compensate for these disadvantages of metal material, new material such as fiber and ceramics were developed. The uses of FRC posts have increased due to its high esthetics and elastic moduli similar to dentin (18GPa), especially when a tooth is prone to vertical root fracture. Goodacre in 2010 performed a systematic review to evaluate the treatment effectiveness of metal versus non-metal post. He found one clinical study involving 200 patients, 100 receiving a fiber post and 100 receiving a cast metal post. Although the fiber post resulted in fewer failures than the cast post and core system after 4 years—0 versus 9—the study was judged to be at high risk of bias. Interestingly, however, all failures were root fractures.

F. Limitations

As a lab bench study, our study includes limitations since it does not completely mimic clinical situations. The teeth were sectioned at 13mm from the apex since we were only interested in how much tooth structure is removed with the removal of a post. In clinical situations, a core build up is present when a post is present, therefore, may have different amount of tooth structure loss depending on the core build up material. As previously discussed, the posts were ultrasonic vibrated without water spray, resulting in heat generation. The use of water may or may not result in different amount of tooth structure loss predicted from the results of this study. During post removal, three specimens had part of the root fracture and were not included in the statistical analysis. The fracture may be due to the brittleness of the root canal treated root and/or the heat generated from the ultrasonic vibration without water spray.

As mentioned before, the study reflected ideal situations where posts with ideal dimensions—thinnest in width and 8mm in length— were cemented in isolated dry conditions. In reality, we encounter posts that are not ideal in dimensions—wider and/or shorter—and also cemented intraorally. The specimen were stored in Hanks balance solution for two weeks without coronal seal in contrast to clinical situations where some coronal seal is present with saliva while withstanding occlusal forces. As previously discussed, the eugenol containing sealer had less of an impact on the adhesion of resin cement to the root dentin surface since most of it was probably washed way. In clinical situations, the canal access is covered with temporary or permanent restorative material and the sealer is not washed away before post cementation. Therefore, the use of resin cement with eugenol containing sealer may results in easier removal of post with less tooth structure loss.

Although we attempted to standardize the protocol and specimen, there are inevitable human error present with the preparation of specimen and carrying on the protocol. Despite using the same drill for 8mm post space preparation, variation existed among specimen. The radiolucency of the post space was calculated before and after post removal to evaluate the amount of tooth structure loss. Although we attempted to remove all gutta percha and residual cement in the post space under a microscope, there may have been some left and calculated as radiopacity (tooth structure) resulting erroneously less post space than reality. The micro CT technique allowed precise three dimensional reconstructions of the teeth but the precision is limited by the resolution of the Skyscan micro-CT machine. This error is did not play a significant role since the images resulting from the same machine was compared. All data was scanned and calculated in standardized values to minimize measurement error. The relatively high standard deviation implied the necessity to increase sample size on future related studies.

G. Clinical Implications

Although our lab bench study has short comings due to non-clinical situation, we recommend the use of serrated parallel sided SS post with GI cement to successfully retain the core of on an endodonically treated tooth unless tooth has a high risk for future retreatment—difficult or complications in root canal therapy, large periapical infection, and/or inadequate oral hygiene. As clinicians, it is our responsibility to guide patients to select the best treatment depending on case selection. Extrapolating the results of this study, we can predict less tooth structure loss and therefore a more predictable retreatment when a patient presents with a failed primary root canal therapy with a FRC post cemented with GI or self-adhesive RC compared to that of SS posts. As discussed earlier, however, this prediction cannot be generalized to other resin cements since different resin cements behave significantly different from each other.

H. Conclusion

The null hypothesis that there is no statistically significant difference in tooth volume changes following post removal for different prefabricated post and cement combination was rejected. We concluded that serrated parallel-sided SS posts with GI cement had the most tooth structure loss upon post removal. This may reflect superior retention of the post. We predicted that mechanical retention, in addition to adhesive retention of GI cement to the root dentinal surface, played a major role in post retention of serrated SS posts.

We also concluded that micro-CT can be used to accurately assess tooth volume changes as we had used to evaluate the change in post space before post cementation and after post removal. We were able to successfully calculate the amount of tooth structure loss—by comparing the three dimensional reconstruction of the tooth root and post space. The development of micro-CT directly improves individualized patient therapy by three dimensional visualization of individualized anatomy and also indirectly through its use in research to better understand the behavior of dental tissue and dental materials in order to provide evidence based therapy.

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VI. VITA

VII.

NAME:	Jiyeon J. Kim
EDUCATION:	B.A., Neuroscience, Johns Hopkins University, Baltimore, MD 2007 D.M.D., Dentistry, Harvard University, Boston, MA 2011
TEACHING:	College of Dentistry. University of Illinois at Chicago, Chicago, IL Predoctoral Complete Denture Course, 2013
	College of Dentistry. University of Illinois at Chicago, Chicago, IL Predoctoral Removable Partial Denture Course, 2011
	Department of Neuroscience. Johns Hopkins University, Baltimore, MD. Neuroscience Lab Teaching Assistant, 2006-2007
HONORS:	Departmental General Honors, Johns Hopkins University, Baltimore, MD, 2003-2007
PROFESSIONAL MEMBERSHIP:	American College of Prosthodontists American Dental Association
ABSTRACTS:	N/A
PUBLICATIONS:	N/A