EEFICACY OF LASER ON CALCIUM HYDROXIDE REMOVAL FROM ROOT CANALS

By

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This work is dedicated to

ALMIGHTY GOD,

MY PARENTS

&

MY WIFE

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LIST OF ABBREVIATIONS USED

NaOCl	Sodium Hypochlorite
EDTA	Ethylene di-amine tetra acetic acid
mm	millimeters
secs	seconds
Ni-Ti	Nickel-Titanium
W.L.	Working length
S.D	Standard Deviation
%	Percentage
ANOVA	Analysis of Variance

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INTRODUCTION

One of the important goals of root canal therapy of teeth is the elimination or reduction of microorganisms in the root canals. Disinfection of the root canal using different types of instruments is the primary technique used for so many years. Although mechanical instrumentation techniques have considerably improved over the years, literature search has shown that none of them can completely disinfect the root canal system. Therefore, the use of various chemicals as intracanal medication has been recommended, especially in cases of infection in the peri-apical region of the root.

The most common material used as intracanal medicament is calcium hydroxide ($Ca[OH]_2$). It is very effective in managing apical periodontitis due to its antimicrobial effects against most of the endodontic micro-organisms and its tissue dissolving properties. In addition, calcium hydroxide is strongly alkaline which dissociates into calcium and hydroxide ions in an aqueous solution; the latter altering the pH gradient of the bacterial cytoplasmic membrane resulting in damage to bacterial DNA and cytoplasmic membranes. Since calcium hydroxide has low solubility in water, it may be used as an inter-appointment dressing in the root canal over extended periods of time to act as a physicochemical barrier and prevent re-infection.

However, calcium hydroxide should be removed completely from the root canal before final obturation of the canal, otherwise there may be certain drawbacks. It has been reported that remnants of calcium hydroxide can interfere with the sealing ability of the root filling material and result in leakage. Any remnants of calcium hydroxide may interact with the zinc oxide-eugenol (ZOE) sealers that are used for obturation, thereby preventing its setting reaction and resulting in a ZOE cement that is brittle in consistency and granular in nature. Moreover, residual calcium hydroxide may also prevent penetration of sealers in the dentinal tubules, interfere with the bonding of resin based sealers and affect the hermetic seal of the permanent root canal filling. Therefore, the complete and predictable removal of calcium hydroxide dressing before root canal filling is critical.

Several techniques have been proposed for removal of calcium hydroxide, with the most frequently described being the use of master apical file that was used during chemo-mechanical preparation along with copious irrigation. The most commonly used irrigating solutions used in root canal therapy are sodium hypochlorite solution and EDTA (ethylene diamine tetraacetic acid) solution However, it has been reported that instrumentation and traditional irrigation alone cannot completely remove the calcium hydroxide from the root canal. Different devices have been used for the activation of the irrigant to enhance its mechanical flushing action. Few examples of devices that have been tested in the past are canal brush, sonic activated Endoactivator (Dentsply Tulsa Dental Specialties, Tulsa, OK), passive ultrasonic irrigation, negative pressure based EndoVac system (Discus Dental, Culver City, CA) and ProUltra piezoflow ultrasonic irrigation needle (Dentsply Tulsa, Tulsa, OK). It has been found that none of these techniques were able to completely remove the calcium hydroxide dressing from the root canals, especially from its apical region.

In the current literature, laser activated irrigation has been proposed to remove debris, smear layer and triple antibiotic paste intracanal medicament from the root canal. The most common lasers that have been investigated and have shown promising results are Er:YAG (Erbium: Yttrium, Aluminium, Garnet) and Er,Cr:YSGG laser (Erbium, Chromium: Yttrium, Scandium, Gallium, Garnet). It has been shown that the laser-activated irrigation creates explosive vapor bubbles inside the root canal with secondary cavitation effects, enhancing fluid exchange and assisting in removal of debris. Similarly, Er,Cr:YSGG laser driven irrigation improves the removal of smear layer in the root canal. However, there is inadequate literature support to evaluate the efficacy of Er,Cr:YSGG laser in removal of calcium hydroxide.

AIMS AND OBJECTIVES

The objective of this research is to assess the efficacy of Er,Cr:YSGG laser in removal of calcium hydroxide from different regions of root canals using micro-computed tomographic (micro-CT) imaging.

LITERATURE REVIEW

The primary goal of root canal therapy is to remove vital or necrotic pulp tissue, microorganisms, and microbial by-products from the root canal system through procedures that maintain the health of the periradicular tissue. This is a challenging task due to the complex anatomy of the root canal system, which may favor the accumulation of the smear layer and hard tissue debris that, in turn, may prevent complete debridement of the root canal space. Disinfection of the root canal using different types of instruments is the major technique used for so many years. Although mechanical instrumentation techniques have considerably improved over the years, literature search has shown that none of them can completely disinfect the root canal system. Therefore, the use of various chemicals as intracanal medication has been recommended, especially in cases of infection in the peri-apical region of the root.

The main objective of intracanal medication is to eliminate bacteria in the root canal, prevent bacterial proliferation between appointments, and act as a physicochemical barrier, preventing root canal reinfection and nutrient supply to the remaining bacteria. A variety of medicaments has been used for this purpose with the most common being calcium hydroxide ($Ca[OH]_2$). It is very effective in managing apical periodontitis due to its antimicrobial effects against most of the endodontic micro-organisms and its tissue dissolving properties. In addition, calcium hydroxide is strongly alkaline which dissociates into calcium and hydroxide ions in an aqueous solution; the latter altering the pH gradient of the bacterial cytoplasmic membrane resulting in damage to bacterial DNA and cytoplasmic membranes. Since calcium hydroxide has low solubility in water, it may be used as an inter-appointment dressing in the root canal over extended periods of time to act as a physicochemical barrier and prevent re-infection. The combination of its antimicrobial potential, tissue dissolution, and degradation of lipopolysaccharide have all made it the intracanal medication of choice.

Some concerns have been raised related to the use of calcium hydroxide as an intracanal medicament. Calcium hydroxide if not removed completely from the canal may interact with the root canal filling materials and thereby, alter their properties. It has been reported that remnants of calcium hydroxide can interfere with the sealing ability of the root filling material and result in leakage. Margelos et al showed that an interaction occurs between remnants of $Ca(OH)_2$ and zinc oxide-eugenol (ZOE) sealers used during obturation of the root canal, with the $Ca(OH)_2$ preferentially engaging the eugenol and preventing a ZOE setting reaction, resulting in a set ZOE cement that is brittle in consistency and granular in nature. Kim and Kim also found that residual $Ca(OH)_2$ may increase apical leakage after obturation when zinc oxide–eugenol sealer is used. Barbizam et al showed that $Ca(OH)_2$ remnants adversely affected the adhesion of resin sealer to the root canal walls. The $Ca(OH)_2$ remnants could also prevent sealer from penetrating the dentinal tubules resulting in a potential reduction in sealer adaption. Therefore, the complete and predictable removal of calcium hydroxide dressing before root canal filling is critical to avoid a negative influence between the root filling materials and remnants of the $Ca(OH)_2$ dressing.

Several techniques have been proposed for removal of calcium hydroxide, with the most frequently described being the use of master apical file that was used during chemo-mechanical preparation along with copious irrigation. The most commonly used irrigating solutions used in root canal therapy are sodium hypochlorite solution and EDTA (ethylene diamine tetraacetic acid) solution. Nevertheless, canal irregularities may be inaccessible for conventional irrigation procedures, and $Ca(OH)_2$ may remain in these extensions and removal of $Ca(OH)_2$ from the apical root canal wall is difficult. Several devices have been used for the activation of the irrigant to enhance its mechanical flushing action. Few examples of devices that have been tested in the past are canal brush, sonic activated Endoactivator (Dentsply Tulsa Dental Specialties, Tulsa, OK), passive ultrasonic irrigation, negative pressure based EndoVac system (Discus Dental, Culver City, CA) and ProUltra piezoflow ultrasonic irrigation needle (Dentsply Tulsa, Tulsa, OK).

Passive ultrasonic irrigation (PUI) was first described by Weller et al. During PUI, a small file is placed at the center of a previously shaped root canal and activated to produce acoustic streaming. This streaming creates small, intense, circular fluid movement around the instrument. The eddying occurs closer to the tip than in the coronal end of the file, with an apically directed flow at the tip. Because the root canal is already enlarged, the file can vibrate freely in a way to enable acoustic streaming, transferring its energy to the irrigant inside the canal.

The EndoActivator System (Dentsply Tulsa Dental Specialties, Tulsa, OK) was introduced as a new modality to improve the irrigation procedure. It is a sonic device that comprises a portable handpiece and 3 types of disposable flexible polymer tips of different sizes that do not cut root dentin. The design of the EndoActivator System allows activation of various intracanal agents and could produce vigorous intracanal fluid agitation.

The ProUltra PiezoFlow ultrasonic irrigation needle (Dentsply Tulsa, Tulsa, OK) has been shown to be an effective tool for improved root canal irrigation. An ultrasonic unit is used in conjunction with these needles to provide the energy for tip oscillation. In contrast to other ultrasonic irrigation systems, the PiezoFlow irrigation needle is connected to an irrigation syringe to provide constant fresh irrigant into the canal system.

The EndoVac system (Discus Dental, Culver City, CA) uses a suction needle placed at the working length (WL). With negative pressure, the irrigant flows down from the pulp chamber into the canal to the apical areas. A study showed that EndoVac irrigation resulted in significantly less debris at 1 mm from the WL. This system has the advantage of less frequency of extrusion of irrigants compared with needle irrigation and superior results in removing the smear layer when compared with passive irrigation and passive ultrasonic irrigation.

Ma et al compared the efficacy of EndoActivator and ultrasonics in the ability to remove calcium hydroxide from different regions of C-shaped root canals of mandibular molars using micro-computed tomography. They observed that there was no significant difference in the amount of residual $Ca(OH)_2$ between the EndoActivator and ultrasonic groups. The proportion of remaining $Ca(OH)_2$ in the apical canals was higher than in the middle and coronal canals in all groups.

Wiseman et al evaluated the efficacy of sonic and passive ultrasonic irrigation (PUI) on calcium hydroxide ($Ca[OH]_2$) removal and to measure the volume and percentage of $Ca(OH)_2$ remaining in the root canal system. They concluded that remnants of $Ca(OH)_2$ were found in all experimental groups. The combination of rotary instrumentation and passive ultrasonic activation resulted in significantly lower amounts of $Ca(OH)_2$ remnants in the canal compared with sonic irrigation.

Alturaiki et al evaluated the effectiveness of different irrigation systems on removing calcium hydroxide ($Ca[OH]_2$) from the root canal by using a scanning electron microscope. 4 techniques were used for $Ca(OH)_2$ removal. In the first group, the canals were cleaned with a master apical file. The second, third, and fourth groups were irrigated using the EndoVac (Discus Dental, Culver City, CA), EndoActivator (Dentsply Tulsa Dental Specialties, Tulsa, OK), and

ProUltra Dentsply Tulsa, Tulsa, OK) systems, respectively. They concluded that none of the investigated techniques removed the $Ca(OH)_2$ dressing completely. However, the EndoActivator System showed better results in removing $Ca(OH)_2$ in each third of the root canals in comparison with the other techniques.

In the current literature, laser activated irrigation has been proposed to remove debris, smear layer and triple antibiotic paste intracanal medicament from the root canal. The most common lasers that have been investigated and have shown promising results are Er:YAG (Erbium: Yttrium, Aluminium, Garnet) and Er,Cr:YSGG laser (Erbium, Chromium: Yttrium, Scandium, Gallium, Garnet). It has been shown that the laser-activated irrigation creates explosive vapor bubbles inside the root canal with secondary cavitation effects, enhancing fluid exchange and assisting in removal of debris. Similarly, Er,Cr:YSGG laser driven irrigation improves the removal of smear layer in the root canal.

Arslan evaluated the efficacy of needle irrigation, the EndoActivator System (Dentsply Tulsa Dental Specialties, Tulsa, OK), and Er:YAG laser based PIPS techique on the removal of antibiotic pastes from an artificial groove created in a root canal. They concluded that Er:YAG laser based PIPS was more effective in removing antibiotic pastes from artificial grooves in root canals than the EndoActivator System and needle irrigation. The EndoActivator was also more effective than needle irrigation. It is difficult to completely remove antibiotic pastes from root canals.

However, there is inadequate literature support to evaluate the efficacy of Er,Cr:YSGG laser in removal of calcium hydroxide. Hence, the objective of this research is to assess the efficacy of Er,Cr:YSGG laser in removal of calcium hydroxide from different regions of root canals using micro-computed tomographic (micro-CT) imaging.

HYPOTHESES

NULL HYPOTHESIS

The null Hypothesis was that there is no significant difference between Needle irrigation and Er,Cr:YSGG laser in removal of calcium hydroxide from different regions of root canals.

ALTERNATE HYPOTHESIS

The alternate Hypothesis was that there is significant difference between Needle irrigation and Er,Cr:YSGG laser in removal of calcium hydroxide from different regions of root canals.

RESEARCH METHODOLOGY

Preparation of Specimens

Forty five single rooted, noncarious, extracted human maxillary and mandibular canines were initially selected on the basis of radiographs taken in both buccolingual and mesiodistal directions to detect any possible root canal obstruction. Any tooth with more than one canal, apical curvature, previous endodontic treatment, crack or resorptive defect was excluded. Teeth were immersed in 5% sodium hypochlorite NaOCl (Clorox Bleach; Clorox, Oakland, CA) for 48 hours to remove any organic debris. Thereafter, the external tooth surfaces were scaled with ultrasonic instruments, and the teeth were then stored in distilled water until use.

Root Canal Preparation

Root canals were accessed according to standard endodontic procedures and the patency of the canals was verified by passing a size 10 K-file (Kendo, VDW, Germany). The working length (WL) was determined 1 mm short of the length where the file extruded the apical foramen and a glide path was prepared using a 15 K-file.

The canals were prepared with ProTaper Universal rotary instruments (Dentsply Maillefer, Ballaigues, Switzerland) in the sequence recommended by the manufacturer upto a master apical size (MAF) of F4 having D_0= 0.40mm. During instrumentation, the root canals were irrigated with 2 ml of 1% sodium hypochlorite (NaOCl) solution after each instrument delivered by 30-gauge Max-I Probe needle (Dentsply-Rinn, Elgin, IL, USA) placed 1 mm short of the working length.

When instrumentation was complete, a final irrigation protocol was performed on all canals using 10 mL 5% NaOCl for 5 minutes followed by 5 mL 17% EDTA solution (Pulpdent Corporation, Watertown, MA) for 2 minutes. Any remaining solution was removed by aspiration and the canals were dried with paper points (Dentsply Maillefer). A micro-CT scan (Skyscan 1172; Bruker Micro-CT, Kontich, Belgium) at a resolution of 27.5 µm (details provided later) was performed for each sample after instrumentation to determine the volume of the canals after conventional preparation.

Calcium Hydroxide Placement

Metapaste (Meta Biomed Co., Cheongju, Korea), which is a water soluble temporary root canal filling material of $Ca(OH)_2$ with barium sulphate was injected into each canal until the material extruded from the apex. Radiographs were taken in mesiodistal and buccolingual directions to ensure complete filling of the root canals. The access cavities were temporarily sealed with a cotton pellet and Cavit (3M ESPE, St Paul, MN) temporary filling material. The apex of all samples was sealed with sticky wax to simulate the closed environment of a clinical situation. The samples were then placed in a sponge saturated with natural water and incubated in 100% relative humidity at 37^0 C for 7 days. After placement of $Ca(OH)_2$, another micro-CT scan was performed on all teeth to calculate the volume of $Ca(OH)_2$ in the canals.

Removal of Calcium Hydroxide

After removal of the temporary filling material, samples were randomly divided into three groups depending upon the final irrigation system used.

Group A: Positive control [n = 15]. The canals were only mechanically instrumented with a F4 instrument (MAF), with no final irrigation.

Group B: Er,Cr:YSGG laser activated irrigation [n = 15]. The Waterlase MD dental laser (Biolase, CA, USA) was used at panel settings of 0.75 watt average power and 20 hertz and was focused through an endodontic tip of 275 µm diameter. The coaxial water spray and air of the laser unit were switched off. After cleaning the canal by MAF to the WL, 1% NaOCl was deposited in the canal and activated by a 2780 nm wavelength Erbium chromium: Yttrium-Scandium-Gallium-Garnet (Er,Cr:YSGG) for 60 seconds. Thereafter, the canal was irrigated with 17% EDTA solution for 60 seconds. A total of 4 ml each of both the irrigants was used. The pulp chamber served as a reservoir for the irrigation solution. The tip of the optic fiber was placed 3 mm from the WL and it was withdrawn gently from the apical to the coronal region with helical movement and reintroduced to the apex.

Group C: Needle irrigation [n = 15]. The removal of $Ca(OH)_2$ was performed using 30-G Max-I probe (Dentsply-Rinn, Elgin, IL, USA). After cleaning the canal by MAF to the WL, 30 seconds of irrigation was done with 2 ml of 17% EDTA followed by 3 cycles of irrigation using 2 ml each of 1% NaOCl, 17% EDTA and 1% NaOCl. The tip of the needle was maintained at 1 mm from the WL.

Micro-computed Tomography Imaging

Each specimen was subjected to high-resolution micro-CT scanning after instrumentation, before and after removal of $Ca(OH)_2$. The scanning procedure was completed using 100 kV, 100 µA, a 500 millisecond exposure time, 360^0 rotation and 0.7^0 rotation step, with a cross-sectional pixel size of 27.45 µm. The filter used was 0.5 mm aluminium and 0.5 mm copper. Series of x-rays were taken using the Skyscan 1172 machine (Bruker Micro-CT, Kontich, Belgium) which was considered as raw data in a form of Tag Image File Format (TIFF). This TIFF file format was reconstructed by NRecon software version 1.6.4.8 (Skyscan 2011, Belgium) to Bitmap (BMP) which is a file readable by CTAn version 1.11.10.0 (64 bit) Skyscan, 2011 to do the analysis of the total calcium hydroxide volume remaining in the canal. Reconstruction parameters were adjusted as follows: Gaussian filter (smoothing, kernel = 2), beam hardening correction of 15% and ring artifact reduction of 10.

The volume of interest was selected by dividing the whole length of the tooth specimen into three parts, that is, coronal, middle and the apical area, resulting in the acquisition of 550 to 750 transverse cross-sections per tooth. In CTAn, reconstructed files were binarised separately for each slices, regions of interest were chosen to allow the calculation of the volume of calcium hydroxide (in mm^3). After standardizing the number of slices and getting the region of interest, we did the automatic thresholding from the dataset separating canal, dentin and calcium hydroxide for analysis.

Thereafter, the images were viewed by CTVol ver. 2.2.1.0 (64 bit) for 3-dimensional realistic visualization and for making the pictures. The percentage of the volume of $Ca(OH)_2$ removed from the canals was calculated as:

$$\frac{\text{Volume of } Ca(OH)_2 \text{ before removal - Volume of } Ca(OH)_2 \text{ after removal x 100}}{\text{Volume of } Ca(OH)_2 \text{ before removal}}$$

STATISTICAL ANALYSIS

One-way analysis of variance with the post hoc Tukey test was used to test for differences between volumes of root canals after instrumentation and volumes of $Ca(OH)_2$ dressing in canals among groups. The Kruskal–Wallis analysis of variance was used to identify any significant difference amongst the groups. If significant differences were found, a one-way ANOVA, Tukey test was used to determine which group was significantly different from the others for the collected data at a 95% confidence level ($P < 0.05$).

RESULTS

The mean canal volume after instrumentation was 14.15 ± 1.25, 15.14 ± 1.45, 14.96 ± 1.85 mm^3 for Groups A, B and C respectively. There was no significant difference among the four groups in the root canal volume after instrumentation ($P > 0.05$). The mean and standard deviation of the volume of root canal after instrumentation, after placement of $Ca(OH)_2$ and after removal of $Ca(OH)_2$ is shown in Table 1. The volume of $Ca(OH)_2$ after filling was significantly higher in the coronal third than the middle and apical thirds ($P < 0.05$). Statistically significant differences were found among the experimental groups in relation to $Ca(OH)_2$ removal.

The mean volume of residual $Ca(OH)_2$ was significantly higher in the group with no irrigation than the other 2 groups ($P < 0.05$) (Fig. 1). The mean percentage of $Ca(OH)_2$ removed from the coronal, middle and apical thirds was significantly higher in Er,Cr:YSGG laser group compared to needle irrigation group ($P < 0.05$) (Table 2).

FIGURES

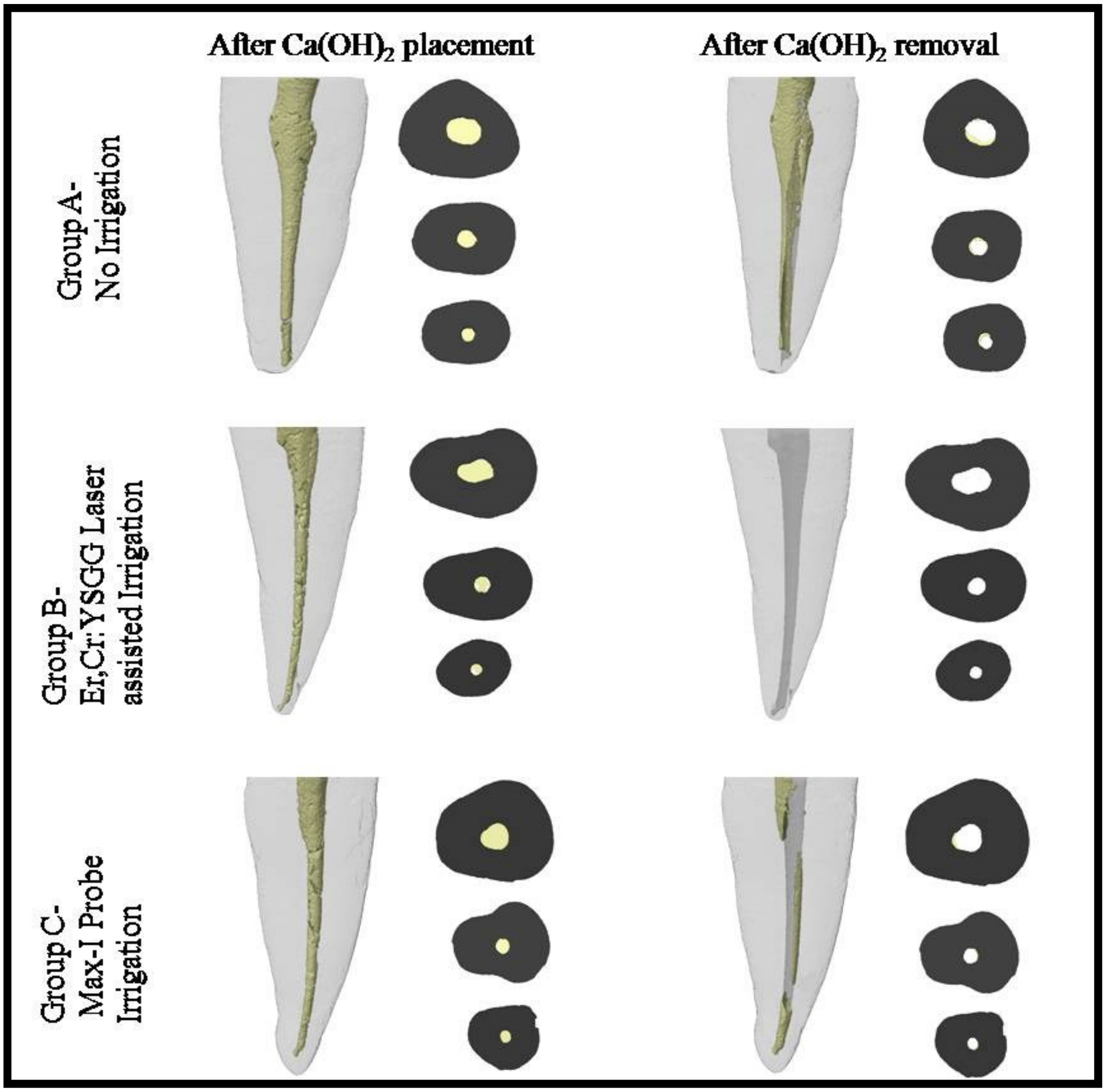

Figure 1: Representative 3-dimensional reconstruction of micro-CT scans of root canals of canines under investigation showing calcium hydroxide ($Ca[OH]_2$) paste (*light green*) placed into canals after instrumentation and after removal of $Ca(OH)_2$ using different irrigation techniques followed by the respective cross-sections from the coronal, middle, and apical thirds of the roots.

TABLES

Table 1 Volume (mm^3) of root canals after instrumentation, after filling calcium hydroxide and after removal of calcium hydroxide in different groups (Mean ± Standard Deviation)

	Group A - No irrigation (n=15)			Group B - Er,Cr:YSGG laser (n=15)			Group C - Max-I Probe (n=15)		
	Canal	Filled CH	Residual CH	Canal	Filled CH	Residual CH	Canal	Filled CH	Residual CH
Coronal	8.79 ± 0.95	8.20 ± 0.75	3.25 ± 0.54	9.98 ± 1.11	9.40 ± 1.05	0.00 ± 0.00	9.48 ± 1.12	8.78 ± 1.06	1. 51 ± 0.32
Middle	3.75 ± 0.42	3.41 ± 0.35	1.72 ± 0.21	3.72 ± 0.49	3.55 ± 0.53	0.00 ± 0.00	3.65 ± 0.68	3.27 ± 0.56	1.05 ± 0.23
Apical	1.61 ± 0.21	1.52 ± 0.21	1.32 ± 0.18	1.44 ± 0.24	1.34 ± 0.12	0.07 ± 0.01	1.83 ± 0.45	1.72 ± 0.41	0.85 ± 0.12
Total	14.15 ± 1.25	13.13 ± 1.08	6.29 ± 0.60	15.14 ± 1.45	14.29 ± 1.15	0.07 ± 0.01	14.96 ± 1.85	13.77 ± 1.82	3.41 ± 0.71

CH- calcium hydroxide

Table 2 Mean percentage of $Ca(OH)_2$ removed in each third of root canal in different groups

	Coronal	**Middle**	**Apical**
Group A - No irrigation (n=15)	60.37 ± 16.35 [a]	49.56 ±10.75 [a]	13.16 ± 6.75 [b]
Group B - Er,Cr:YSGG laser (n=15)	100 [c]	100 [c]	94.78 ± 0.76 [c]
Group C - Max-I Probe (n=15)	82.80 ± 5.71 [d]	67.89 ± 4.76 [d]	50.58 ± 2.67 [e]

Different superscript letters indicate statistically significant differences between groups (P < 0.05)

DISCUSSION

This study was designed to evaluate the effectiveness of Er,Cr:YSGG laser assisted irrigation in comparison to conventional needle irrigation (Max-I probe) in removing $Ca(OH)_2$ from root canals. In reviewing the literature, various methods have been used to measure residual $Ca(OH)_2$ in root canals, such as direct visualization, digital microscopy and scanning electron microscope (Kenee *et al.* 2006, Balvedi *et al.* 2010, Alturaiki *et al.* 2015). However, there are certain limitations of these techniques such as loss of residual $Ca(OH)_2$ during splitting of root, variation between observers during scoring owing to subjective evaluation and inaccurate quantitative evaluation as a result of two dimensional imaging. In the present study, micro CT imaging was used for cross-sectional examination of the root canal which offers numerous advantages like evaluation of 3-dimensional volume of $Ca(OH)_2$ at high resolution, specimen preparation is not required and thereby it is a non-invasive technique (Wiseman *et al.* 2011). Micro CT scans of the teeth were evaluated to measure the volume of $Ca(OH)_2$ in each thirds of the root canal before and after removal using different methods.

The results of this study showed that Er,Cr:YSGG laser was highly effective in removing $Ca(OH)_2$ from the coronal and middle thirds and upto 95% from the apical third of the root canal. Thus the null hypothesis was rejected. Previous studies have shown Er:YAG laser based PIPS technology (Photon induced photoacoustic streaming) to be highly effective in removal of intracanal tissue and debris (Lloyd *et al.* 2014) as well as double and triple antibiotic paste (Arslan *et al.* 2014). Similarly Er,Cr:YSGG laser has been shown to effectively remove debris and smear layer from the apical region of a root canal (Peeters & Suardita 2011), though there is no published study that has evaluated its efficacy in removing intracanal $Ca(OH)_2$.

In the present study, teeth with laser assisted irrigation showed 100% removal of $Ca(OH)_2$ in the coronal and middle third; and 95% in the apical third which was significantly higher than Max-I probe irrigation group. This could be attributed to the ability of laser-driven irrigation to create cavitation (Blanken & Verdaasdonk 2007) and a turbulent flow by virtue of creating a gaseous bubble at the laser tip as the irrigant is vaporized, resulting in expansion of a bubble as the laser continues to emit energy and evaporates the irrigant at the leading edge (Mir *et al.* 2009). At the end of the cycle, the vapor cools, causing the bubble to implode and separate from the firing tip. The alternating bubble expansion and implosion create a shear stress along the canal wall, facilitating the detachment of $Ca(OH)_2$ remnants and their subsequent removal by the irrigation procedure.

The results of this investigation were in agreement with previous studies (Ma *et al.* 2015) and revealed that irrigation with Max-I probe in addition to using master apical file could remove only 50% of $Ca(OH)_2$ from the apical third of the root canal which was significantly lower than that in the Er,Cr:YSGG laser irrigated groups.

CONCLUSION

While considering the limitations of this ex-vivo study, the micro-CT analysis of root canals in different thirds revealed that although none of the irrigation methods could completely remove $Ca(OH)_2$ from the apical third of the root canal, Er,Cr:YSGG laser assisted irrigation could significantly remove higher volume of $Ca(OH)_2$ from the coronal, middle and apical thirds of the root canal in comparison to conventional needle irrigation.

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