EVALUATION OF DEBRIS REMOVAL EFFICACY OF DIFFERENT ROOT CANAL IRRIGANTS DURING FINAL IRRIGATION PROTOCOL USING LASER ACTIVATED IRRIGATION AND PASSIVE ULTRASONIC IRRIGATION- AN *IN VITRO* STUDY

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DECLARATION BY THE CANDIDATE

I hereby declare that this dissertation titled **"EVALUATION OF DEBRIS REMOVAL EFFICACY OF DIFFERENT ROOT CANAL IRRIGANTS DURING FINAL IRRIGATION PROTOCOL USING LASER ACTIVATED IRRIGATION AND PASSIVE ULTRASONIC IRRIGATION- AN *IN VITRO* STUDY"** is a bonafide and genuine research work carried out by me under the guidance of **Dr. P. Shankar, M.D.S., Professor**, Department of Conservative Dentistry and Endodontics, Ragas Dental College and Hospital, Chennai.

Nithyalakshmi

Dr. J. Nithyalakshmi

Dept. of Conservative Dentistry and Endodontics, Ragas Dental College and Hospital, Chennai

Date: 30/12/2016

Place: CHENNAI

CERTIFICATE

This is to certify that this dissertation titled **"EVALUATION OF DEBRIS REMOVAL EFFICACY OF DIFFERENT ROOT CANAL IRRIGANTS DURING FINAL IRRIGATION PROTOCOL USING LASER ACTIVATED IRRIGATION AND PASSIVE ULTRASONIC IRRIGATION- AN *IN VITRO* STUDY"** is a bonafide record work done by **Dr. J. Nithyalakshmi** under our guidance during her postgraduate study period between 2014 - 2017.

This dissertation is submitted to **THE TAMILNADU Dr. M.G.R. MEDICAL UNIVERSITY**, in partial fulfillment for the degree of **MASTER OF DENTAL SURGERY – CONSERVATIVE DENTISTRY AND ENDODONTICS, BRANCH IV**. It has not been submitted (partial or full) for the award of any other degree or diploma.

Guided By:

RAGAS DENTAL COLLEGE Chennai

30/12/16

Dr. P. Shankar, M.D.S.,
Professor,
Department of Conservative Dentistry & Endodontics,
Ragas Dental College & Hospital,
Chennai.

Dr. R. Anil Kumar, M.D.S.,
Professor and Head,
Department of Conservative Dentistry & Endodontics,
Ragas Dental College & Hospital,
Chennai.

Dr.R.ANIL KUMAR,M.D.S.,
PROFESSOR AND HEAD,
DEPARTMENT OF CONSERVATIVE DENTISTRY & ENDODONTICS,
RAGAS DENTAL COLLEGE & HOSPITAL,
CHENNAI - 119.

Dr.P.SHANKAR,M.D.S.,
PROFESSOR,
DEPARTMENT OF CONSERVATIVE DENTISTRY & ENDODONTICS,
RAGAS DENTAL COLLEGE & HOSPITAL,
CHENNAI - 119.

Dr. N.S. Azhagarasan, M.D.S.,
Principal,
Ragas Dental College & Hospital,
Chennai.

PRINCIPAL
RAGAS DENTAL COLLEGE AND HOSPITAL
UTHANDI, CHENNAI-600 119.

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LIST OF ABBREVIATIONS

S. NO.	ABBREVIATION	EXPANSION
1.	PUI	Passive ultrasonic irrigation
2.	LAI	Laser activated irrigation
3.	ErCr:YSGG laser	Erbium, chromium: yttrium-scandium-gallium-garnet laser
4.	NaOCl	Sodium hypochlorite
5.	CHX	Chlorhexidine
6.	SEM	Scanning electron microscope
7.	EDTA	Ethylene diamine tetra acetic acid

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Introduction

INTRODUCTION

The basis of endodontic therapy is the endodontic triad that includes biomechanical preparation, complete disinfection and three dimensional obturation of the root canal space. Failure in endodontics is caused by the microorganisms that remain in the root canal space after treatment or those that re-colonize the filled canal system. Mechanical instrumentation alone leaves untouched zones, debris, smear layer and microorganisms and their by-products, which can result in persistent inflammation [65]. According to Peters et al (2001), at least 35% of the root canal surface remains uninstrumented regardless of the canal preparation technique. The primary endodontic treatment goal must thus be to optimize root canal disinfection and debris removal [67].

Irrigation, according to the glossary of endodontic terms given by the American Association of Endodontists, is defined as the process of washing by a stream of fluid. Intracanal irrigation facilitates physical removal of materials from the canal and introduction of chemicals for antimicrobial activity, demineralization, tissue dissolution, bleaching, deodorizing and hemorrhage control. The objectives of irrigation can be classified into mechanical, chemical and biologic. The mechanical and chemical objectives include flushing out the debris, lubricating the canal, dissolving organic and inorganic tissue and preventing the formation of smear layer or dissolving it during instrumentation. The biologic objective of the irrigant is associated with its effectiveness against anaerobic and facultative microorganisms in their planktonic and biofilm state, ability to inactivate the endotoxin, be nontoxic when in contact with vital tissues and have little potential to cause an anaphylactic reaction.

The complex nature of the root canal system results in the irrigant reaching only the central body of the canal and being incapable of cleaning the lateral canals, canal fins, cul-de-sacs, canal isthmi. Persistent periradicular inflammation is caused by microbes, their by-products and tissue debris left behind in these untouched areas. The apical third of the root canal system is the most challenging to clean and shape because of the ever-increasing complexity of the anatomy; that is, due to the presence of ramifications and tortuosities.

Of all the irrigants currently available, sodium hypochlorite is the most widely used because it covers more of the requirements for an endodontic irrigant than any other known compound. Grossman L, Meiman et al in 1941 described that sodium hypochlorite has the unique capacity to dissolve necrotic tissue and the organic components of the smear layer. Additionally, it also kills sessile endodontic pathogens in biofilms and in dentinal tubules as efficiently as chlorhexidine. The drawback with sodium hypochlorite is its toxic effect on vital tissues, resulting in haemolysis, skin ulceration and necrosis[39]. Chlorhexidine's antimicrobial effect is similar to that of sodium hypochlorite, but it has poor tissue dissolution capability. However, the cationic structure provides a unique advantage of substantivity for up to twelve weeks. Hence, it is recommended as an irrigant solution to be used as a final flush of the root canal system.

Conventional irrigation with syringes was the most widely used and accepted method of irrigant delivery before the advent of other agitation techniques. In this technique, the irrigant is dispensed into the canal through needles/cannulas of variable gauges, either passively or with agitation by moving the needle up and down the length of the canal. Newer designs deliver the irrigant laterally through close-ended, side-vented channels as opposed to traditional needles that were designed to dispense the irrigant through their most distal ends. The side-vented needles were suggested to better the irrigant's hydrodynamic activation and decrease the chance of apical extrusion. To allow the irrigant to reflux and ensure that more debris is displaced coronally, the cannula/needle must be loose inside the canal during irrigation and this process should be completed while avoiding the inadvertent entry of the irrigant into periapical tissues[25]. Various studies conducted with conventional syringe needle irrigation have reported that the needle tip is usually positioned in the coronal third of a narrow root canal or at the most the middle third of a wide canal, and the irrigant solution is carried only 1mm beyond the tip of the needle[11]. Hence, not just the delivery of the irrigant, but its agitation is imperative to effectively disinfect the apical ramifications.

Irrigation with ultrasonic activation and without simultaneous instrumentation is called passive ultrasonic irrigation (PUI) and the term ‘passive’ is related to the ‘noncutting’ action of the ultrasonically activated file. PUI is based on the principle of acoustic energy transmission from an oscillating smooth file or wire to an irrigant inside the root canal space. The root canal is first shaped to the master apical file following which, anything from a small file or smooth wire to endodontic ultrasonic tips is introduced in the centre of the root canal, as far as the apical region. Cavitation and acoustic streaming is caused by ultrasonic waves generated by the oscillating file[2,4]. In intermittent flush ultrasonic irrigation, the irrigant is delivered to the root canal by a syringe needle and the irrigant is then activated using ultrasonically oscillating instrument, following which the root canal is flushed with fresh irrigant to remove the dislodged or dissolved remnants from the canal walls[25].

Laser activated irrigation (LAI) is a machine-assisted agitation technique that differs from other agitation techniques in that the tip is placed short of the apex[20]. This technique uses an erbium/chromium–yitrrium-scandium-gallium–garnet (Er Cr:YSGG) laser with a radial and stripped tip at subablative power settings. The LAI works by laser thermal effect that generates the expansion-implosion of the water molecules of the irrigant solution, generating a secondary cavitation effect on the intracanal fluids. Each impulse, absorbed by the water molecules, creates a strong “shock wave” that leads to the formation of an effective streaming of fluids inside the canal[21].

The aim of this study was to determine debris removal efficacy after final irrigation protocol performed with 2.5% NaOCl, and 2% CHX using LAI and PUI from a simulated canal groove in the apical third of prepared root canals. The null hypothesis was that there would be no difference in the debris removal scores regardless of the irrigant and technique used.

Aim and Objectives

AIM AND OBJECTIVE

AIM

The aim of this in vitro study was to compare the debris removal efficacy of final irrigation protocols that included, saline using conventional syringe irrigation, 2.5% sodium hypochlorite and 2% chlorhexidine, using laser activated irrigation (LAI) and passive ultrasonic irrigation (PUI) separately.

The null hypothesis was that there would be no difference in the debris removal scores regardless of the irrigant and technique performed.

OBJECTIVE

To determine debris removal efficacy of final irrigation protocols with two irrigants- 2.5% NaOCl, and 2% CHX when used with two activation techniques, namely, LAI and PUI, from a simulated canal irregularity placed in the apical third of prepared straight root canals using SEM.

Review of Literature

REVIEW OF LITERATURE

Spångberg L, Rutberg M et al (1979)[50] evaluated camphorated paramonochlorphenol, camphorated phenol, Cresatin, formocresol and iodine potassium iodide for toxicity and tissue irritation utilizing in vitro and in vivo methodologies. In addition to the presented new data, information in existing literature was critically analysed. Based on current and old information related to these medicaments, recommendations were made for the rational use of endodontic antiseptics.

Martin H, Cunningham WT et al (1980)[35] compared the ultrasonic versus hand-powered K type files for their ability to remove dentin from a standardized canal. They concluded that ultrasonic energized file removed significantly greater amount of dentin in a fixed time period.

Weller RN, Brady JM et al (1980)[63] used resin blocks containing simulated root canal spaces and compared it with extracted teeth as models for measuring the efficiency of endodontic debridement with hand instrumentation, ultrasonication, or a combination of both techniques. Canal spaces were filled with radioisotope-laden gelatin and the loss of radioactivity was measured after treatment. No significant difference in efficiency of debridement was observed in teeth prepared with hand instruments or ultrasonics alone; both techniques reduced radioactivity by 77% and 79% respectively. Ultrasonication after hand instrumentation was the most efficient method; it reduced radioactivity in the teeth and blocks by 88% and 92%, respectively.

Chow TW (1983)[11] studied the mechanical effectiveness of conventional root canal irrigation using hypodermic needle and syringe which was carried out using an artificial system of standardized root canals and particles. They also investigated the influence of needle size, the depth of insertion of the needle, and the pressure of irrigation on the effectiveness of irrigating the apical portion of root canals. It was concluded that there was little flushing and displacement of the particles beyond the tip of the needle and that the apical extent of effectiveness of irrigation is a function of the depth of insertion of the needle. Hence needle sizes appropriate to the canal preparation should be selected.

Pashley EL, Birdsong NL et al (1985)[39] evaluated the cytotoxicity of various dilutions of sodium hypochlorite using three independent biological models. Dilutions as low as 1:1000 caused complete hemolysis of RBC's in vitro. Undiluted and 1:10 dilutions produced moderate to severe irritation to rabbit eyes which healed after 24 to 48 h. Intradermal injections of undiluted, 1:1, 1:2, and 1:4 dilutions of NaOCl produced skin ulcerations following intradermal injections. They concluded that although the use of 5% NaOCl for biomechanical preparation of root canals is a clinically acceptable and highly effective procedure, it must be used judiciously and with great caution to prevent it from reaching the periapex where it can elicit severe inflammatory reactions.

Griffiths BM, Stock CJR et al (1986)[24] used three types of irrigants – 2.6% sodium hypochlorite, water and Solvidont to compare their ability to remove debris during root canal preparation with ultrasonically operated K files. Twenty seven freshly extracted human teeth were divided into three groups and each group was prepared using one of the irrigants. The teeth were sectioned longitudinally, stained and photographed for assessment by a ranking system. Canals prepared with sodium hypochlorite were found to have significantly less debris remaining than those prepared with water or Solvidont. No significant difference was found between preparations with water and Solvidont.

Ahmad M, Pitt ford TR et al (1987)[2] investigated the phenomena of cavitation and acoustic streaming in an ultrasonic endodontic unit. A comparison between the cleaning efficiency of ultrasonic and hand instruments using either tap water or 2.5% sodium hypochlorite was made by scanning electron microscopy. Under scanning electron microscopy no difference in the surface debris was observed between the two techniques, although less smear was apparent in the ultrasonic groups. Canals instrumented with sodium hypochlorite exhibited less debris regardless of the techniques used. It was concluded that transient cavitation does not play a role in canal cleaning; however, acoustic streaming appeared to be the main mechanism involved.

Walmsley AD et al (1987)[58] reported that clarification was needed of the possible roles of cavitation and acoustic microstreaming together with the 'synergistic' effect of the combined use of ultrasound and irrigant (usually sodium hypochlorite). They observed that the oscillation of the file within the root canal may be prone to the load applied to it and that this will greatly affect its efficiency. They concluded that further investigations are required to understand fully the action of the instrument.

Ahmad, Pitt Ford et al (1988)[4] investigated the phenomenon of cavitation in an ultrasonic unit using a #15 Cavi- Endo file 25mm long. One group of 10 teeth was subjected to the cavitating file while a second group served as a control. Scanning electron microscopic observations revealed that there was no difference in cleanliness between the two groups of teeth studied. They concluded that cavitation might have resulted in the formation of pits in some of the canals and should not be regarded as an important mechanism in debridement.

van Leeuwen TG, van de Veen MJ et al (1991)[57] assessed the feasibility of intra-arterial tissue ablation by Holmium:YSGG laser pulses (2.1 microns) in a noncontact mode, the transmission of the laser pulses through saline and blood was measured. In blood at 37 degrees C, the penetration depth varied from 1.2 to 2.1 mm for intensities of 3.1 to 12.4 J/mm2 per pulse, respectively. The large penetration depth was due to the development of a transparent vapour cavity around the fiber tip. In saline, its maximum length was 4.7 mm. Its maximum width was 2.8 mm. The lifetime of the cavity was 450 microseconds. The results suggested that large fissures in adjacent tissue were likely to be caused by the expansion of the vapour cavity. They concluded that, due to a "Moses effect in the microsecond region," Holmium:YSGG tissue ablation was possible.

Ahmad M, Roy RA et al (1993)[5] studied the pattern of oscillation of a Piezon-Master 400 ultrasonic file driven by a piezoelectric transducer in air and in water. The findings were compared with those observed with the Cavi-Endo unit reported in another study (Ahmad 1969). It was observed that the file vibrated such that a standing wave was formed on the file and it exhibited points of maximum deflection (antinode) and points of minimum deflection (node) with the largest deflection occurring at the apical end. This pattern of oscillation was similar to that exhibited by the Cavi-Endo file which employed a magnetostrictive transducer.

Wu MK, Wesselink PR et al (1995)[64] compared the various techniques for root canal instrumentation in the apical portions. They used mesiobuccal canals of human mandibular molars with an average curvature of 25° and treated them with step-back, crown-down pressure less, or balanced-force techniques. 2% sodium hypochlorite was used as the irrigant. The cleaning efficacy of these techniques was evaluated by counting the remaining surface debris under a stereomicroscope with a calibrated eyepiece micrometre. Their results indicated that the apical portion of the canal was less clean than the middle and coronal portions regardless of the technique performed and that the balanced-force technique produced a cleaner apical portion of the canal than the other techniques studied.

Jensen SA, Walker TL et al (1999)[28] compared the cleaning efficacy of passive ultrasonic activation with that of passive sonic activation after hand instrumentation. Sixty curved molar canals were hand-instrumented to size 35 and divided into three groups. Group 1 received no further treatment. Group 2 received 3 min of passive sonic activation. Group 3 received 3 min of passive ultrasonic activation. The debris scores for the sonic and ultrasonic activation groups were significantly lower than that for the hand instrumentation only group; however, there was no significant difference between the sonic and ultrasonic activation groups.

Scelza MFZ, Antoniazzi JH et al (2000)[46] determined the degree of removal of pulpal remnants and smear layer from root canals after final irrigation with three different solutions. The final 4-min, 30-ml irrigation varied as follows: group I, 10 ml of 1% NaOCl + 10 ml of 10% citric acid + 10 ml of distilled water; group II, 15 ml of 0.5% NaOCl + 15 ml of EDTA-T; and group III, 10 ml of 5% NaOCl + 10 ml of 3% H2O2 + 10 ml of 5% NaOCl. The largest number of visible tubules in the three groups was in the cervical third, followed by the middle and apical thirds. There was no statistically significant difference between groups I and II however, groups I and II had significantly more visible dentinal tubules than group III.

Peters OA, Schönenberger K et al (2001)[42] compared the effects of four preparation techniques(K-Files, Lightspeed instruments, ProFile.04 and GT rotary instruments) on canal volume and surface area using three dimensionally reconstructed root canals in extracted human maxillary molars. A micro computed tomography scanner was used to analyse root canals in extracted maxillary molars. They concluded that, there were few differences between the four canal instrumentation techniques used. By contrast, a strong impact of variations of canal anatomy was demonstrated. Further studies with 3D-techniques are required to fully understand the biomechanical aspects of root canal preparation.

Sim TP, Knowles JC et al (2001)[49] tested the effect of sodium hypochlorite irrigation on root canals to see if it altered the properties of dentine and contributed to the weakening of root-treated teeth. The effect of two concentrations (0.5%, 5.25%) of NaOCl and saline on (i) the elastic modulus and flexural strength of machined dentine bars, and (ii) changes in strain of 'whole' extracted human teeth were evaluated. They concluded that 5.25% NaOCl reduced the elastic modulus and flexural strength of dentine and that irrigation of root canals of single, mature rooted premolars with 5.25%

NaOCl affected their properties sufficiently to alter their strain characteristics when no enamel was present.

Wu MK, Wesselink PR et al (2001)[65] assessed the quality of obturation of uninstrumented recesses in oval canals. The canals in group 1 were enlarged to conventional sizes, whereas canals in group 2 were enlarged more widely. All canals were obturated with cold laterally condensed gutta-percha. They concluded that uninstrumented recesses may be left in many oval canals after preparation using the balanced force technique and these recesses may often not be completely obturated with cold laterally condensed gutta-percha.

Walters MJ, Baumgartner JC et al (2002)[61] evaluated the efficacy of a handpiece-mounted irrigation device and compared it to irrigation with a syringe and needle in the apical 5 mm of the root canal system. A syringe and needle were used in group A and the handpiece-mounted system in group B. In group A, there was significantly more debris in the 1-mm section than in the 3- or 5-mm sections. In group B, the differences between levels were not significant. There was no significant difference in the amount of debris remaining in the apical 5 mm of canals when comparing the handpiece-mounted irrigation device to irrigation with a syringe and needle.

Zamany A, Safavi K et al (2003)[66] investigated whether addition of a 2% chlorhexidine rinse to a conventional treatment protocol enhances the rate of the successful disinfection of the root canal system in vivo. Twenty-four teeth with infected necrotic pulps and resorbing apical periodontitis were treated with a conventional technique in which 1% NaOCl as irrigant was used. Half of the cases received an additional rinse with 2% chlorhexidine. Cultivable bacteria were retrieved at the conclusion of the first visit in 1 out of 12 chlorhexidine cases whereas in the control group 7 out of 12 cases showed growth.

Lee S J, Wu M K et al (2004)[33] compared the ability of syringe irrigation and ultrasonic irrigation to remove artificially placed dentine debris from simulated canal irregularities within prepared root canals. 2% NaOCl was delivered into each canal either using syringe irrigation or using ultrasonic irrigation. The amount of remaining dentine debris in the grooves and depressions was evaluated by using a scoring system between 0–3: the higher the score, the more the debris. They concluded that ultrasonic irrigation ex vivo is more effective than syringe irrigation in removing artificially created dentine debris placed in simulated uninstrumented extensions and irregularities in straight, wide root canals.

Rosenthal S, Spangberg L et al (2004)[45] evaluated the substantivity of chlorhexidine (CHX) within a root canal system and assessed how long the CHX remains antimicrobially effective. Sections which served as controls, were treated with 1% sodium hypochlorite and 1 mol/L EDTA, then obturated with gutta percha and AH26 sealer. Experimental sections were treated similarly except they were placed in 2% CHX for 10 minutes prior to obturation. The extracts from experimental and control groups were mixed with cultures of Enterococcus faecalis. They concluded that CHX is retained in root canal dentin in antimicrobially effective amounts for up to 12 weeks.

Falk KW, Sedgley CM et al (2005)[22] tested the hypothesis that the mechanical efficacy of irrigation in reducing intracanal bacteria was dependent on canal preparation size. Root canals were inoculated with Pseudomonas fluorescens and bioluminescence was measured before inoculation, after inoculation and after irrigation with 6 ml of irrigant delivered 1 mm from WL using a 28G safety-ended needle. Irrigation 1 mm from WL was significantly less effective in canals prepared to size 36.

Gutarts R, Nusstein J et al (2005)[26] 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. Group 1 consisted of 16 teeth prepared with a hand/rotary technique whereas Group 2 consisted of 15 teeth prepared in similar fashion but followed by 1 min of ultrasonic irrigation, per canal, utilizing an ultrasonic needle. Five uninstrumented mandibular molars served as histologic controls. It was concluded that, the 1 min use of the ultrasonic needle after hand/rotary instrumentation resulted in significantly cleaner canals and isthmuses in the mesial roots of mandibular molars.

van der Sluis LW, Wu MK, et al (2005)[55] investigated the influence of the taper of root canals on the effectiveness of ultrasonic irrigation to remove artificially placed dentine debris. The canines were then divided into three groups and prepared using either size 20, .06 taper System GT instruments, size 20, .08 taper or size 20, .10 taper System GT instruments. In each canal ultrasonic irrigation was performed with a size 15 K file using 2% NaOCl as an irrigant. They summarized that ultrasonic irrigation was more effective in removing artificially placed dentine debris from simulated canal extensions from canals with greater tapers.

van der Sluis, Gambarini et al (2006)[52] determined the influence of volume, irrigant and method of flushing on the removal of artificially placed dentine debris from the apical part of root canals during passive ultrasonic irrigation. All canals were ultrasonically irrigated, using a size 15, 0.02 taper smooth wire. In Group 1, continuous flow of 50 mL 2% sodium hypochlorite (NaOCl) was used. Group 2 canal was flushed with 12 mL 2% NaOCl, at a rate of 2 mL per 30 s using a syringe. Group 3 was treated in the same way as Group 2 but the canal was flushed with 6 mL 2% NaOCl, at a rate of 2 mL per min. Group 4 was treated in the same way as Group 1 but water was used as the irrigant. The results suggested that syringe delivery of 2% NaOCl (6 and 12 mL) was as effective as a continuous flow of 2% NaOCl (50 mL) and that water was not effective.

Zehnder M et al (2006)[67] stated that local wound debridement in the diseased pulp space was the main step in root canal treatment to stop the tooth from being a source of infection. In this review article, the specifics of the pulpal microenvironment and the resulting requirements for irrigating solutions were spelled out. Sodium hypochlorite solution was recommended as the main irrigant. Chemical and toxicological concerns related to their use were discussed, including different approaches to enhance local efficacy without increasing the caustic potential. In addition, chelating solutions were recommended as adjunct irrigants to prevent the formation of a smear layer and/or remove it before filling the root canal system. Based on the actions and interactions of currently available solutions, a clinical irrigating regimen was proposed.

Athanassiadis B, Abbott PV et al (2007)[9] stated that the primary aim of endodontic treatment was to remove as many bacteria as possible from the root canal system and then to create an environment in which any of the remaining organisms could not survive. This they stated, can only be achieved through the use of a combination of aseptic treatment techniques, chemomechanical preparation of the root canal, antimicrobial irrigating solutions and intracanal medicaments. The choice of the intracanal medicament to be used was dependent on making an accurate diagnosis of the condition being treated. Commonly used medicaments include calcium hydroxide, antibiotics, non-phenolic biocides, phenolic biocides and iodine compounds.

Schoop U, Barylyak A et al (2007)[47] assessed the effects of Er,Cr:YSGG laser irradiation in conjunction with newly designed radial firing tips. The bacteriological evaluation revealed a decisive disinfectant effect whereas the scanning electron microscopy showed the homogeneous removal of smear layer from the root canal walls. The temperature rise at the root surface during the irradiation was moderate, yielding 1.3°C for the 0.6 W setting and 1.6°C for the 0.9 W setting. The investigations indicated that the Er,Cr: YSGG laser, in conjunction with radial-firing tips, is a suitable tool for the elimination of bacteria in root canals and for the removal of smear layer.

Schoop U, Goharkhay K et al (2007)[48] conducted an in vitro study to assess the effects of Er,Cr:YSGG laser irradiation on root canals. The authors inoculated root canals with two bacteria, laser irradiated them at two power settings and subjected them to a quantitative microbiological evaluation and used scanning electron microscopy (SEM) to assess the morphological changes. The bacteriological evaluation revealed a disinfecting effect in the root dentin samples that was dependent on the output power but not specific for the bacterial species investigated. SEM showed the removal of the smear layer from the root canal walls and the exposure of dentinal tubules. The temperature rise during irradiation was moderate when standardized power settings were used.

van der Sluis LWM, Versluis M et al (2007)[54] described that ultrasonic irrigation of the root canal can be performed with or without simultaneous ultrasonic instrumentation and when canal shaping was not undertaken the term passive ultrasonic irrigation (PUI) was used to describe the technique. They explained that passive ultrasonic irrigation can be performed with a small file or smooth wire (size 10–20) oscillating freely in the root canal to induce powerful acoustic microstreaming and that PUI can be an important supplement for cleaning the root canal system. When compared with traditional syringe irrigation, it removed more organic tissue, planktonic bacteria and dentine debris from the root canal. They concluded that the influence of irrigation frequency and intensity on the streaming pattern as well as the complicated interaction of acoustic streaming with the adherent biofilm needs to be clarified to reveal the underlying physical mechanisms of PUI.

van der Sluis LW, Wu MK et al (2007)[56] evaluated the capacity to remove a calcium hydroxide ($Ca(OH)_2$) paste from the root canal and the efficacy of $Ca(OH)_2$ removal during passive ultrasonic irrigation using either sodium hypochlorite (NaOCl) or water as an irrigant. In Group 1 (n = 16), the teeth were ultrasonically irrigated using 50 mL of 2.0% NaOCl as the irrigant. Group 2 (n = 16) was treated in the same manner as Group 1, but using 50 mL water in place of the NaOCl. In Group 3 (n = 16), the teeth were irrigated by syringe injection of 50 mL 2.0% NaOCl. Passive ultrasonic irrigation with 2% NaOCl was found to be more effective in removing $Ca(OH)_2$ paste from artificial root canal grooves than syringe delivery of 2% NaOCl or water as irrigant.

George R, Meyers IA et al (2008)[23] examined the ability of improved laser tips, when Er:YAG and Er,Cr:YSGG lasers were used in root canals in which thick smear layers had been created intentionally. Smear layer was assessed from scanning electron microscopy images with an objective digital method. Lasing improved the action of ethylene diamine tetraacetic acid with cetavlon (EDTAC) in removing smear layer. Conical fibers performed better than plain fibers, but there was no difference in performance between the 2 laser systems when matched for all other parameters.

Blanken J, De Moor GR et al (2009)[10] observed that limited information existed regarding the induction of explosive vapor and cavitation bubbles in an endodontic rinsing solution and hence investigated the fluid movements and the mechanism of action caused by an Er,Cr:YSGG laser in a transparent root model. Er,Cr:YSGG laser was used at pulse energies of 75, 125, and 250mJ at 20 Hz using a 200 mm fiber. Fluid movement was investigated by means of dyes and explosive vapor bubbles were visualized. Their recordings in the glass model showed the creation of expanding and imploding vapor bubbles with secondary cavitation effects.

de Groot SD, Verhaagen B et al (2009)[15] tested ex vivo the efficiency of laser-activated irrigation in removing dentine debris from the apical part of the root canal and to visualize in vitro the fluid dynamics during the activation of the irrigant by laser, using high-speed imaging at a relevant timescale. Results showed that laser-activated irrigation was significantly more effective in removing dentine debris from the apical part of the root canal than passive ultrasonic irrigation or hand irrigation when the irrigant was activated for 20 s and suggest that streaming, caused by the collapse of the laser-induced bubble, is the main cleaning mechanism of LAI.

De Moor RJ, Blanken J et al (2009)[16] compared the efficacy of LAI for removal of debris in root canals as compared to conventional irrigation (CI) and passive ultrasonic irrigation. Group 1 root canals were irrigated with 2.5% NaOCl by hand (20 seconds) with the needle 1 mm short from the apical stop, in Group 2 NaOCl was ultrasonically activated (20 seconds) with an Irrisafe tip 1 mm short from the apical stop, and in Group 3 NaOCl was activated with an Er,Cr:YSGG laser. LAI resulted in significantly less debris than PUI and CI. PUI also showed significantly less debris than CI

Desai P, Himel V et al (2009)[19] evaluated the safety of various intracanal irrigation systems by measuring the apical extrusion of irrigant. The irrigation systems used were EndoVac Micro and Macro Cannula, EndoActivator, manual irrigation with Max-I-Probe needle, Ultrasonic Needle Irrigation, and Rinsendo. This study showed that the EndoVac did not extrude irrigant after deep intracanal delivery and suctioning the irrigant from the chamber to full working length. Manual, Ultrasonic, and Rinsendo groups had significantly greater amount of extrusion compared with EndoVac and EndoActivator

Gu L, Kim JR et al (2009)[25] presented an overview of the irrigant agitation methods currently available and their debridement efficacy. They divided these devices into manual and machine assisted agitation systems. Overall, they said that it appeared to have resulted in improved canal cleanliness when compared with conventional syringe needle irrigation. They also raised concerns on the need for studies that could more effectively evaluate specific irrigation methods by using standardized debris or biofilm models They concluded that understanding these fundamental issues is crucial for clinical scientists to improve the design and user-friendliness of future generations of irrigant agitation systems.

Nadalin MR, da Cruz Perez et al (2009)[36] evaluated *in vitro* the capacity of debris removal from the apical third of flattened root canals, using different final irrigation protocols. The 5 groups were: Group I: 10 mL of distilled water (control), Group II: 10 mL of 1% NaOCl for 8 min, Group III: 2 mL of 1% NaOCl for 2 min (repeated 4 times), Group IV: 10 mL of 2.5% NaOCl for 8 min, and Group V: 10 mL of 2.5% NaOCl for 2 min (repeated 4 times). They concluded that the final irrigation protocols evaluated in this study using the Luer syringe presented similar performance in the removal of debris from the apical third of flattened root canals.

de Gregorio C, Estevez R et al (2010)[14] studied the effect of currently used irrigation and activation systems on the penetration of sodium hypochlorite into simulated lateral canals and to working length in a closed system. The roots were then randomly assigned to 4 experimental groups: Group 1-Endoactivator (sonic activation); Group 2 -passive ultrasonic activation; Group 3 -F file; Group 4 -apical negative pressure (ANP) irrigation; and control Group 5 -positive pressure irrigation. Their results demonstrated that the ANP irrigation system showed limited activation of the irrigant into lateral canals but reached the working length significantly more than the other groups tested and in contrast, PUI group demonstrated significantly more penetration of irrigant into lateral canals but not up to the working length.

De Moor RJ , Meire M et al (2010)[17] assessed the efficacy of laser activated irrigation with Er:YAG and Er,Cr:YSGG wavelengths and compared it with passive ultrasonic irrigation. Five groups of 20 straight canine roots were evaluated as follows: Group 1: hand irrigation for 20 s with 2.5% NaOCl (CI); Group 2: PUI performed once for 20 s with the #20 Irrisafe (PUI 1); Group 3: PUI for 3x 20 s with the Irrisafe (PUI 2); Group 4: LAI with the Er,Cr:YSGG laser and Z2 (200 microm) Endolase tip at 75 mJ for 4x 5 s (LAI 1); Group 5: LAI with the Er:YAG laser and a 200 µm endodontic fiber at 75 mJ for 4x 5 s (LAI 2). Results showed that LAI techniques using erbium lasers

(Er:YAG or Er,Cr:YSGG) for 20 seconds (4x 5 seconds) were found to be as efficient as PUI with the intermittent flush technique (3x 20 seconds).

DiVito E, Peters O A et al (2010)[21] analyzed in vitro the debriding ability of an Er:YAG laser system (2,940 nm) equipped with a newly designed radial and stripped tip of 400 μm diameter using scanning electron microscopy (SEM). Group 1 was irrigated for 2 min with saline water as a control group. Groups 2, 3 and 4 were irradiated with an Er:YAG laser at 25 mJ and 15 Hz with a pulse duration of 50s .Group 2- 20 s, laser irradiation in sterile distilled water, wet canal; Group 3- 20 s, laser irradiation in 17% EDTA, wet canal; and Group 4- 40 s, laser irradiation in 17% EDTA, wet canal. The study showed that standardized instrumentation, followed by a final Er:YAG laser irradiation in wet canals with EDTA irrigation resulted in more cleaning of the root canal walls and a higher quantity of open tubules in comparison with the traditional irrigation method

Haapasalo M, Shen Y et al (2010)[27] summarized the chemistry, biology, and procedures for safe and efficient irrigation. They described that irrigants have traditionally been delivered into the root-canal space using syringes and metal needles of different size and tip design. Clinical experience and research have shown, however, that this classic approach typically results in ineffective irrigation. They concluded that many of the compounds used for irrigation have been chemically modified and several mechanical devices have been developed to improve the penetration and effectiveness of irrigation.

Klyn SL, Kirkpatrick TC et al (2010)[32] compared the debris removal efficacy of the EndoActivator system, the F file, ultrasonic irrigation, or 6% NaOCl irrigation alone in human mandibular molars after hand-rotary instrumentation. Group 1 used F file for 30 seconds, Group 2 used EndoActivator system for 30 seconds, Group 3 used ultrasonic irrigation for 30 seconds, and Group 4 used irrigation with 6% NaOCl within 1 mm of working length. All groups received a final irrigation with 6% NaOCl in each canal. Their results showed no statistically significant difference in canal or isthmus cleanliness among the 4 groups, but there was a statistically significant difference in canal cleanliness between the 1-mm level versus the 3-mm and 5-mm levels for all of the groups.

Paragliola R, Franco V, et al (2010)[38] examined the effect of different root canal irrigant agitation protocols in the penetration of an endodontic irrigant into dentinal tubules. Shaping was done with nickel-titanium instruments, and a final rinse of 5% sodium hypochlorite labeled with 0.2% alizarin red was performed. Specimens were assigned to 7 groups and submitted to the following rinse activation protocols: no agitation (control group), K-File or gutta-percha agitation, or different sonic and ultrasonic agitations. According to the results the groups were ranked in the following order: control = K-file = gutta-percha < Sonic < Ultrasonic.

Rödig T, Bozkurt M et al (2010)[44] compared the efficiency of a sonic device (Vibringe), syringe irrigation, and passive ultrasonic irrigation in the removal of debris from simulated root canal irregularities. Three different irrigation procedures were performed with NaOCl (1%) and (1) syringe irrigation, (2) Vibringe, and (3) passive ultrasonic irrigation. The amount of remaining debris was evaluated by using a 4-grade scoring system. They found that passive ultrasonic irrigation is more effective than the Vibringe System or syringe irrigation in removing debris. The sonic device demonstrated significantly better results than syringe irrigation in the apical root canal third.

van der Sluis LW, Vogels MP et al (2010)[53] evaluated dentin debris removal from the root canal during ultrasonic activation of sodium hypochlorite (2% and 10%), carbonated water, and distilled water and determined the influence of 3 ultrasonic refreshment/activation cycles of the irrigant by using the intermittent flush technique. Ultrasonic activation of the irrigant combined with the intermittent flush method produced a cumulative effect over 3 refreshment/activation cycles. They concluded that sodium hypochlorite as an irrigant is significantly more effective than carbonated water, which is significantly more effective than distilled water, in removing dentin debris from the root canal during ultrasonic activation.

Adcock JM, Sidow SJ, Looney SW, et al (2011)[1] compared canal and isthmus debridement efficacies between side-vented needle irrigation (SNI) and continuous ultrasonic irrigation (CUI) in the mesial root of mandibular first molars. Final irrigation was performed with either SNI or CUI. They concluded that compared with SNI, CUI removes significantly more debris from narrow isthmuses of mandibular mesial roots.

Jiang LM, Verhaagen B et al (2011)[29] evaluated the effect of the ultrasonic intensity on PUI to remove dentin debris and whether there is any lateral effect beyond the ultrasonic tip. The highest intensity was applied in Group 1, the lowest intensity was applied in Group 3, and syringe irrigation was performed in Group 4 as a control. Group 1 exhibited significantly better cleaning than all the other groups; no significant difference was found between the four levels of the depressions within any of the four groups. High-speed imaging showed that the amplitude of the oscillating file increased as the intensity went up, which leads to a higher velocity of the irrigant around the file.

Kanter V, Weldon E et al (2011)[31] compared two irrigation techniques by evaluating canal cleanliness and obturation of lateral/accessory canals. The EndoActivator (EA) was compared with an ultrasonic unit for final irrigation. Each unit was used for 1 minute with 2% NaOCl and 17% EDTA. A control group received syringe irrigation. The EA was significantly better in removing debris at all levels when compared with other treatment groups and resulted in obturation of significantly more numbers of lateral canals.

Curtis TO, Sedgley CM et al (2012)[12] compared a continuous ultrasonic irrigation device with conventional needle irrigation when used as a final irrigation procedure to debride the apical region of the root canal. Teeth were randomly assigned to receive final irrigation with either ultrasonic irrigation or conventional needle irrigation. The gauge of the needle (#30), the irrigation cycles (5 mL NaOCl, 5 mL 15% EDTA, and 5 mL NaOCl), the irrigant flow rate (5 mL/min), and needle depth placement (1 mm from the working length) were kept as experimental constants. They concluded that final irrigation with the ultrasonic irrigation compared with conventional needle irrigation delivery resulted in significantly less debris present in root canals at 1 and 3 mm from the WL

DiVito E, Lloyd A et al (2012)[20] reasoned that laser-activated irrigation at subablative levels had the potential for complete tubular dentin disinfection in endodontics. They pointed out the fact that the PIPS photoacoustic effect does not create thermal damage and travels 3-dimensionally wherever there is fluid, making it advantageous as a treatment modality for removing biofilms associated with periodontal pockets that are in difficult to access furcation areas and interproximal vertical defects.

Olivi G, DiVito E et al (2012)[37] reviewed photoacoustic endodontics using PIPS: the experimental background and clinical protocol. They observed that clinically traditional endodontic techniques fell short of successfully removing all of the infective microorganisms and debris. This was attributed to the complex root canal anatomy and the inability of common irrigants to penetrate into the lateral canals and the apical ramifications. The findings of this study demonstrated that PIPS technique resulted in safe and effective debriding and decontamination of the root canal system. Their clinical trials also showed that the PIPS technique greatly simplifies root canal therapy while facilitating the search for the apical terminus, debriding and maintaining patency.

Pedullà E, Genovese C et al (2012)[40] assessed ex vivo, the antibacterial effectiveness of PIPS on irrigants using an Er:YAG laser equipped with a newly designed, stripped and tapered tip in extracted teeth with infected root canals. Teeth inoculated with E faecalis were pulsed with erbium/YAG laser at nonablative settings for 30 s with sterile bi-distilled water (Group A) or 5% NaOCl (Group B); without laser-activated sterile bi-distilled water irrigation for 30 s (Group C) or 5% NaOCl irrigation for 30 s (Group D); the positive control group received no treatment in infected teeth. Their results showed that there was no significant difference in bacterial reduction between laser and NaOCl or NaOCl alone and thus the use of a laser did not improve microbial killing over and above the use of NaOCI alone.

Pereira, Peixoto et al (2012)[41] evaluated the protocols of sonic and vacuum irrigation regarding the capacity of debris removal from root canal systems. Group 1 used sonic irrigation and Group 2 used vacuum irrigation protocol. It was concluded that at the whole apical third, the sonic irrigation protocol removed significantly more debris than the vacuum protocol. However, in the region at 2 mm from the working length, the second irrigation method demonstrated a better performance.

Al-Ali M, Sathorn C et al (2012)[6] compared the smear layer and debris removal effectiveness of four root canal irrigation protocols as well as their effectiveness in removing remaining soft tissues in curved root canals. Group 1 employed manual agitation of 1% NaOCl and 15% EDTA; Group 2 - CanalBrush agitation of 1% NaOCl and 15% EDTA; Group 3 - 3% H_2O_2 alternated with 1% NaOCl; Group 4 - passive ultrasonic agitation of 1% NaOCl and 15% EDTA. Their results showed that the Canal Brush was as effective as passive ultrasonic irrigation in smear layer and debris removal. Alternating H_2O_2 with NaOCl was effective in removing soft tissues from root canal complexities.

Ribeiro EM, Silva-Sousa YT et al (2012)[43] analysed the presence of debris and smear layer on the internal walls of root canal. The Irrigant agitation protocols used were: conventional syringe irrigation with NaviTip needle (no activation), active scrubbing of irrigant with brush-covered NaviTip FX needle, manual dynamic irrigation, continuous passive ultrasonic irrigation, and apical negative pressure irrigation (EndoVac system). Results showed that although none of the irrigant agitation protocols completely removed debris and smear layer from flattened root canals, the machine-assisted agitation systems (ultrasound and EndoVac) removed more debris than the manual techniques.

Zhu X, Yin X et al (2013)[68] investigated the antibacterial efficacy and smear layer removal ability of PIPS when used with conventional syringe irrigation in vitro. The colony-forming units (CFUs) per mL were determined after infection as the baseline. Then, the teeth were subjected to either PIPS plus 3% sodium hypochlorite (PIPS+NaOCl) or conventional syringe irrigation with 0.9% saline, 3% NaOCl, 17% EDTA, 0.2% chlorhexidine gluconate (CHX), or 3% NaOCl alternating with 17% EDTA. The reduction of CFUs in the individual group was determined. The conclusion was that PIPS supplied with NaOCl is comparable to conventional syringe irrigation with NaOCl+EDTA in its ability to remove E. faecalis and smear layer in single-rooted canals.

Arslan, Capar et al (2014)[8] compared the efficacy of photon-induced photoacoustic streaming (PIPS) technique with conventional, sonic and ultrasonic irrigation on the removal of apically placed dentinal debris from an artificial groove created in a root canal. Irrigation was performed as follows: (i) conventional irrigation with 1% NaOCl, (ii) sonic, (iii) ultrasonic irrigation, and (iv) PIPS. Their results showed photon-induced photoacoustic streaming removed significantly more dentinal debris than conventional irrigation, sonic irrigation or ultrasonic irrigation and there was no significant difference between sonic and ultrasonic irrigation.

Alkahtani, Al Khudhairi et al (2014)[7] evaluated the effectiveness of the EndoVac irrigation system, regarding 1) debris removal and 2) the control of apically extruded irrigating solution. Group 1 used EndoVac irrigation system, Group 2 used 30-gauge, tip-vented irrigation needle and Group 3 used 30-gauge, side-vented irrigation needle. They concluded that the EndoVac irrigation system extruded significantly less irrigant solution than either of the two needle irrigation systems and the debris collection was the least in the apical third for the EndoVac irrigation system. No significant difference was found in the cleaning efficiency among the three irrigation systems.

Justo, da Rosa, et al (2014)[30] performed an in vitro study to compare the effectiveness of saline, 2.5% sodium hypochlorite, and 2% chlorhexidine, with or without passive ultrasonic irrigation, in debris removal from simulated canal irregularities within prepared root canals. Different final irrigation protocols including saline, sodium hypochlorite and chlorhexidine, with and without PUI were performed. They concluded that the final irrigation protocols that used PUI were more effective in removing debris from simulated canal irregularities into the apical third than those that did not use it.

Lloyd A, Uhles JP et al (2014)[34] investigated laser-activated irrigation to remove organic debris from canal isthmuses using x-ray microfocus computed tomographic imaging. Two groups (n = 7) underwent final irrigation using either standard needle irrigation (SNI) or PIPS. They concluded that irrigation using PIPS increased the canal volume and eliminated debris from the canal system 2.6 times greater than SNI.

Deleu E, Meire AM et al (2015)[18] compared the efficacy of different irrigant activation methods in removing debris from simulated root canal irregularities. Six irrigant activation procedures were tested: conventional needle irrigation, manual-dynamic irrigation with a tapered gutta percha cone, passive ultrasonic irrigation, laser activated irrigation with 2,940-nm Er:YAG laser with a plain fiber tip inside the canal (Er-flat), LAI with Er:YAG laser with a conical tip held at the canal entrance (Er- PIPS), and LAI with a 980-nm diode laser moving the fiber inside the canal (diode). Their results showed that conventional irrigation removed significantly less debris than all other groups and the Er:YAG with plain fiber tip was more efficient than manual-dynamic irrigation, conventional irrigation, diode, and Er:YAG laser with PIPS tip in removing debris from simulated root canal irregularities.

Sunil Kumar, Bhavya et al (2015)[51] studied the efficacy of Endo activator (sonic), ultrasonic-activated irrigation and conventional syringe irrigation in removing dentin debris in straight and curved root canals. 3 irrigation techniques were used: syringe irrigation, Endoactivator irrigation, and Passive ultrasonic irrigation. Their conclusion was that in straight canals, ultrasonic irrigation and Endoactivator were the most effective, but in the curved root canals, ultrasonic irrigation was superior.

Materials and Methods

MATERIALS AND METHOD

ARMAMENTARIUM:

- Extracted mandibular premolar teeth
- Diamond disc and lab micro-motor
- K- files (#15 to #80, MANI, INC)
- Gates-Glidden drills (2# to 6# MANI, INC)
- Aerotor hand piece (NSK PANAAIR)
- Contra angle micro motor hand piece (NSK)
- Normal saline (Baxter)
- 2.5% sodium hypochlorite solution (Prime dental products Pvt Ltd)
- 2% chlorhexidine solution (RC- Chlor, Deorcare)
- 17% EDTA solution(Dent Wash, Prime dental products)
- 30 gauge needle (Unolok)
- Side vented needle (RC Twents, Prime dental products)
- Digital Vernier calliper
- Round bur no 2 (MANI, INC)
- Double ended amalgam carrier (Surmedix Ltd)
- Modelling wax (Hindustan)
- Sticky wax (DPI)
- Polyvinyl siloxane impression material (Dentsply)
- Ultrasonic file(#20) (Irrisafe, Satelec Acteongroup)

- Radial-firing tips no 2-21mm (Biolase Technology)

SPECIAL EQUIPMENT:

- Satelec scaler unit
- ErCr:YSGG laser unit (Waterlase IPlus, Biolase Technology)
- Scanning electron microscope

SPECIMEN SELECTION:

50 extracted human mandibular premolars were selected

INCLUSION CRITERIA:

Extracted single rooted teeth with mature apices

EXCLUSION CRITERIA:

Teeth with dental caries, cervical abrasion, previous restoration or fractures or cracks, dilaceration were excluded

TOOTH SAMPLE SELECTION

Lower single rooted first premolar teeth with intact roots were selected for the study. Examination of all roots was performed under a magnifying glass and defective roots, including those with lacerations, resorption, fractures and incomplete root formation, were excluded. Using a periodontal scaler, soft tissue and calculus were removed from the surface and the teeth were radiographically verified as having a single root canal. Teeth were decoronated using a double-sided diamond disc to a length of 15 mm.

CHEMOMECHANICAL PREPARATION

Working length was set at 1 mm shorter than root length, namely 14mm. Gates Glidden drills no 2-4 (MANI, INC) were used for the coronal shaping of the root canal. Instrumentation of the canal was performed with stainless steel hand k files (MANI, INC) to size 50 at the working length and to sizes 55, 60, 70 and 80 to 1, 2, 3 and 4 mm from the working length respectively. Each specimen was flushed periodically with the respective irrigant (2 ml). This was done at the end of preparation as well as with file changes. The irrigants used were saline, 2.5% sodium hypochlorite and 2% chlorhexidine. These solutions were delivered into the root canals with a 30-G irrigation needle (attached to a 10 ml disposable syringe) to a length 1 mm short of the working length. The teeth were grooved longitudinally on the mesial and distal external surfaces with a diamond disc under irrigation, taking care not to penetrate the root canal. Using a chisel, the specimens were then split into two.

SIMULATED CANAL IRREGULARITIES, DENTIN DEBRIS INSERTION

Using a digital Vernier calliper, a mark was made 2 mm from the apex, on the inner canal wall. A standard depression was made with a round bur no 2, measuring 1 mm in diameter. Dentin debris was produced by longitudinal splitting of other teeth and using a round bur to create dentin shavings. These shavings were then mixed with 0.1 ml of saline to produce a wet sand like consistency. 0.02g of this mixture was weighed on an analytical balance and placed into the depression made, using a double sided amalgam carrier.

SPECIMEN EMBEDMENT

Approximation of the root halves was followed by placement of modelling wax at the apex of each sample. Any gaps along the sides of the reassembled segments were sealed with sticky wax. The entire unit was embedded in polyvinyl siloxane impression material. This was done for two reasons, firstly, to attain apical vapour lock by creating a close-ended channel and secondly, to prevent overflow of the irrigating solution[40]. Irrigation was performed immediately after embedment.

IRRIGATION PROTOCOL

The specimens were divided randomly into 5 groups (n=10):

1) **Group I** (control group): Saline: 6 mL saline + 5 mL 17% EDTA + 2 mL saline.

   Syringe irrigation was done with a 30-gauge cannula side vented needle that was placed 1 mm short of the working length, without binding to the canal walls.
2) **Group II:** NaOCl/PUI: 6 mL 2.5% NaOCl + PUI for 1 minute (3 activations of 20 seconds) + 5 mL 17% EDTA + 2 mL 2.5% NaOCl.

2.5% NaOCl was placed into the canal with a needle and a smooth ultrasonic file (#20) (Irrisafe, Satelec Acteongroup) (size 15, .02 taper) was then inserted 1 mm short of the working length (Lee et al. 2004). Ultrasonic activation was done at a frequency of 30 Hz and done for a duration of a minute[30].

3) **Group III:** CHX/PUI: 6 mL 2% CHX + PUI for 1 minute (3 activations of 20 seconds) + 5 mL 17% EDTA + 2 mL 2% CHX.

   Procedure similar to Group II was followed, the only difference being the irrigant used. In this group, 2% chlorhexidine was used.

4) **Group IV:** 6 mL 2.5% NaOCl + 4 Photon activations for 5 seconds each + 5 mL 17% EDTA + 2 mL 2.5% NaOCl

   Laser activation was done using an ErCr:YSGG laser with an emission wavelength of 2780 nm. A 200 µm diameter radial-firing tip (Biolase Technology), 21 mm long fiber tip was applied at 20Hz and 75mJ per pulse, pulse duration of 140 microseconds, nominal peak power of 535W. The water and air on the laser system were turned off. The optical fiber was placed 5 mm from the apex of the tooth. Suitable irrigant solution was maintained, by replenishing the solution in the coronal reservoir with supplemental NaOCl solution. 4 Photon activations were performed for 5 seconds each[17].

5) **Group V:** 6 mL 2% CHX + 4 Photon activations for 5 seconds each + 5 mL 17% EDTA + 2 mL 2% CHX

   Procedure similar to Group IV was followed, the only difference being the irrigant used. In this group, 2% chlorhexidine was used.

Each group was irrigated with 18 ml of the respective solution during chemomechanical preparation. Final irrigation was done with 8 ml of the respective irrigant + 5 ml 17% EDTA, totaling to 31 ml of solution.

The specimens were then disassembled. Gold sputtering was done to the samples followed by examination under a scanning electron microscope. The simulated canal irregularity was examined under a scanning electron microscope at 10kV and 20x magnification.

QUANTIFICATION OF DEBRIS REMOVAL

The extent of debris removal was recorded using a scoring system put forth by Justo et al (2014). Higher score represents presence of larger amount of debris.

1) the groove is empty- 1
2) <50% of the groove filled with debris- 2
3) >50% of the groove filled with debris- 3
4) the groove is completely filled with debris-4

The SEM images were processed using GIMP 2.8.16 software where the number of squares occupied by the debris and the number of squares free of the debris were calculated and the corresponding percentages were estimated.

$$Debris\ Reduction\ \% = \frac{Area\ free\ of\ debris}{Area\ of\ the\ depression} * 100$$

Area is calculated by counting the number of squares free of debris using GIMP. The data obtained was subjected to statistical analysis.

METHODOLOGY FLOWCHART

50 lower single rooted 1st premolar teeth with intact roots were selected

↓

Teeth decoronated to a length of 15 mm

↓

Access cavity was prepared with round access bur #2

↓

Coronal flaring done with Gates Glidden drills (#2-4). Instrumentation to MAF #50 and step back preparation to size #80 k file

↓

Periodic irrigation with 2 ml of irrigant was performed with each file change and at the end of preparation

↓

Teeth were grooved longitudinally on mesial and distal external root surfaces and split into two

↓

Mark made 2 mm from apex and standard depression made with round bur #2

↓

Dentin debris produced and placed in it

↓

2 halves approximated. Modelling wax placed at apex. Site sealed with sticky wax. Entire unit embedded in putty impression material

↓

Group – I	Group – II	Group – III	Group – IV	Group – V
Saline/syringe	NaOCl/PUI	CHX/PUI	NaOCl/LAI	CHX/LAI

↓

Specimens were disassembled

↓

SEM Analysis done

↓

Images studied with GIMP software and scored

Figures

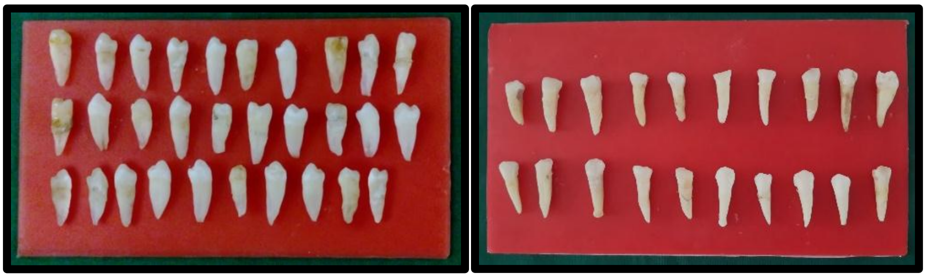


Fig 1: Extracted mandibular premolar teeth

Fig 2: Armamentarium

Fig 3: Irrigants used

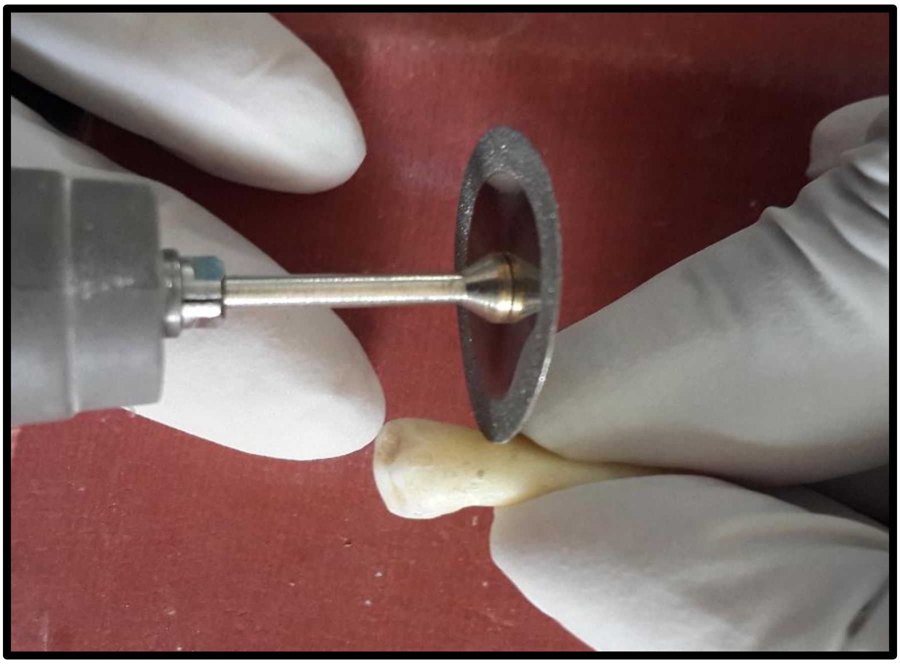


Fig 4: Decoronation of teeth

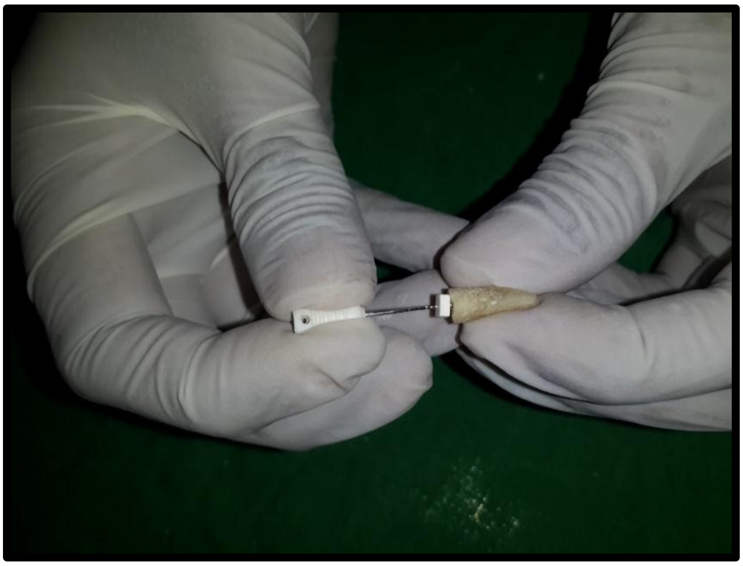


Fig 5: Canal patency established with # 15 k file

Fig 6: Coronal flaring with GG drills

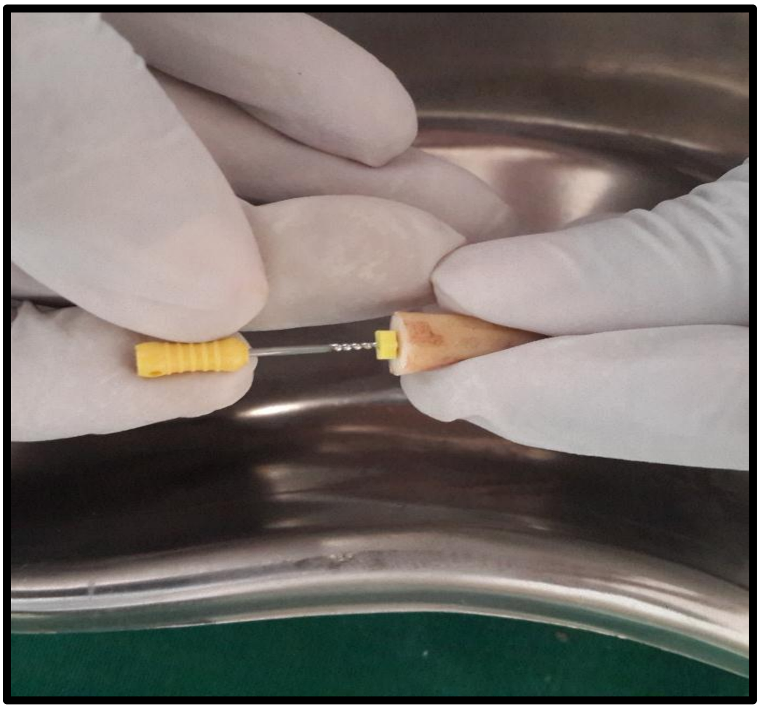


Fig 7: Preparation to MAF #50 k file

Fig 8: Tooth longitudinally sectioned in half

Fig 9: Debris placed in artificial depression

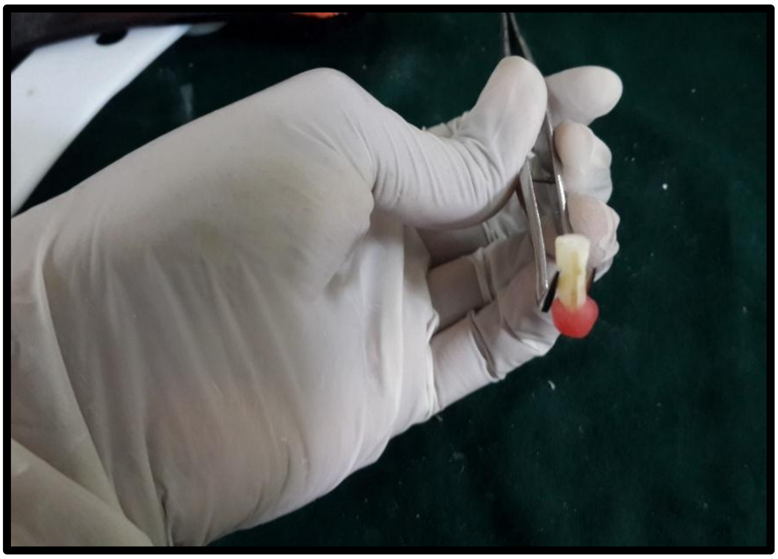


Fig 10: Sections reassembled

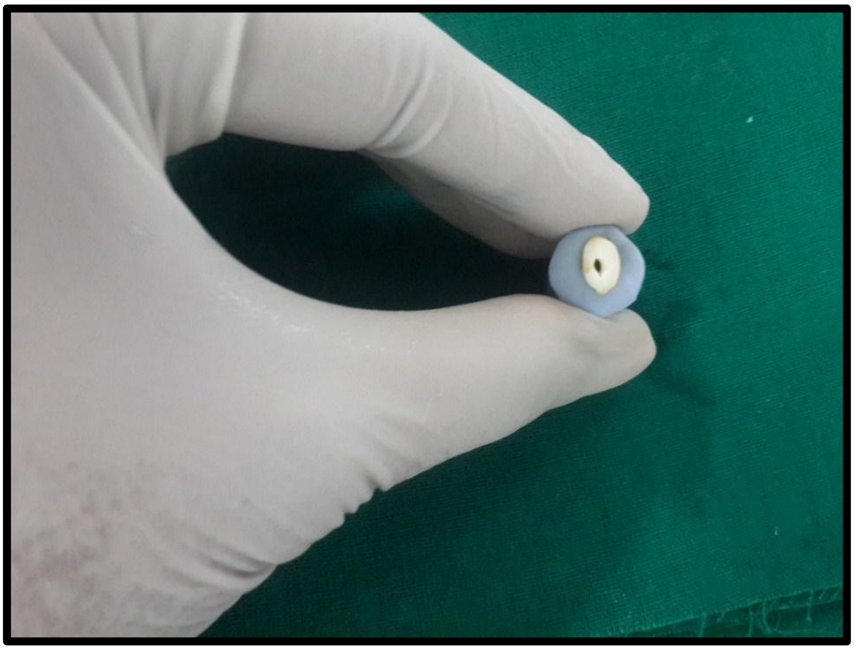


Fig 11: Specimen embedded in putty

Fig 12: Embedded samples of a group

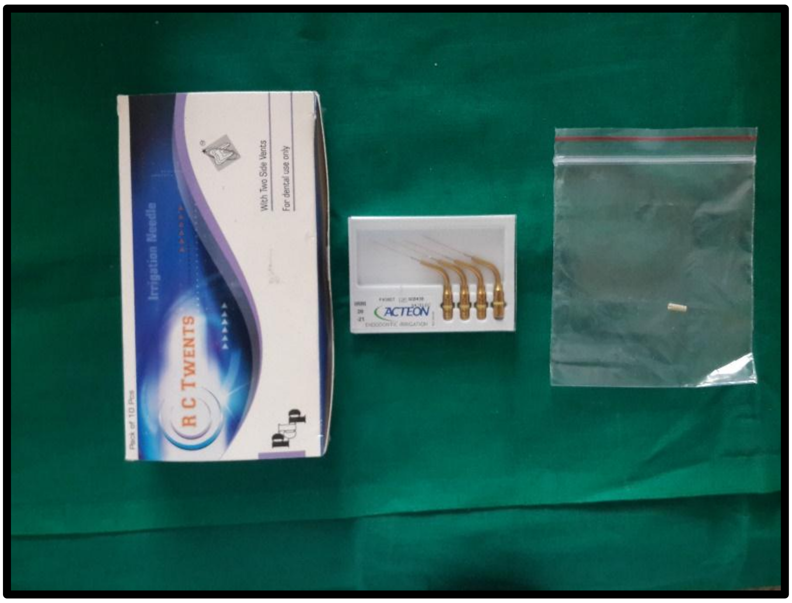


Fig 13: Irrigant delivery and activation tips

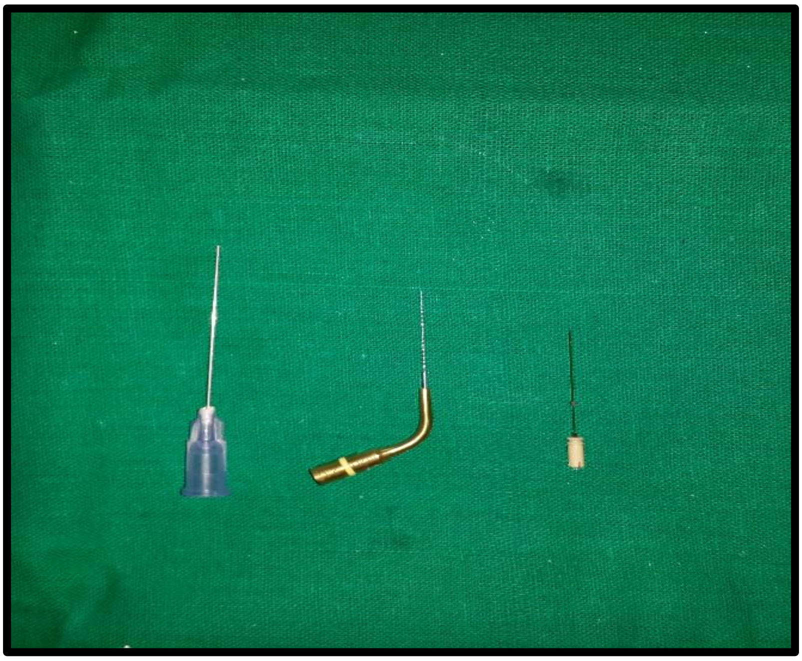


Figure 14: Side vented needle, Irrisafe ultrasonic tips, RFT 2 laser activation tip

Fig 15: Satelec unit attached with irrisafe tip

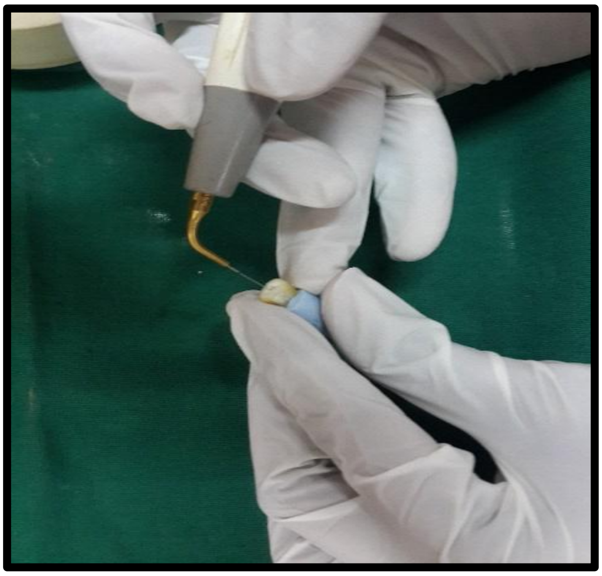


Fig 16: Passive ultrasonic activation

Fig 17: ErCr:YSGG laser unit (Waterlase)

Fig 18: Laser activated irrigation

Fig 19: Gold sputtering unit

Fig 20: Gold sputtered samples

Fig 21: Scanning electron microscope

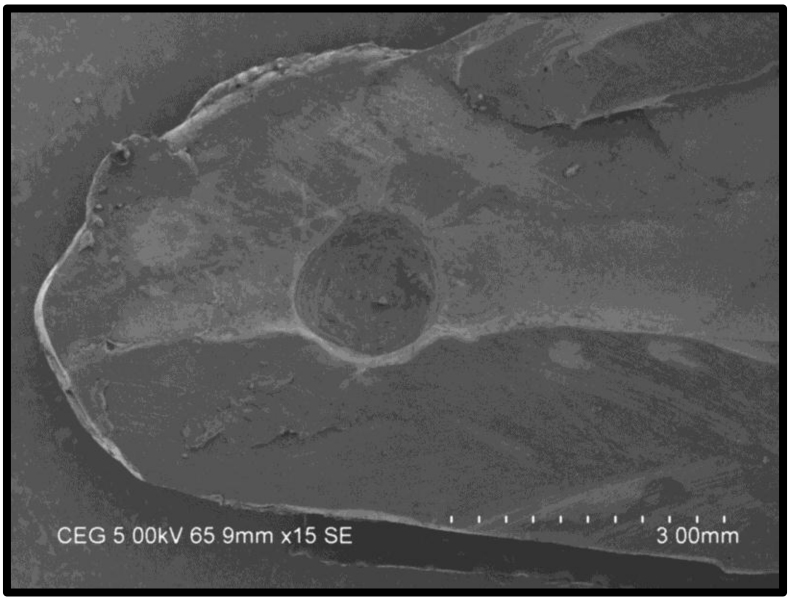


Fig 22: SEM image representing depression completely free of debris-score 1

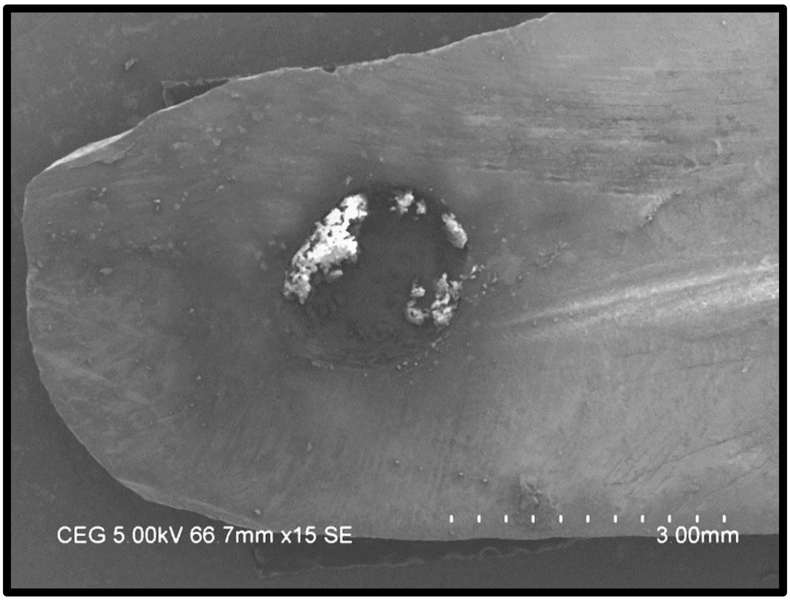


Fig 23: SEM image showing < 50% of depression filled with debris-score 2

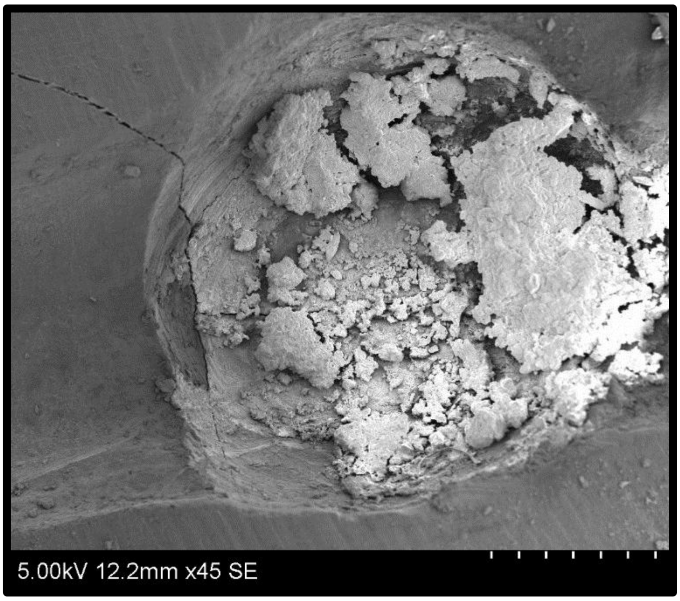


Fig 24: SEM image showing > 50% of depression filled with debris-score 3

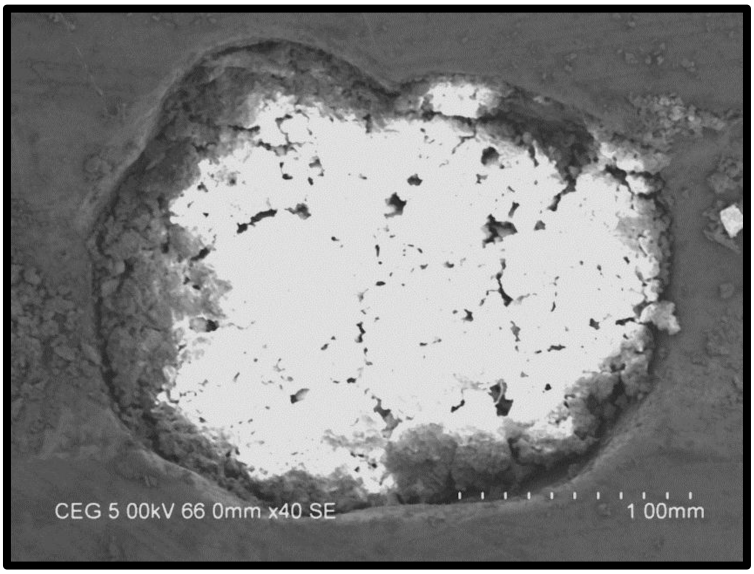


Fig 25: SEM image showing the entire depression filled with debris-score 4

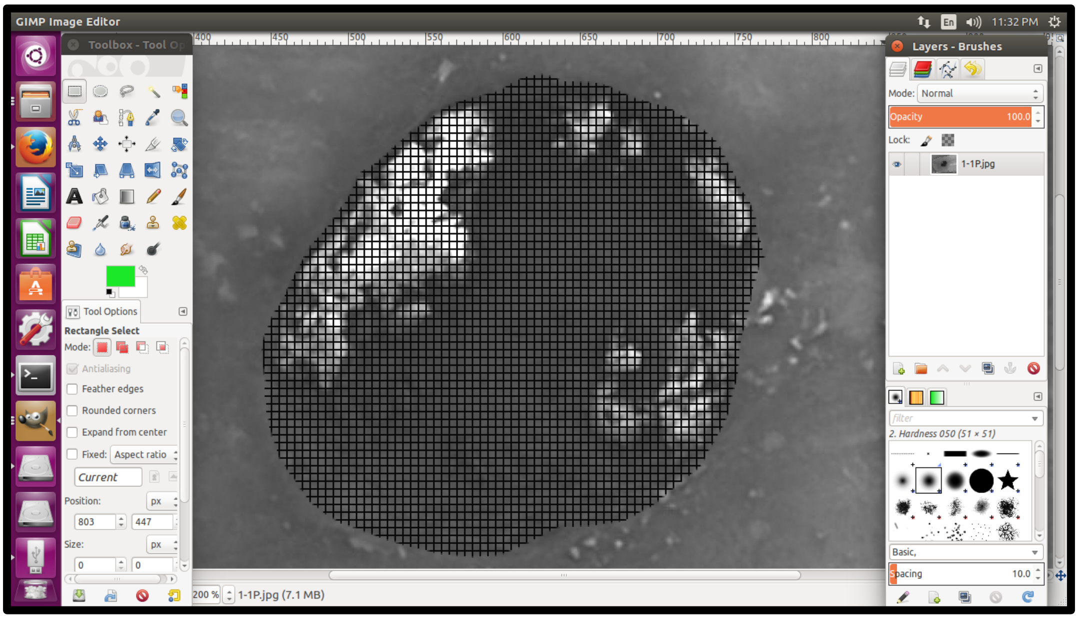


Fig 26: GIMP software for processing of SEM images

Results

RESULTS

Data obtained were entered in an excel spread sheet and analyzed using SPSS (Statistical Package for Social Sciences) V.20 software. Kolmogorov Smirnov test was used to check normality and the data was found to follow non-normal distribution. p value < 0.05 was considered statistically significant. Chi square distribution was used to assess the frequency distribution of events among the groups and the association among them.

The frequency scores of debris removal from the depression were analyzed by the non-parametric Kruskal Wallis test followed by the Mann Whitney U test. Kruskal Wallis ANOVA test revealed a statistically significant difference ($p<0.000$) between the groups. Multiple comparisons were done using Mann Whitney U test.

Table 1 denotes the individual scores for debris removal of each of the samples. The samples are numbered from 1 to 10 and the groups I to V.

Table 2 denotes the group wise frequency distribution of the debris removal scores. In Group I, 8 of the 10 samples had a score of 4 which corresponds to the depression being fully filled with debris. The remaining 2 had a score of 3, wherein more than 50% of the depression is filled with debris.

In Group II, 6 samples were completely free of debris (with a score of 1), 3 less than 50% and 1 sample had debris greater than 50% filling the depression.

In Group III, 4 samples had been completely cleaned of debris, 4 samples had debris covering less than 50% of the depression and 2 samples had debris covering more than 50% of the depression.

In Group IV, 8 samples had a completely clean depression with a score of 1, while 2 samples had a score of 2- representing less than 50% of the groove filled with debris.

In group V, 7 samples had a score of 1- completely free of debris and 3 samples, a score of 2- less than 50% of the depression filled with debris.

Table 3 represents the score wise frequency distribution. 25 samples out of the 50 (50%) had a score of 1 which was completely free of debris. 12 samples (24%) had less than 50% of their depressions filled with debris. 5 samples (10%) of the samples had more than 50% of their depressions filled with debris and 8 samples (16%) had the entire depression filled with debris. The last score was found only in the saline + syringe irrigation group (Group I).

Since this is a qualitative data with more than 2 groups, the Chi square test was performed and it showed asymmetrical 2-sided significance of

<0.000 which represents a statistically significant difference between the groups.

Table 4 represents the frequency distribution of samples falling under the <50% score criteria, i.e., based on <20% and >30%. 2 samples in groups II, III, IV and V had debris covering <20% of the artificial depression. One sample each in groups II and V showed debris covering more than 30% of the depression.

Table 5 denotes the median and range (which is the difference between the highest and the lowest values) for the five different groups. The Kruskal Wallis test with a p value of <0.000 showed a statistically significant difference between the groups (p<0.05)

Table 6 represents the intergroup comparison done using the Mann Whitney U test since this is non-parametric data with more than 2 unrelated groups. A statistically significant difference was found between Group I and the rest of the groups with a p value of <0.000. All the other group comparisons did not show a statistically significant difference.

Groups II and III had a p value of 0.362. The p value between Groups II and IV was 0.300, between Groups II and B was 0.557. p value between Groups III and IV was 0.056 and between Groups III and V was 0.126. The p value between Groups IV and V was found to be 0.615. The inter group comparison of all of these groups showed no statistically significant difference.

Tables and Graphs

Table 1: Debris removal score distribution for five different groups

S.NO	GROUPS	SAMPLE SCORES									
		1	***2***	***3***	***4***	***5***	***6***	***7***	***8***	***9***	***10***
1	SALINE/ SYRINGE (I)	3	4	4	4	3	4	4	4	4	4
2	NaOCl/ PUI (II)	1	2	1	1	2	3	1	1	1	2
3	CHX/PUI (III)	1	2	2	3	3	1	2	1	2	1
4	NaOCl/ LAI (IV)	1	1	2	1	1	1	2	1	1	1
5	CHX/LAI (V)	1	1	2	1	1	2	1	2	1	1

Table 2: Frequency distribution of debris removal scores for the five groups

S No	GROUPS	DISTRIBUTION BASED ON DEBRIS REMOVAL			
		GROOVE EMPTY	< 50% OF GROOVE FILLED WITH DEBRIS	>50% OF GROOVE FILLED WITH DEBRIS	GROOVE COMPLETELY FILLED WITH DEBRIS
1	SALINE/ SYRINGE	0	0	2	8
2	NaOCl/ PUI	6	3	1	0
3	CHX/ PUI	4	4	2	0
4	NaOCL/ LAI	8	2	0	0
5	CHX/ LAI	7	3	0	0

Table 3: Score wise frequency distribution of all the samples

S No	DEBRIS SCORES	NUMBER OF SAMPLES
1	GROOVE EMPTY	25
2	< 50% OF GROOVE FILLED WITH DEBRIS	12
3	>50% OF GROOVE FILLED WITH DEBRIS	5
4	GROOVE COMPLETELY FILLED WITH DEBRIS	8

Table 4: Distribution amongst groups with < 50% debris removal

GROUPS	< 20% OF GROOVE FILLED WITH DEBRIS	>30% OF THE GROOVE FILLED WITH DEBRIS
NaOCl/ PUI	2	1
CHX/PUI	2	2
NaOCl/LAI	2	0
CHX/LAI	2	1

Table 5: Kruskal Wallis test for overall group comparison

p value< 0.05- significant

GROUPS	MEDIAN	RANGE	p- value
SALINE/ SYRINGE	4	1	**<0.000***
NaOCl/ PUI	1	2	
CHX/PUI	2	2	
NaOCl/LAI	1	1	
CHX/LAI	1	1	

Table 6: Mann Whitney U test- intergroup comparison

p value< 0.05- significant

GROUP	COMPARISON GROUPS	P- value
SALINE/ SYRINGE	NaOCl/ PUI	**<0.000***
	CHX/PUI	**<0.000***
	NaOCl/LAI	**<0.000***
	CHX/LAI	**<0.000***

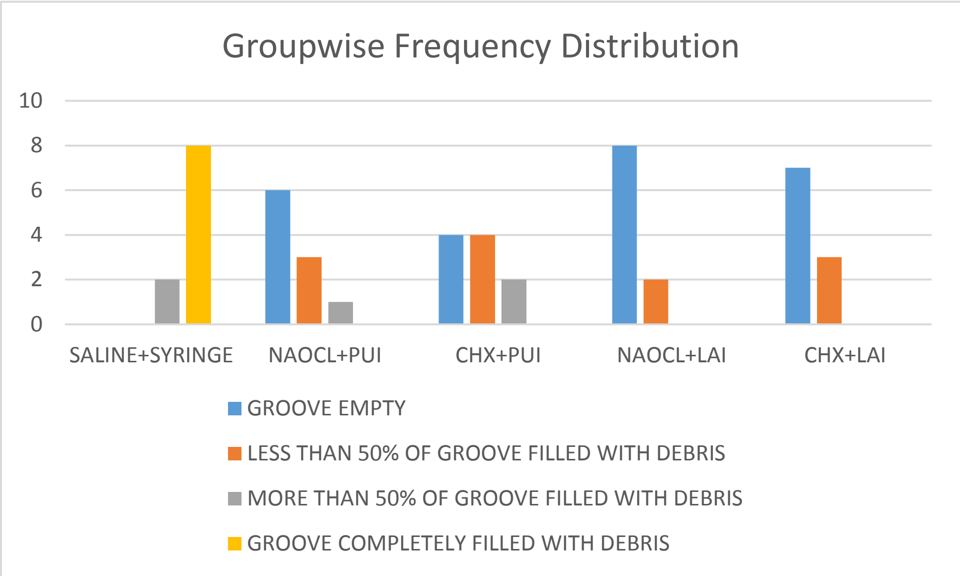
***Mann-Whitney test**

GROUP	COMPARISON GROUPS	P- value
NaOCl/ PUI	CHX/PUI	0.362*
	NaOCl/LAI	0.300*
	CHX/LAI	0.557*

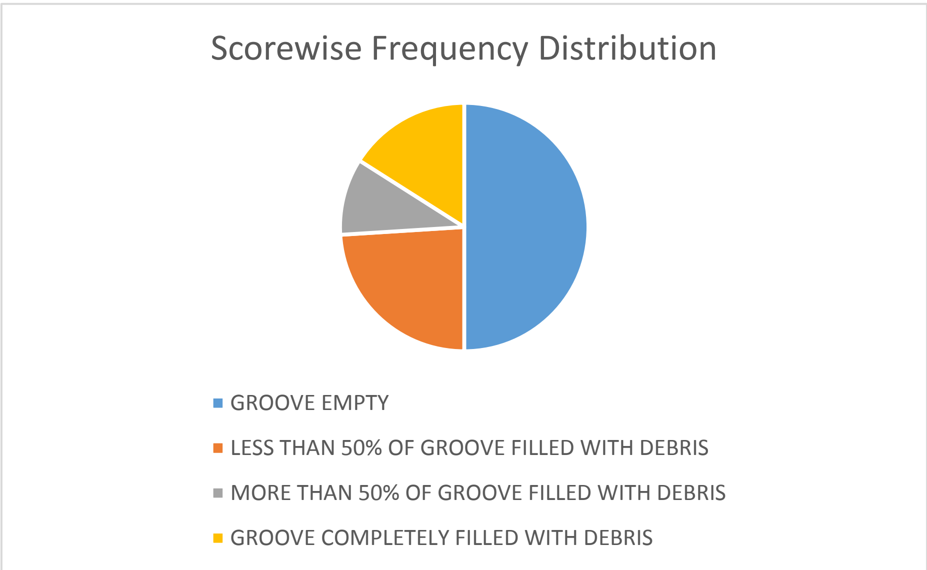
GROUP	COMPARISON GROUPS	P- value
CHX/PUI	NaOCl/LAI	0.056
	CHX/LAI	0.126

GROUP	COMPARISON GROUPS	P- value
NaOCl/LAI	CHX/LAI	0.615

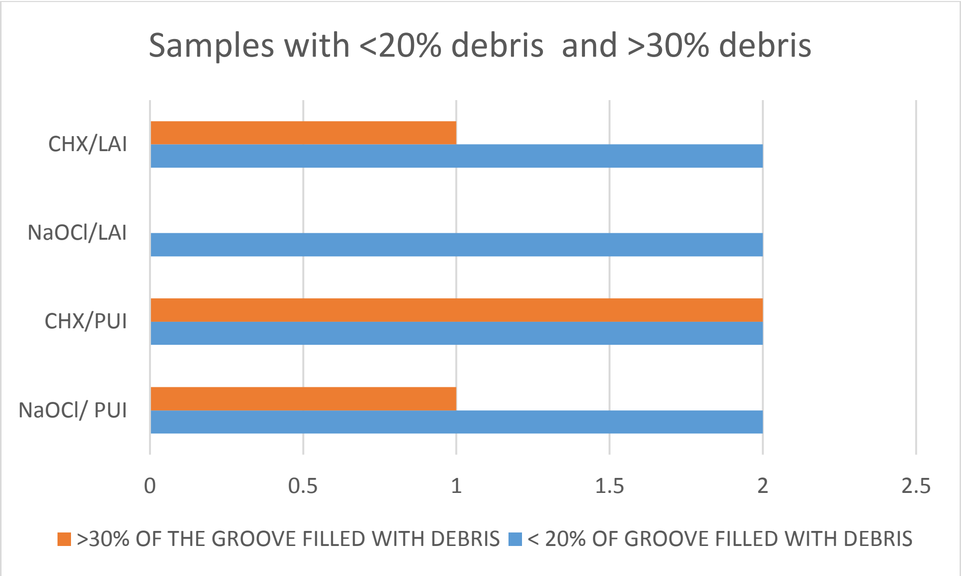
GRAPH 1: Frequency distribution of debris removal scores for the five groups



GRAPH 2: Score wise frequency distribution of all the samples



GRAPH 3: Distribution amongst groups with < 50% debris removal



Discussion

DISCUSSION

Cleaning, shaping and disinfection, together, form the corner stones of root canal therapy. In fact, the key purpose of shaping or instrumentation of the root canal is for mechanical debridement and to make space for the supply of the antimicrobial agents. This enables effective irrigation and thereby disinfection. Studies utilizing microcomputed tomography have revealed that large parts (35%) of the principle root canal continue to remain uncleaned by instrumentation alone[42]. In addition to the main canal there exists multiple lateral canals, crevices, isthumi, ramifications which also remain inaccessible to instruments. This reiterates the need for mandatory chemical means of disinfection of these untouched areas.

According to Haapasalo et al (2010) the desired functions of irrigating solutions include:

- Washing action to help remove debris
- Reduce instrument friction during preparation (lubricant)
- Facilitate dentin removal (lubricant)
- Dissolve inorganic tissue
- Penetrate to canal periphery
- Dissolve organic matter
- Kill bacteria and yeasts also in biofilm

- Do not irritate or damage vital periapical tissue; no caustic or cytotoxic effects
- Do not weaken tooth structure

At present, a lone irrigating solution that encompasses all of the above mentioned requirements is yet to come into practice. Therefore, a combined use of two or more irrigants, in a specific sequence is required in order to bring out the optimal effect.

Amongst the existing endodontic irrigants in practice, sodium hypochlorite is the most popular and widely used. In the beginning, hypochlorite solutions were used as bleaching agents, but by the end of 19th century Koch and Pasteur performed controlled lab studies to prove the disinfectant capacity of hypochlorite that came to be widely accepted. In addition to its wide spectrum of activity and nonspecific killing ability on microbes, it also displays excellent virucidal and sporicidal properties[13]. Another advantage of hypochlorite is that it has a substantially higher tissue dissolving influence on necrotic than vital tissues. These properties resulted in the use of aqueous solution of sodium hypochlorite as an irrigant in endodontics during early 1920s. Its use in practice was aided by the fact that it demonstrated good shelf life, was cheap and easily available.

The antibacterial effectiveness and tissue dissolution capacity of aqueous hypochlorite is a function of its concentration, but so is its toxicity[50].

When Dakin used 0.5% sodium hypochlorite, it was on open burnt wounds. For endodontic usage in a confined area such as a root canal, higher concentrations were required. However, the use of sodium hypochlorite in its “full strength” - 5.25% (the concentration used in household bleach) caused severe irritation when expressed inadvertently beyond the apex or when it leaked through the rubber dam. On vital tissues it caused haemolysis, skin ulceration and necrosis. Moreover, this concentration considerably reduced the flexural strength and modulus of elasticity of dentin[49]. This is attributed to the proteolytic action of concentrated NaOCl on root canal dentin. The intracanal antibacterial effect is also not found to be any greater between concentrations of 2.5% and 5.25% sodium hypochlorite. Hence from these invitro studies it appears that concentrations of 1 to 2.5% sodium hypochlorite would suffice for endodontic purposes. In the present study, 2.5% sodium hypochlorite was preferred.

Another popular irrigant used in endodontics is chlorhexidine. Imperial Chemical Industries Ltd. (Macclesfield, England) in the late 1940s developed chlorhexidine in their research labs. Initially polybisguanide was manufactured with the intent of using it as an antiviral agent. However, it was discovered that it had little antiviral efficacy and was a potent antibacterial agent. Chlorhexidine (most potent bisguanide) in a concentration of 0.1 to 0.2% was introduced into dentistry as a chemical plaque control agent to be used in oral rinses. Studies reported that aqueous solution of 2% chlorhexidine was effective as an endodontic irrigant[66]. The disadvantage with chlorhexidine is its inability to dissolve organic, necrotic remnants in the root canal and its reduced efficacy against gram negative compared to gram positive bacterium. Therefore its use as a main irrigant of the root canal system is not advocated.

In spite of these drawbacks the popularity of chlorhexidine remains due to its property of substantivity. The positively charged ions of chlorhexidine get adsorbed onto the root dentine and bring about a sustained release and continued antimicrobial effect over a period of time[9]. Rosenthal et al in 2004 studied the substantivity after 10 minute application of 2% chlorhexidine and established that chlorhexidine was retained in the root canal dentin with its antimicrobial action intact for up to 12 weeks. Hence, its use as a final irrigant is established.

Cleaning of the entire root canal entails the removal of both organic and inorganic components. Since both the above mentioned irrigants show little to no effect on the inorganic component of debris or smear layer in the root canal, demineralizing agents like EDTA (ethylene diamine tetra acetic acid) came into practice. It is used in concentration of 17%, in paste or solution form.

According to Zhender et al (2006), final irrigation protocol or regimen should depend on the step to be followed after biomechanical preparation. If calcium hydroxide is to be used as an intracanal dressing, then sodium hypochlorite is the preferred final irrigant as the two chemicals are complimentary to each other. On the other hand, if the canals are ready to be filled or if an inter visit dressing of chlorhexidine needs to be placed, then final flush with chlorhexidine becomes the irrigant of choice. Whether sodium hypochlorite or chlorhexidine is used as a final irrigant, a demineralizing agent like EDTA is to be used along with the irrigant to deal with the inorganic portion of the debris that has been created during the process of instrumentation.

Apart from the type of irrigant used, other factors that influence the effectiveness of irrigants include volume and pressure of the irrigant within the canal, the method of delivery and the mechanical flushing action produced, the penetration depth of the needle inside the canal, the time the irrigant remains in the canal and its contact area[36]. Among these, the volume of the irrigant is a major factor that affects root canal cleaning[52]. In this study, the overall volume of the irrigant was kept at a constant 31ml, i.e., 18ml during chemomechanical preparation and 13ml (8ml of the test solution+ 5ml EDTA) as final irrigant.

Studies have shown use of 18ml of NaOCl was as effective as continuous flow of 50ml of the solution [52]. Hence, in this study 18ml of the respective solution was preferred during chemomechanical preparation.

The mechanical flushing action of the irrigants is crucial to eliminate dentin debris, organic debris and microorganisms from the root canal. Baker et al in 1975 stated that this physical phenomenon of flushing out the debris becomes more important that the ability of an irrigant to dissolve tissue within a clinically relevant time frame. Increasing the volume of the irrigant does not result in concomitant increase in the flushing action or debris removal[61]. So, activation of irrigant has taken center stage over mere delivery of the irrigant inside the root canal. Hence, in contemporary endodontic practice, a combination of the irrigant and an irrigation agitation technique is followed for effective cleaning and disinfection of the root canal.

Conventional syringe irrigation was one of the commonest and widely used approaches for the delivery of the irrigant before the advent of irrigant activation techniques. Several advantages that made this method popular were the ease of control over the depth of penetration and the volume of the irrigant delivered[52]. The initial designs in the needle required delivery of the irrigant through its most distal end. However, this resulted in extrusion of the irrigant beyond the apex especially when delivered forcefully. Later, close-ended side vented needles were developed and have proven to produce better hydrodynamic activation of the irrigant while reducing the possibility of apical extrusion. It is imperative to place the needle loose in the canal as this will allow the irrigant to reflux coronally thus preventing inadvertent expression of the irrigant into the periapical tissues.

There are two great disadvantages to the use of hand held syringe irrigation. Firstly, the mechanical flushing action produced in this method is comparatively weak. Secondly, the irrigant solution was expressed only 1 mm beyond the tip of the needle and the needle is usually placed in the coronal third of narrow canal and at best the middle third of wide canals[11].

Grossman as early as 1943 studied the relation between the size of the canal enlargement to the depth of the needle placement and consequently the irrigation efficacy. He reported that irrigation with a hand held syringe is less effective when the canal is enlarged to less than size 40 at the apex. Falk and Sedgley confirmed these findings in 2005 and added that no real advantage was provided when the apical canal enlargement was done to a size greater than 60. Hence in this study, the MAF was restricted to # 50.

The control group in this study involved the use of conventional syringe irrigation using a 30-G stainless-steel side-vented R C Twents irrigation needle with normal saline. The needle was placed 1 mm short of the apex without binding to the canal walls. 6ml of saline was used followed by 5ml 17% EDTA and 2ml saline at the end.

Ultrasonic devices were in use in the field of periodontics much before Richman introduced it for the purpose of root canal debridement in the year 1957. Martin H, Cunningham WT et al in 1980, created the first ultrasonic unit for endodontic purposes and it became commercially available. Ultrasonic devices produce higher frequencies but lower amplitude when compared to their sonic counterpart. The ultrasonic frequency ranges between 25-30 kHz that is beyond human auditory sound perception which is 20 kHz. A file attached to the ultrasonic unit operates in a transverse vibration, setting up a characteristic pattern of nodes and anti-nodes along their length[58, 60].

In literature, two varieties of ultrasonic irrigation have been described. One involves simultaneous ultrasonic irrigation and instrumentation and is broadly termed ultrasonic irrigation (UI) while the other involves only ultrasonic irrigation and is termed passive ultrasonic irrigation (PUI). Drawbacks with the use of UI had been noted. It was found that it was difficult to control the cutting of dentin which resulted in strip perforations and irregularly shaped canals. Ahmad M et al in 1987 described that constraint to the vibratory motion of the ultrasonic file in non-flared root canals resulted in its uneven preparation.

Weller et al. (1980) first described passive ultrasonic irrigation where the term “passive” is a misnomer, as PUI in actuality is an “active” process. The use of the word passive here relates to the “noncutting” action of the ultrasonically activated file. The ultrasonic device uses the principle of magnetostriction or piezoelectricity to convert electrical energy to ultrasonic waves of a particular frequency. Devices that use piezoelectricity are more popular. Piezoelectricity is the generation of stress in dielectric crystals subjected to an applied voltage[5].

The energy transmission from a smooth oscillating wire or file to the irrigant it contacts produces two phenomena, namely, cavitation and acoustic streaming. Acoustic streaming is the rapid movement of fluid in a circular or vortex-like motion around a vibrating file[58]. The streaming pattern that results from this acoustic microstreaming resembles the characteristic pattern of nodes and antinodes along the length of the oscillating file. At the tip of the file, the displacement amplitude is maximum, resulting in a directional flow to the coronal part of the root canal[3]. When the file is unable to move freely inside the root canal, acoustic microstreaming becomes less intense. The shear flow caused by acoustic microstreaming produces shear stresses along the root canal wall, which removes debris and bacteria from the wall.

Cavitation can be defined as the creation of new bubbles or the expansion, contraction and/or distortion of pre-existing bubbles (so-called nuclei) in a liquid, the process being coupled to acoustic energy[4]. Two types of acoustic cavitation have been noted with the use of PUI - transient and stable cavitation. Transient cavitation occurs when vapour bubbles undergo highly energetic pulsations while stable cavitation results from the linear pulsation of gas filled bodies in low amplitude ultrasound. When the acoustic energy is high enough, it causes the bubbles to expand and then violently collapse producing a focus of energy.

Irrigant application during PUI can be done using two methods. The first is called the continuous ultrasonic irrigation where, as the name suggests, a continuous flush of the irrigant is maintained in the ultrasonic device. The second is the intermittent flush ultrasonic irrigation, wherein the irrigant is delivered into the root canal with the help of a syringe and ultrasonically activated, followed by flushing the root canal with fresh irrigant. This is done in order to remove the dislodged debris or dissolve the remnants from the root canal walls.

In the present study, PUI was performed similar to the protocol put forth by Justo AM et al, 2014. Activations were performed for 1 minute in 3 periods of 20 seconds each with the renewal of irrigant between activations. The intermittent flush technique was chosen based on studies like De Moor RJ et al, 2009; van der Sluis et al, 2010 that stated that ultrasonic activation of the irrigant combined with 3 refreshment/activation cycles produces a cumulative effect on debris removal. In addition, short periods of activation facilitate the maintenance of the ultrasonic tip in the center of the root canal, thereby preventing its contact with the dentinal wall.

Weichman JA et al studied the use of lasers in endodontics as early as 1971. Its use in endodontics expanded in the 1990s with the advent of fiber optic delivery systems. Based on the wavelength they emit, lasers can be broadly classified into the following[37]:

Near-infrared lasers (810 nm to 1340 nm) - have negligible attraction for water and the hydroxyapatite of dental hard tissues; penetrate to a large extent through dentinal tubules and are absorbed by the bacteria pigments.

Mid-infrared lasers (2780 nm and 2940 nm) are primarily absorbed by water and, to a lesser degree, hydroxyapatite in the dentinal walls and their bactericidal effect, via photothermal energy, is more superficial.

Carbon dioxide laser (10,600 nm) has a strong affinity for water and especially hydroxyapatite. The inability of this wavelength to utilize a fiber-optic delivery system limits its utility in intracanal applications.

Erbium, chromium: yttrium-scandium-gallium-garnet (Er,Cr:YSGG) lasers provide suitable wavelength (2780nm) to be absorbed by the water. When the water of the hydroxyapatite absorbs this irradiation, it instantaneously evaporates thus ablating the surrounding tissue with minimal thermal side effects (photothermal phenomenon).

Laser activated irrigation is shown to produce a combined photothermal and cavitation effect. Vaporization of the irrigant due to the radiation from the laser beam results in the formation of vapor bubbles, which expand and implode with secondary cavitation effects. According to Blanken J et al (2009) these bubbles have a volume that is about 1,600 times the original volume. In a narrow canal therefore a pressure gradient will arise that will act as a fluid pump. When the vapor bubble implodes, the fluid velocities are very high and are likely to cause secondary cavitation along canal walls where irregularities are present that can cause shear stresses in the fluid passing it.

The Er,Cr:YSGG laser emits its energy in pulses of about 130 microseconds. At the beginning of the laser pulse, the energy is absorbed in a 2 mm-thick layer that is instantly super-heated to boiling temperature (100°C) at high pressure and turned into vapor. This vapor at high pressure starts to expand at high speed and provides an opening in front of the fiber for the laser light. As the laser continues to emit energy, the light passes through the bubble and evaporates the water surface at the front of the bubble. In this way it ‘‘drills’’ a channel through the liquid until the pulse ends after about 140 microseconds. This mechanism is well known and has been referred to as ‘‘the Moses effect in the microsecond region’’ by van Leeuwen et al (1991).

With the use of conventional fiber tips, the laser beam is slightly expanded when it leaves the end of the fiber tip. This is due to the reflectance at the fiber walls. Nevertheless, the major part of the laser light still propagates straight towards the apex of the root. A new generation of fiber tips has been developed that allows a more homogeneous irradiation of the root canal walls. The ends of these radial-emitting fiber tips show a conical outline with a cone angle of 60°. The laser light, therefore, is expanded to a broad cone, facilitating an even coverage of the whole root canal wall[47].

It was observed that apical extrusion of the irrigant occurred when laser activation was performed using fiber tips. A study by George et al, 2008 showed that there was higher dye penetration (twice as much) through the apical constriction with the fiber tip at 4 mm than at 5 mm. Hence, the fiber tip was placed 5 mm short of the apical stop in this study.

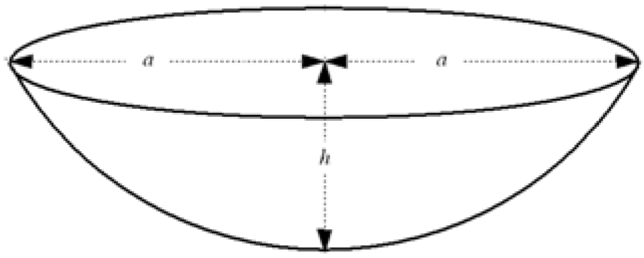
The present study utilized radial firing tip no 2 (Endolase Tip, Biolase) that has a diameter of 200 micron and a length of 21 mm. It was placed in the root canal at a length of 5 mm from the apex (15 mm) indicated by a black band marker. The Er,Cr:YSGG laser (Er,Cr:YSGG laser; Waterlase Millenium, Biolase, San Clemente, CA) was set at 20 Hz frequency, pulse duration of 140 microseconds, nominal peak power of 535 watts and pulse energies of 75 mJ and laser activation was performed at 4 x 5 secs each according to the protocol put forth by de Moor et al ,2010.

This experiment was designed to assess the debris removal efficacy in the apical third of the root canal using two irrigants- 2.5% sodium hypochlorite and 2% chlorhexidine, used with two activation techniques- passive ultrasonic irrigation and laser assisted irrigation, when performed as a final irrigation protocol.

The study was performed on lower single rooted first premolar teeth with straight roots and wide canals to facilitate easy longitudinal sectioning through the canals. The most challenging part of the root canal to clean and shape is the apical third because of the ever-increasing complexity of the anatomy; that is, due to the presence of ramifications and tortuosities. Hence this study was performed specifically in the apical third of the root canal by simulating canal irregularity 2 mm from the apex.

This study model utilized round bur no 2 to replicate uninstrumented canal irregularities. A point 2 mm from the apex was measured using a digital Vernier Caliper and a mark was made using a graphite marker. A depression was created in each tooth at this mark using the round bur. After securing the root canal walls, the canal wall was penetrated using the round bur. The depressions were created 2 mm short of the working length and measured 1 mm in diameter.

By using Pythagorean Theorem, the depth of the depression thus created was calculated. “R” denotes the radius of the round bur, “a” denotes the radius of the depression created and “h” denotes the depth. The shape of the depression is a spherical segment. As denoted in the figure given below, the depth of the depression was calculated to be 0.5 mm. By the method described above, the depressions in all the tooth samples were standardized, enabling a standard amount of debris to be placed in each depression. All the depressions had the same diameter and depth.



$$R^2 = a^2 + (R - h)^2$$

$$h = R - \sqrt{(R^2 - a^2)}$$

This standardization allowed for technical reproducibility and helped ensure that identical amount of debris was placed in each of the tooth samples. This served as an advantage over previous methods where the amount of debris was evaluated only after the irrigation[64] failing to standardize the amount of debris placed before irrigation. Hence, 0.2 mg of the debris collected during sectioning of the specimen was immediately placed in the depression created.

Following this, the specimens were reassembled and were subjected to different irrigation protocols as discussed above. All the specimens were then disassembled and the longitudinal sections containing the debris in the depression were viewed under a scanning electron microscope.

SEM analysis involved the process of sputter coating the samples with gold nanoparticles of 99.99% purity, followed by examination under the microscope at 10kv and magnifications of 20x to 40x. Images obtained from the SEM analysis were processed using the GIMP 2.8.16 software. A grid filter was applied on the SEM image and the number of squares of the grid that covered the depression and the region free of debris were used to calculate the debris reduction percentage.

$$Debris\ Reduction\ \% = \frac{Area\ free\ of\ debris}{Area\ of\ the\ depression} * 100$$

The scoring of the samples were based on the following 4 quantitative criteria as described by Justo et al (2014):

1) the groove is empty - 1
2) <50% of the groove filled with debris - 2
3) >50% of the groove filled with debris - 3
4) the groove is completely filled with debris -4

Many of the previous studies, including Lee S.J. 2004; De Moor RJ 2009; C Sunil Kumar et al, 2015 utilized the judgement of independent observers to give a subjective score for debris removal. Since this study employed a software with inbuilt functions to ascertain the area of debris removal, the error associated with intraobserver and interobserver agreement was reduced.

According to the results obtained in this study, there was a statistically significant difference (p =.000) between Group I (saline + syringe) and all of the other groups (Groups II, III, IV and V). For a given volume of the irrigant (31ml) it was found that, conventional syringe irrigation with saline was unable to remove debris from the apical third of straight root canals. The above observation is in line with the study conducted by van der Sluis, Gambarini et al (2006)

When debris removal efficacy (p value) of Group II (NaOCl/PUI) was compared with the Groups III, IV, V it was found that there was no statistically significant difference. Similarly, there was no statistically significant difference in the debris clearing efficacy between Group III (CHX/PUI) and Groups IV and V as well as between Group IV (NaOCl/LAI) and Group V (CHX/LAI).

Since all the four groups (Groups II, III, IV and V) showed similar effectiveness in terms of debris removal, the samples that fell under score number 2 (<50% of depression filled with debris) were further analyzed. The samples were examined to see how many of them had <20% debris left and how many had >30% debris left in the depression. Two samples in each group had debris covering <20% of the depression. One sample in Group II, two samples in Group III, none in Group IV and one sample in Group V had debris covering >30% of the depression. This suggests that samples with debris <20% was more prevalent and this confirms effective debris removal due to mechanical activation in all the four groups.

The groups that employed NaOCl as irrigant (Groups II and IV) had higher number of samples with a score of 1 (completely free of debris). This can be attributed to the fact that dentinal debris contains both organic and inorganic components, and NaOCl unlike chlorhexidine has the ability to dissolve the organic content. However, the difference in debris removal efficacy was not found to be statistically significant. This can be explained by observations made in previous studies by Scelza MFZ et al, (2000); van der Sluis LW, et al (2005) which stated that debris removal is related more closely to the mechanical activation and volume of the irrigant than the type of solution used.

In this study, intermittent flush technique with PUI and laser activation of the irrigant was found to produce similar results. This has been previously demonstrated by De Moor RJ et al, 2010. The secondary cavitation that is caused by the laser contacting the irrigant seems to produce comparable results with the cavitation and acoustic streaming produced by the ultrasonic activation of the irrigant. When the irrigant is activated by PUI or LAI, the shear flow of the solution is increased that causes shear stresses along the root canal walls and this is responsible for its successful effect on debris removal.

Overall, irrigation of saline with side vented needle resulted in the highest mean score. This can be attributed to the fact that the mechanical flushing action produced by syringe irrigation is weak when compared to PUI and LAI.

The null hypothesis that there would be no difference in the debris removal scores regardless of the irrigant and technique performed stands validated.

Further studies in an in vivo setup is required to extrapolate these results to a clinical situation. Apical negative pressure irrigation with EndoVac system (Discus Dental, Culver City, CA) is gaining popularity as it proposes to avoid air entrapment as well as safely deliver the irrigant to full working length with minimal extrusion. Hence additional studies that compares these techniques are needed to further the results of this study.

Summary

SUMMARY

Thorough disinfection is one of the major reasons for success of root canal treatment. This is dependent on a combinations of factors that include canal anatomy and effective irrigation. However, the currently available irrigants do not possess all the desired qualities. Secondly, they are unable to reach the lateral canals, crevices, isthumi to bring about their action. Hence the use of a combination of irrigants along with an activation technique is required to optimize the effects of disinfection.

The aim of the present study was to compare the effectiveness of final irrigation protocols for debris removal using two irrigants, namely, NaOCl and chlorhexidine and two activation techniques, namely, passive ultrasonic irrigation and laser activated irrigation.

50 single rooted lower premolar teeth with intact roots were selected. The teeth were then decoronated below the level of the cementoenamel junction to obtain a uniform length of 15mm. The teeth were coronally flared with Gates Glidden drill and apically prepared to size # 50 k file. Step back preparation was done till size #80 k file. Periodic irrigation with 2 ml of the respective irrigant was done during each file change and at the end of the preparation. The teeth were then cleaved longitudinally into two by creating grooves on the mesial and distal external root surfaces. A mark was made 2 mm short of the apex, and a canal depression was simulated using a round bur

no 2. Dentinal debris produced by longitudinal splitting of other teeth was placed in the depression created. The two halves were approximated and modelling wax was placed at the apex. Any gaps on the sides were sealed with sticky wax and the entire unit was embedded in putty material. These specimens were then divided into 5 groups to perform the different irrigation protocol.

In Group I, irrigation was performed with saline using a side vented needle. In Group II, irrigation was performed with 2.5% sodium hypochlorite activated by PUI. Group III involved use of 2% chlorhexidine as the irrigant which was activated with PUI. Groups IV and V used LAI for irrigant activation and the difference lay in the choice of the irrigant. In Group IV 2.5% NaOCl was used, whereas in Group V, 2% chlorhexidine was used. The specimens were then disassembled and subjected to scanning electron microscopic analysis to evaluate the debris removal efficacy in the depression created. The SEM images were processed with GIMP 2.8.16 software using the scoring criteria for debris removal.

The results of the present study suggests that the use of the different irrigants and activation techniques produced similar results and was statistically better when compared with saline irrigation with side vented needle.

Conclusion

CONCLUSION

According to the results of the present study,

1. The debris removal efficacy of the control group that employed saline as an irrigant which was delivered with a side vented needle showed the highest score, indicating poorest debris removal efficacy.
2. The debris removal scores with the use of 2.5% sodium hypochlorite when used with passive ultrasonic irrigation and laser activated irrigation produced similar results with statistically no significant difference.
3. The debris removal scores with the use of 2% chlorhexidine when used with PUI and LAI showed similar results with statistically no significant difference.
4. Overall comparison of the four groups showed similar scores indicating that all the four groups behaved similarly with respect to debris removal and were better than the control group.
5. The present study showed no difference in the debris removal scores regardless of the irrigant and technique performed. The null hypothesis was found validated.
6. However, based on the frequency distribution the combination of 2.5% sodium hypochlorite with laser activated irrigation produced the best results with respect to debris removal.

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Annexure

ANNEXURE

RAGAS DENTAL COLLEGE & HOSPITAL

(Unit of Ragas Educational Society)

Recognized by the Dental Council of India, New Delhi

Affiliated to The Tamilnadu Dr. M.G.R. Medical University, Chennai

2/102, East Coast Road, Uthandi, Chennai - 600 119. INDIA.

Tele : (044) 24530002, 24530003-06. Principal (Dir) 24530001 Fax : (044) 24530009

TO WHOMSOEVER IT MAY CONCERN

Date: 29/12/2016

From

The Institutional Ethics Board,

Ragas Dental College and Hospital,

Uthandi,

Chennai- 600119

The dissertation topic titled **"EVALUATION OF DEBRIS REMOVAL EFFICACY OF DIFFERENT ROOT CANAL IRRIGANTS DURING FINAL IRRIGATION PROTOCOL USING LASER ACTIVATED IRRIGATION AND PASSIVE ULTRASONIC IRRIGATION- AN *IN VITRO* STUDY"** submitted by **Dr.J.Nithyalakshmi**, has been approved by the Institutional Ethics Board of Ragas Dental College and Hospital.

Dr. N.S. Azhagarasan, MDS.,

Member secretary, Institutional Ethics Board,

Head of the Institution,

Ragas Dental College and Hospital,

Uthandi,

Chennai-600119

PRINCIPAL

RAGAS DENTAL COLLEGE AND HOSPITAL

UTHANDI, CHENNAI-600 119.

RAGAS DENTAL COLLEGE Chennai