INTRODUCTION

The success of root canal therapy depends on the method and quality of instrumentation, irrigation, disinfection and the three dimensional obturation of root canal.

One of the functions of irrigation is the removal of tissue remnants and dentin debris during instrumentation. It is the only way to impact those areas of the root canal wall not touched by mechanical instrumentation such as fins, isthmuses and large lateral canals. Also, large areas in the oval and flat canals may remain untouched despite careful instrumentation. These areas contain tissue remnants and biofilms. The apical root canal possesses a special challenge to irrigation as the balance between safety and effectiveness is particularly important. Sodium hypochlorite is the main irrigating solution used to dissolve organic matter and kill microbes effectively. During irrigation, radicular and coronal dentins were exposed to solutions deposited in the pulp chamber. This caused alteration on dentin surface.

Dentin microhardness depends on the amount of calcified matrix per mm^2 and its determination provides indirect evidence of mineral loss or gain in the dental hard tissue. The effectiveness of irrigation relies on both the mechanical flushing and the chemical ability of irrigants to dissolve tissue.

Different means of delivery are used for root canal irrigation, from traditional syringe-needle delivery to various machine-driven systems, including automatic pumps and sonic or ultrasonic energy. It has been demonstrated that an irrigant in conjunction with ultrasonic vibration which generates a continuous movement of the irrigant is directly associated with the effectiveness of the cleaning of the root canal space. Based on such facts it was thought that the evaluation of different irrigation protocols and ultrasonic activation methods on canal cleanliness and microhardness is of value.

In this part of the study the following titles are presented to review the effect of irrigating solutions on canal cleanliness, ultrasonic activation of irrigation solutions is also introduced.

Furthermore, the effect of this final irrigation solutions and their ultrasonic activation on microhardness of root canal dentin.

Effect of different irrigating solutions on cleanliness of root canal:

During biomechanical instrumentation, an amorphous layer known as smear layer is formed and deposited on the root canal walls. Irrigation is considered to be one of the best methods for the removal of tissue remnants and the smear layer produced during root canal preparation, as well as for reducing adherence of microorganisms to dentin. Complete removal of the smear layer demands the use of chelating agents followed by tissue solvents, because no single solution alone is capable of providing both the effects of removing organic and inorganic material. Accordingly, alternate use of ethylene diamine-tetraacetic acid (EDTA) and sodium hypochlorite (NaOCl) solutions have been advocated as an effective irrigation regimen to remove the organic and inorganic remnants of smear layer and has gained wide acceptance. Chelating agents are used to improve chemomechanical debridement in the root canal treatment by removing the smear layer. Various chemical agents like EDTA, Citric acid, MTAD, QMix, etc have been used for the removal of smear layer, but EDTA is the most

commonly used agent. Recently ultrasonic activation of the irrigant showed better results than manual irrigation.

NaOCl:

Timothy and John 1981[(1)] studied the effectiveness of effervescence in producing clean root canals. They prepared the canals in the extracted, single-rooted human teeth were chemomechanically using either the combination of hydrogen peroxide and sodium hypochlorite solutions or sodium hypochlorite solution alone as irrigants. The sections taken from the 1-mm and 3-mm levels from the anatomic apex were microscopically evaluated and graded for cleanliness. They showed no significant differences in cleanliness of root canal at the 1-mm or 3-mm levels between using the combination of irrigants or the single irrigant.

Abou-Rass and Piccinino, 1982[(2)] evaluated the effectiveness of four clinical irrigation methods on the removal of root canal debris. They used 48 mesial roots of mandibular molars. They prepared 24 teeth (48 canals) with a step back technique to a size 25.The other half was prepared to a size 40 and which allow a D-11 1mm from the apex. They irrigated teeth 4 different times by four different methods. Method (1): 3ml of tap water stirred with a 15 file. Method (2): 3ml of tap water with a 23-gauge endodontic needle. Method (3): 1.8ml of anesthetic solution from a 30-gauge needle. Method (4): 1.5ml of 3%H2O2 and 1.5ml of 2.5 % NaOCL via a 23 gauge needle.

The results showed that in method 3 the needle was able to reach an average of 17.4mm in to an average of 20.4m teeth. They concluded that the proximity of the delivering needle plays an important role in the removal of canal debris.

Braumgartner and Cuenin 1992[3] reported the effect of using several concentrations of NaOCl (5.25%, 2.5%, 1% and 0.5%) on cleanliness of root canal dentin. They examined instrumented and uninstrumented surfaces in the middle third of root canals following these different concentrations using scanning electron microscopy. NaOCl was delivered with either an endodontic irrigation needle or an ultrasonic device. All of the concentrations of NaOCl with either delivery system were very effective in flushing out loose debris from the root canals. They showed that NaOCl in concentrations of 5.25%, 2.5%, and 1% completely removed pulpal remnants and predentin from the uninstrumented surfaces and that 0.5% NaOCl removed the majority of pulpal remnants and predentin from the uninstrumented surfaces. Needle must be in close proximity to be effective.

Nadalin et al. 2009[4] examined in vitro thirty human mandibular central incisors with a mesiodistal flattened root that were prepared using rotary instrumentation to evaluate the capacity of debris removal from the apical third of flattened root canals, using different final irrigation protocols using optical microscope at x40.The specimens `were randomly distributed into 5 groups according to the final irrigation of root

canals: 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 found no statistically significant difference among the groups regarding the efficacy of removal of debris from the apical third of flattened root canals.

Van der Sluis et al. 2010[5] evaluated dentin debris removal from the root canal during ultrasonic activation of NaOCl (2% and 10%), carbonated water and distilled water to determine the influence of 3 ultrasonic refreshment/activation cycles of the irrigant by using the intermittent flush technique. Root canals with a standardized groove in 1 canal wall, which was filled with dentin debris, were irrigated ultrasonically 3 times for 30 seconds. The results showed that ultrasonic activation of the irrigant combined with the intermittent flush method produces accumulative effect over 3 refreshment/ activation cycles. They concluded that NaOCl as an irrigant is more effective than carbonated water which is more effective than distilled water.

Stojicic et al. 2010[6] compared the effectiveness of three sodium hypochlorite solutions from two different manufacturers in concentrations of 1%, 2%, 4%, and 5.8% were tested at room temperature, 37°C, and 45°C with and without agitation by ultrasonic and sonic energy. Distilled and sterilized tap water was used as controls.

They concluded that you must optimize the concentration, temperature, flow, and surface tension to improve the tissue-dissolving effectiveness of hypochlorite.

Al-Ali et al. 2012[7] compared the effectiveness of four root canal irrigation protocols on smear layer and debris removal as well as their effectiveness in removing remaining soft tissues in curved root canals. They used the mesiobuccal and mesial root canals of 107 extracted human maxillary and mandibular molars and were instrumented using Mtwo rotary NiTi instruments then randomly divided into four groups according to a final rinse protocols. All irrigation protocols were performed in a closed system. Eleven roots per group were prepared and histologically stained (H&E) to assess percentage of remaining pulpal tissues in the apical thirds. The remaining specimens were split longitudinally and examined under scanning electron microscope at ×2000 magnification to assess smear layer and debris removal.

They found that CanalBrush and passive ultrasonic irrigation were equally effective with significantly less smear layer and debris than manual agitation and H_2O_2 alternated with NaOCl. Furthermore they found that the H_2O_2 alternated with NaOCl protocol was significantly more effective in removing pulp tissue remnants in the apical level than manual agitation and passive ultrasonic irrigation. They concluded that CanalBrush 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. Further studies are required to evaluate effectiveness of this regimen taking into account irrigant volume differences and effect of root canal system configuration.

Abraham et al. 2015[8] reviewed the available literature on root canal irrigants and the possible complications during their usage. They concluded that no irrigant till date provides 100% elimination of bacteria and cleansing the root canal. However, despite the complications, NaOCl is the gold standard irrigant used in day to day clinical practice and that proper administration of the desired irrigant helps to achieve sufficient antimicrobial effect and thereby boosting the endodontic success.

EDTA:

O'Connell et al. 2000[9] used three solutions of EDTA-a 15% concentration of the alkaline salt, a 15% concentration of the acid salt, and a 25% concentration of the alkaline salt to evaluate smear layer removal in root canal systems. The results showed that they completely removed the smear layer in the middle and coronal thirds of canal preparations, but were less effective in the apical third. They concluded that none of the EDTA solutions by themselves were effective at completely removing the smear layer at any level.

de Menezes et al. 2003[10] evaluated the cleaning qualities and smear layer removal from root canal walls by SEM. Fifty extracted teeth were instrumented and irrigated with 2.5% NaOCl, 2% chlorhexidine and saline solutions. Fifty extracted teeth were used in this study. Groups were divided into Group 1: 2.5% NaOCl (10 roots); Group 2: 2.5% NaOCl and 17% EDTA for 2 minute (10 roots); Group 3: 2% chlorhexidine (10 roots); Group 4: 2.0% chlorhexidine and 17% EDTA for 2 minutes (10 roots); Group 5: saline solution (5 roots); Group 6: saline solution and 17% EDTA for 2 minutes (5 roots).

They found that the use of 17% EDTA decreased the smear layer significantly for all evaluated solutions in all thirds. When EDTA was not used, a significantly higher quantity of smear layer on the apical third was observed only in the NaOCl groups. They concluded that using 17% EDTA was significant in debris removal except for the chlorhexidine groups. They concluded that using of 17% EDTA was necessary to enhance cleanliness of the root canals.

Lui et al. 2007[11] compared the in vitro efficacy of Smear Clear (Sybron Endo, CA), a 17% ethylenediaminetetraacetic acid (EDTA) solution with surfactants, to 17% EDTA, with and without the use of ultrasonics, in removal of the smear layer using SEM. Seventy-five extracted teeth which were randomly distributed into 5 test groups, prepared by using profile rotary instruments and subjected to different final irrigating regimes; group A; 1% sodium hypochlorite; group B; 17% EDTA; group

C; 17% EDTA with ultrasonics; group D; Smear Clear; and group E; Smear Clear with ultrasonics. Statistical analysis showed that groups D and E did not perform significantly better than groups B and C. Group C performed significantly better than group B. Addition of surfactants to EDTA in Smear Clear did not result in better smear layer removal. They concluded that the use of ultrasonics with 17% EDTA improved smear layer removal.

Mello et al. 2010[12] examined the impact of the final rinse technique on smear layer removal ability of 17% ethylene-diaminetetraacetic acid (EDTA) by SEM. Sixteen single-rooted human teeth were instrumented and divided into 2 groups at the final rinse step: continuous rinse group, continuous rinse with EDTA during 3 minutes, and rinse and soaking group, rinse with 1 mL of EDTA, soaking of the canal for 2 minutes and 30 seconds, and rinse completion with the remaining 4 mL for 30 seconds. They found that the continuous rinse group presented more debris-free surfaces when compared with the rinse and soaking group. They concluded that a continuous rinse with 5 mL of EDTA for 3 minutes can more efficiently remove the smear layer from root canal walls.

Darrag 2014[13] compared smear layer removal after root canal final irrigation with 17% Ethylenediaminetetraacetic acid (EDTA), 10% citric acid (CA), Biopure MTAD, and 0.2% chitosan solutions. Fifty extracted maxillary central incisors were decoronated to a root length of 16 mm. They were cleaned

and shaped using ProTaper system up to size F4 and 2.5% sodium hypochlorite (NaOCl) irrigation throughout instrumentation. The specimens were divided into 5 equal groups according to the final irrigation solution; group I: 17% EDTA, group II: 10% CA, group III: MTAD, group IV: 0.2% chitosan, group V (control): 2.5% NaOCl.

The results showed that 0.2% chitosan solution has the lowest mean rank of smear layer scores at all tested root sections. The efficacy of MTAD in smear layer removal was better than that of 17% EDTA and 10% CA at the apical level. Results showed that coronal sections had the lowest mean ranks of smear layer score and the highest was found at the apical section. He concluded that final irrigation with 0.2% chitosan solution was more efficient in smear layer removal. EDTA (17%), 10% CA, MTAD and 0.2% chitosan effectively but not completely remove the smear layer especially at the apical root levels.

Kandil et al. 2014 [14] compared the effect of different irrigants on smear layer removal. A total of fifty roots were equally divided into two halves to evaluate the amount of smear layer. One hundred root halves were divided into five equal groups 20 sample each according to the final irrigants used: Group 1: 2.5% NaOCl, Group 2: 2.5% sodium hypochlorite (NaOCl) followed by 7% maleic acid (MA), Group 3: 2.5% NaOCl followed by 17% ethylenediamine tetraacetic acid (EDTA), Group 4: 2.5% NaOCl followed by mixture of tetracycline, acid and detergent (MTAD) and Group 5: saline.

The results showed that EDTA, malic acid and MTAD efficiently removed smear layer, respectively, in the coronal and middle thirds of root canal. However, in the apical region, malic acid showed more efficient removal of the smear layer than the other irrigants. They concluded that malic acid is the most efficient final irrigant solution after NaOCl irrigation throughout instrumentation.

Mendonça et al. 2015[15] evaluated, by means of scanning electron microscopy (SEM), the cleaning of flattened root canals, varying irrigation/aspiration protocols during biomechanical preparation. Thirty human mandibular incisors were distributed into three groups (n = 10) according to the aspiration/irrigation protocols: conventional, conventional+ brush, and apical negative pressure irrigation. Irrigation procedure was performed with 5 mL of 1% NaOCl at each change of instrument; final irrigation was conducted with 17% EDTA for 5 min. Results showed that apical negative pressure irrigation was more effective in cleaning, showing lowest scores ($p < 0.05$), compared with the other tested protocols. Comparing each root canal third revealed that the apical portion was difficult to clean as all the tested protocols showed similar high scores ($p > 0.05$), both for the presence of debris and smear layer. They concluded that none of the studied irrigation/aspiration protocols have completely cleaned flattened root canals but apical negative pressure irrigation was more effective in smear layer removal, whereas the conventional + brush protocol was the least effective in removing the debris and smear layer.

QMix 2 in 1:

Dai et al. 2011[16] studied the ability of two versions of QMix, an experimental antimicrobial irrigant, on removal of canal wall smear layers and debris using an open canal design. They had irrigated single-rooted human root canals were with 5.25% NaOCl as the initial irrigant and one of the following as the final irrigant: (1) QMix I (pH = 8), (2) QMix II (pH = 7.5), (3) distilled water, (4) 17% EDTA, and (5) BioPure MTAD. They evaluated smear and debris scores in the coronal, middle, and apical thirds of longitudinally fractured canal spaces using scanning electron microscopy. When the overall canal was considered they found differences were observed among groups except groups 1 versus 4 and groups 2 versus 4. After adjusting the findings for canal levels, the groups showed a statistically significant difference from each other with the exception of groups 2 versus 5. Regarding the debris scores, they found no significant difference among the treatment groups when the overall canal was considered and also after adjusting for the effect of canal level. They concluded that when using an open-canal design the two experimental QMix versions are as effective as 17% EDTA in removing canal wall smear layers after the use of 5.25% NaOCl as the initial rinse.

Stojicic et al. 2012[17] assessed the efficacy of a novel root canal irrigant, QMiX, in removing smear layer. They exposed Qmix 2in 1, 2% chlorhexidine (CHX), MTAD and 1% sodium hypochlorite (NaOCl) for 5 s, 30 s and 3 min to

Enterococcus faecalis and mixed plaque bacteria. After exposure, samples were taken, serially diluted and grown aerobically and anaerobically on tryptic soy agar (TSA) plates or on blood agar plates for 24 and 72 h respectively. They measured the effectiveness of the four irrigants in killing bacteria by growing the *E. faecalis* and plaque biofilms were grown for 3 weeks on collagen-coated hydroxyapatite or dentine discs and exposed for 1 and 3 min to QMix, 2% CHX, MTAD, 1% and 2% NaOCl using scanning electron microscopy. QMix removed smear layer equally well as EDTA. When they exposed dentine blocks to QMix and 17% EDTA for 5 min. They concluded that the ability of QMix to remove smear layer was comparable to EDTA.

***Wang et al. 2013*[18]** examined the effect of the smear layer on the antibacterial effect of different disinfecting solutions in infected dentinal tubules. Cells of *Enterococcus faecalis* were forced into dentinal tubules. After a 3-week incubation period of infected dentin blocks, a uniform smear layer was produced. Forty infected dentin specimens were prepared and subjected to 3 and 10 minutes of exposure to disinfecting solutions including sterile water, 2% and 6% sodium hypochlorite (NaOCl), 2% chlorhexidine (CHX), 17% EDTA, and QMix. The following combinations were also included: 2% NaOCl + 2% CHX, 2% NaOCl + QMix, 6% NaOCl + QMix, and 6% NaOCl + 17% EDTA + 2% CHX. Four other dentin specimens similarly infected but with no

smear layer were subjected to 3 minutes of exposure to 2% CHX and 6% NaOCl for comparison. Confocal laser scanning microscopy and viability staining were used to analyze the proportions of dead and live bacteria inside the dentin.

The results showed that in the presence of a smear layer, 10 minutes of exposure to QMix, 2% NaOCl + QMix, 6% NaOCl + QMix, and 6% NaOCl + 17% EDTA + 2% CHX resulted in significantly more dead bacteria than 3 minutes of exposure to these same disinfecting solutions. No statistically significant difference between 3 and 10 minutes was found in other groups; 6% NaOCl + QMix and 6% NaOCl + 17% EDTA + 2% CHX showed the strongest antibacterial effect. In the absence of a smear layer, 2% CHX and 6% NaOCl killed significantly more bacteria than they did in the presence of a smear layer. They concluded that the smear layer reduces the effectiveness of disinfecting agents against *E. faecalis* in infected dentin. Solutions containing 6% NaOCl and/or QMix showed the highest antibacterial activity.

Aranda-Garcia et al. 2013[19] by scanning electron microscopy assessed the efficacy of QMix, SmearClear, and 17% EDTA for the debris and smear layer removal from the apical and cervical thirds of forty extracted human maxillary canines, each group includes 10 teeth were assigned to the following final rinse protocols: G1-distilled water (control), G2-17% EDTA, G3-SmearClear, and G4-QMix. In sequence, forty extracted human maxillary canines with the root canals