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Irrigation and Activation in Endodontics

A Project Submitted to
The College of Dentistry, University of Baghdad, Department of Restorative & Aesthetic Dentistry in Partial Fulfillment for the Bachelor of Dental Surgery

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Certification of the Supervisor

I certify that this project entitled “**Irrigation and Activation in Endodontics"** was prepared by the fifth-year student **Yasser Mohammed Kadhim** under my supervision at the College of Dentistry/University of Baghdad in partial fulfilment of the graduation requirements for the Bachelor Degree in Dentistry.

Lec. Ammar Azeez Lateef

Dedication

I dedicate this project to the warmest embrace, the greatest bond and the owner of the greatest merit to our country and our origins to (Iraq).

To those who have reached this stage thanks to them, their fatigue, their constant struggle, and their constant support, to our parents and family, our teachers.

Yasser Mohammed Kadhim

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Yasser Mohammed Kadhim

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ABBREVIATIONS	WORD
CHX	Chlorhexidine Gluconate
MMP	Matrix Metallopeptidases
EDTA	Ethylene Diamin Tetraacetic Acid
CA	Citric Acid
MTAD	Mixture Of Tetracycline Isomer, Acid, And Detergent
HEBP	1-Hydroxyethylidene- 1, 1-Bisphosphonate
ECA	Electrochemically Activating
UI	Ultrasonic Irrigation
PUI	Passive Ultrasonic Irrigation
LAI	Laser-Activated Irrigation
MDT	Master Delivery Tip
MA	Maleic Acid
TETRACLEAN	Mixture Of Doxycycline, Citric Acid And Detergents
CLOREXIMID	Mixture Of CHX And Cetrimide
SMEAR CLEAR	Mixture Of EDTA, Cetrimide And Polyoxyethylene
PIPS	Photon-Induced Photoacoustic Streaming
PDT	Photodynamic Therapy

Introduction

Endodontics is the branch of dentistry concerning dental pulp*pulp champer and root canal and tissues surrounding the roots of a tooth. “Endo” is the Greek word for “inside” and “odont” is Greek for “tooth.” Endodontic treatment, or root canal treatment, treats the soft pulp tissue inside the tooth. **[Nisha Garg. Et al 2010]**

Endodontic procedures are usually performed to clean out infection and save the tooth the root canal treatment is performed by removing the infected pulp, meticulously cleaning the root canals and sealing them off. **[Dr. Kade Roundy Endodontic et La Cantera]**

Irrigation is a key part of successful root canal treatment as it fulfils of several important mechanical, chemical and (micro) biological functions. Irrigation is also the only way to impact those areas of the root canal wall. Irrigants exert their effects, by mechanical, chemical and biological actions. **[Haapasalo M. et al 2005]**

Chemicals: dissolution of organic and inorganic tissue, removal of dentine and smear layer residues. These effects can be expected only from chemically active irrigators (sodium hypochlorite, EDTA).

Mechanics: canal lubrication, mechanical removal of microorganisms/biofilms, pulp tissue remnants, as well as the remains of dentin thanks to the forces applied by the irrigant flow. These effects can be expected both from chemically active irrigators (sodium hypochlorite) and from inert irrigants (water, saline). **[Zehnder M. et al 2006]**

Biological: efficacy against anaerobic and facultative microorganisms, biofilm eradication or in activation, endotoxins inactivation. **[Mohammad Z. et al 2014]**

Different means delivery are used for root canal irrigation, from traditional syringe-needle delivery to various machine-driven systems. **[Hauser V. et al 2007]**

The goal of the various ways to improve irrigation is to secure optimal spreading of the irrigants throughout the root canal system for more predictable cleaning of the difficult-to-reach areas.

Activated irrigation: - may be defined as using a method to agitate and improve the flow of irrigants to the intricacies of root canal system by mechanical or other energy forms. While conventional irrigation purely depends on the positive pressure of injection and the viscosity of the irrigant to flow in the root canal system**. [Tronstad L. et al 1985]**

Root canals are considered **"closed systems"**. **[Parente JM. et al 2010]**

Where the fluid dynamics of the irrigant plays a major role in ensuring optimal actions. **[Hargreaves K. et al 2016]**

1.1 Irrigation Material

The most important aspects of cleaning and shaping is effective irrigation of the root canal system. Mechanical instrumentation alone using hand or rotary instruments cannot reduce the number of bacteria to allow for favorable outcomes. **[Byström A. et al 1981]** When irrigation with an antimicrobial solution is used, the bacterial load is significantly reduced compared to mechanical preparation alone. **[Byström A. et al 1983]**

Ideal Requirements of Root Canal Irrigants [Zehnder M. et al 2006]

1. Broad antimicrobial spectrum
2. High efficacy against anaerobic and facultative microorganisms organized in biofilms
3. Ability to dissolve necrotic pulp tissue remnants
4. Ability to inactivate endotoxin
5. Ability to prevent the formation of a smear layer during instrumentation or to dissolve the latter once it has formed.
6. Systemically nontoxic when they come in contact with vital tissues, noncaustic to periodontal tissues, and with little potential to cause an anaphylactic reaction

1.1.1 Normal Saline

In endodontics, Normal saline is one of the solutions used as an irrigant. It results in root canal debridement and lubrication. Because of its moderate activity, it may be used in conjunction with chemical irrigants. After root canal preparation, it may be used as a last rinse to flush out any leftover chemical irrigant. The most common saline solution is 0.9 percent W/V normal saline. **[Nisha Garg et al 2010]**

Fig (1):- Sodium Chloride 0.9%

1.1.2 NaOCl

Fig (2):- Sodium Hypochlorite

Solutions of sodium hypochlorite have been widely used to this effect. Their concentration can vary from 0.5 to 5.25%. **[Rutala WA. et al 1998]**

Sodium hypochlorite as a clear, pale, yellowish-greenish, extremely alkaline liquid, with strong scent to chlorine. It exerts dissolving action over organic remains as well as necrotic tissue. It is also a potent anti-microbial agent. **[Glossary et al 1998]**

These concentrations can be used directly from the bottle or derived from a solution. Considered the gold standard in irrigation solutions, NaOCl is the irrigant of choice among endodontists[10] due to several properties. **[Dutner J. et al 2012]**

Advantages of sodium hypochlorite

1. The ability to dissolve pulp tissue
2. Kill bacteria: - Bacteria use pulpal tissue as a nutrient source, so it is important that NaOCl is able to dissolve both vital **[Rosenfeld EF. et al 1978]** and necrotic **[Svec TA. et al 1977]** pulp tissue. This alone helps eliminate a nutriment source for bacterial reproduction. This bactericidal agent has a direct killing effect on bacteria. **[Waltimo T. et al 2005]**
3. Removal of the organic portion of the smear layer created by the mechanical instrumentation of dentin **[Baumgartner JC. et al 1987].**
4. Acting as a lubricant in the canal. **[Chandler N. et al 2018].**

The mechanisms of action of NaOCl

Action include saponification, neutralization of amino acids, and chloramination.

These mechanisms either directly alter the bacterial cell wall or interfere with cellular processes. In addition, NaOCl's high pH of >11 leads to disruption of enzymatic activity.

Saponification reaction:-

Sodium hypochlorite acts on fatty acids, transforming them into fatty acid salts (soap) and glycerol (alcohol) that reduce the surface tension of the remaining solution.

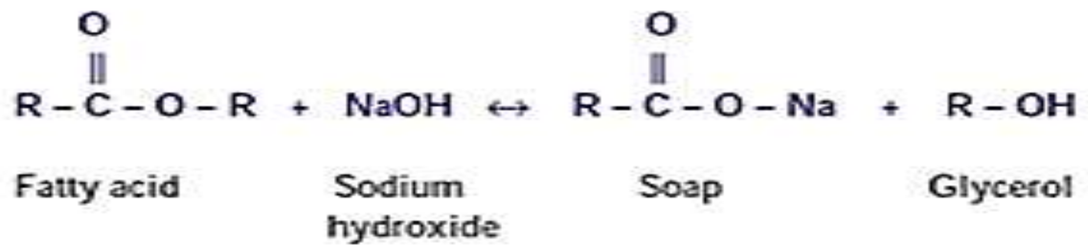

Fig (3):- Saponification reaction

Neutralization reaction:-

NaOCl neutralizes amino acids and forms water and salt. With the exit of hydroxyl ions, there is a reduction of ph.

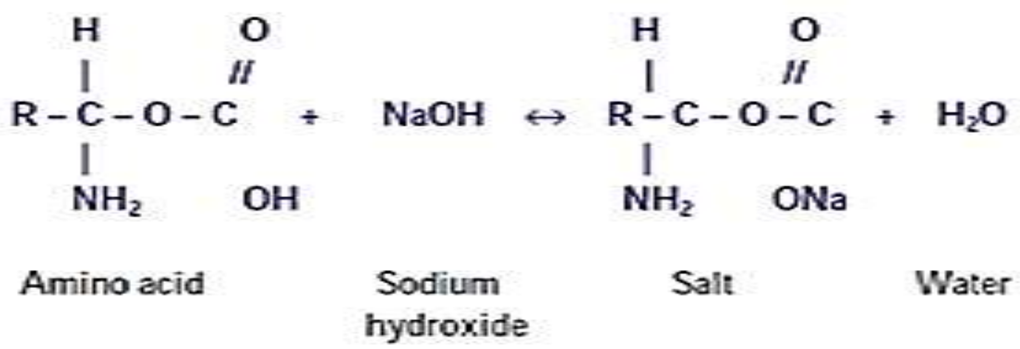

Fig (4):- Neutralization reaction

Chloramination reaction:-

Hypochlorous acid, present in NaOCl solution, when in contact with organic tissue acts as a solvent, releases chlorine that, combined with the protein amino group, forms chloramines that interfere in cell metabolism, helping to render its antimicrobial affect**. [Estrela C. et al 2002]**

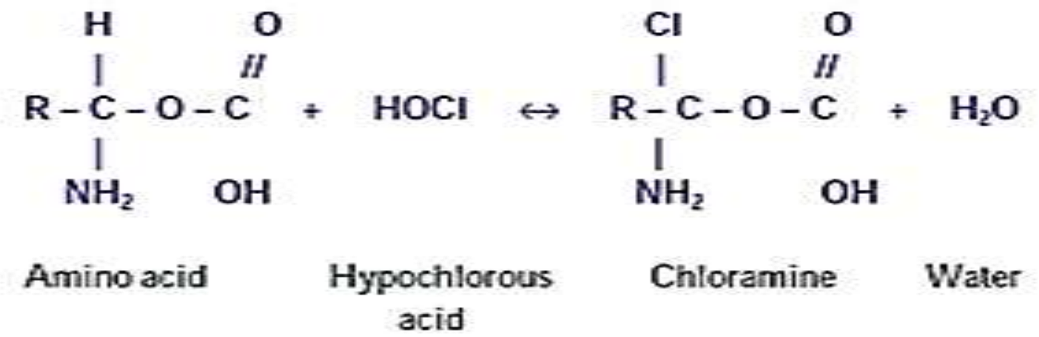

Fig (5):- Chloramination reaction

Note:- Smear layer removal will expose dentinal tubules that can harbor bacteria, thus allowing access for improved elimination of the bacterial load.

Lubrication in the canal facilitates navigation of the canal space with the goals of reaching working length and establishing patency.

The current methods of root canal preparation might produce a smear layer that covers the instrumented areas of the canal walls. **[Shen Y. et al 2008]** The smear layer contains inorganic and organic substances such as fragments of odontoblastic processes and necrotic debris, **[Torabinejad M. et al 2002]** and may also contain bacteria. It may act as a physical barrier and affect the sealing efficiency of the root canal filling.

To avoid these consequences

Irrigation is used to remove the smear layer **[Haapasalo M. et al 2007]** thus requiring the use of a chelating agent and a soft-tissue solvent. **[Zehnder M et al 2005]** The combination of ethylenediaminetetraacetic acid (EDTA) and sodium hypochlorite (NaOCl) was suggested as an effective irrigation procedure to disinfect the root canal and to eliminate the organic and inorganic materials. **[Torabinejad M. et al 2002]**

In most cases, NaOCl is used during instrumentation, and EDTA is preferably used at the end of instrumentation to complete the removal of the smear layer. **[Zehnder M. et al 2002]** The application of NaOCl ensures a high disinfection efficacy and enables the material to penetrate into the dentin. In contrast, a final flush of NaOCl has also been suggested to allow better NaOCl penetration to areas that were earlier covered with the smear layer. **[Goldman M. et al 1982]**

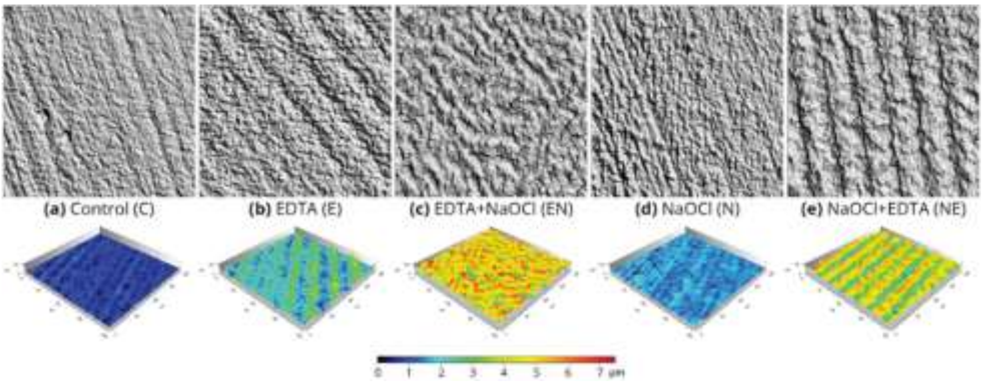

Fig (6):- Surface image (top) and surface topography (bottom) of the dentin surfaces following the irrigation protocols. (**a**) Control (**b**) EDTA 17% (**c**) EDTA 17% followed by NaOCl 5.25% (**d**) NaOCl 5.25% (**e**) NaOCl 5.25% followed by EDTA 17%.

Note the reduced roughness of the control and NaOCl 5.25% (d) groups compared to the other treatments (b, c, e).The color map indicates the measured height in micrometers above the lowest point for each surface. **[Zehnder M. et al 2002]**

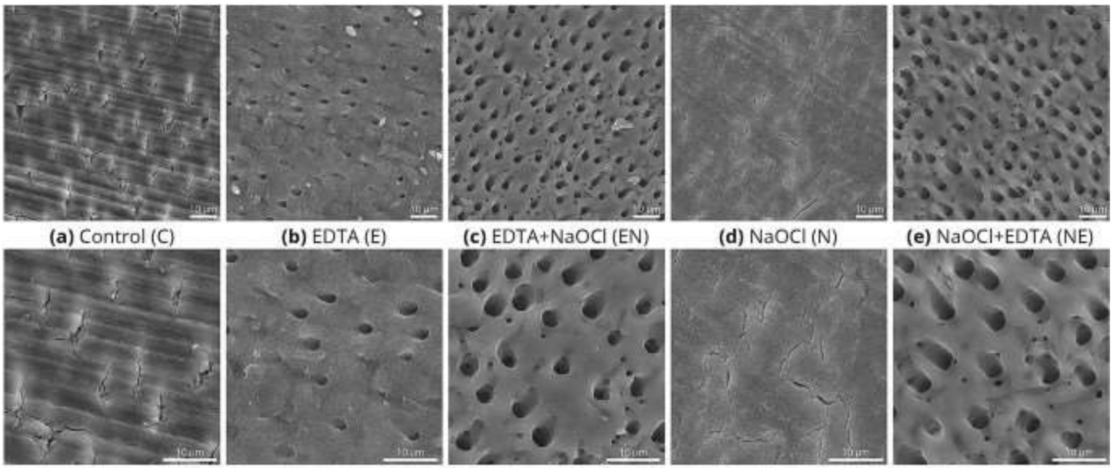

Fig (7):- SEM images of the dentin surfaces following the different irrigation protocols. (a) Control (b) EDTA 17% (c) EDTA 17% followed by NaOCl 5.25% (d) NaOCl 5.25% (e) NaOCl 5.25% followed by EDTA 17%. Scale bar: 10 µm. **[Goldman M et al 1982]**

Bacteria in the root canal can aggregate and form microcolonies of biofilm. **[Nair PN. Et al 2014]** the colonies consist of bacterial cells embedded in an extracellular polymeric substance of polysaccharides. **[Costerton JW. et al 1995]** Biofilms are also very resistant to antibiotics. Another property of NaOCl is its ability to disrupt biofilms by removing the protective extracellular polymeric barrier, giving access to climax communities of bacteria present within. **[Clegg MS. et al 2006]**

The main disadvantage of NaOCl

1. It is cytotoxic. **[Pashley EL. et al 1985]**

2. Extrusion of NaOCl beyond the apical foramen can create an NaOCl accident.

3. Injury of this nature results in severe pain, edema, profuse intracanal bleeding, ecchymosis, potential permanent anesthesia, and inevitable litigation. This can be avoided by using a side-vented needle in place of an open-ended needle (Figures 8A and 8B), and always keeping the needle loose in the canal during irrigation.

4. NaOCl is that it does not stay active for long; thus, NaOCl solutions are refreshed frequently during cleaning and shaping. This results in a high fluid volume that maintains tissue dissolving and bactericidal properties. **[Siqueira JF JR. et al 2000]**

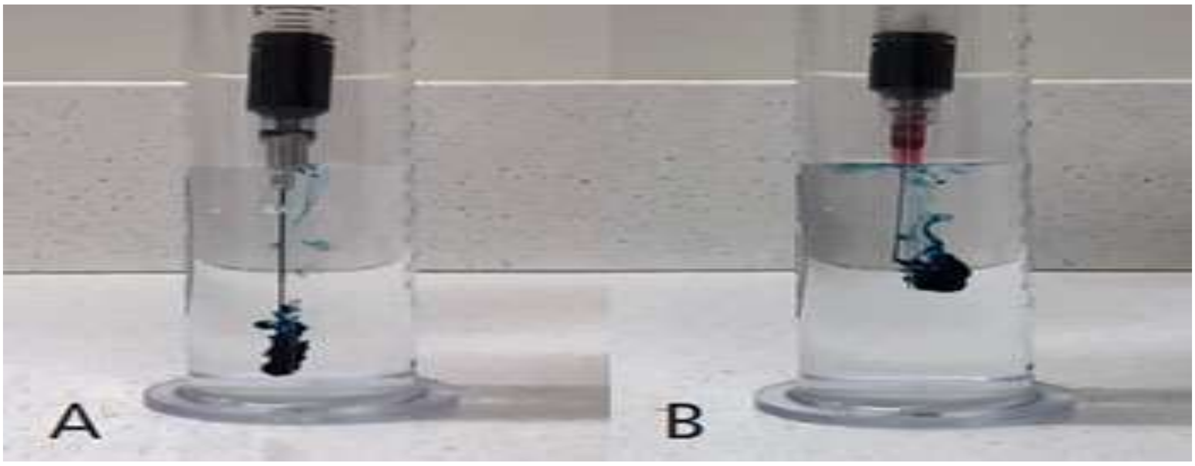

Fig (8A and 8B):- An open-ended, 20-gauge irrigation needle expressing dye forcefully in an apical direction (A) compared to a side-vented, 28-gauge irrigation needle expressing dye in a lateral direction, with minimal apical involvement (B).

The tissue dissolution capacity and debridement properties can be significantly improved by

1. Increasing the temperature sodium hypochlorite
2. Increase concentration of sodium hypochlorite. **[Abou-Rass M et al 1981]**
3. The penetration ability to the uninstrumented area of root canal systems can be increased by lowering the surface tension of NaOCl. **[Palazzi F. et al 2012]**

Note- Regardless of its significant effect on the organic component of dentin, NaOCl has no effect on dentin's inorganic part **[Kandaswamy D. et al 2010].**

Note- increase in the antibacterial effect of 5.0% NaOCl when used alternately with 10% EDTA solution. This is related to the demineralizing action of EDTA, which prevents smear layer formation during instrumentation, resulting in an increased NaOCl penetration into the dentinal tubules. **[Andersen M et al 1995]**

On the other hand, it was reported that applying EDTA and NaOCl solutions to the root canal resulted in an eroded appearance of the dentin and enlarged tubular orifice diameters. **[Qian W. et al 2011]**

1.1.3 Chlorhexidine (CHX)

Is a strong antiseptic that is often used to chemically control plaque in the mouth. Mouthwash is made up of 0.1-0.2% aqueous solutions, while root canal irrigation in endodontic treatment is done with a 2% concentration. The antibacterial action of CHX is dependent on achieving an ideal pH (5.5-7). At lower quantities, CHX is bacteriostatic; at larger quantities, it is bactericidal. **[Siqueira JF Jr et al 2007]**

Chlorhexidine gluconate (CHX)

Is a broad-spectrum antimicrobial agent that has been advocated for root canal disinfection. **[Ohara P. et al 1993]** When used as an irrigant or intracanal medication, its antibacterial efficacy is comparable to that of NaOCl, it is effective against certain NaOCl-resistant bacterial strains. **[Basrani B. et al 2002]**

Fig (9):- Chlorhexidine gluconate 2%

Prolonged exposure of the root dentin to CHX may impart a residual antimicrobial property to the dentin surface. **[Basrani B et al 2003]**

CHX has a low grade of toxicity: - [Loe H. et al 1973] however, its inability to dissolve organic matter maybe a drawback in its clinical use. **[Okino LA. et al 2004].**

Mode of Action

CHX is a wide-spectrum antimicrobial agent, active against Gram-positive and Gram-negative bacteria, and yeasts. **[Denton G. et al 1991]** Due to its cationic nature,

CHX is capable of electrostatically binding to the negatively charged surfaces of bacteria. **[Davis JM. Et al 2007]** Damaging the outer layers of the cell wall and rendering it permeable. **[Hugo WB. Et al 1996]** Depending on its concentration, CHX can have both bacteriostatic and bactericidal effects. At high concentration CHX acts as a detergent, and by damaging the cell membrane it causes precipitation of the cytoplasm and thereby exerts a bactericidal effect

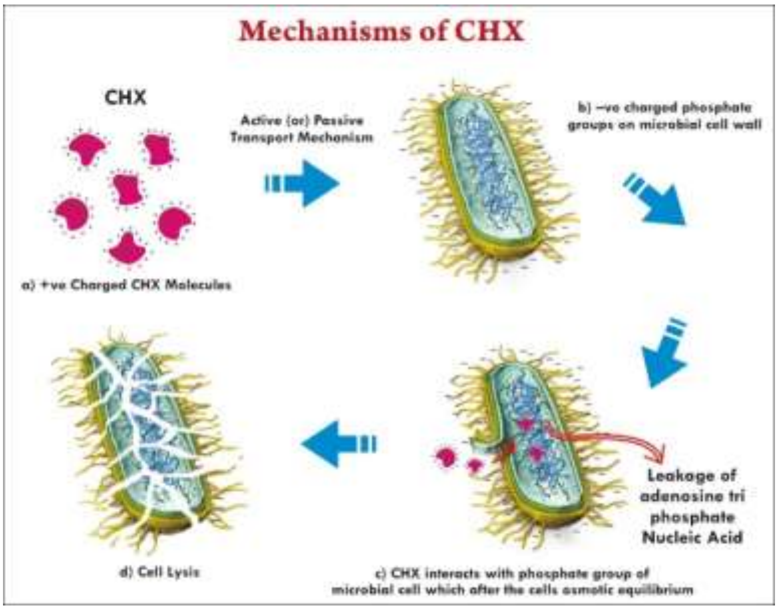

Fig (10):- Mechanisms of CHX **[Siqueira JF JR et al 2007]**

Chlorhexdine Application in Endodontics:-

In endodontics, CHX has been studied as an irrigant and intracanal medication, both in vivo and in vitro.

In vitro, CHX has at least as good, or even better antimicrobial efficacy than $Ca(OH)_2$ Notably, 2% CHX was very effective in eliminating a biofilm of E. faecalis. **[Basrani B. et al 2003]**

In vivo, it inhibits experimentally-induced inflammatory external root resorption when applied for four weeks. **[Paquette L. et al 2007]**.

In infected root canals, it reduces bacteria as effectively as $Ca(OH)_2$ when applied for one week. **[Barbosa CA. et al 1997]** Unlike $Ca(OH)_2$, CHX has substantive antimicrobial activity that, if imparted onto the root dentin, has the potential to prevent bacterial colonization of root canal walls for prolonged periods of time. **[Komorowski R. et al 2000]** This effect depends on the concentration of CHX, but not on its mode of application, which maybe either as liquid, gel or a controlled release device. **[Basrani B. et al 2003]**
CHX and dentine bonding was also studied in details, on the whole, because of its broad-spectrum MMP-inhibitory effect, CHX can significantly improve the resin-dentine bond stability.

1.1.4 Decalcifying Materials

Almost always referred to by its acronym, EDTA is another commonly used irrigant, and is often employed in combination with NaOCl. Used as a chelating agent during chemomechanical preparation,

EDTA:-

1. Can bind and remove calcium and demineralize dentin, leading to removal of the inorganic portion of the smear layer while
2. Also acting as a lubricant. Some believe that leaving the smear layer intact may be beneficial by entombing bacteria present in the canal. However, clinicians who choose to remove the smear layer do so to facilitate disinfection. **[Morago A. et al 2019]**

3. Aid diffusion of calcium hydroxide when used as an intracanal medicament. **[Foster KH. et al 1993]**
4. Help sealer penetrate into the dentinal tubules. **[Kokkas AB. et al 2004]**

In dentistry, EDTA is commonly available as a 17% solution, and because EDTA demineralizes dentin, it should not be overused. The recommended volume and contact time to safely remove the smear layer without over-eroding dentin is a volume of 1 ml **[Crumpton BJ. et al 2005]** for 60 seconds. Since EDTA is often used with NaOCl, it is important to understand the potential interactions between the two solutions.

When mixed together, EDTA limits the effectiveness of NaOCl by reducing the amount of free chlorine needed for the mechanism of action.

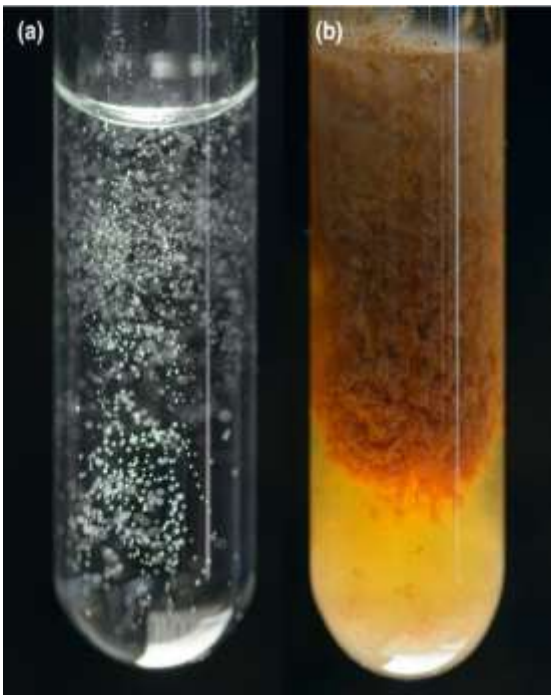

Fig (11):- (a) Bubble formation a few seconds after mixing equal amounts of 5% NaOCl and 17% disodium EDTA indicating their chemical reaction. (b) Orange-brown mass formed due to the interaction between 5% NaOCl and 2% CHX (mixed in equal amounts). **[Prado M. et al 2013]**

On the other hand, NaOCl does not affect the chelating ability of EDTA. **[Grawehr M. et al 2003]**

NOTE: - Clinicians should dry canals when switching between these two irrigants. **[Zehnder M et al 2005]**

Fig (12):- EDTA 17%

Note:- In the apical third of the root, a minute-long ultrasonic application of 17% EDTA is highly helpful, and the use of liquid EDTA during root canal therapy is also advised. **[Nygaard-Ostby B et al 1975]**

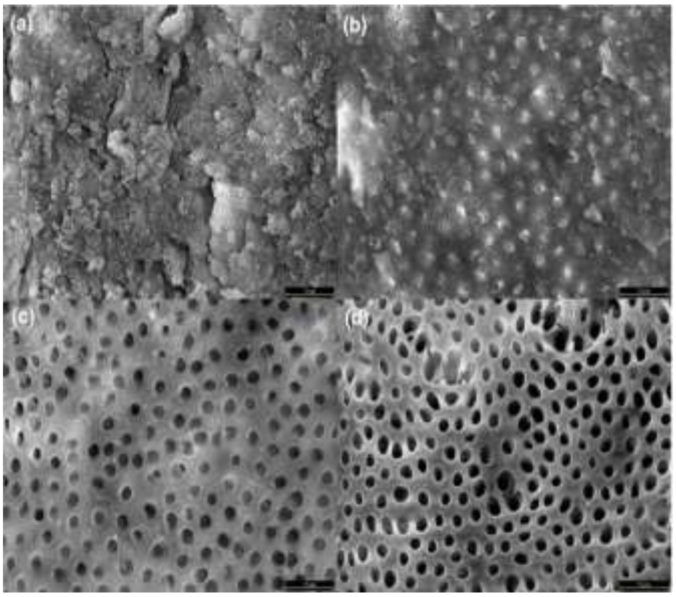

Fig (13):- Scanning electron microscope photomicrographs of dentine following chemomechanical preparation. A thick contaminated smear layer was evident when distilled water was used as irrigant (a). Irrigation with 2.5% NaOCl during preparation resulted only in partial removal of the smear layer (b) whilst an additional final rinse with 17% disodium EDTA (c) or continuous chelation with a mixture containing 2.5% NaOCl and 9% etidronic acid throughout preparation (d) resulted almost in complete removal **[Hülsmann M. et al 2003]**

1.1.5 Citric Acid

Is available in quantities ranging from 1% to 50%. Using 10% CA as a final irrigation solution offered good results for removing smear layers. Although

EDTA and CA are equally effective in removing the smear layer from root canal walls

Fig (14):- Citric Acid 10%

CA has shown some advantages over EDTA when used at comparable doses. The cytotoxicity of chelators has been studied in vitro.

The biocompatibility of a 10% CA solution against a 17% EDTA solution has been shown. On three separate occasions (1, 5, and 10 min), a 25% CA solution was shown to be ineffective in the removal of Enterococcus faecalis biofilms. **[Sceiza MF. et al 2001]**

1.1.6 Mixture of Tetracycline Isomer, Acid, and Detergent (MTAD)

A compound has been developed with combined chelating and antibacterial properties. **[Torabinejad M. Khademi A.A. et al 2003]**

MTAD is a mixture of

1. Doxycycline.
2. Citric acid.
3. Tween 80.

Fig (15):- MTAD

It is applied as a 5-minute final rinse after canal instrumentation and irrigation with 1.3% NaOCl. **[Torabinejad M. Cho Y. et al 2003]** Preliminary in vitro studies have suggested effective elimination of root canal bacteria by MTAD **[Newberry B.M. et al 2007]** subsequent in vivo studies did not support those results. **[Tay F.R. et al 2007]**

NOTE:- Because it does not dissolve organic tissues, it is best to use this after NaOCl at the end of the chemomechanical preparation step.

MTAD is made up of three different compounds that together are expected to have a potent antibacterial action.

E. faecalis biofilm is more susceptible to NaOCl solution's bactericidal action at concentrations of 1-6%.

The smear layer removal with CA is conceivable, allowing the antibacterial effects of doxycycline to penetrate the dentinal tubules.

Note:- Root canal bacteria may become resistant to tetracycline if MTAD is used in place of EDTA.

A biocide such as NaOCl or CHX is usually preferred over an antibiotic since antibiotics were designed for systemic rather than local use and have a restricted scope. **[Torabinejad M. Khademi AA. et al 2003]**

1.1.7 Tetraclean

Tetraclean: - has a process similar to that of MTAD, but with a lesser dose of doxycycline and detergent.

1. Propylene glycol is the detergent type, whereas
2. the antibiotic concentration is 50 mg/ml of doxycycline,

Which differs from what is utilized in MTAD.

Fig (16):- Tetraclean

Because it will not dissolve organic tissue as NaOCl does, tetraclean is best used at the end of the chemomechanical preparation after NaOCl.

This product has a lot of power against both facultative and anaerobic bacteria. Planktonic and in vitro biofilm E. faecalis cultures as well as mixed-species biofilms respond better to tetraclean than MTAD. **[Pappen FG. et al 2010]**

1.1.8 HEBP

HEBP (1-hydroxyethylidene- 1, 1-bisphosphonate), also known as etidronic acid or etidronate, has been proposed as a potential alternative to EDTA or citric acid because this agent shows no short-term reactivity with NaOCl. **[Zehnder M. et al 2005]** HEBP is

1. Nontoxic
2. Has been systematically applied to treat bone diseases. **[Russell RG. et al 1999]**
3. The demineralization kinetics promoted by both 9% HEBP and 18% HEBP were significantly slower than those of 17% EDTA. **[De-Deus G. Et al 2008]**

4. Reported that the soft chelating irrigation protocol (18% HEBP) optimized the bonding quality (3.1–6.1 MPa) of Resilon/Epiphany. **[De-Deus G. et al 2008]**

Note:- Etidronic acid or etidronate (HEBP)

A decalcifying substance, interacts very little with sodium hypochlorite (NaOCl). A substitute for EDTA or CA has been proposed.

In the treatment of osteoporosis and Paget's disease, HEBP is a systemic drug that decreases bone resorption.

To determine whether this therapy shortens or lengthens endodontic irrigation, an additional study is required. It takes longer to remove minerals from the body with 9% or 18% HEBP than it does with 17% of the same concentration of EDTA.

1.1.9 Superoxide Water

Is obtained by the electrochemical treatment of a saline solution. It can be obtained from regular tap water and low-concentration salt solutions by electrochemically activating (ECA) them. Oxidizing compounds having microbicidal action against bacteria, viruses, fungi, and protozoa make up anolyte solutions. the names 'superoxidized water' and 'oxidative potential water' are both used to describe this kind of water.

1. They are non-toxic
2. Do not harm key biological tissues. **[Olovyeva AM. et al 2000]**

ECA has promising results for effective root canal irrigation.

1.1.10 Ozonated Water

Ozonated Water at low quantities, ozone (O_3) can kill pathogens, including spores (0.01 ppm). It is simply prepared using an ozone generator.

Ozone dissolves quickly and easily in water.

Lipopolysaccharides in root canals were discovered to have biological consequences, including the induction of apical periodontitis and could not be neutralized by ozonated water, despite the fact that ozonated water kills bacteria. Before ozonated water is used as a frequent therapeutic technique for root canals, more research is needed. **[Huth KC. et al 2009]**

1.1.11 Maleic acid

Is a mild organic acid used as an acid conditioner in adhesive dentistry. Reported that final irrigation with 7% maleic acid for 1 min was more efficient than 17% EDTA in the removal of smear layer from the apical third of the root canal system. **[Ballal NV. Et al 2009]**

1.1.12 Factors Influencing Intracanal Irrigant Activity

1. The tissue dissolving power of NaOCl is higher at 5.2% than at 2.5% and 0.5%, and therefore, the higher the concentration, the greater the effectiveness.
2. Touch: To be effective, the irrigant must contact the substrate. The presence of organic tissue must be removed for irrigation to be successful.
3. Quantity of irrigant utilized: The more irrigant is used, the more effective it is. Irrigating needle gauze: 27 or 28 gauze is used for improved canal penetration.

4. Irrigant's surface tension: The lower the surface tension, the better the wettability.
5. Irrigant's temperature: Warming the NaOCl boosts its efficacy.
6. Irrigation frequency: The higher the frequency, the better the outcomes.
7. Canal diameter: The wider the canal, the better the irrigant's effect.
8. Irrigant's age: Newly produced solutions are more efficient than older solutions. **[Nisha Garg. et al 2010]**

1.2 Activation of irrigation

An ideal irrigant should

1. Reduce instrument friction during preparation,
2. Facilitate dentin removal,
3. Dissolve inorganic and organic tissue,
4. Penetrate to canal periphery,
5. Kill bacteria and yeasts and
6. Least irritating to the periapical tissues

However, there is no one unique irrigant that can meet all these requirements, even with the use of methods such as lowering the pH, increasing the temperature, as well as addition of surfactants to increase the wetting efficacy of the irrigant.

More importantly, these irrigants must be brought into direct contact with the entire canal wall surfaces for effective action, particularly for the apical portions of small root canals. To accomplish these objectives, there must be an effective delivery system to working length. An improved delivery system for root canal irrigation is highly desirable. Such a delivery system must have adequate flow and volume of irrigant to working length to be effective in debriding the canal system without forcing the solution into periradicular tissues. In selecting an irrigant and technique, consideration must be given to their efficacy and safety. **[LS Gu. Et al 2009]**.

Irrigation armamentarium presents a diverse variety of tools [Fig (17)] and techniques that can assist the practitioner in reducing bacteria and debris within the canal system. However, currently there is no universally accepted standard irrigation technique. Since most research comparing the efficacy of different irrigation techniques are in vitro studies with low levels of clinical evidence, caution is advised when considering the purchase of these devices **[KW Falk. et al 2005]**

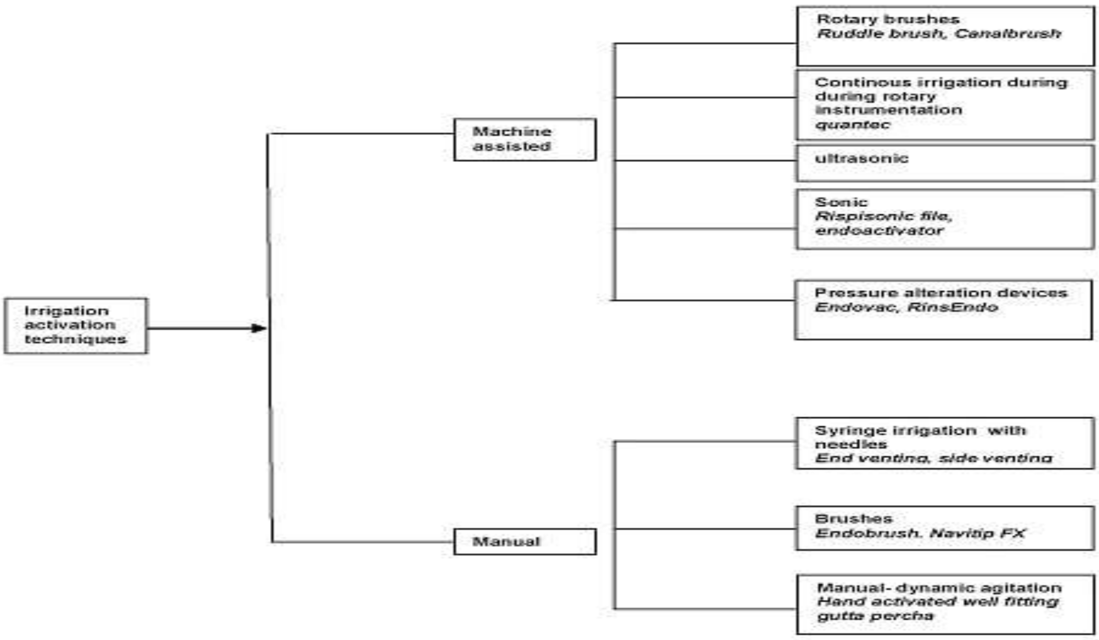

Fig (17):- Mode of activation technics of irrigants

1.2.1 Manual Agitation Techniques

1.2.1.1 Syringe Irrigation with Needles/Cannulas

Conventional irrigation with syringes has been advocated as an efficient method of irrigant delivery before the advent of passive ultrasonic activation. This technique is still widely accepted by both general practitioners and endodontists. The technique involves dispensing of an irrigant into a canal through needles/cannulas of variable gauges, either passively or with agitation. The latter is achieved by moving the needle up and down the canal space. Irrigation tip gauge and tip design can have a significant impact:-

1. On the irrigation flow pattern.
2. Flow velocity.
3. Depth of penetration.

4. Pressure on the walls and apex of the canal. **[LS Gu. Et al 2009]**.

Irrigation tip gauge will largely determine how deep an irrigant can penetrate into the canal.

1. 21-gauge tip can reach the apex of an ISO size 80 canal,
2. 23-gauge tip can reach a size 50,
3. 25-gauge tip can reach a size 35 canal and
4. 30-gauge tip can reach the apex of a size 25 canal.
5. 27 gauge needle is the preferred needle tip size for routine endodontic procedures.

Several studies have shown that the irrigant has only a limited effect beyond the tip of the needle because of the dead-water zone or sometimes air bubbles in the apical root canal, which prevent apical penetration of the solution. **[C Boutsioukis. C Gogos. et al 2010]**

1.2.1.2 Needle-tip design

The smaller needles allow delivery of the irrigant close to the apex, this is not without safety concerns. Several modifications of the needle-tip design [Fig (18a -18b)] have been introduced to facilitate effectiveness and minimize safety risks. Open-ended tips express irrigant out the end towards the apex and consequently increase the apical pressure within the canal. Closed-ended irrigant tips are side-vented and thus create more pressure on the walls of the root canal and improve the hydrodynamic activation of an irrigant and reduce the chance of apical extrusion. This allows the irrigant to reflux and causes more debris to be displaced coronally, while avoiding the inadvertent expression of the irrigant into periapical tissues. **[CM Sedgley. et al 2005]**.

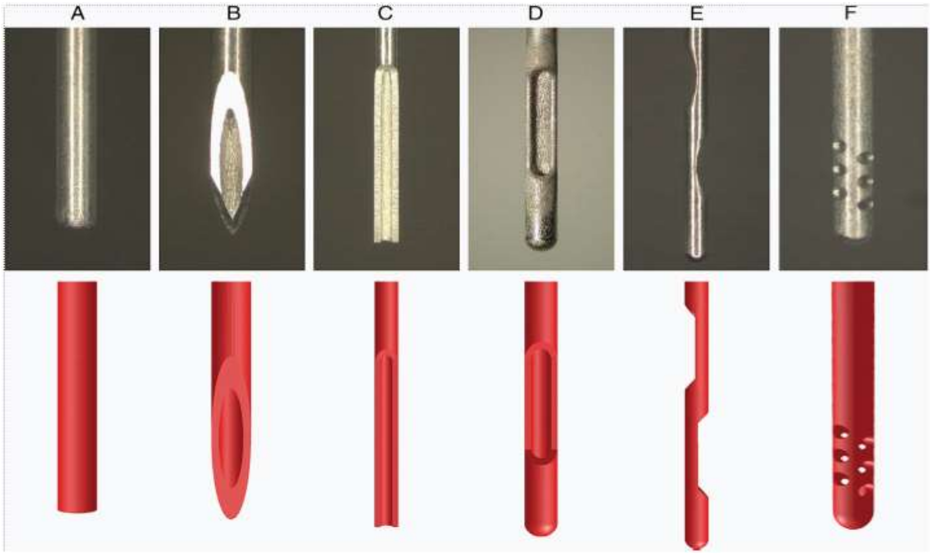

Fig (18):- (A-C) Open-ended needles: (A) flat, (B) beveled, (C) notched, (D-F) Closed-ended needles: (D) side vented, (E) double side vented, (F) multivented.

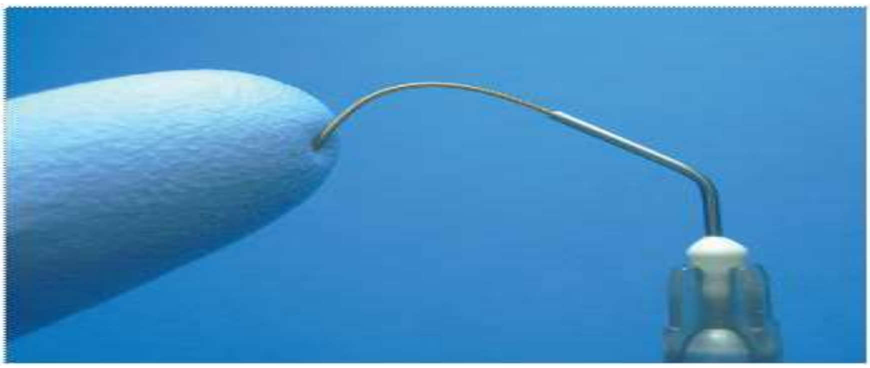

Fig (19):- Flexiglide needle for irrigation also easily follows curved canals

Note: - One of the advantages of syringe irrigation is that it allows comparatively easy control of the depth of needle penetration within the canal and the volume of irrigant that is flushed through the canal. **[C Boutsioukis. B Verhaagen. Et al 2010].**

1.2.1.3 Syringes

Plastic syringes of different sizes (1–20 mL) are most commonly used for irrigation. [Fig (20)] Although large-volume syringes potentially allow some time-savings, they are more difficult to control for pressure and accidents may happen. Therefore, to maximize safety and control, use of 1- to 5-mL syringes is recommended instead of the larger ones. All syringes for endodontic irrigation must have a Luer-Lok design. Because of the chemical reactions between many irrigants, separate syringes should be used for each solution. **[Haapasalo Markus. et al 2010]**

Fig (20):- Plastic syringes of different sizes

1.2.1.4 Brushes

Are not directly used for delivering an irrigant into the canal spaces. They are adjuncts that have been designed for debridement of the canal walls or agitation of root canal irrigant. They might also be indirectly involved with the transfer of irrigants within the canal spaces. Recently, a 30-gauge irrigation needle covered with a brush was introduced commercially. [Fig (21a -21b)] A recent study reported improved cleanliness of the coronal third of instrumented root canal walls irrigated and agitated with the NaviTip FX needle over the brushless type of NaviTip needle. However, friction created between the brush bristles and the canal irregularities might result in the dislodgement of the radiolucent bristles in the canals that are not easily recognized by clinicians, even with the use of a surgical microscope. **[NP Migun. Et al 1996]**

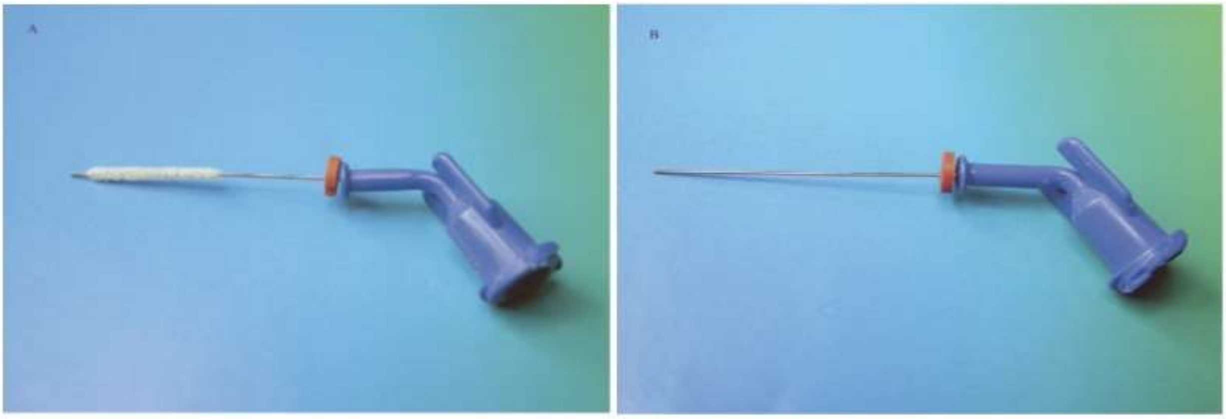

Fig (21):- (a) NaviTip FX, (b) NaviTip

During the early 1990s, similar findings indicating improved canal debridement with the use of canal brushes. They used the Endobrush in an active brushing and rotary motion. The Endobrush - is a spiral brush designed for endodontic use that consists of nylon bristles set in twisted wires with an attached handle and has a relatively constant diameter along the entire length. However, the Endobrush could not be used to full working length because of its size, which might lead to packing of debris into the apical section of the canal after brushing. **[SM Al-Hadlaq. Et al 2006]**

Vapor Lock Effect

Air entrapment by an advancing liquid front in closed-end microchannels is a well-recognized physical phenomenon and has been referred to as the vapour lock effect. [Fig (22)] The ability of a liquid to penetrate these closed-end channels is dependent on:-

1. The contact angle of the liquid
2. The depth
3. Size of the channel.

Because endodontic irrigation is performed within a time frame of minutes instead of hours or days, air entrapment in the apical portion of the canal might preclude this region from contact or disinfection by the irrigant. **[NP Migun. Et al 1996]**.

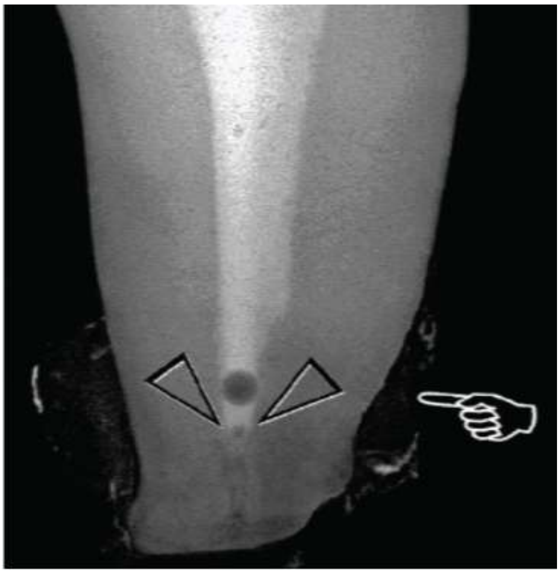

Fig (22):- Vapour Lock Effect

Demonstrated that NaOCl did not extend any closer than 3 mm from working length, even after root apex was enlarged to a size 30. **[M Abou-Rass. Et al 1982]**

This might be attributed to the fact that NaOCl reacts with organic material in the root canal and quickly forms micro gas bubbles at the apical termination that coalesce into an apical vapour lock with subsequent instrumentation. Because the apical vapour lock cannot be displaced within a clinically relevant time frame through simple mechanical actions, it prevents further irrigants from flowing into the apical region. More importantly, acoustic microstreaming and cavitation can only occur in a liquid phase. Therefore, once a sonic or ultrasonically activated tip leaves the irrigant enters the apical vapor lock, acoustic microstreaming and/or cavitation becomes physically impossible. **[Schoeffel G. Et al 2008]**

A simple method to disrupt the vapor lock might be achieved via the use of a hand-activated well-fitting root filling material (e.g., a size 40, 0.06 taper gutta-percha point) that is introduced to working length after instrumentation with the corresponding nickel-titanium rotary instrument (i.e., size 40, 0.06 taper). This method, although cumbersome, eliminates the vapour lock because the space previously occupied by air is replaced by the root filling material, carrying with it a film of irrigant to the working length **[LS Gu. et al 2009].**

1.2.2 Manual-Dynamic Irrigation

An irrigant must be in direct contact with the canal walls for effective action. However, it is often difficult for the irrigant to reach the apical portion of the canal because of the so-called vapor lock effect. Research has shown that gently moving well-fitting gutta-percha master cone up and down in short 2 to 3 mm strokes (manual dynamic irrigation) within an instrumented canal can produce an effective hydrodynamic effect and significantly improve the displacement and exchange of any given reagent. This was recently confirmed by the studies of **McGill et al.** and **Huang et al.** These studies demonstrated that manual dynamic irrigation was significantly more effective than an automated dynamic irrigation system and static irrigation. **[CJ Ruddle. Et al 2001]**

1.2.2.1 Factors Affecting Manual Dynamic Irrigation

Several factors could have contributed to the positive results of manual dynamic irrigation:

1) The push-pull motion of a well-fitting gutta-percha point in the canal might generate higher intracanal pressure changes during pushing movements, leading to more effective delivery of irrigant to the "untouched" canal surfaces.

2) The frequency of push-pull motion of the gutta-percha point (3.3 Hz, 100 strokes per 30 seconds) is higher than the frequency (1.6 Hz) of positive-negative hydrodynamic pressure generated by RinsEndo, possibly generating more turbulence in the canal.

3) The push-pull motion of the gutta-percha point probably acts by physically displacing, folding, and cutting of fluid under ‘‘viscously-dominated flow’’ in the root canal system. The latter probably allows better mixing of the fresh unreacted solution with the spent, reacted irrigant.

Although manual-dynamic irrigation has been advocated as a method of canal irrigation as a result of its simplicity and cost-effectiveness, the laborious nature of this hand-activated procedure still hinders its application in routine clinical practice. Therefore, there are a number of automated devices designed for agitation of root canal irrigants that are either commercially available or under production by manufacturers. **[CJ Ruddle. et al 2001]**

1.2.3 Mechanical Agitation Techniques

Both 1. Ruddle brush 2. Canal Brush

A rotary hand piece attached micro brush has been used to facilitate debris and smear layer removal from instrumented root canals. the brush includes a shaft and a tapered brush section. The latter has multiple bristles extending radially from a central wire core. During the debridement phase, the micro brush rotates at about 300 rpm, causing the bristles to deform into the irregularities of the preparation. This helps to displace residual debris out of the canal in a coronal direction.

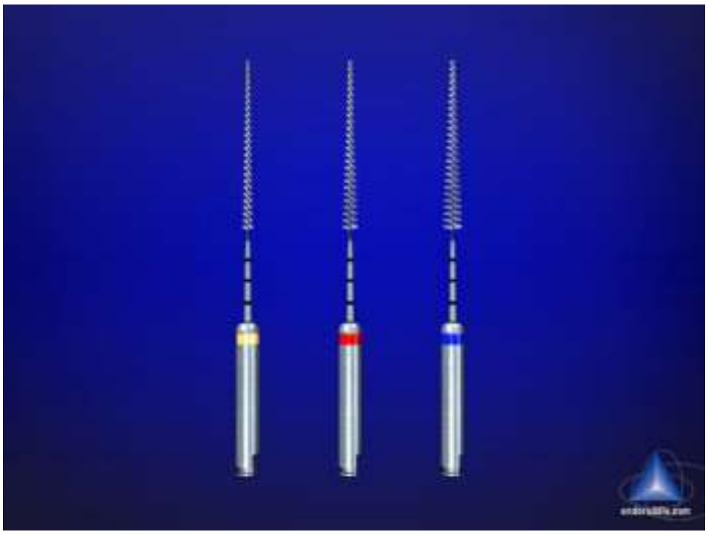

Fig (23):- A rotary hand piece attached micro brush

Canal Brush is another endodontic micro brush that has recently been made commercially available. This highly flexible micro brush is molded entirely from polypropylene and might be used manually with a rotary action. **[M Weise. Et al 2007]**.

Fig (24):- Canal Brush

Showed that debris was effectively removed from simulated canal extensions and irregularities with the use of the small and flexible Canal Brush with an irrigant. **[Tronstad L. Et al 1985]**

1.2.4 Sonic Irrigation

Sonic instruments for endodontics were first reported by **Tronstad et al 1985.** Sonic irrigation operates at a lower frequency (1–6 kHz) and produces smaller shear stresses than ultrasonic irrigation **Ahmed cleanlinesset et al 1987.**

Fig (25):- Sonic instruments

The EndoActivator is one form of the sonic irrigation that uses noncutting polymer tips to quickly and vigorously agitate irrigant solutions during treatment.

Fig (26):- EndoActivator

A study has shown this method to be effective of Irrigation [Table 1] [CJ Ruddle. et al 2008].

		Irrigation		Evaluation	
Year	**Author**	**Irrigation instrument**	**Irrigant**	**Evaluation method**	**Evaluation criteria**
1985	Tronstad et al.,	#20 K-file	2.5% NaOCl	SEM	Smear layer, dentin debris
1985	Barnett et al.,	#35 K-file	15% EDTA	-	-
1987	Stamos et al.,	#30 K-file	2.6% NaOCl	Histologic evaluation	Pulpal tissue and dentin debris
1987	Reynolds et al.,	#20 k file	Water	Histologic evaluation	Predentin and dentin debris
1989	Pugh et al.,	-	Tap water	Injection with impression material and clearing	Canal morphology
1989	Walker and del Rio	#25, 20 Trisonic file #15 Endostar file	Tap water	Histologic evaluation	Debris
2003	Sabins et al.,	#15 Rispisonic file	5.25% NaOCl	Surgical operating microscope	Dentin debris
2008	Ruddle	EndoActivator tips			dentinal cleanliness

1.2.5 Vibringe

Vibringe is a new sonic irrigation system that combines battery-driven vibrations (9000 cpm) with manually operated irrigation of the root canal. Vibringe uses the traditional type of syringe/needle delivery but adds sonic vibration. No studies can be found on Medline **[NP Migun. et al 1996].**

Fig (27):- Vibringe

1.2.6 Ultrasonic Irrigation

Ultrasonics is another group of instruments that can be used for irrigation in the ultrasonics and subsonic handpieces. Ultrasonic handpieces pass sound waves to an endodontic file and cause it to vibrate at ~25,000 vibration/s. It cuts dentin as well as causes acoustic streaming of the irrigant (Martin and Cunningham). It was also found that debris dislodgment from canal walls occurs through cavitation occurring within the irrigating solution.

The dental report has described two types of ultrasonic irrigation:-

1. The first one is a combination of simultaneous ultrasonic instrumentation and irrigation (UI).

2. The second one operates without simultaneous instrumentation and is referred to as passive ultrasonic irrigation (PUI).

PUI is more effective than syringe needle irrigation at removing pulpal tissue remnants and dentine debris. This may be due to the much higher velocity and volume of irrigant flow that are created in the canal during ultrasonic irrigation.

Ultrasonics can effectively clean debris and bacteria from the root canal system, but cannot effectively get through the apical vapor lock. **[K Carver. Et al 2007]**

Fig (28):- mode of action of Ultrasonic

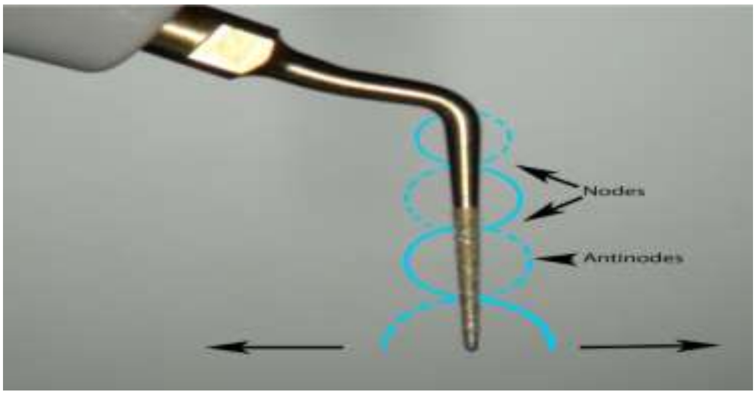

Fig (29):- Ultrasonic device with deferent tips

1.2.7 Laser-activated irrigation (LAI) **[Dioguardi M et al 2018]**

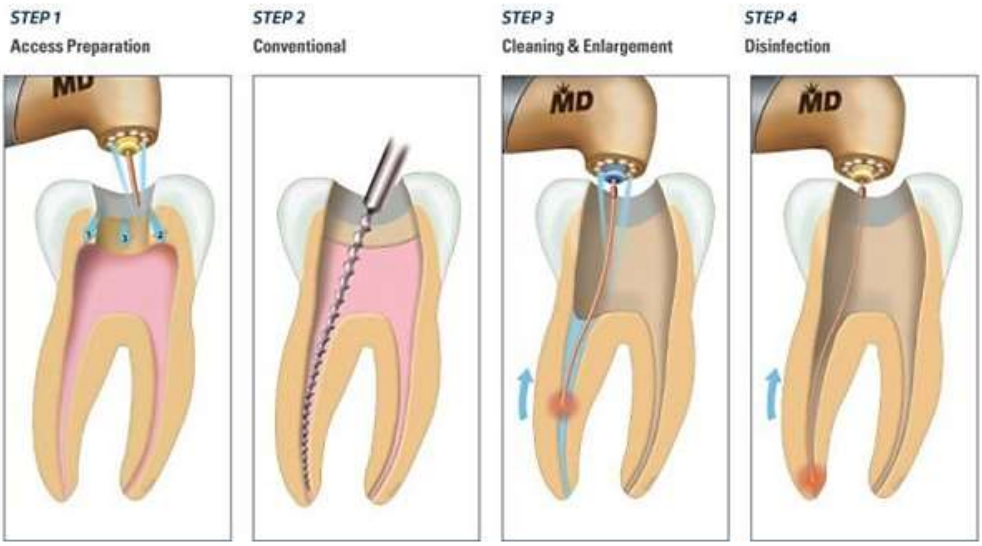

Fig (30):- Laser-activated irrigation (LAI)

1. The effect of LAI is based on cavitation, a physical phenomenon in which the static pressure of a liquid reduces to below the liquid's vapor pressure, leading to the formation of small vapor-filled cavities in the liquid. The laser-emitted light is absorbed in a thin superficial layer (∼1 μm thick) of the irrigant around the tip. The irrigant is then superheated over its boiling point, resulting in the formation of vapor and bubbles. The bubbles expand until the pressure in the bubble reaches that of the surrounding liquid, leading finally to a collapse of the bubble that leads to shock waves, which,

in turn, enhance the cleaning effect of the irrigant. **[Gregorcic P. et al 2012]**

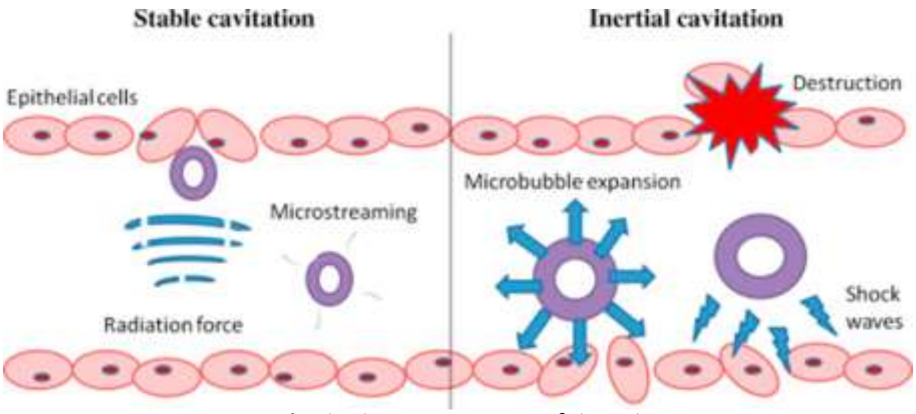

Fig (31):- cavitation of (LAI)

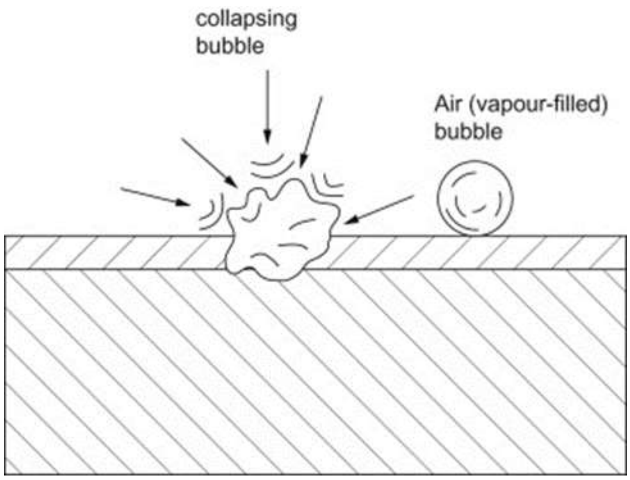

Fig (32):- The implosion of the vapor bubble

The implosion of the vapor bubble creates a pressure wave, leading to streaming of the liquid with velocities up to 20 m/s **[Blanken J. et al 2009].**The resulting forces and shear stress on the dentinal walls due to the streaming of the irrigant are sufficient to pump the tissue debris out of the canal and remove the smear layer and biofilm from the surfaces **[Matsumoto H. et al 2011]**. These effects are directly dependent on the energy and pulse duration parameters of the laser system, which modulate the time of vapor formation, as well as the size and life cycle of the vapor bubbles **[de Groot SD. Et al 2009].**

For LAI, the wavelength on which a laser operates and its applied power is of importance as the absorption coefficient of the irrigating liquid is wavelength dependent, while the power influences the amount of cavitation. Until now, wavelengths of 1,000–3,000 nm have been used **[Anagnostaki E. et al 2020]**

2. The Er:YAG laser has been of particular interest due to its wavelength (2,094 nm), which allows a very powerful interaction with water (absorption coefficient 1.2 × 104/cm) **[Do QL. et al 2020]**.

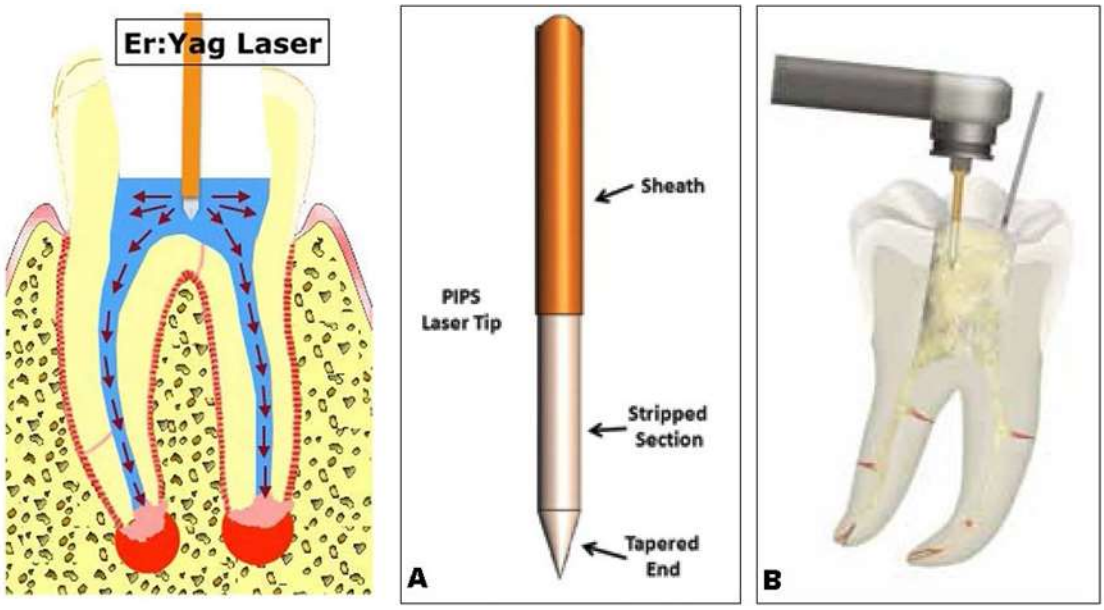

Fig (33):- The Er:YAG laser

3. Recently, CO_2 lasers with new wavelengths have been successfully developed with an absorption coefficient in the range of 6 × 102/cm. The 9,300-nm wavelength has gained attention for its possibility to ablate dental soft and hard tissues **[Nguyen D. et al 2011]**. As this wavelength is strongly absorbed in hydroxyapatite and water, it might also be suitable for the LAI technique. To the authors' best knowledge, there is no existing literature on cavitation capacities and possible applications in LAI with the 9,300-nm CO_2 laser.
4. Another group of lasers, diode lasers with visible and near-IR wavelengths, has already been well described in endodontics **[Anagnostaki E. et al 2020]**. Their classic indication in the endodontic treatment process is photothermal disinfection and activation of the chemical action of irrigants, such as sodium hypochlorite (NaOCl) and ethylene diamine tetraacetic acid (EDTA) **[Alfredo E. et al 2009]**. there is only limited report coping with the application of near-IR diode lasers in the mechanical activation of

liquids, mainly concentrating on the 940- and 980-nm wavelengths (absorption coefficient of approximately 9×10^{-1}/cm), as they are much more absorbed in water than other available near-IR diode wavelengths **[Gutknecht N. et al 2004]**, which act more as heaters of the irrigant than creating direct cavitation. Comparatively high-power settings and very long pulses must be applied for the formation of vapor bubbles. They are likely to aversively interact with the dentinal tissues of the root and possibly even with the surrounding periodontium. **[Hmud R. Et al 2010]**

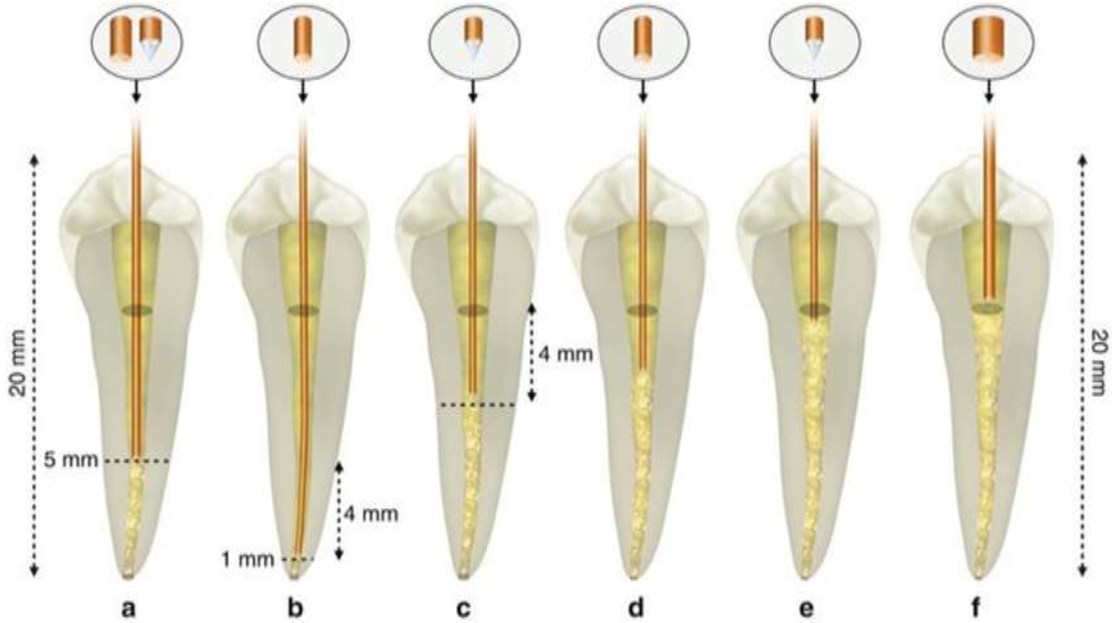

Fig (34):- Evaluation of the effectiveness of cavitation of CO_2 and diode lasers **[Gulabivala K. et al 2010]**

Laser-activated irrigation (LAI):- relies on rapid heating of the irrigant by Er:YAG or Er, Cr:YSGG lasers, which produces optic cavitation **[De Groot. et al 2009]**. Laboratory studies have shown that, when the laser tip is placed close to the WL, this technique is more effective than ultrasonic activation regarding the removal of biofilm **[De Meyer S. et al 2017]**. Or hard-tissue debris **[De Moor R.J. et al 2010].** Variants of LAI, such as Photon-Initiated Photoacoustic Streaming (PIPS) and Shock-Wave Enhanced Emission Photoacoustic Streaming (SWEEPS), which employ slightly different device settings and special laser tips placed in the pulp chamber, have been advocated for the cleaning of minimally shaped root canals but the evidence is still limited and conflicting findings are not unusual **[Yang Q. et al 2020].**

1.2.8 Pressure Alternation Devices

1. The RinsEndo irrigation system
2. The EndoVac irrigation system are examples of negative-pressure irrigation.

1.2.8.1 The RinsEndo irrigation system

Irrigates the canal by using pressure-suction technology. It is composed of:

1. Handpiece.
2. Cannula with 7-mm-long exit aperture.
3. Syringe carrying irrigant **[S McGill. et al 2008].**

Fig (35):- The RinsEndo irrigation system

1.2.8.2 The EndoVac system

Is regarded as an apical negative pressure irrigation system composed of three basic components:

1. Master Delivery Tip (MDT).
2. The Macrocannula.
3. The Microcannula.

Fig (36):- The EndoVac system

The MDT delivers irrigant to the pulp chamber and evacuates the irrigant concomitantly. Both the macrocannula and microcannula are connected via tubing to a syringe of irrigant and the highspeed suction of a dental unit.

The Macrocannula is made of plastic flexible polypropylene with an open end of 0.55 mm in diameter, an internal diameter of 0.35 mm, and a 0.02 taper, used to suction irrigants up to the middle segment of the canal.

Lastly, the Microcannula threeis made of stainless steel and has 12 microscopic holes disposed in four rows of three holes, laterally positioned at the apical 1 mm of the cannula **[BA Nielsen. et al 2007].**

Compared the efficacy of the EndoVac system and needle irrigation to debride the apical 3 mm of a root canal. No significant difference between the two irrigation techniques was noted at the apical 3 mm level. But at 1 mm apical level, the EndoVac system significantly resulted in less remaining debris. The Endovac irrigation system was also shown to achieve better microbial control than the traditional irrigation delivery system **[JL Hockett. et al 2008].**

Another study indicated that EndoVac left significantly less debris behind than the conventional 30-gauge needle irrigation methods **[SJ Shin. et al 2010].**

Note: - In contrast, two very recent studies showed the opposite results. The first by **Townsend and Maki et al 2009** who conducted a study on plastic simulated canals, found that the EndoVac irrigation system was significantly less effective in removing bacteria when compared with ultrasonic irrigation [149]. Another study by **Brito et al 2009** found no significant difference in bacterial reduction efficiency between the Endovac system, the NaviTip needle and the EndoActivator sonic system.

1.3 Protocol of irrigation

A successful endodontic treatment or retreatment is based on the combination of adequate instrumentation, irrigation and obturation of the canal system. Of these three phases, irrigation is the most important determinant when promoting the healing of pulp-periapical pathologies. This is so, because the irrigant can remove the remains of necrotic tissue and disinfect the canals, favoring the bacteria elimination or reduction, especially in those teeth with complex internal anatomy.

1.3.1 Clinical protocols

Due to the fact that it is not possible to determine beforehand the canal treatment, which microorganisms are present, we can't choose, with consequence, a single irrigator. That is why there is no one ideal and perfect solution for all cases, hence the importance of adopting an irrigation protocol, to achieve maximum root canal disinfection. Thus, although NaOCl possesses many qualities and properties, by itself it is not capable of totally cleaning the root canal system from organic and inorganic remains **[Kandaswamy D. et al 2010]**.

Therefore, for optimal irrigation, different irrigating solutions have to be combined **[Beus C. et al 2012**] Presented an action protocol combining several irrigants and choosing PUI activation method [Fig (37)] However, comparing the passive ultrasonic activation method with the non-ultrasonic activation method, which consists of pouring into the ducts 6 ml of 1% NaOCl with a continuous flow of 2 ml/min, it turns out that there are no statistically significant differences between the two protocols.

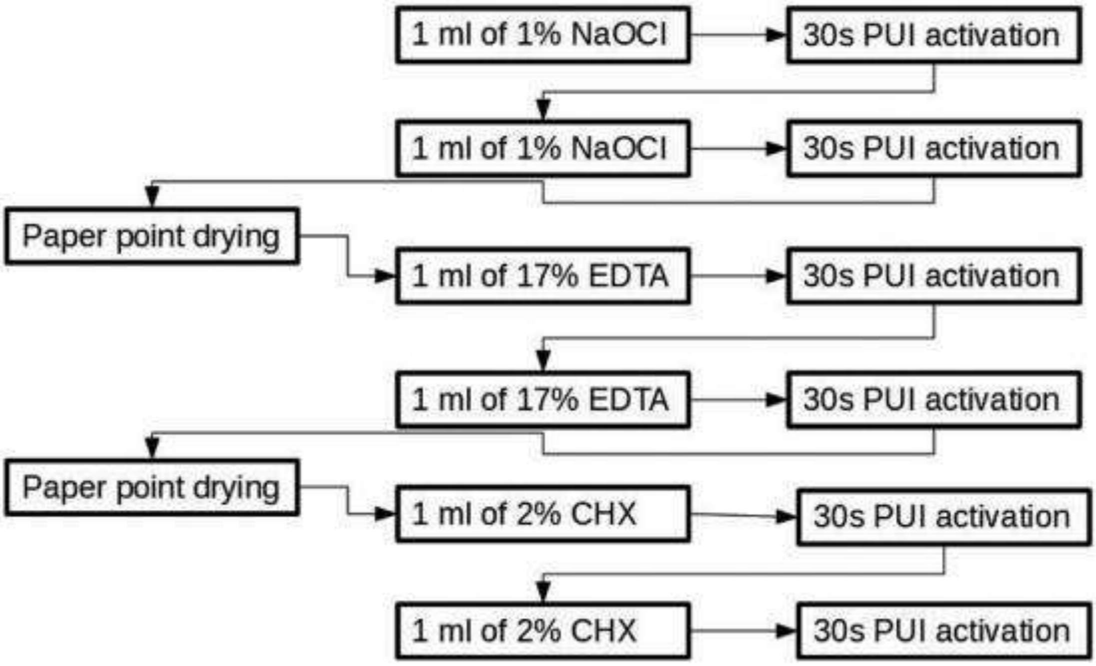

Fig (37):- Irrigation protocol with passive ultrasonic irrigation (PUI) **[Beus C. et al 2012**].

On the other hand, the study by **[Nakamura VC. et al 2018]**, determines that by activating the irrigating solutions with ultrasounds, it is possible to obtain statistically significant differences following the protocol proposed in [Fig (38)] The differences obtained with the **Beus' study** are probably due to the amount of irrigant used, in this study it is duplicated with respect to **Beus' study** and to the fact that in the previous study the ultrasonic irrigation was passive while in this study it is active **[Beus C. et al 2012**].

The difference between PUI and UI is:-

1. The first the ultrasound tip does not come into contact with the dentinal walls.
2. While in the active method the tip touches the walls and instrumentation done simultaneously **[Nakamura VC. et al 2018]**.

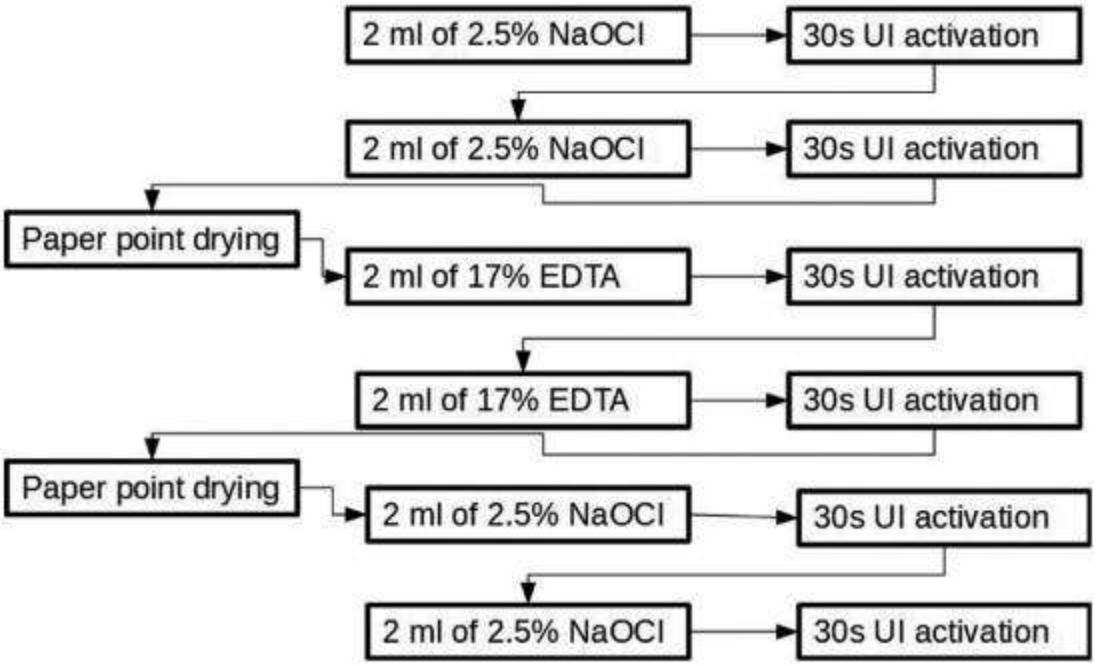

Fig (38):- Irrigation protocol with UI **[Van Der Sluis LWM. et al 2007].**

On the other hand, the results obtained **by Hertel M. et al 2016**. Are similar to those of Beus:

1. Applying a conventional irrigation protocol with 1% NaOCl throughout the instrumentation and a final wash with 2 ml of NaOCl during 30s there are no statistically significant differences with respect to the PUI protocol.
2. This second protocol consists of combining 1% NaOCl with activation with PUI during the instrumentation followed by a final wash with 2 ml of 1% of NaOCl activated during 30s with PUI and with 2 ml of 20% EDTA activated during 30s with PUI. The success rate of the first protocol is 72.6% while that of the second is 82.8%.

The study **by Kishen A. et al 2008**. On the contrary, states that when EDTA is used as a last irrigator, this increases the number of E. faecalis bacteria adhered, therefore, it is advisable to irrigate, applying in sequence, as last wash, EDTA, NaOCl and CHX, given that this protocol results in the lowest number of bacteria adhered, that means 19%. **Baca P. et al 2011**.However, suggest that, as an irrigation protocol, to achieve the eradication of E. faecalis, the following is more indicated:

1. Irrigation during the instrumentation with 2.5% NaOCl, which confers an immediate antimicrobial action and a final irrigation with 2.5% NaOCl, followed by 7% MA followed by 0.2% CTR or 2% CHX, which confers 100% inhibition of bacteria in long term.
2. Four years later, the study by **Ferrer-Luque CM. et al 2015**. confirms that to effectively and in the long term eliminate E. faecalis it is convenient to use for the final irrigation 7% MA or 0.2% CTR; the only difference marked with the previous study is that **Ferrer and cols** advise to use them always combined with the 2% CHX since the result obtained by this combination shows statistically significant differences with respect to the agents used alone.

1.3.2 Discussion

1. A large variety of irrigants has been used for this irrigation, NaOCl being the gold standard. Carried out to evaluate the antimicrobial efficacy of 5.25% NaOCl and Tetraclean (a mixture of doxycycline, citric acid and detergents) and MTAD (a mixture of doxycycline, citric acid and detergents), confirmed the supremacy of NaOCl, since it was the only irrigator able to remove the entire biofilm after 5 min. In the same time period Tetraclean was able to remove 90% of the biofilm, reaching 99.9% after 30 min and 100% at 60 min whereas MTAD was never able to completely eradicate biofilm. **[Savoldi E, Rimondini R. et al 2007]**

2. Two years later, the same authors compared the effects of 5.25% NaOCl, Tetraclean, Cloreximid (a mixture of CHX and Cetrimide) and MTAD against two different bacterial groups: bacteria strict anaerobes, represented by Prevotella and by Porphyromonas, and facultative anaerobic bacteria. **[Giardino L. Ambu E et al 2007].**

In the first group, NaOCl was more effective, with statistically significant differences compared to the other irrigants, while NaOCl was not equally effective against E. faecalis, being overcome, with statistically significant differences by MTAD and Tetraclean that led to wider inhibition zones. Cloreximid, in both groups, was the one that showed the least antibacterial action **[Giardino L. et al 2009].**

3. Completely opposite are the results obtained by **Dunavant TR. et al 2006.** That placed the MTAD in last position with a 16% lethality against E. faecalis; probably these results are due to the fact that the study by **Giardino et al 2009**. Has been carried out on planktonic cells of E. faecalis, while the study by **Dunavant et al 2006.** was on biofilms of the same bacteria. These authors determined that:

   a) The most effective antimicrobial agent is 1% and 6% NaOCl, without statistically significant differences between the two concentrations but between the same and the other irrigants analyzed.

   b) Smear Clear (a mixture of EDTA, Cetrimide and polyoxyethylene), CHX, REDTA and MTAD which, achieved a case-fatality rate of 78%, 60%, 26% and 16% respectively. In contrast, in the study by **Gomes BPF. et al 2001**. the three irrigating solutions that led most rapidly (<30s) to the elimination of 100% of E. faecalis were 5.25% NaOCl and the CHX liquid at 1% and 2%, with statistically significant differences with respect to the other concentrations of NaOCl and the CHX in gel.

4. On the other hand, **Menezes MM. et al 2004**. Determined that a concentration of 2.5% NaOCl is not capable of completely eliminating E. faecalis, being the antibacterial efficacy obtained by this irrigant statistically inferior to CHX at 2 %. However, the same two irrigants work equally well against C. albicans since no results were obtained with statistically significant differences.

5. Completely opposite were the results obtained by **Hope CK. et al 2010**. In effect, they determined that 1% of concentrations has a higher lethality, with statistically significant differences, against E. faecalis, compared with 2% CHX and the super-oxidized water. However, CHX is significantly more effective than super-oxidized water.

6. In addition to the irrigating solutions necessary to carry out a correct chemo-mechanical instrumentation, in the canals can also be introduced, especially in cases of endodontic failure, drugs such as $Ca(OH)_2$; however, there are controversial opinions on its use and efficacy, given that microorganisms often turn out to be resistant to this disinfection measure **[Siqueira JF JR et al 2008].**

7. The study by **Evans M. et al 2002**, underlines the $Ca(OH)_2$ importance: in fact, after having exposed E. faecalis to $Ca(OH)_2$ with a pH of 11.1, has been seen that only 0.4% of microorganisms survive; undoubtedly, increasing the pH to 11.5 also increases the lethality, reaching 99.9%.

1.4 Conclusions

During instrumentation canals should be irrigated using copious amounts of the NaOCl solution. Once the shaping procedure is completed, canals can be thoroughly rinsed using aqueous EDTA or citric acid. Generally each canal is rinsed for at least 1 min using 5 to 10 ml of the chelator irrigant. After the smear layer removal procedure, a final rinse with an antiseptic solution appears beneficial. Chlorhexidine appears to be the most promising agent for use as a final irrigant in this situation. It has an affinity for dental hard tissues and, once bound to a surface, it has prolonged antimicrobial activity, a phenomenon called substantivity. After the introduction of MTAD irrigant, newer irrigating regimen followed was initial rinse with 1.3 % NaOCl for 20 min and followed by final rinse with MTAD for 5 min. Future research on irrigants needs to focus on finding a single irrigant that has tissue dissolving capacity, smear layer removal property, and antibacterial efficacy.

The most effective irrigation protocol to eliminate E. faecalis responsible for the majority of endodontic failures consists of:

Irrigation with 2.5% NaOCl, Choice of LAM, irrigants activation with ultrasound by the following form: 2 ml of 2.5% NaOCl plus 30s of activation with UI (x2); aspirate NaOCl; 2 ml of 17% EDTA plus 30s of activation with UI (x 2); aspire EDTA; 2 ml of 2.5% NaOCl plus 30s of activation with UI (x 2), Final wash with 7% MA + 2% CHX or 7% MA + 0.2% CTR + 2% CHX.

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