Ministry of Higher Education
and Scientific Research
University of Baghdad
Institute of Laser for Postgraduate Studies

Effect of (940nm), (2780nm) Lasers and Some Endodontic Irrigant Activators on Radicular Dentin Permeability and Smear Layer Removal. (An In Vitro Study)

A Thesis Submitted to the Institute of Laser for Postgraduate Studies, University of Baghdad in Partial Fulfillment of the Requirements for the Degree of Master of Science in Laser / Dentistry

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2017 A.D. **1439 A.H.**

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Dedication

I dedicate this thesis to my family for their love, encouragement, support and patience.

Acknowledgments

First of all, I would like to thank **Allah Almighty** for inspiring me with tolerance, strength and enthusiasm to perform this work.

I wish to express my admiration and respect to **Prof. Dr. Abd-Alhadi Al-Janabi, Dean** of Institute of Laser for Postgraduate Studies for his full support and kind attention to all the students.

I wish to express my sincere appreciation to my supervisor, **Assist. Prof. Dr. Lutfi Gh. Awazli** whom I was fortunate to be under his supervision for his excellent supervision.

My special appreciation to the **Assist. Prof. Dr. Mohammed Karim Dhahir, Associate Dean** of Institute of Laser for Postgraduate Studies for his continuous support.

Many Thanks are to Head of Department **Lecturer Dr. Layla M. Al-Amery** as well as all the teaching staff of Institute of Laser for Postgraduate Studies for their continuous support and efforts during the study.

I am so fortunate for the advice, encouragement and support of **Assist. Prof. Dr. Ali Sh. Mahmoud**, **Assist. Prof. Dr. Hussein A. Jawad** and **Assist. Lec. Dr. Mohammed A. Al-Maliky** for his scientific advice, help and for providing a friendly environment during the work.

Also I want to thank the staff of dental department in **Biomedical Technical College/** Middle Technical University, **Dr. Latif Issa, Dr. Khalid Talib and Dr. Sabiha Mahdi** for their kindly help in my work.

Great thanks and respect to **Assist. Lec. Dr. Mohammed Ghalib** for his statistical advices.

Many thanks and appreciation to my **close friends** for their constantly love and support.

I wish to express my thanks and respect to my **colleagues** for their continuous support during the study journey and I want to thank my colleague **Zahra'a Rafeeq** for her continuous help and support in my research work.

Last but not least, I wish to express my grateful respect and admiration for **my family**; who without their love, care, and patience, I am of little worth.

Rua'a
2017

Abstract

Background: The cleaning and shaping of root canals is an important step in root canal treatment. Mechanical instrumentation of root canals produces an irregular layer of debris, known as the smear layer. It has been reported that the smear layer impeded the penetration of intracanal medicaments and sealers into the dentinal tubules, which may lead to compromising the seal of canal filling. Therefore, many studies reported that the general agreement has proceeded toward preferring the removal of the smear layer.

The aim of this study was to assess and compare the effect of Er:Cr:YSGG laser, 940 nm Diode laser, Endoactivator and Xp-endo finisher file in the elimination of smear layer in terms of radicular dentin permeability and SEM evaluation.

Method: seventy single rooted extracted lower premolars were instrumented up to size X4 (protaper Next, Dentsply) and divided into five groups: the first was the control group and four experimental groups according to the irrigation system, second group was activated by Endoactivator sonic system, third group by Xp-endo finisher, fourth by Er:Cr:YSGG laser 2780 nm, pulsed mode, 1.25 W and finally fifth group activated by Diode laser 940 nm, CW mode, 1.7 W . Afterward, the roots were coated with nail varnish externally, and then the dye penetration examined under stereo- microscope, and measured by using analytical software (measure picture CAD-KAS Kessler Germany). Additionally, scanning electron microscope investigations were accomplished.

Results: Data analysis was done by using Kruskal –wallis test showed a highly significant difference between Erbium laser group and all other groups except with the diode laser group which shown a non-significant difference between them regardless the root thirds. Percentage of dye penetration in Erbium and Diode laser groups was significantly higher over

the whole root length compared to other groups. Scanning electron micrographs of Erbium laser group showed a distinctive removal of smear layer with the presence of the annular structure of dentinal tubules which indicate that the laser irradiation results in dentin ablation, especially in the apical third. For Diode laser group also showed a distinct removal of smear layer, while for XP-endo finisher and Endoactivator groups result in uneven removal of the smear layer.

Conclusion: Based on the results of this in vitro study, we can concluded that the use of 940 nm diode laser for activation of irrigation in root canal treatment (delivered by fiber-optic endodontic tip, of 200 μm in diameter, 1.7 W, CW mode, for two rounds and speed of 1mm/s) is efficient in smear layer removal without any signs of melting or carbonization, while for Er:Cr:YSGG laser the ablative effect was clear specifically in apical third. From another point of view, all experimental groups showed better results than the control group in smear layer removal so, activation of irrigation in root canal treatment is essential.

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List of Abbreviation

Abbreviations	Terms
°C	Degree Celsius (unit of temperature)
CO2	Carbon Dioxide
cpm	Cycles per minute
CW	Continues Wave
DEJ	Dentino-Enamel Junction
DFU	Directions for use
df	Degree of Freedom
DT	Dentinal tubules
EDTA	Ethylene di-amine tetra-acetic acid
Er:Cr:YSGG	Erbium, chromium:Yattrium, Scandium Gallium
Er:YAG	Erbium-doped:Yttrium, Aluminum, and Gernet
ES	Effect size
GIC	Glass ionomer cement
HeNe	Helium Neon
Hz	Hertz, Unit of Frequency
LLLT	Low level laser therapy
msec	Millisecond (= 10-3 second)
mW	Milliwatt (= 10-3 Watt)
NaOcl	Sodium Hypochlorite
Nd:YAG	Neodymium doped Yttrium –Aluminum Garnet
nm	Nanometer (= 10 -9 m)
PAD	Photo-Activated Detergents
PDT	Photo-dynamic therapy
PIPS	Photon Induced Photo acoustic streaming
SD	Standard Deviation
SEM	Scanning Electron Microscope
RFT	Radial Firing Tip
W	Watt, Unit of Power
µm	Micro-meter (= 10-6 meter)
µsec	Micro-second (= 10-6 second)

Chapter One

Introduction and basic concept

Chapter one: Introduction and basic concept

1.1: Introduction

Dentin-pulp complex:

Dentin's composition is much richer in organic material than enamel [1]. Externally, dentin is covered by enamel on the anatomic crown, and internally, dentin forms the walls of the pulp chamber. Dentin is the hard tissue portion of the pulp-dentin complex and forms the bulk of the tooth. Dentin is described as small canals that extend across its entire width; these canals are called the dentinal tubules **(DTs)**. Each tubule is lined with a layer of peritubular dentin, which is much more mineralized than the surrounding intertubular dentin [2]. The color of dentin varies from light yellow in deciduous teeth to pale yellow in permanent teeth, becoming darker with age. The lower content of mineral salts in dentin renders it's more radiolucent than the enamel[1]. Dentine consist of approximately 70% inorganic material, 20% organic material, and 10% water by weight, and 45%, 33% and 22%, respectively, by volume. The organic substance consists of about 90% collagenous fibrils (mainly type I with small amounts of types III and V) and a ground substance of mucopolysaccharides (proteoglygans and glycosaminoglycans) and phosphoproteins with small amounts of citrate, chondroitin sulphate, insoluble protein and lipids [2]. The inorganic component of dentin consists of hydroxyapatite crystals ($Ca_{10}(OH)_2(PO_4)_6$) as in enamel, and are described as plate shaped, and are much smaller than the hydroxyapatite crystals of enamel [3].

Dentinal tubules are structures that span the entire thickness of dentine and form as a result of mechanism of dentine formation. DTs extend through dentine from the pulp to the dentino-enamel junction forming a network for the diffusion of nutrients throughout the dentin. The tubules follow an S-shaped path from the outer surface of dentin to the

boundary of the pulp. These S-shaped pattern result from the crowding and the path followed odontoblasts as they move toward the center of the pulp [2].The number of tubules increases from 15,000 to 20,000 /mm^2 at the DEJ to 45,000 to 65,000 /mm^2 at the pulp chamber, the diameter and density of tubules are varied and they are greatest near the pulp, the diameter of tubules decreasing from 2.5 μm at the pulp to 1.2 μm in the middle of dentine and 0.9 μm peripherally[4]. The DTs show branching at their terminal parts. The lateral branches are called as canaliculi or microtubules. These microtubules originate at right angles to the main tubules every one to two microns along its length. These microtubules are one micron or less in diameter and enter the intertubular dentin. Some of them enter the adjacent or distal tubules[3].

Dentin is a permeable tissue because of the presence of dentinal tubules that path through the whole width of dentine. When the enamel is lost from the periphery of the dentinal tubules due to caries, cavity preparation, abrasion or erosion, the exposed tubules act as channels between the pulp and the external oral environment. Restored teeth are also at risk of seepage if micro-leakage is present between the restorative material and the tooth structure. Bacterial substances can also diffuse though the permeable dentinal tubules to reach the pulp, in which the tooth becomes at risk for pulpal inflammation and sensitivity[5] . In fact, dentinal tubules occupy approximately 20-30% of the total volume of human dentin, so, it is permeable and may allow detrimental stimuli to the pulp[6].

1.2: Endodontic management

A- Chemo-mechanical preparation:-

A major goal in endodontic treatment is the elimination of microorganisms from infected root canal systems using a combination of biomechanical procedure with an antibacterial therapy to achieve healing of the periapical tissue [7]. The effective removal of organic and inorganic

tissue remnants along the complex root canal system raises the success rate of endodontic therapy. These tissue remnants reduce the entrance of intra-canal medicaments into the dentinal tubules and can considered as a harbor of bacteria. In order to disinfect root canal system, chemical agents are commonly used[8]. Mechanical preparation of root canals will be formed dentin chips and debris that were called smear layer which was if left caused blocking of the dentinal tubules[9, 10]**.** Presence of smear layer reduce the inter-locking mechanism between filling material and dentin walls [11, 12]. Mechanical preparation of root canal with saline irrigation could not be eliminate microorganisms from infected root canal system, so that, the use of satisfactory irrigation is mandatory to reduce bacteria and complete cleaning effect [13, 14].

The main goal of irrigant solutions is disinfection ,dissolving pulp tissue, and enhance mechanical debridement of the canal by flushing out the debris, but there is no single irrigant that achieve all those goals[15]. So the way that is widely used is the successively using of sodium hypochlorite and ethylene di-amine tetra-acetic acid (EDTA) solutions[16]. In spite of this widely used of conventional irrigation method but it has not been sufficiently effective in removing debris and smear layer from the irregularities of the canal[17], for this reason multiple irrigation systems have been established [18]**.** Anatomy of the canal and system used for delivery of the irrigant solution determine that if the irrigant reach the apical part of the canal [19]. For the best effect, irrigant solution should be in direct contact with the whole root canal dentin wall [16].

B- Irrigation:-

Irrigation is a crucial step in endodontic treatment protocol during and after instrumentation, the irrigants expedite elimination of microorganisms, tissue remnants, and dentin chips from the root canal by flushing mechanism. Flusing of irrigant solutions also help to prevent

stuffing of the hard and soft tissue in the apical part of root canal and extrusion of infected material into the periapical area. Some irrigating solutions dissolve organic tissues and the others act on the inorganic substances in the root canal. On the other hand, several irrigating solutions have antimicrobial activity so they actively kill bacteria and yeasts when they come into direct contact with the micro-organisms. Otherwise, several irrigating solutions also have cytotoxic effect, and they may cause severe pain if they reach into the periapical tissues [20].

1.2.1 Root Canal Irrigants [21]**:**

•Sodium Hypochlorite (NaOCl)

•Chlorhexidine (CHX)

•Hydrogen Peroxide (H2O2)

•Saline

•Distilled Water

•Chelator Solutions

o Ethylene di-amine tetra-acetic Acid (EDTA)

o Citric Acid

• Antiseptic Solutions

o BioPure MTAD (Mixture of Tetracycline, Acid, and Detergent)

o Tetraclean

• QMix (Combination of CHX, EDTA and a Surfactant).

• Herbal Irrigants

o Triphala

o Green Tea

o Morinda Citrifolia

1.2.1.1: Sodium Hypochlorite:-

Sodium hypochlorite is both an oxidizing and hydrolyzing agent. It has a strong proteolysis activity, so it acts as a good helper during instrumentation. Necrotic tissue and debris were dissolved through a

complex biochemical process. The breakdown of the proteins into amino Groups depend on the percentage of free chlorine [22]**.** The original concentration recommended by Dakin was 0.5%, but the concentration used in dentistry has been as high as 5.25% [23, 24]**.**

The efficacy of NaOCl to remove the organic part of the smear layer becomes obvious at higher concentrations (1.3-5.25%).

Sodium hypochlorite (NaOCl) was announced in endodontic treatment first in 1920 [25], from that moment, NaOCl was considered as the best irrigation solution in root canal therapy.

It has excellent properties that are required in endodontic procedure as disinfectant, lubricant, and both vital and necrotic tissue solvent[26]. On the other hand, van der Sluis [27] found that the repeated replacement of NaOcl during root canal treatment makes the solution more effective. NaOcl proved to be acting on broad spectrum of bacteria in addition to be sporicidal and virucidal [28]**.** The PH value of NaOCl ranging from 11-12, it's toxicity, antimicrobial property, and the ability to dissolve tissues decrease when reducing concentration of hypochlorite [29]. Studies revealed by Hülsmann and Hahn in 2000 [20] showed that, the symptoms that patient suffering from after extrusion of Sodium Hypochlorite outside the canal which are severe pain with rapidly exaggerated swelling, other studies had reported the location where patients were admitted with a swelling in the area between the angle of mandible and periorbital region with the formation of hematoma in the infra-orbital region [30]. Hypochlorite accident occur mostly due to false determination of working length, lateral perforation, iatrogenic widening of apical constriction, or wedging of the needle inside the canal during irrigation, so precautions should be follow to prevent happening of such mishaps[20]**.**

1.2.1.2 Chelating agent/ EDTA

Ethylene di-amine tetra acetic acid (EDTA) is one of the Chelating agents that are used to negotiate canals with small diameter and to remove the smear layer from the root canal dentin walls of a complete prepared canal[31]. In general, the purpose of an aqueous chelating agent is to remove the smear layer during root canal preparation protocol. EDTA is a surfactant, which assists to decrease surface tension, raising the irrigant's potential to circulate and penetrate [31].

The aqueous solution of 17% EDTA flooded into a prepared canal for one minute, shown to be removed the smear layer[32, 33]. Prominently, studies were showed that, alternating between solutions of NaOCl and EDTA during root canal preparation diminishes the accumulation of debris and results in cleaner canals[34, 35]**.** The aqueous solution of (EDTA) allows removing the smear layer, which is known to block the dentinal tubules and lateral anatomy. Reasonably, if the smear layer is removed, then a potentially, good adaptation between the obturation materials and the dentin walls of the canal is possible [11].

1.3: Irrigation Devices and Techniques:-

The efficacy and safety of irrigation be determined by the means of delivery. Usually, irrigation has been achieved with a plastic syringe and an open-ended needle into the canal space. An increasing number of novel needle-tip designs and devices are emerging in an effort to better address the challenges of irrigation. During the history of endodontic, attempts have been made continuously to produce a more active irrigant delivery and activation systems for root canal irrigation[18].

These systems was divided into two wide categories, manual activation techniques and machine-assisted activation systems (Figure 1.1)

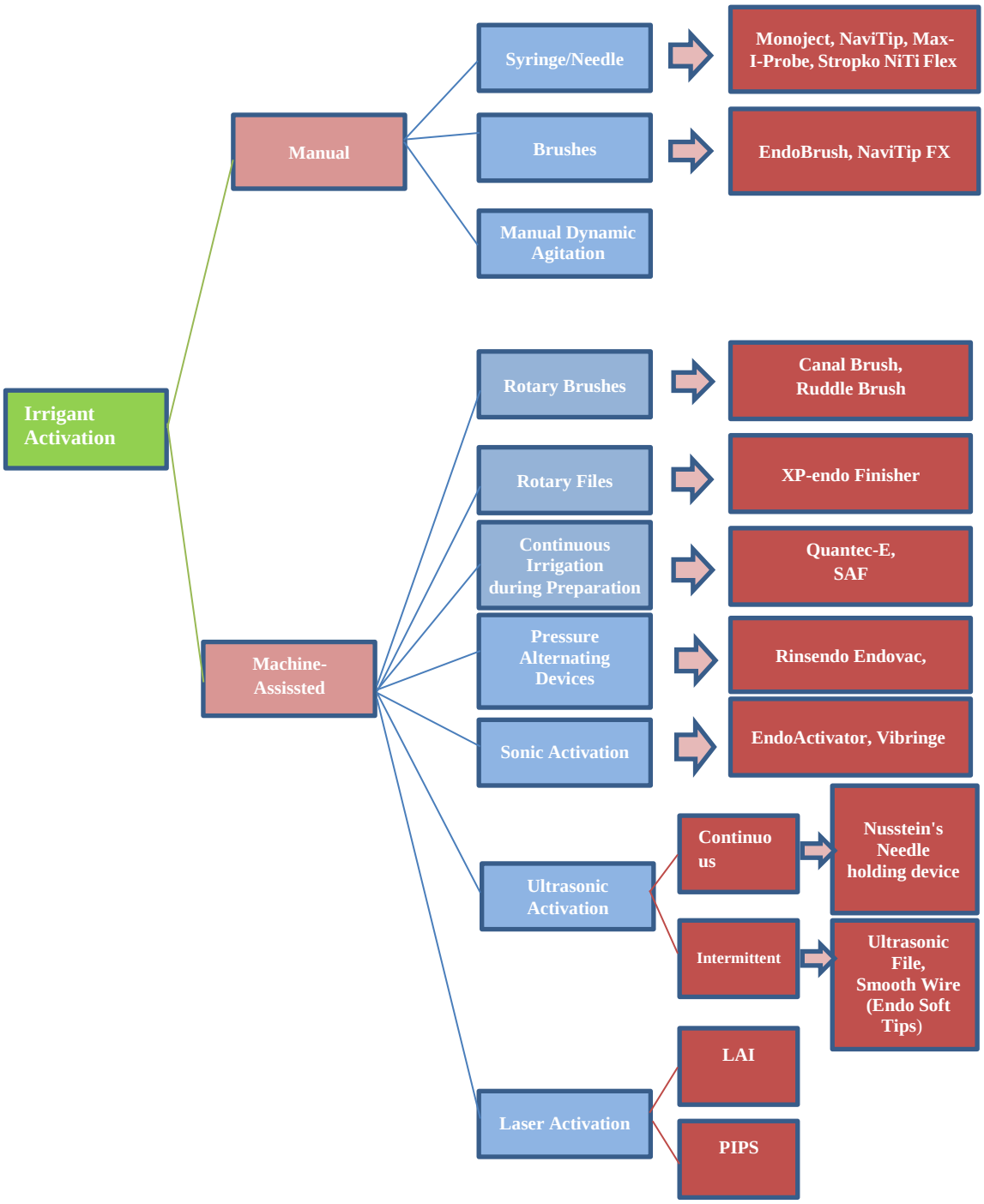


Figure (1-1): Simple diagram of the types of endodontic irrigant activation techniques[18].

1.3.1: Manual Agitation Techniques:-

1.3.1.1: Syringe Irrigation with Needles and Cannulas:-

Conventional irrigation with syringes has been known as an effective method of irrigation before the introduction of passive ultrasonic irrigation

[36]. This technique is still accepted widely by endodontists and general practitioners. The technique includes administration of an irrigant into a canal through needles or cannulas of variable gauges either passively or with agitation by moving the needle up and down in the canal space.

Irrigation tip, gauge, and tip design have a major influence on irrigation pattern of flow, velocity of flow, penetration depth, and pressure on the walls and apex of root canal [18]**.** Irrigation tip gauge will mostly determine the depth of an irrigant that penetrated inside the canal; 27-gauge is the preferable size in routine endodontic procedure. Several studies have shown that irrigants have only limited effect beyond needle tip because of the dead water zone or air bubble in the apical part of the root canal, which prevent penetration of the irrigant apically[37, 38]**.**

Many studies have been directed in an effort to understand the behavior of the irrigant solution within the root canal system. Boutsioukis [39] looked at the needle design and clinical realistic flow rate values recorded using virtual studies with computational fluid dynamic models with FLUENT 6.2 software. The flow rate, velocity, and turbulence were recorded. According to the experiment findings, a laminar flow was always detected regardless of the pressure applied to the solution. The maximum velocity was detected near the end of the needle suggesting that the needle should be placed 1 mm shorter than the working length. The same author [40] studied the formation and removal of the vapor lock during the root canal irrigation when a needle was used following the same type of virtual experiments. Their results showed that there is a direct correlation between the size of the root canal preparation and the size of the needle used and the penetration of the needle to disrupt or avoid vapor lock from occurring. Similar findings made by Hsieh et al. [41] found that the diameter of the irrigating needle and the distance from the working length in the prepared

canals will prevent the irrigation solution from reaching the apical portion of the root canal during the cleaning and shaping phase.

1.3.1.2: Manual Dynamic Irrigation:-

For an effective action, the irrigation solution should be in a direct contact with the canal walls. However, because of the vapor-lock effect, it seems to be difficult to reach the irrigant to the apical region of the canal. It has been shown by research that the gentle movement of a master gutta-percha cone (well-fitting) up and down to an instrumented canal in short 2-3 millimeter strokes can result in an active hydrodynamic movement that considerably, result to improve the displacement and the exchange of the endodontic irrigant. This was achieved by the studies of Huang et al. and McGill et al. in 2008[42, 43]. These studies showed that manual dynamic irrigation was significantly more effective than static irrigation and automated dynamic irrigation system: "RinsEndo; Duerr Dental Co, Bietigheim-Bissingen, Germany"[44]

1.3.2: Mechanical activation techniques:-

1.3.2.1: Sonic irrigation:

Tronstad et al**.** in 1985,[45] were the first to report sonic instruments use in endodontics. Sonic irrigation operates at lower frequencies (1-6 kHz) and produce smaller shear stresses than ultrasonic irrigation [46]**.** Furthermore, the oscillation patterns of sonic devices are different in comparison with ultrasonic devices. A maximum oscillation of the amplitude might be considered as an antinode, while a minimum oscillation of the amplitude represents a node **Figure (1-2)**.

Figure (1-2): Oscillation pattern of sonically activated instruments. N represents the minimum oscillation while AN represents the maximum oscillation of the amplitude [47].

The file has a node near the attachment, and an antinode at its tip. When the sonic file movement is constrained, the sideway oscillation disappears, resulting in a pure longitudinal oscillation of the file. It has been shown that this mode of vibration is predominantly efficient for the debridement of the root canal, because it exhibits large displacement amplitudes and is largely unaffected by loading[47].

1.3.2.1.1 EndoActivator System

The EndoActivator System is consisting of a handpiece and variously sized polymer tips **(Figure 1- 3).** This sonically-driven system is aimed to safely activate various intracanal reagents and produce the hydrodynamic phenomenon[48].

Figure (1-3): EndoActivator handpiece and tips [31]**.**

Research has shown that the EndoActivator System is able to debride into deep root canal anatomy, remove the smear layer and dislodge biofilm clusters within the curved canals [49]**.**

Uses of EndoActivator tip consequently provide a cloud of debris that can be noticed within pulp chamber full of fluid. The function of the EndoActivator is to create dynamic intra-canal fluid activation through acoustic streaming and cavitation **(Figure 1-4).**

This hydrodynamic activation act to improve the penetration, circulation and flow of irrigant into the more inaccessible regions of the complex root canal system [50].

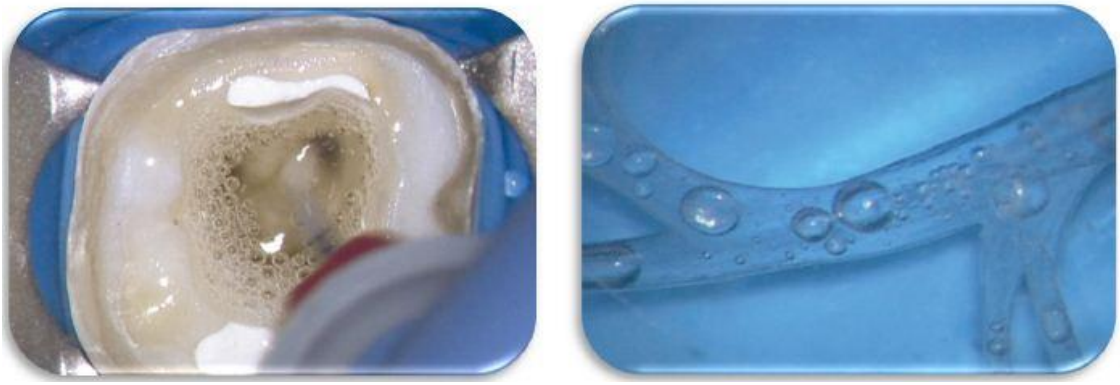


Figure (1-4): Fluid activation with the EndoActivator causing vigorous hydrodynamics [31].

The sonic handpiece is contra-angled, cordless, and is used to drive the Endo Activator tips. It operates and activates the strong and flexible polymer tips. It provides three speeds of 10,000, 6.000 and2.000 cycles per minute (cpm). When the handpiece is activated, the default power is 10,000 cpm. When the selected tip moves toward the full working length, its shape more closely approximates the shape of the prepared canal. This, in turn, serves to displace any given reagent laterally while allowing safe reflux coronally. Vibrating the tip, in combination with moving the tip up and down in short vertical strokes, synergistically produces a powerful hydrodynamic phenomenon. In general, 10,000cpm has been shown to optimize debridement and promote the disruption of the smear layer and biofilm[49, 51]**.** EndoActivator tips are designed for an easy snap-on/snap-off. They are colorcoded (yellow, red, blue) corresponding to size small (15/.02), medium (25/.04) and large (35/.04), respectively **(Figure 1-5)**.

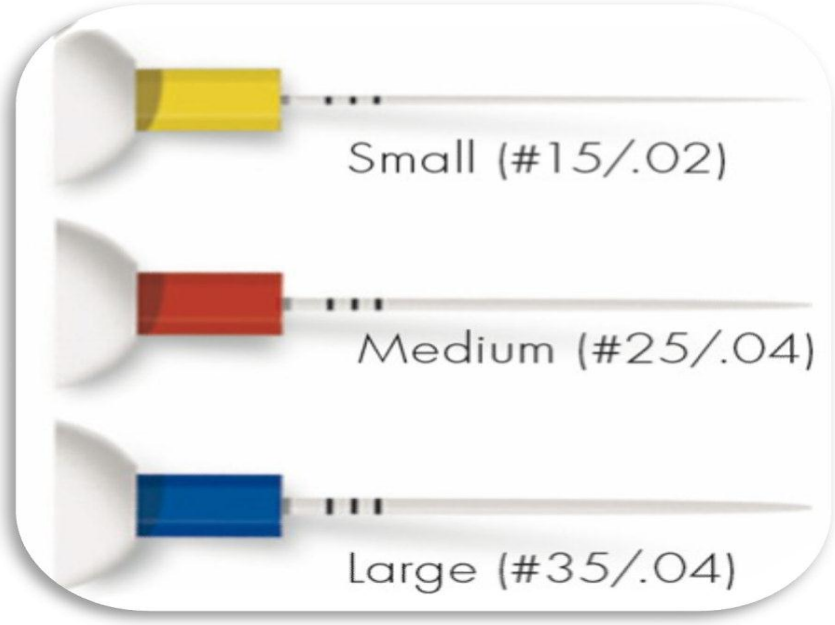


Figure (1-5): EndoActivator tips [31].

The hydrodynamic phenomenon forms when a vibrating tip produces fluid activation and intra-canal waves. For example, in the physical world, underwater seismic activity releases energy that can induce a large wave formation called a tsunami. In the endodontic world, the vibrational energy inside the fluid-filled canal produces intra-canal waves. These waves will be fractured randomly, forming bubbles that oscillate within any given solution.

These bubbles will be expanded and become unstable, then collapse in what is termed an implosion. Each implosion releases miniature tsunamis, or shockwaves that dissipate at 25,000 to 30,000 times per second [52].

1.3.2.2 Ultrasonic irrigation:

Ultrasonic devices introduced first in periodontics since 1957 by Richman [53]**.**

In 1980, an ultrasonic unit for endodontic use as a means of debridement of root canals, which was designed by **Martin et al.** [54]

became available commercially. Compared with sonic energy, the ultrasonic energy produces higher frequencies but with lower amplitudes [55]**.** The files are designed to oscillate at frequencies of 25-30 kHz, which are beyond the human auditory perception limit. They operate in transverse vibration, which sets up a characteristic pattern of antinodes and nodes along the file length [47]**.**

There are two types of ultrasonic irrigation. The first type is a combination of both ultrasonic instrumentation and irrigation (UI), while the second type, which operates without simultaneous instrumentation is referred to as passive ultrasonic irrigation (PUI). Passive ultrasonic irrigation is defined as the agitation of an irrigation solution located inside the root canal system. This is done with the help of an ultrasonic unit equipped with a small smooth wire oscillating freely inside the root canal system to induce a powerful acoustic streaming [47]. Studies on the endo-sonic systems have demonstrated that root canals that are prepared ultrasonically with UI devices are cleaner than canals prepared by conventional root canal system alone, while some other studies have failed to show the superiority of UI as a primary cleaning and shaping technique. These results might be attributed to the limitation in the vibration motion and cleaning efficacy of the ultrasonic file inside the non-flared root canal space [31, 47]**.**

In addition, it is very difficult during UI to control dentin cutting, and the shape of the prepared canal. Highly irregular-shaped root canals as well as strip perforations were frequently produced [56].

Generally, UI is not perceived as an alternative technique to conventional hand instrumentation. On the contrary, endodontic literature supports that, it is more favorable to apply ultrasonics after the completion of root canal preparation [15]

1.3.2.3 Rotary instruments:

XP-endo Finisher (FKG, La Chaux-de-Fonds, Switzerland) **(Figure 1-6)** is a universal NiTi-based instrument with many properties that allow it to reach the walls that are untouched by the round files used during canal instrumentation, and is used to scrape those walls. Moreover, those files cause turbulence of the irrigant solution, causing an enhancement in its antimicrobial properties[57].

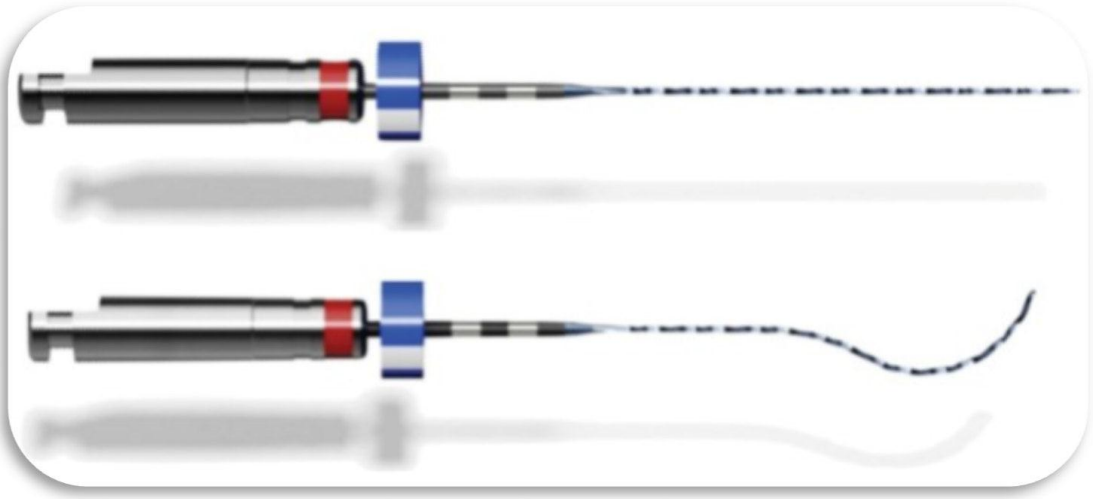


Figure (1-6): XP-endo Finisher [57].

XP-endo Finisher is made of a proprietary alloy, which is called MaxWire (Martensite-Austenite Electropolish-FleX), that reacts at different temperature levels **(Figure 1-7)**. When the file is cooled below 35^{o}C, it is in the martensitic phase in which it can be shaped according to the requirements of the practitioner.

It can also be bent to any other shape while in this phase.

When it is heated to body temperature (35^{o}C), it will change to the austenitic phase. When the file is rotated in this phase, it creates a cleaning instrument that is very particular. The apical 10mm of this file will transform into a bulb-shape coronally, while maintaining a tip in the last few millimeters.

The total diameter of this bulb is 3mm. When the tip is squeezed, the bulb will expand. If the bulb is squeezed, the tip will expand to a maximum of 6mm.

So if it is moved up and down in the root canal, the tip and the bulb will contract and expand following the canal's real three dimensional diameters.

The maximum loss of length when the file transform from straight to a full austenite phase is 1mm, but the change to this shape in the canal is very occasional **(Figure 1-8)** [57]**.**

Figure (1-7): XP-endo Finisher under different temperature conditions [58].

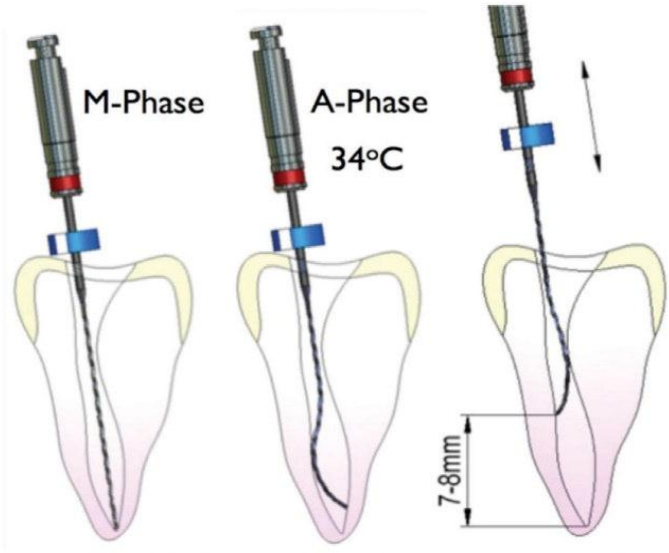


Figure (1-8): XP-endo Finisher shape transformation. The apical 10mm of the file transform to a bulb shape more coronally, while retaining a tip in the last few millimeters [57].

Because of the small diameter of the core of the file, it maintains its flexibility, resistance to cyclic fatigue, and will scrape but not shape the canal walls. This, in addition to the turbulence created in the irrigant, will result in a large surface area of the canal being touched by the file and removes the biofilm that would not be removed by the round files [57].

1.3.2.4 Laser activated irrigation (LAI)

Activation or agitation of root canal irrigants by the use of lasers is a relatively new concept in endodontic. Previous work with laser has focused on direct canal cleaning and shaping (similar to ultrasonic, UI), disinfection, and smear layer removal. However, issues have ascended in terms of potential damage to the root canal wall dentin, overheating of the root and periodontium, access around the canal curvatures, and the size of the laser tip. Blanken and Verdaasdonk [59] reported the effects of using an Er,Cr:YSGG (erbium-chromium- yttrium-scandium-gallium-garnet) laser on irrigating fluids. They stated that; there was immediate fluid movement after each laser pulse and they visualized cavitation (expansion and implosion of gas bubbles) effects.

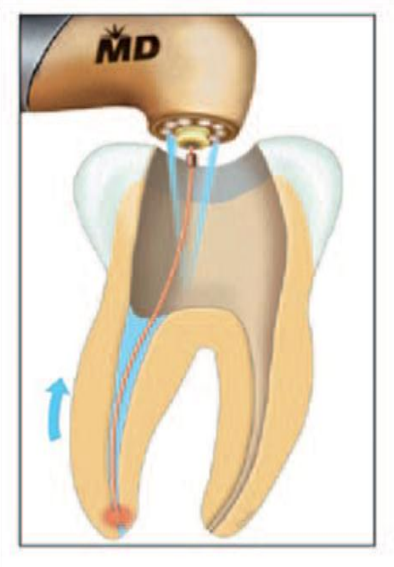


Figure (1-9) Technique for laser positioning tip in canal [60].

1.3.2.4.1 Er:Cr:YSGG laser

The mechanism of interaction between Erbium lasers family and dental hard tissue (enamel, dentine) is explosive thermo-mechanical ablation or water-mediated ablation, the process that occurs with wavelengths between 2.7 and 3 μm and leads to ejection of mineral particles with preservation of their mineral structure [61]. Water within the dental hard tissues absorbs the laser energy, quickly expands and vaporizes. The pressure generated by the water expansion is enormously high (pressure stress) and overcomes the strength of the mineral matrix. This pressure stress causes Microexplosions that remove the hard tissue [62].

Blanken and Verdaasdonk [59] in 2009 recorded video sequences of bubble expansion and implosion with the fiber tip of an Er,Cr:YSGG in degasified water. The effect is based on cavitation: in a water environment the activation of the laser at ablative settings may result in the formation of large elliptical vapor bubbles which expand and implode. It was demonstrated that these vapor bubbles may cause a volumetric expansion of 1,600 times the original volume. This expansion mechanism causes high pressure and as a result the pressure drives fluid out of the canal. When the bubble implodes after 100– 200 μs and under pressure develops and sucks fluid back into the canal and induces secondary cavitation effects. Hereafter, the laser works as a fluid pump[59].

This phenomenon could have a potential effect in RCT for enhancing the removal of debris and smear layer when laser is used in conjunction with an irrigant[61].

Consequently, the Erbium lasers due to their affinity to water molecules that present either within the dental hard tissue composition or as an irrigant solution can act on dental hard tissue in two different mechanisms: thermo-mechanical ablation that is also called water-mediated ablation or by inducing a cavitational effect.

1.3.2.4.2 Diode laser

Although lasers in near infrared region are poorly absorbed neither by minerals nor by water allowing it to penetrate deeply (about 500 μm) and transmit through the dentine to give the disinfection action [63]. It seems necessary to mention that the degree of transitivity of 810-nm diode laser through 1 mm dentin block is approximately 17%. Many investigations proved that both 940 nm and 980 nm diode laser can induce a cavitation bubbles if they are combined with an aqueous irrigant [64, 65]**.**

In fact, wavelengths in the near infrared region like (810, 940 and 980) nm Diode lasers and 1064 nm Nd:YAG laser have little absorption in dental hard tissue allow them to propagate deeply and scattered within the dental hard tissue. This fact nominated these wavelengths to eradicate microorganisms that trapped in deep dentine [66]. On contrary, diode lasers have the potential to cause thermal cracking and amorphous change in the hydroxyapatite crystal structure. Additionally, they can also have a deleterious effect on pulp tissue due to the intra-pulpal temperature rise because of relatively high transmission of NIR wavelengths through enamel and dentin [66]**.**

Cavitation is the formation of vapor-containing bubbles inside a fluid. This process results in the formation of pressure waves/shockwaves characterized by rapid changes in pressure at high amplitude [67]**.** A forced collapse of bubbles causes implosions that impact on surfaces, causing shear forces, surface deformation, and removal of surface material [68]**.**

1.4 Laser basics

LASER: is an acronym of **L**ight **A**mplification by **S**timulated **E**mission of **R**adiation". Lasers are devices that generate and amplify light and cover radiation at wavelengths ranging from infrared to ultraviolet range, This word was used for the first time by American physicist Gordon Gould,

when his notes certified in 1957, with the first page titled "Some rough calculations on the feasibility of a LASER [69]**.**

Light is a form of energy which travels as a wave, the smallest units of energy are called photon and are normally considered to having negligible mass or charge. Light is just a small portion of a greater arrangement of photonic energy called the electromagnetic spectrum [69]**.**

1.4.1 Laser history:

In 1960, the first laser, was established by Theodore H. Maiman. This laser was a pulsed ruby laser emitted light in 694 nm wavelength [70]. In 1961, the gas laser had been discovered and was the first continuously operating He-Ne laser in visible region of 632.8 nm [71], R. N. Hall demonstrated the first diode laser made of gallium arsenide (GaAs) in 1962, which emitted radiation at 850 nm, and later in the same year Nick Holonyak developed the first semiconductor visible-light-emitting laser[72]. Parallel to this development was the design by Johnson in 1961 of laser with a wavelength of 1064 nm using Neodymium doped Yttrium–Aluminum Garnet (Nd:YAG) rod [73].

One year later, the dye laser was discovered in 1963 [73]. Afterward, in 1964, Bridges of Hughes Research Laboratories developed the argon ion laser [74].

Then, the CO_2 laser was developed in 1964 by Patel et al**.**, following this discovery, there was a rapid development of multiple laser systems, and the production of the continuously operating higher power laser [75].

Ten year later, The Er:YAG laser was introduced in 1974 by Zharikov et al. as a solid-state laser that generates light with a wavelength of 2940 nm [76].

Myers [77] received the US Food and Drug Administration's permission to sell a dedicated dental laser, a Nd:YAG device. Since that time, numerous instruments have been made available for use in dental

practice, and more are being developed. This event marked the beginning of the clinical use of lasers by dentists.

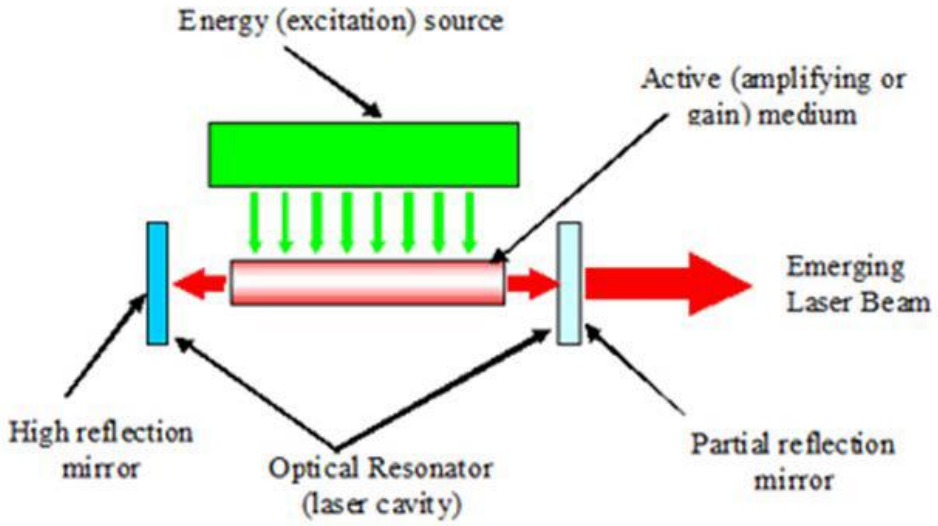
1.4.2 Components of the Laser System: **(Figure 1-10)**

Every LASER consists of three basic components. These are -

1. Lasing material or active medium.
2. External energy source or pumping mechanism.
3. Optical resonator.

The active medium is composed of molecules, or compounds. Lasers are generally named for the material of the active medium, which can be (1) a container of gas, such as a canister of carbon dioxide (CO_2) gas in a CO_2 laser; (2) a solid crystal, such as a crystal of yttrium, aluminum, and garnet (YAG) in an erbium (Er) YAG or a neodymium (Nd) YAG laser; (3) a solid-state semiconductor, such as the semiconductors found in diode lasers; or (4) a liquid, such as found in some medical laser devices [78].Surrounding this active medium is an excitation source, such as a flash lamp strobe device, electrical circuit, electrical coil, or similar source of energy that pumps energy into the active medium. When this **pumping mechanism** drives energy into the active medium, the electrons in the outermost shell of the active medium's atoms absorb the energy. These electrons have absorbed a specific amount of energy to reach the next shell farther from the nucleus, which is at a higher energy level [78]. A "population inversion" occurs when more of the electrons from the active medium are in the higher energy level shell farther from the nucleus than are in the ground state**.** The electrons in this excited state then return to their resting state and emit that energy in a form known as a photon**.** This is called **spontaneous (not stimulated)** emission. Completing the laser cavity are two mirrors, one at each end of the optical cavity, placed parallel to each other; or in the case of a semiconductor diode laser, two polished surfaces at each end. These mirrors or polished surfaces act as **optical**

resonators, reflecting the waves back and forth, and help to collimate and amplify the developing beam. A cooling system, focusing lenses, and other controlling mechanisms complete the mechanical components [78].



(Figure 1-10) Laser components [77].

1.4.3 Properties of laser light

1. **Coherence:** It means that all the photons coming out of laser system are in the same phase, i.e. they are synchronized in time and space. This property produces a specific form of focused electromagnetic energy. This property measures the ability of the waves to interfere with each other, so two coherent waves can combine to produce destructive or constructive interference, depending on their phases and meeting points [79].
2. **Collimation**: All the light rays or waves are traveling in specific direction, parallel to each other. So laser can travel to long distances with least divergence [79].
3. **Monochromaticity**: Laser beam usually has a single wavelength (may be visible or invisible). This property indicates the specificity of the wavelength of laser beam [79].

4. **Focusability**: The laser has precise focusing beam that can be in a very small spot size [79].
5. **Brightness (intensity)**: it is the power of the laser beam divided by the cross section area of the beam, given in watt per square centimeter (W/cm^2). It measures the amount of energy that is applied to a specific region within a specific duration[79].

1.4.4 Emission Modes Dental laser devices can emit light energy in two modalities as a function of time: (1) constant on or (2) pulsed on and off. [80]. The pulsed lasers can be further divided into gated and free-running modes for delivering energy to the target tissue. Thus, three different emission modes are described, as follows:

1. **Continuous-wave mode,** in which the beam is emitted at only one power level for as long as the operator depresses the foot switch.

2. **Gated-pulse mode,** characterized by periodic alternations of the laser energy, similar to a blinking light. This mode is achieved by the opening and closing of a mechanical shutter in front of the beam path of a continuous-wave emission. All surgical devices that operate in continuous-wave mode have this gated-pulse feature. Some instruments can produce pulses as short as microseconds (μsec) or milliseconds (msec). Peak powers of approximately 10 to 50 times that of continuous-wave power measurements are produced, and charring of the tissue can be reduced. The more advanced units have computer-controlled shutters that allow for these very short pulses. Manufacturers have coined many terms to describe these short pulse durations, including "super pulse" and "ultra speed"[78].

3. **Free-running pulsed mode,** sometimes referred to as true pulsed mode. This emission is unique in that large peak energies of laser light are emitted usually for microseconds, followed by a relatively long time in which the laser is off. For example, with a free-running pulsed laser with pulse

duration of 100 μsec and pulses delivered at 10 per second (10 Hz), the energy at the surgical site is present for 0.01% of a second and absent for the remaining 99.99% of that second. Free-running pulsed devices have a rapidly strobing flash lamp that pumps the active medium. With each pulse, high peak powers in hundreds or thousands of watts are generated. Because the pulse duration is short, however, the average power that the tissue incurs is small. Free-running pulsed devices cannot have a continuous-wave or gated-pulse output. True pulsed lasers are driven by the action of the pumping mechanism within the laser cavity [78]. Gated-pulse lasers are pulsed as a result of a shutter outside the laser cavity. Medical and scientific laser instruments are available with pulse durations in the nanosecond (one billionth of a second), picosecond (one trillionth of a second), or smaller range. These can generate tremendous peak powers, but the calculated average pulse energies are small, allowing increased surgical precision. Some instruments can be controlled to emit a single pulse[78] .

1.4.5 Laser Effects on Tissue

Depending on the optical properties of the tissue, the light energy from a laser may have four different interactions with the target tissue **(Figure 1-11),** as follows [81]:

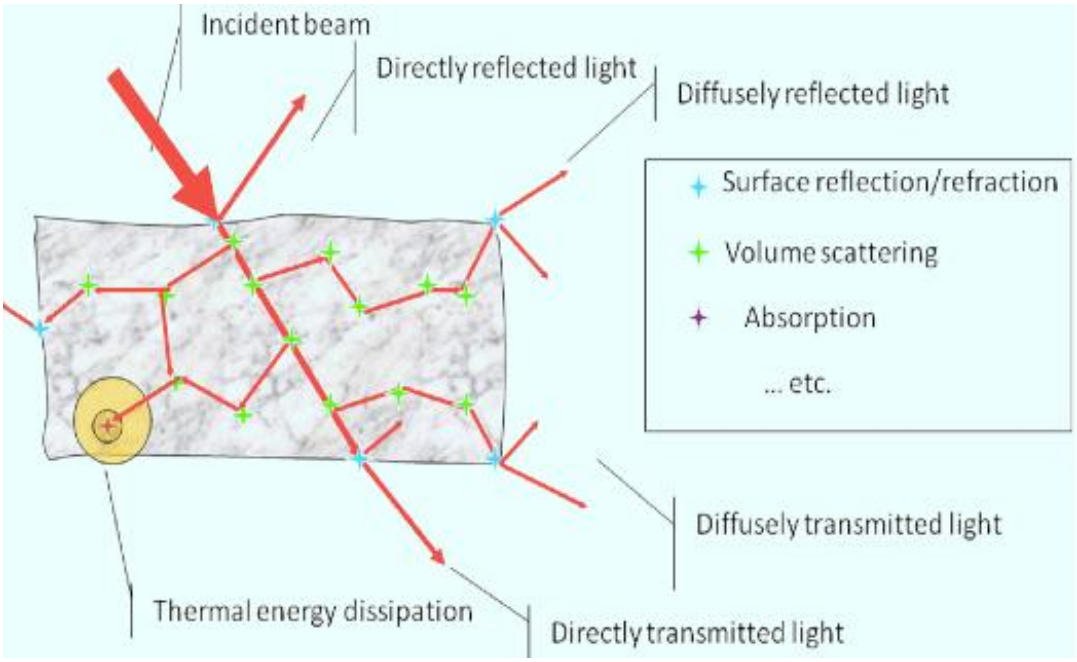
• **Reflection:** Reflection is simply the beam being redirected off the surface, with no effect on the target tissue. The reflected light may maintain its collimation in a narrow beam, or it may become more diffuse. In any event, this reflection can be dangerous because the energy could be redirected to an unintentional target, such as the eyes. This potential mistargeting is a major safety concern in laser operation and the reason that every person in the dental treatment room must wear wavelength-specific safety glasses with appropriate side shields. An example of reflection would be the interaction between a CO2 laser and a patient’s titanium

implants. CO2 laser energy reflected off the implants could be redirected to the dentist's eyes [81].

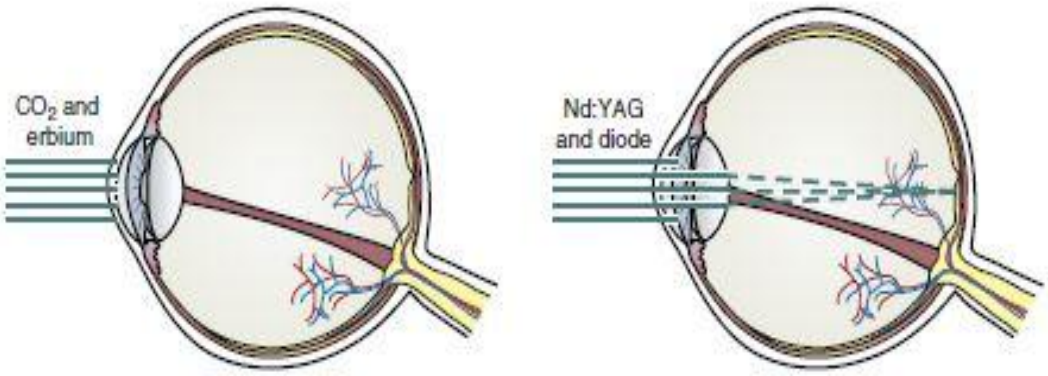
• **Absorption:** Absorption of the laser energy by the intended target tissue usually is the most desirable effect. The amount of energy absorbed by the tissue depends on that tissue's characteristics, such as pigmentation and water content, and on the laser wavelength. The primary and beneficial goal of laser energy is therefore absorption of the laser light by the intended biologic tissue [81].

• **Transmission:** The third effect is transmission of the laser energy directly through the tissue, with no effect on the target tissue. This effect also is highly dependent on the wavelength of laser light. Water, for example, is relatively "transparent" to (does not absorb) the diode and Nd:YAG wavelengths, whereas the water component of tissue fluids readily absorbs erbium and CO2 wavelengths at the surface, so minimal energy is transmitted to adjacent tissues. The diode and Nd:YAG wavelengths are transmitted through the sclera, lens, iris, cornea, vitreous humor, and aqueous humor of the eye before being absorbed on the retina **(Figure 1-12)** [78].

• **Scattering:** The fourth tissue interaction is scattering of the laser light, which weakens the intended energy, occurs when the irradiation bounces from molecules within the tissue. It is inversely related with absorption; when absorption is high, the scattering is less. When it is high, it distributes the energy of laser over a larger volume of tissue, i.e. dissipate the irradiation inside the tissue [78].



(Figure 1-11) The four different laser tissue interactions with the target tissue [82].



(Figure 1-12) Diagram of the eye showing the effects of different wavelengths on various tissue types. In general, CO2 and erbium lasers interact with the cornea and lens, whereas Nd:YAG and diode lasers penetrate to the retina [78].

1.4.6 Classification of laser tissue interaction

Mainly it is divided into[83]:

A. Wavelength dependent interactions.

B. Wavelength independent interactions.

Further subdivisions are explained for more details.

1.4.6.1 Wavelength dependent mechanisms

I. Photochemical Interaction

In this type, the irradiation induces chemical effect and reacts with specific molecules in the tissue. This mechanism is important during photodynamic therapy (PDT) and Biostimulation. It usually uses lasers with low power densities (not more than 1 W/cm^2) with long exposure times. The tissue utilizes the scattered beam on this mechanism to determine factor of radiation distribution inside the tissue [84].

1. Photodynamic Therapy (PDT)

In this reaction, an exogenous photosensitizer which is activated by specific laser is used. Together with the tissue oxygen, they destroy the target tissue (e.g. malignant tumor). The photosensitizers are drugs, i.e. chemical compounds. They are activated only by specific wavelength light and needs an oxygen molecule to work[85]. The Photo-Activated Disinfection (PDA) is an example of this type of interaction used in endodontic treatments. It activates some irrigants to release single oxygen radical and rupture the cell membrane of the bacteria. This type is very effective in disinfecting the root canal system during endodontic therapy. It is also used for caries detection by applying some pigments on the tooth which fluorescence when irradiated by laser and is also used in composite curing [86].

2. Biostimulation

This interaction uses very low laser powers, used to enhance the metabolism of the living cells and for that it is named Low Level Laser Therapy (LLLT). Mostly, it is limited to the near IR wavelength lasers in dental applications because of their high penetration depth on living tissues. It can heal the wounds rapidly, relief pain, increase collagen growth, and enhance the immune system[84], Therefore, it was very useful in treatment of TMJ arthritic disease[87].

II. Photo-thermal Interaction

It is a thermal interaction of the cellular molecule, occurs as a result of laser beam hitting a tissue, i.e. the light energy is converted to heat. It has different effects on tissue, starts by hyperthermia, coagulation, vaporization, carbonization, and lastly melting. Its effect depends on the duration of exposure and the peak value of the temperature collected inside the tissue, it also depends on the cooling factors on the tissue such as the ability of the tissue and the blood circulation around the area to dissipate the heat [85].

The **Normal** body temperature is 37 º C [85].

Hyperthermia: It refers to the elevation of temperature on tissue above the normal level but without any damage or destruction. It occurs at 45 º C. This level might inactivate the non-sporulated bacteria at less than 50º C. At 50 º C, a reduction in enzyme activity occurs accompanied with cell immobility[84, 85].

Coagulation: It is the process of protein denaturation at approximately 60º C and cause necrosis of the cells. It is used to remove a diseased tissue. It appears as whitening on the tissue surface and is accompanied by hemostasis due to increase blood viscosity[85].

Increase of temperature uniformly to 70-80º C causes adherence of tissue layers by collagen stickiness; therefore, it is used in tissue welding or anastomosis[88].

Vaporization: It starts when temperature of tissue is elevated to 100º C, the water on tissue vaporizes and causes tissue ablation by its expansion and explosion. This is the main process in tooth ablation mechanism[85].

Carbonization: It occurs when temperature is raised to 200º C, a complete dehydration occurs. Carbone, which is the end product that located at the surface layer, absorb all the energy if lasing continuous and work as heat sink, cause rapid spread to heat and sever collateral damage to the underlying tissue called tissue charring, it prevents ablation [85] .

Melting: It occurs when heat is raised beyond 300º C; it depends on the target material [85].

III. Photoablation Therapy

This reaction is considered a pure ablation in clean and precise fashion without any thermal features. The used lasers normally belong to UV region with pulsed high intensities and short duration usually in nanosecond scale. It is also called ablative photodecomposition; i.e. the high intense laser irradiation decomposes the tissue[84, 89]. This technique is mainly used in corneal surgery, to treat myopia, hyperopia, and astigmatism, and it is not used in dental applications [84].

1.4.6.2 Wavelength independent mechanisms

I. Plasma – induced ablation

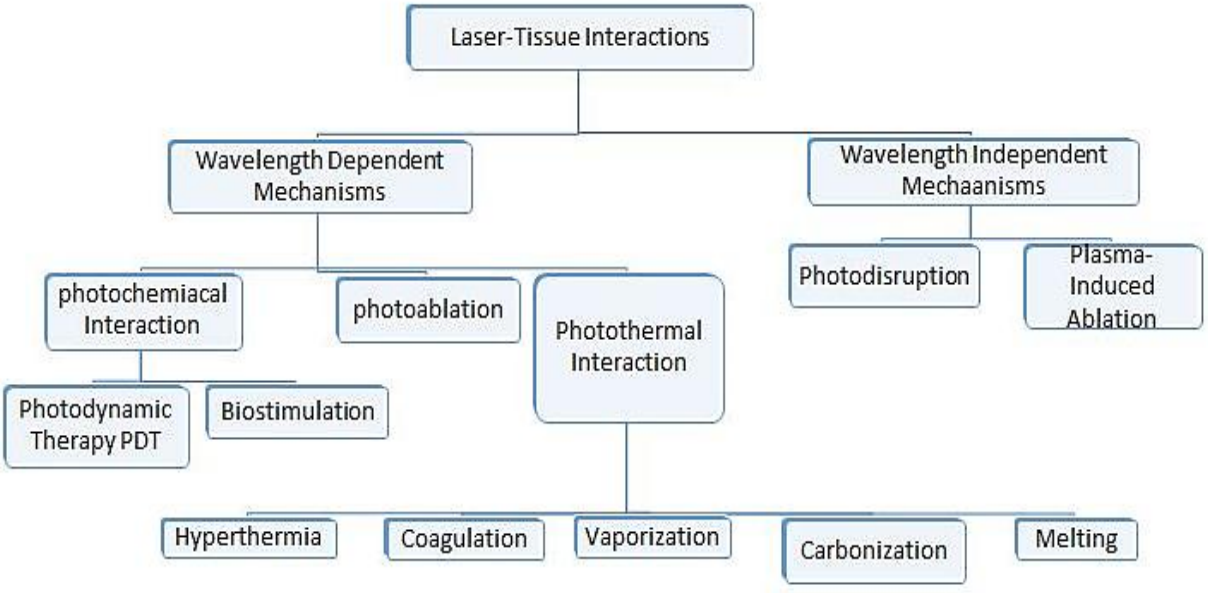
These mechanisms use a very high power density lasers with pulse duration in picosecond to femtosecond ranges. The tissue molecules and atoms go through multiphoton ionization and this is called Optical Breakdown. It is also associated with plasma formation and shock wave generations inside the tissue which all leads to ablation. In dentistry, this

technique was used for hard tissue ablation with very precise and clean manner[84].

II. Photodisruption

It uses the same laser parameters of plasma – induced ablation. The optical breakdown is usually accompanied by some physical effects; they are plasma formation and shock wave generation. If this occurs inside the soft tissue, an additional cavitation and jet formation occur. Cavitation occurs when the laser beam focusing is inside the tissue rather than on its surface. A gaseous bubble full of water vapor is diffused against the surrounding tissue. The cavitation collapse or rupture of this bubble due to adjacent solid boundary causes jet formation, and tissue ablation [84].

Figure (1-13) is a simple diagram that represents the laser-tissue interactions.



(Figure 1-13) simple Diagram summarize the mechanisms of laser-tissue interactions [84].

1.4.7 Laser Safety Standards and Hazard Classification

Laser classification is based on their potential to cause biological damage. Classification of a laser can be determined using the American National Standard Institute (ANSI) Z136.1-2007 Section 3 and Appendix B standard [90].

Class 1 Laser System:

Class 1 laser system is considered to be incapable of producing damaging radiation levels during operation, and exempt from any control measures or other forms of surveillance.

Class 1M Laser System:

Class 1M laser system is considered to be incapable of producing hazardous exposure conditions during normal operation unless the beam is viewed with an optical instrument such as an eye-loupe (diverging beam) or a telescope (collimated beam), and Exempt from any control measures other than to prevent potentially hazardous optically aided viewing; and is exempt from other forms of surveillance [90].

Class 2 Laser System:

The emission of this class lasers is in the visible portion of the spectrum (0.4 to 0.7 μm), and Eye protection is normally afforded by the aversion response. This class not exceeding an average radiation power of 1mW.

Class 2M Laser System:

The emission of this class lasers is in the visible portion of the spectrum (0.4 to 0.7 μm), and Eye protection is normally afforded by the aversion response for unaided viewing. However, Class 2M is potentially hazardous if viewed with certain optical aids [90].

Class 3 Laser System (medium-power):

Lasers in this class may be hazardous under direct and specular reflection viewing conditions, but is normally not a diffuse reflection or fire hazard.

There are two subclasses:

• A **Class 3R** laser system is potentially hazardous under some direct and specular reflection viewing condition if the eye is appropriately focused and stable, but the probability of an actual injury is small. This laser will not pose either a fire hazard or diffuse-reflection hazard. HeNe lasers above (1 mW) but not exceeding (5 mW) is an example of this class [91].

• A **Class 3B** laser system may be hazardous under direct and specular reflection viewing conditions, but is normally not a diffuse reflection or fire hazard. Continuous wave lasers not exceeding 0.5 watts for any period greater than 0.25 seconds, pulsed visible lasers not emitting more than 0.03 joules per pulse, pulsed infrared or ultraviolet lasers not emitting more than 0.125 joules during any period less than 0.25 seconds [91].

Class 4 Laser System (high-power):

Lasers in this class are hazardous to the eye or skin from the direct beam, and may pose a diffuse reflection or fire hazard. May also produce laser generated air contaminants (LGAC) and hazardous plasma radiation. lasers operating at power levels greater than 0.5 watts for continuous wave lasers or greater than 0.03 Joules for a pulsed system[90].

1.5 Review of irrigation systems studies

Successful endodontic therapy, which mainly depends on the elimination of microorganisms from the root canal system, is accomplished by means of biomechanical instrumentation of the root canal. Studies have shown, however, that complete removal of microorganisms from the root canal system is virtually impossible[92, 93] and a smear layer covering the

instrumented walls of the root canal is formed. The smear layer consists of a superficial layer on the surface of the root canal wall approximately 1 to 2 μm thick and a deeper layer packed into the dentinal tubules to a depth of up to 40 μm [94]. **Pashley** considered that a smear layer containing bacteria or bacterial products might provide a reservoir of irritants [95].

Takeda et al. (1999) studied the efficacy of Er:YAG laser irradiation for cleaning RC walls and have demonstrated that this type of laser is more effective in removing the smear layer than other types of lasers and endodontic irrigants [96],[97]. The dentinal walls mostly showed open tubules and were free of debris or a smear layer [98].

Pecora et al. (2000) and **Brugnera et al**. (2003) noticed that the use of distilled and deionized water and Er:YAG in laser assisted root canal treatment, showed an increase in dentine permeability [99] [61].

In 2002, the US Food and Drug Administration (FDA) approved the Er,Cr:YSGG laser for use in conventional endodontic therapy.

Gordon [100], using an in vitro model, found that, the use of Er,Cr:YSGG laser 2780 nm to have a good antimicrobial effect on dentinal tubules infected with E. faecalis . The FDA has approved this type of laser to clean, shape, and enlarge the root canal and also for its use in osseous, apical, and periodontal surgery.

Contrary results for RC wall cleanliness have been found including: **Radati et al.** [101] at 2006 hypothesized less debris removal in radicular dentine using Er,Cr:YSGG laser than with a conventional technique; while **Jahan et al.** [102] at 2006 reported presence of an area of clean dentine surface free debris with preservation of tubular structure with 2W and 20 Hz. Er:YAG and Er,Cr:YSGG lasers can be successfully used to remove organic tissue and smear layers. Their absorption in hydroxyapatite and water is high that germ reduction would predominantly take place only in the main canal, although germ reduction through thermal effects can still be

detected in the lateral dentinal tubules up to depths of 300μm to 400μm [103].

Marchesan et al. [104] in2008 studied the effect of diode laser 980 nm on permeability of root canal dentine using power setting of 1.5 W of either CW or Pulsed 100Hz for 20s, assumed that using diode laser in combination with EDTA can improve dentine permeability, same authors in another study [105], they detected a sparse lava-like areas of dentine fusion on intraradicular dentine after irradiation at 3 W. It was suggested that 980nm diode laser irradiation of RC, a modified smear layer was observed in specimens that were irrigated with water and then laser irradiated with 1.5 W/100 Hz and 3.0 W/100 Hz. The 980nm diode laser altered the morphology of the dentine but did not affect the fracture resistance of the roots. [106]

Arslan et al. [107] at 2013 stated the high effect of EDTA agitation during lasing the canal with 808 nm diode laser on removing the smear layer in apical portion of the canal.

El-Naghy et al [108] at 2017 study and compare the effectiveness of XP-endo finisher, Endoactivator, and File agitation on both smear layer and debris removal, they found that there is no significant difference between XP-endo finisher and Endoactivator grousps and at the same time there is no significant difference between file agitation and control groups. In conclusion, none of the irrigation methods assessed in this study were totally removed the debris and smear layer.

Al-karadaghy T. et al. [109] they study and compare the effect of Er:Cr:YSGG laser and dual wavelength laser(2780 nm & 940 nm) laser on radicular dentin permeability and ultra-structural changes of dentin morphology, they concluded that radicular dentin irradiation with dual wavelength laser (three rounds, Pave=1.06Wfor Er,Cr:YSGG laser, Pave=0.51Wfor diode laser, and 162 s irradiation time) is effective in

increasing dentin permeability with superior statistical results when compared with Er,Cr:YSGG laser group. A smear layer and debris were removed effectively from root canal walls and appear to have an interesting application in laser-assisted root canal treatment.

Caron G. et al. [110] they studied effectiveness of different final Irrigant activation (sonic, automated-dynamic activation, manual-dynamic activation, and no activation) Protocols on Smear layer removal in curved canals. they concluded that, the activation of irrigating solutions resulted in cleaner canals compared with no activation, and a tapered activator that closely adapts to the dimensions of a shaped canal is the most effective (ie, the master gutta-percha cone and Endoactivator).

1.6 Aims of study

1- To assess and compare the effect of Er:Cr:YSGG laser, Diode laser 940 nm, EndoActivator and XP-endo finisher on smear layer removal by SEM analysis.

2- To measure and compare the effect of Er:Cr:YSGG laser, Diode laser 940 nm, EndoActivator and XP-endo finisher on radicular dentin permeability.

Chapter Two

Materials and methods

Chapter two: Materials and methods

2.1 Materials and equipment

Some of the materials that were used in this study included the following items **(Figure 2-1):**

(Figure 2-1) Some of the materials and equipment used in the study.

2.1.1 Materials:

1. Barbed broaches.
2. Clean stand sponge (China). (Fig 2-1 a).
3. Clear test tubes 5.0 ml (AFCO, Amman, Jordan)
4. Diamond disc (22x 0.4) (China). (Fig 2-1 b).
5. Disposable syringe 5ml (UltraHealth, Changzhou Kangfulai Medical, Jiangsu, China). (Fig 2-1 c).
6. EDTA 17%, 15 ml (PD, Switzerland), (Fig 2-1 d).
7. EndoActivator tips (Medium 25/ .04) (Dentsply, Maillefer, Ballaigues, Switzerland). (Fig 2-1 e).

8. Endodontic fiber tip Ez diameter 200 μm, 14mm in length (epic, Biolase, CA, USA). (Fig 2-1 f).
9. Endodontic ruler (Mini-Endo-Bloc, Dentsply, Maillefer, Ballaigues, Switzerland). (Fig 2-1 g).
10. Glass Ionomer cement. (Fig 2-1 h)
11. Silicon impression material (putty + catalyst gel) (prtesil. Vannini Dental Industry. Florence. Italy). (Fig 2-1 i).
12. Ethyl-chloride spray (Italy). (Fig 2-1 j).
13. Methylene blue dye powder (India). (Fig 2-1 k).
14. Protaper NEXT rotary NiTi files (X1, X2, X3, X4) (Dentsply, Maillefer, Ballaigues, Switzerland).
15. Radial Firing Tip fibers (RFT3) diameter=415 μm, length=21.17mm, calibration factor= 0.85 (Biolase, San Clemente, CA, USA). (Fig 2-1 l).
16. Side-vented irrigation needles 29 Gauge (NaviTip, Ultradent product Inc., South Jordan, UT, USA). (Fig 2-1 m).
17. Sodium hypochlorite solution 5.25% (Chloraxid Extra, PPH Cerkamed, Stalwa Wola, Poland). (Fig 2-1 n).
18. Stainless steel k- file #10 (dentsply, Maillefer, Ballaigues, Switzerland).
19. Teflon.
20. Thymol crystals (BDH chemical Ltd.,Poole, England).
21. XP-endo Finisher (FKG Dentaire, La Chaux-deFonds, Switzerland). (Fig 2-1 o).

2.1.2 Equipment:

1. Bench vice (china).
2. CAD-KAS Kassler (measure picture Computer software GbR, V 1.0, Germany).
3. Digital caliper (NSI, China).

4. Digital stop watch (China).
5. Diode laser 940 nm (Biolase, epic, CA, USA).
6. EndoActivator (Dentsply Tulsa Dental Specialties, Tulsa, OK, USA).
7. Endodontic micro motor (X.smart plus, Dentsply, Maillefer, Ballaigues, Switzerland).
8. Er:Cr:YSGG laser (waterlase iplus Biolase, CA, USA).
9. Electronic balance.
10. Goggles.
11. Mallet. (Fig 2-1 p)
12. Professional Digital SLR camera (Nikon D7100, Nikon Corporation, Thailand).
13. Scanning electron microscope (Inspect S50, Czech Republic).
14. Sputter coater**.**
15. Stereomicroscope (Hamilton, Altay Scientific, Rome, Italy).
16. Surveyor.
17. Ultrasonic cleaner (CD-7810(A), New Trent, China).

2.2 Methods

2.2.1 Sample Collection and Selection

Seventy single-rooted completely formed, straight mandibular premolars freshly extracted for orthodontic demands were used for this study selected from the age group (18 to 34 year-old patients). Immediately after collection teeth have been cleaned by washing under distilled water and then soft tissue remnants were removed using ultrasonic scalar, polished carefully with pumice and finally samples were put in ultrasonic bath for 5 minutes to remove the external debris like pumice particles and then stored in a plastic container containing 0.1% thymol solution [109]**.**

2.2.2 Sample preparation

The roots length was standardized to 14mm from the anatomic apex by using a digital caliper and a permanent black marker **(Figure 2-2 A)**.

Teeth were then mounted on a bench vice, and a double-faced diamond disc mounted on a handpiece was used**,** under water coolant, for sectioning the root perpendicular to the long axis of the root according to the drawn line **(Figure 2-2 B and C).** In figure 2-3 some of root samples after sectioning were shown.

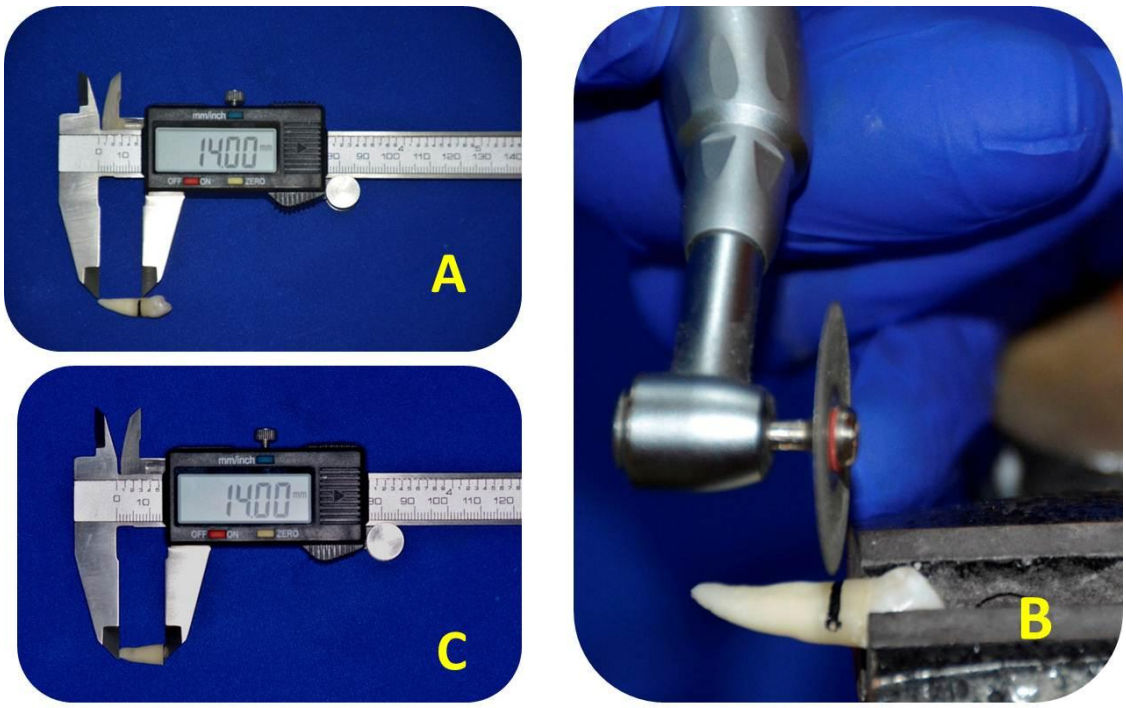
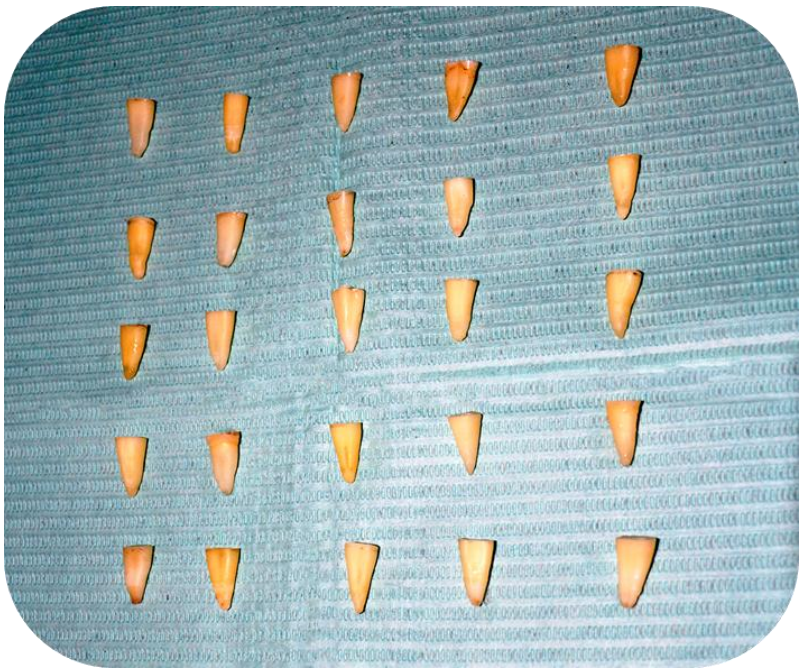


Figure (2-2) A: sample length determination, **B**: sectioning of the sample, **C**: root sample after sectioning.



(Figure 2-3) Some of root samples after sectioning.

Canal orifices flared with small carbide round bur of conventional speed handpiece, Then the pulpal tissues were removed using barbed broaches, and the exact location of the apical foramen and the patency of the canals were established by using a stainless steel K-file #10 inserted slowly until it is visualized at the apical foramen by naked eye **(Figure 2-4)**, any laterally positioned canal was excluded. The silicon stopper was adjusted and the file was removed and measured using an endodontic ruler, and the correct working length was recognized by subtracting 1mm from the length previously determined.

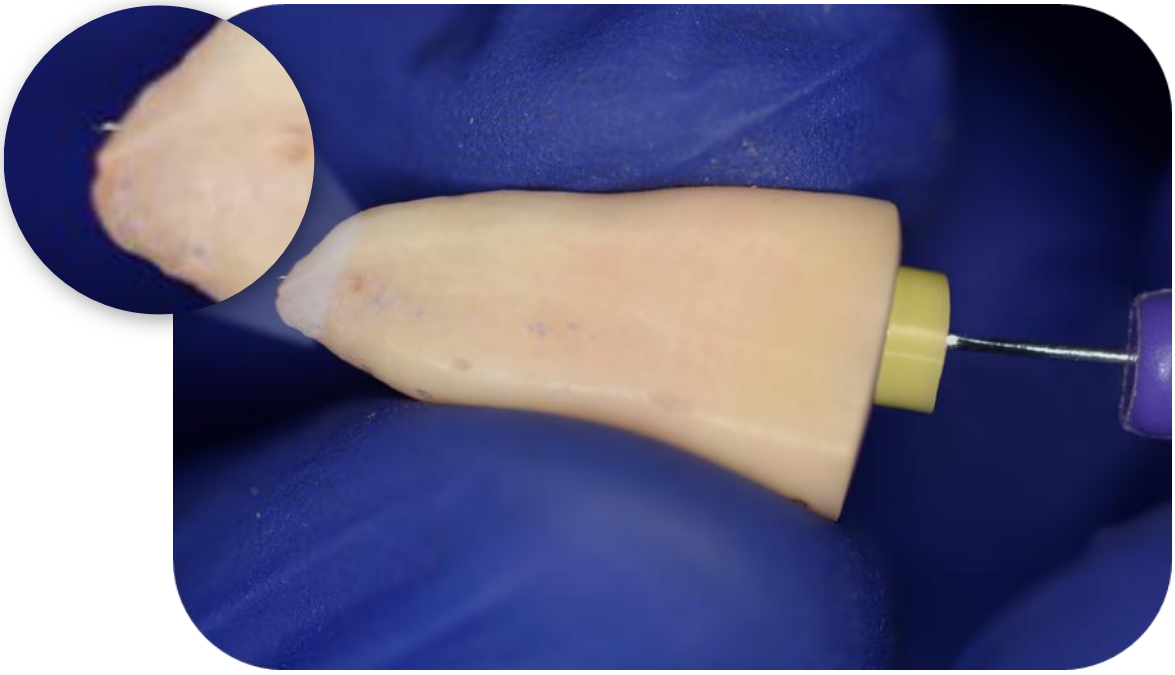


Figure (2-4) Canal patency check and working length determination.

To facilitate handling of the samples during the working steps, the samples were embedded, in a plastic tube containing silicon rubber base impression material (putty consistency), with the exception of the coronal 3 millimeters. With the aid of digital caliper, permanent marker, surveyor, and a rubber mold, a line was drawn 3mm apical to the coronal margin of the sample which acted as a guide showing where sample embedding should stop **(Figure 2-5A)**.

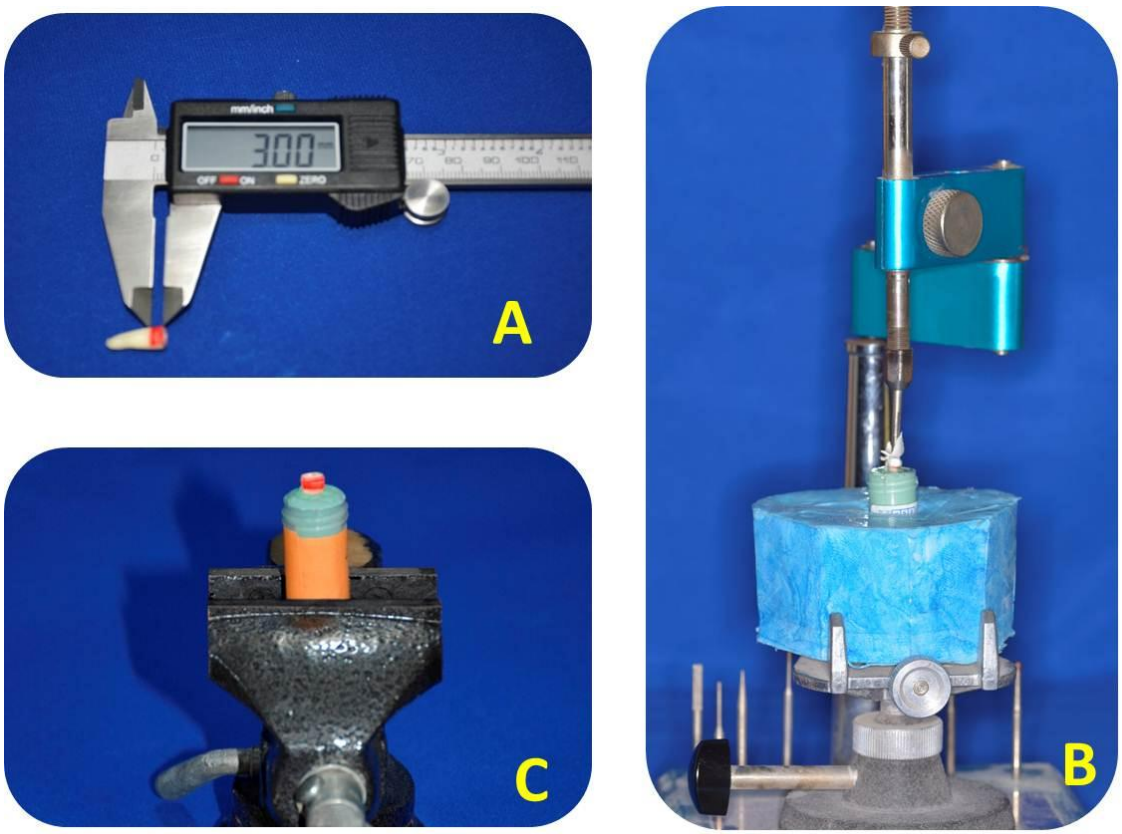


Figure (2-5): A: A line 3mm away from the coronal margin is drawn to mark the level of embedding in silicon-filled plastic tube. **B:** Inserting the sample in the silicon-filled plastic tube with the aid of surveyor**. C:** Mounting of the tube on the bench vice.

A hole was made in the base of the plastic tube to permit the air inside the tube to escape during silicon putty insertion.

The putty was mixed with the catalyst gel according to the manufacturer's instructions, inserted in the plastic container and the sample was embedded in the silicon putty with the aid of surveyor. The canal orifice sealed by Teflon and fixed to the surveyor arm using wax then the sample inserted slowly in the silicon putty to keep insertion at the same long axis **(Figure 2-5B)**. The silicon material was then left until being set, then plastic tubes were then moved to fix by a bench vice to achieve a standardized position during the procedure **(Figure 2-5C)**.

2.2.3 Root Canal Instrumentation

The working length was determined as mentioned with size #10 ISO K file 1 mm from the apex which was 13 mm and, then canals were prepared mechanically by rotary system After mounting the plastic tubes on a bench vice, the root canals were irrigated with 1.0 ml of 5.25% NaOCl solution delivered by a 5.0 ml disposable syringe with a 29-gauge side-vented needle. During all irrigation phases, the needle was placed short of the point where resistance from the canal walls was felt, with respect to that not forcing the needle longer than 2mm shorter than the determined working length. The root canals were prepared with ProTaper NEXT rotary NiTi files using an endodontic micro motor (smart-X plus, Dentsply), with the speed set to 300 rpm and a torque of 2.0 Ncm **(Figure 2-6A) (Dentsply Manufacturer's DFU)**. The instrumentation sequence began with the X1 file, followed by X2, X3 and reached a final size of X4 **(Figure 2-6B)**, all of them reaching the full working length. After each file and before switching to the next file in the instrumentation sequence, apical patency was checked with a #10 stainless steel K-file, and the canal irrigated with 1.0 ml of 5.25% NaOCl.

At the end of preparation the sample irrigate with 1ml distilled water to prevent prolonged effect of sodium hypochlorite and dried with paper point size X4. For standardization purposes, every one set of rotary files was used to prepare five canals and then discarded. All the instruments were cleaned with gauze pad soaked in ethyl alcohol after finishing from one canal and before being used for another time, then put it into sponge endodontic stand.

Figure (2-6): A: The endodontic micro motor adjusted according to the manufacturer's instructions. **B:** Root canal instrumentation by Protaper NEXT NiTi files.

2.2.4 Samples Grouping

The seventy samples were randomly divided into five groups of fourteen samples for each group, depending on the system used to activate the irrigant **(Figure 2-7)**.

G1 (n=14): control group, (without activation).

G2 (n=14): EndoActivator (sonic activation).

G3 (n=14): XP-endo Finisher.

G4 (n=14): Er:Cr:YSGG laser 2780nm.

G5 (n=14): Diode laser 940 nm.

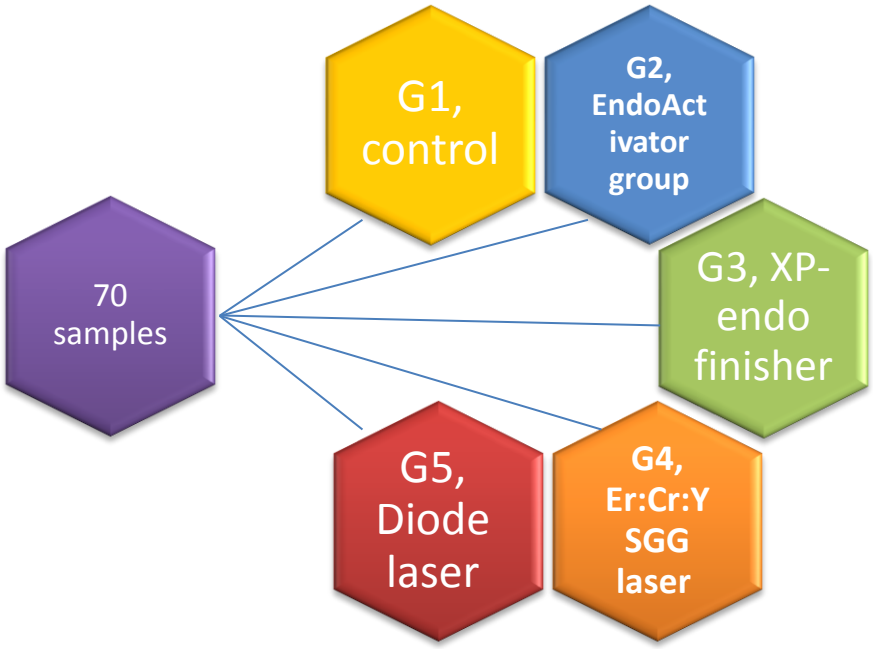


Figure (2-7) sample grouping.

2.2.4.1 Final irrigation protocol

After biomechanical preparation each groups receive a final irrigation as follows:

Each sample irrigated with 1ml EDTA 17% for 1 min., after that the sample receive a 5 ml of NaOcl 5.25% and activated while the irrigant inside the canal according to groups mentioned above then receive the final rinse 5 ml distilled water and dried with paper point.

2.2.4.2 Activation method for all groups successively:

2.2.4.2.1: G1:- control group (n=14) 1 ml EDTA 17% for 1 min then irrigated with 5 ml NaOcl 5.25% injected slowly and leave it inside the canal for 5 min. then delivering 5 ml distilled water and dried with paper point protaper NEXT X4.

2.2.4.2.2 G2:- Sonic activation by Endoactivator (n=14) 1ml EDTA 17% for 1 min. then samples irrigated with 5 ml NaOcl the EndoActivator system was used according to the manufacturer's instructions. The medium-size polymer tip (25/.04) was used to clean the canals **(Figure 2-8A)**.the tip was fitted passively inside the canal, 2mm shorter than the

working length, and activated at 10,000 cpm for 60 seconds with pumping action in short 2-3mm vertical strokes **(Figure 2-8B)**, then delivering the final rinse (5.0 ml distilled water), the canal was dried with paper point X4. For standardization purposes, the activator tip was used for cleaning a single canal, and then discarded.

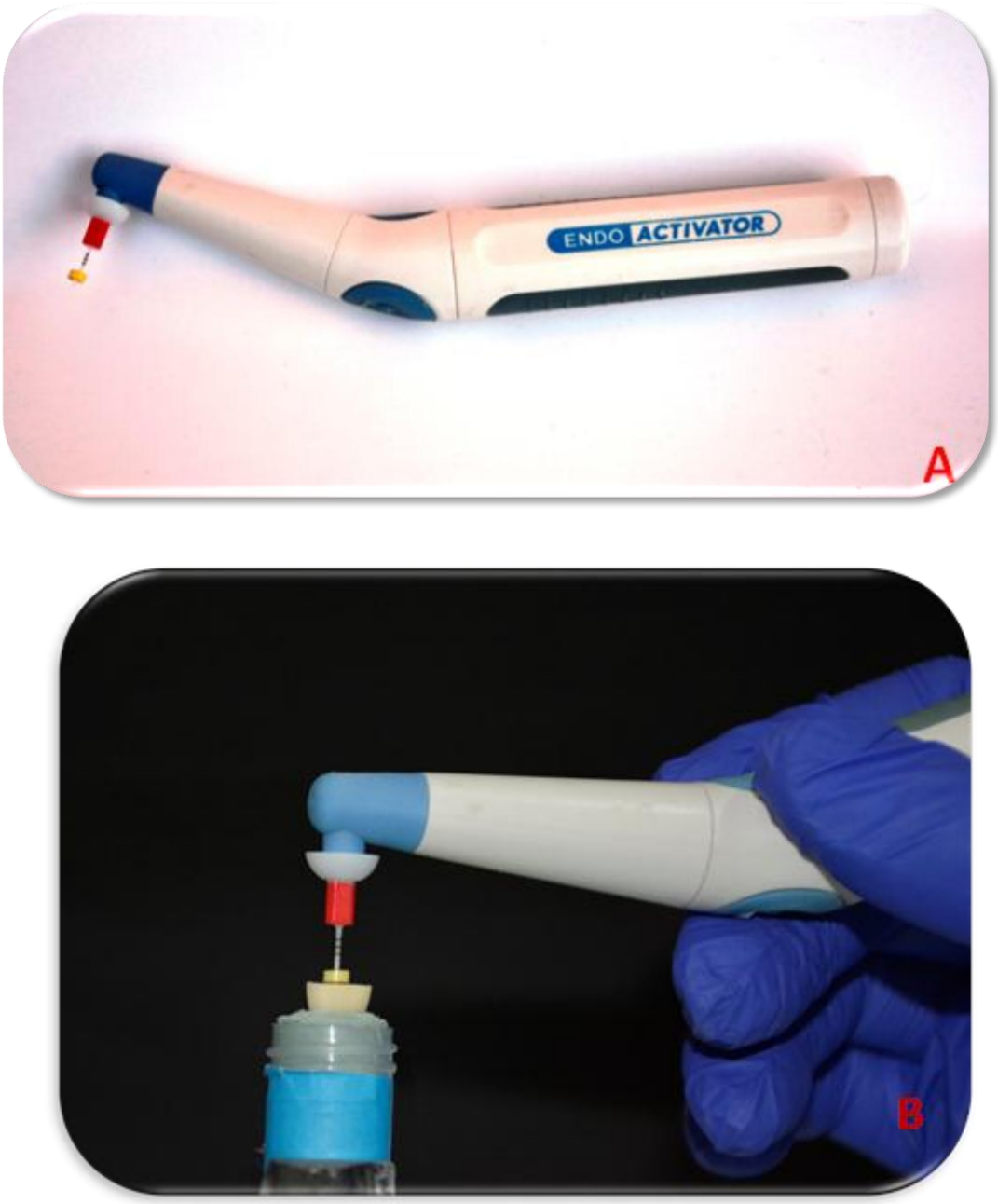


Figure (2-8) A: The EndoActivator system, with the medium-size polymer tip (25/.04).
B: Root canal cleaning by sonic irrigation.

2.2.4.2.3 G3: Xp-endo Finisher (n=14) 1 ml EDTA 17% for 1min then irrigated with 5 ml NaOcl 5.25% and activated with Xp-endo Finisher.

The XP-endo finisher and according to the manufacture and development, at temperatures above 35°C, the file is in its Austenitic phase, which is difficult to be inserted in the canal **(Figure 2-9).** So, after working length adjustment to 12mm with the provided tube, the Finisher was cooled down with ethyl chloride spray while it is inside the tube **(Figure 2-10 A&B).**

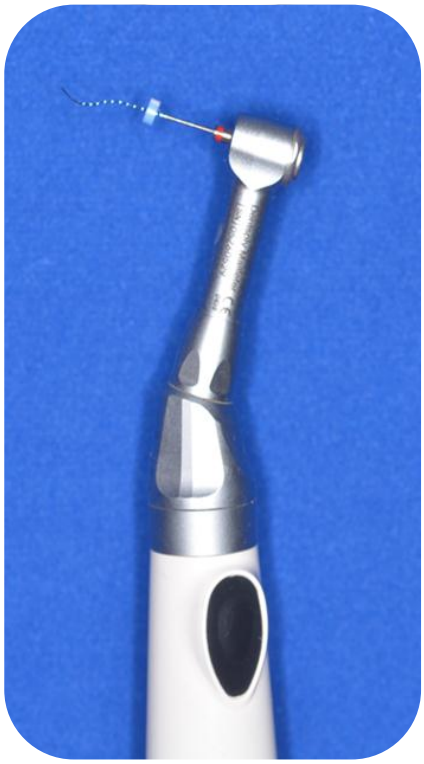


Figure (2-9) XP-endo finisher file in its Austenitic phase.

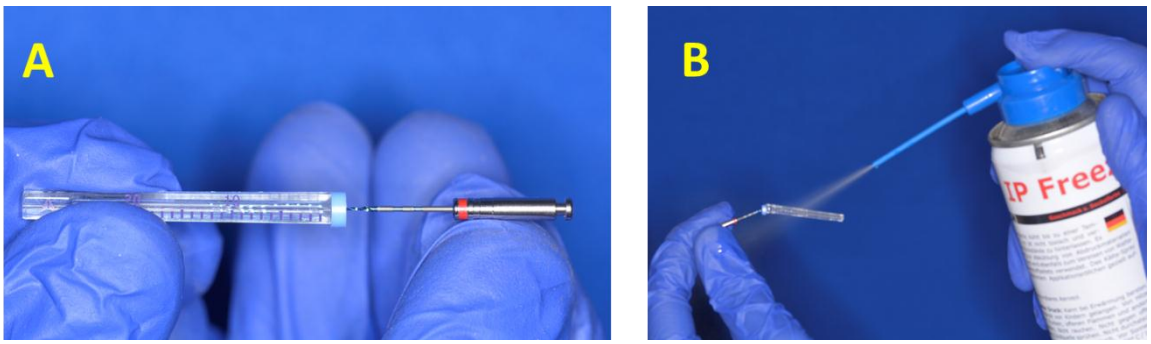


Figure (2-10) A: XP-endo finisher working length adjustment with the provided tube. **B:** Cooling of the XP-endo Finisher while inside the plastic tube with ethyl chloride spray after working length adjustment.

The file was used according to the manufacturer's instructions. The settings of the endodontic micro motor were 800 rpm for the speed and 1.0 Ncm for the torque **(Figure 2-11 A).** After irrigating the canal with 5.0 ml 5.25% NaOCl, the Finisher was removed from the tube and activated while its tip was inside the canal then the specimen subjected to the external heat source to achieve the A-phase of the XP-endo finisher file. The Finisher was activated for 60 seconds inside the canal with gentle lengthwise movements to contact the full length of the canal **(Figure 2-11 B),** followed by the final rinse (5.0 ml) distilled water and drying of the canal with ProTaper NEXT X4 paper points.

For standardization purposes, each file was used for cleaning only one canal, and then discarded.

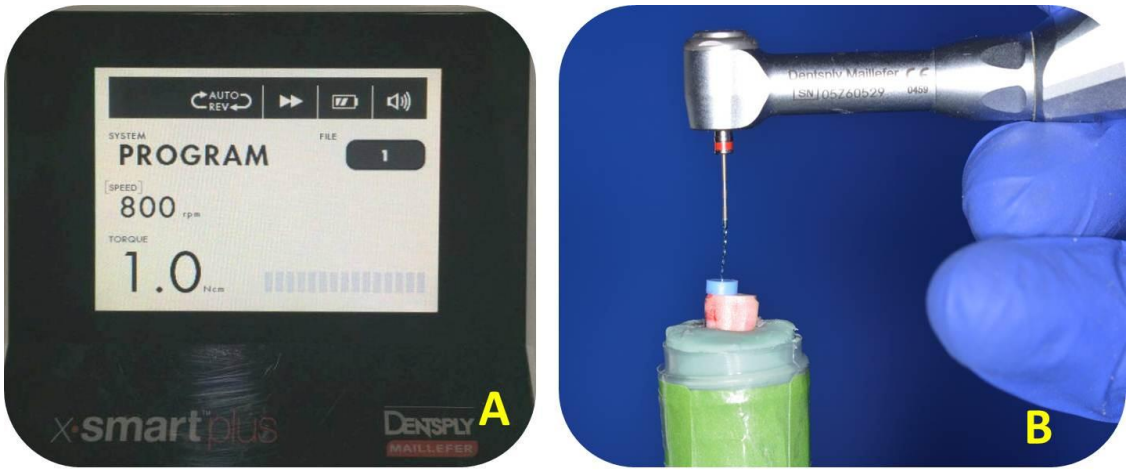
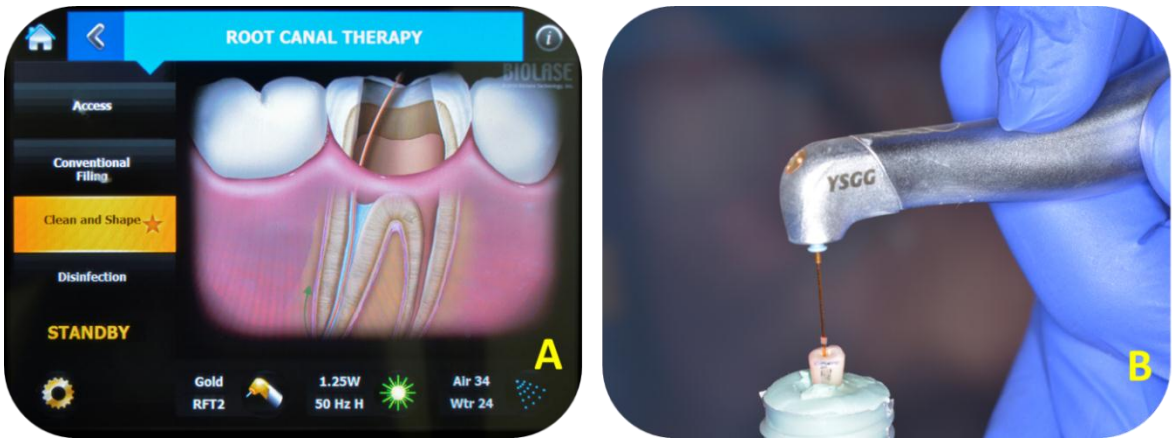


Figure (2-11) A: Program setting for XP-endo finisher according to manufacturer instructions. **B:** Activation of the irrigant using XP-endo finisher.

2.2.4.2.4 G4:- Er:Cr:YSGG laser (n=14) , 1mL EDTA 17% for 1 min., and irrigated with 5mL NaOcl 5.25%, then agitated with Er:Cr:YSGG pulsed laser, (Biolase, waterlase, iplus, CA, USA) 2780 nm**(Figure 2-12 A&B)**. The delivery was by radial firing tip, RFT3, fiber diameter 415 µm, length 21.17 mm, calibration factor 0.85. Panel setting was Pave=1.25 W, pulse energy 25 mj, repetition rate: 50 Hz, pulse duration: 60 µs.

Specimens were irradiated as follow: the fiber tip inserted 2 mm from the apex, contact mode, helicoidal movement in a speed of 1mm/s from apical to coronal direction, in a three cycles, each cycle was accomplished in 12 s and a resting time of 5 s resulted in a total irradiation time of 51 s according to manufacturer's instructions. For standardization purposes, each fiber tip was used for cleaning only one canal, and then discarded **(Figure 2-13 A&B).**

(Figure 2-12) Er:Cr:YSGG laser device (Biolase,waterlase, iplus, CA, USA) **A:** Front view, **B:** Side view.

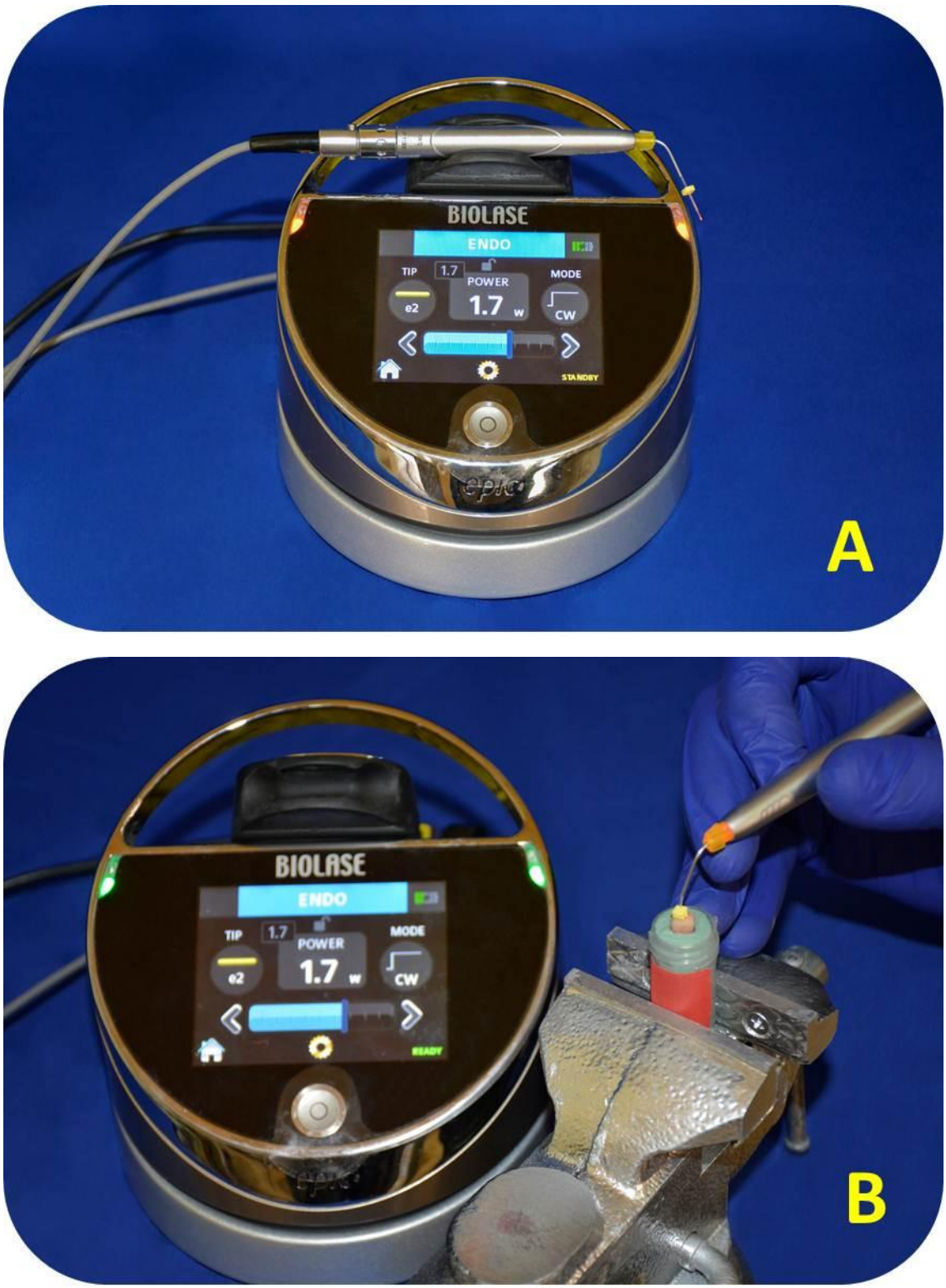


(Figure 2-13) A: program setting of waterlase devise according to manufacturer's instruction, **B:** Activation of irrigant using Er:Cr:YSGG laser.

2.2.4.2.5 G5:- Diode laser 940 nm, (n=14), 1mL EDTA 17% for 1 min., then irrigated with 5mL NaOcl 5.25%, and activated with 940 nm diode laser, the delivery was by fiber-optic endodontic tip, E2 with the tip diameter of 200 µm, Specimens were irradiated with 1.7 w panel setting which is on the power-meter display equal to 1.08 W, CW mode; the fiber tip inserted 2 mm from the apex, in contact mode, and helicoidal movement in a speed of 1mm/s from apical to cervical direction, this was accomplished in 12 s and repeated one more time after resting time of 5 s resulted in a total irradiation time of 34 s according to manufacturer's instructions **(Figure 2-14 A&B).** For standardization purposes, each fiber tip was used for cleaning only one canal, and then discarded.

After agitation procedure, specimens of all groups were irrigated with 5 mL distilled water and dried with paper point.

All samples of all the groups immediately after drying the canal, were sealed coronally with chemical cure glass ionomer cement as a temporary filling to prevent contamination of the canal during sectioning.



(Figure 2-14) A: Diode laser apparatus, Biolase, with endodontic fiber tip.

B: Activation of irrigant by 940 nm Diode laser.

2.2.5 Root sectioning for SEM evaluation

Twenty samples (four from each group) were selected randomly for SEM evaluation, to evaluate ultra-structural changes, smear layer removal by SEM. The roots were removed from their tubes and a marker was used to draw guiding lines longitudinally on the buccal and palatal sides. The roots were then mounted on the bench vice and longitudinally grooved on the previously marked lines with a diamond disc mounted on a low speed handpiece under water cooling **(Figure 2-15A)**. The grooves were then cleaned from any remaining debris with a slight air blowing. Then the roots were split by placing a surgical blade #11 in the groove and striking the blade gently with a small mallet **(Figure 2-15B)**, one half was examined and the other was discarded **(Figure 2-15C).**

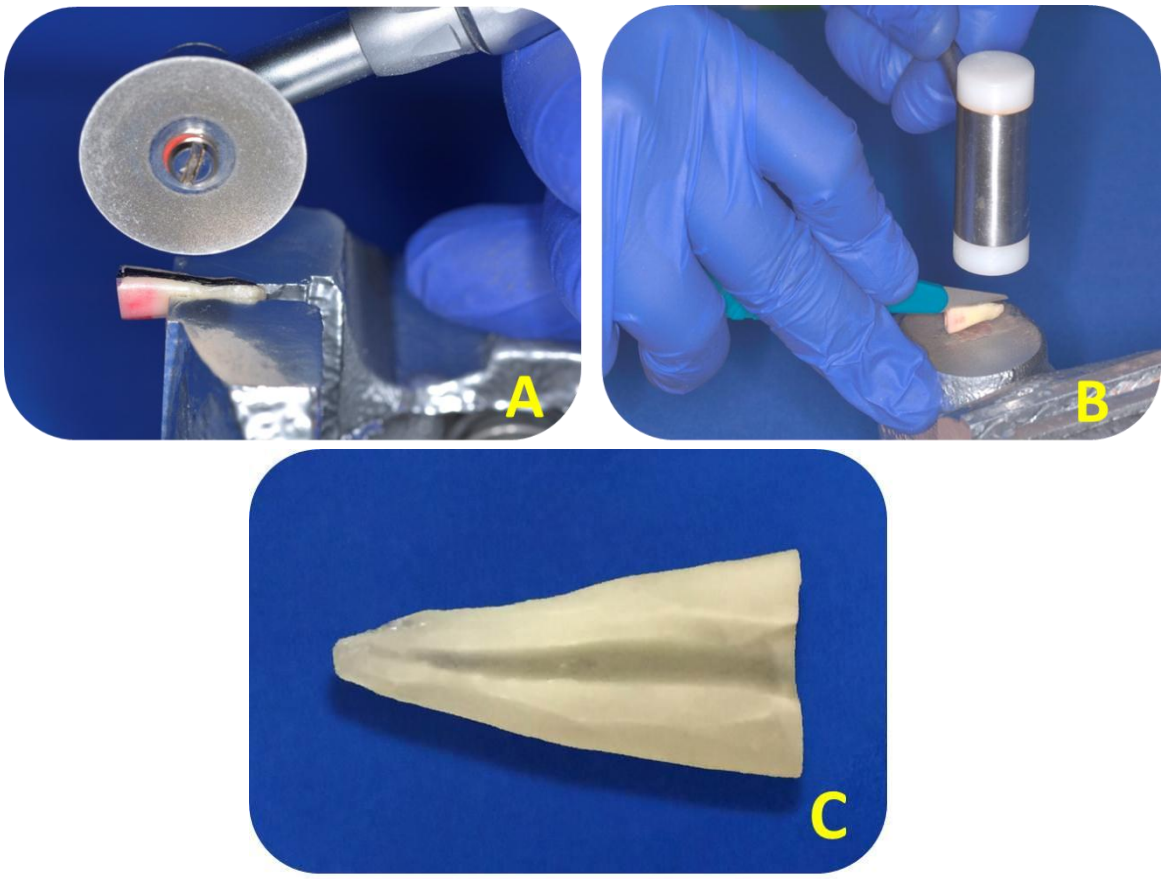
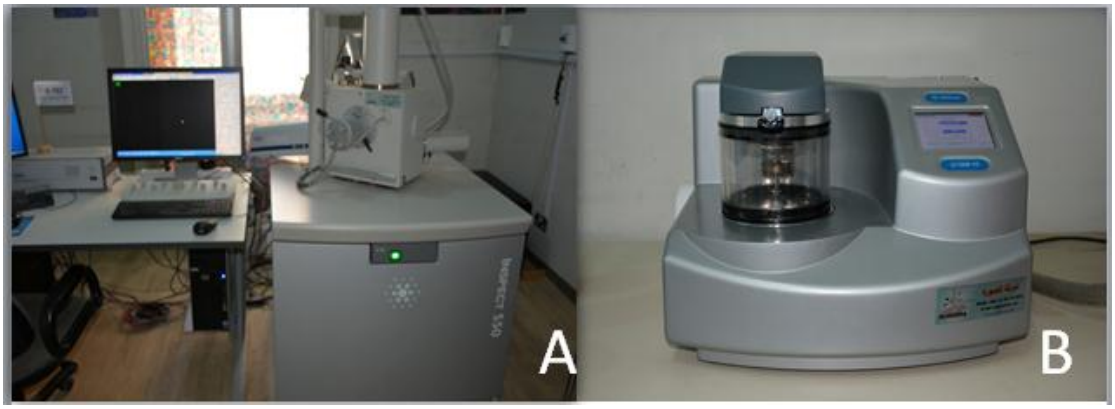


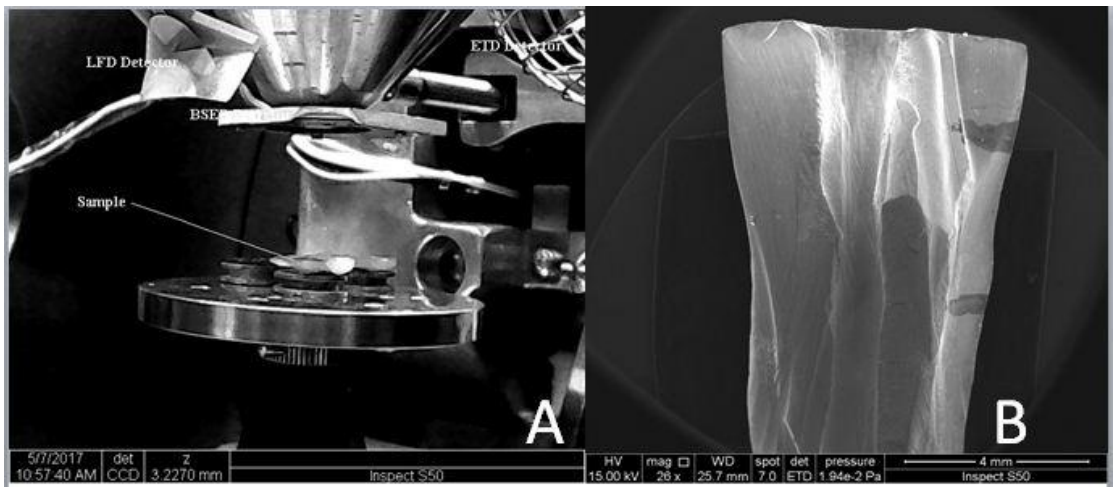
Figure (2-15) A: Mounting of the root for longitudinal groove placement. **B:** Root sectioning by striking the surgical blade with a small mallet. **C:** Longitudinal section of the root.

2.2.5.1 Preparation protocol for SEM evaluation

The samples fixation and dehydration were done according to the protocol used by Marchesan et al. [105] the samples were immersed in 2.5% buffered glutaraldehyde (EOBA CHEMIE PVT , India) and 0.1 ml sodium cacodylate (BDH Chemicals Ltd , England) (pH =7.4) at 4°C for 12 h, then washing with distilled water for 3 min, then the samples were left in distilled water for 1 h (the water was changed every 20 min), after that samples were dehydrated in an ascending graded ethyl alcohol beginning from 25% (20 min), 50% (20 min), 75% (20 min), 95% (30min), and end with 100% (60 min). After dehydration, the specimens were left to dry for 24h., then the specimens were fixed on aluminum stubs after metallized with a layer of gold, using vacuum evaporation. Then the samples were analyzed by SEM (Inspect S50, Czech Republic) and were divided into three regions, 4mm each represent apical, middle, and coronal then observed under 1000, 2000 x magnification. **(Figure 2-16)** and **(Figure 2-17).**



(Figure 2-16) A: SEM (Inspect S50, Czech Republic). **B:** Vacuum and sputter coater.



(Figure 2-17) A: Specimen fixed on the aluminum stub inside SEM device after gold metallized. **B**: Specimen at magnifying power 26x.

2.2.6 Permeability test experiment

For these experiment fifty samples; (ten of each group) were examined. This test was done to evaluate the area of dye penetration in apical, middle, and coronal thirds of root canal.

Root apex was sealed with wax. The roots surface was coated by two layers of nail varnish and left to dry. After that the canal was filled with 2 % methylene blue dye injected by hypodermal syringe gauge with needle gauge 23, by inserting the needle 2 mm inside the canal, then k-file # 20 inserted and withdrawn one time to ensure that the dye was reached to the apical third of the root.

After that the dye left inside the canal for 20 min. at room temperature (27-29 ◦c).

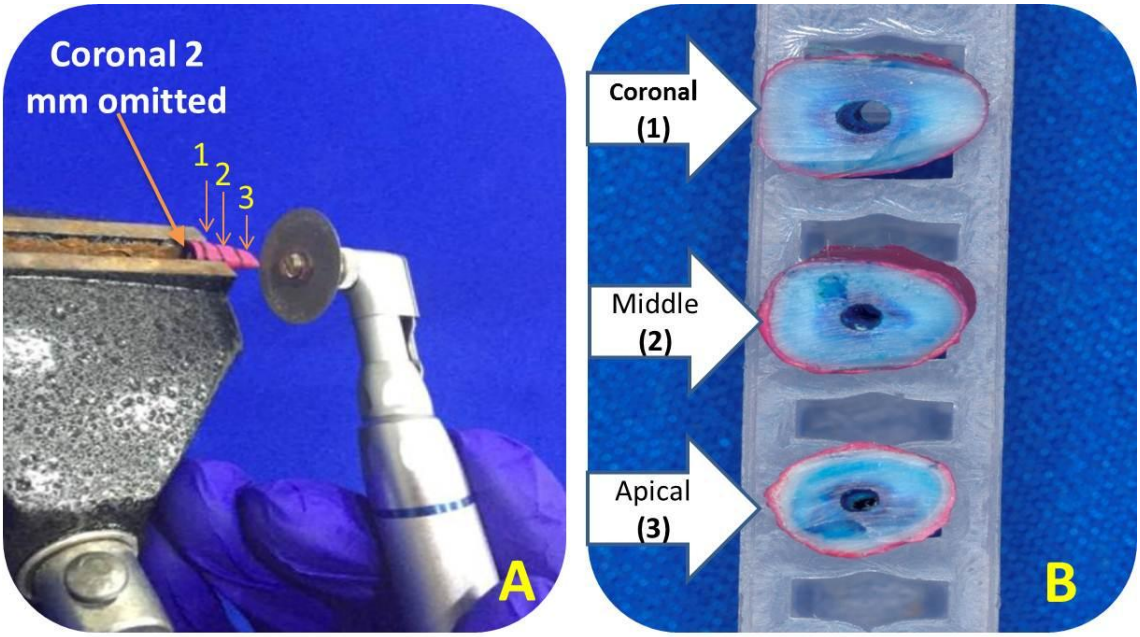
When this time had been elapsed, they were rinsed thoroughly under running tap water to clean the root externally and the root canal was dried with absorbent paper cones continuously until the cone appears white [111, 112].

2.2.6.1 Root sectioning for permeability test

With the aid of permanent marker, three guiding lines were drawn horizontally at the fourth, eighth, and twelfth millimeters. Then the tooth was mounted on the bench-vice and with a diamond disc mounted on a

low speed handpiece the tooth was sectioned just beneath the guiding lines into three parts representing the apical, middle, and coronal thirds **(Figure 2- 18, A&B)**. The first two mm stating from the cemento-enamel junction was cut and excluded from microscopic evaluation because it always covered with dye so it will give a false results.

The prepared root sections were observed under Stereomicroscope (Hamilton, Altay Scientific, Rome, Italy) under the magnification of ×40 **(Figure 2-19).**



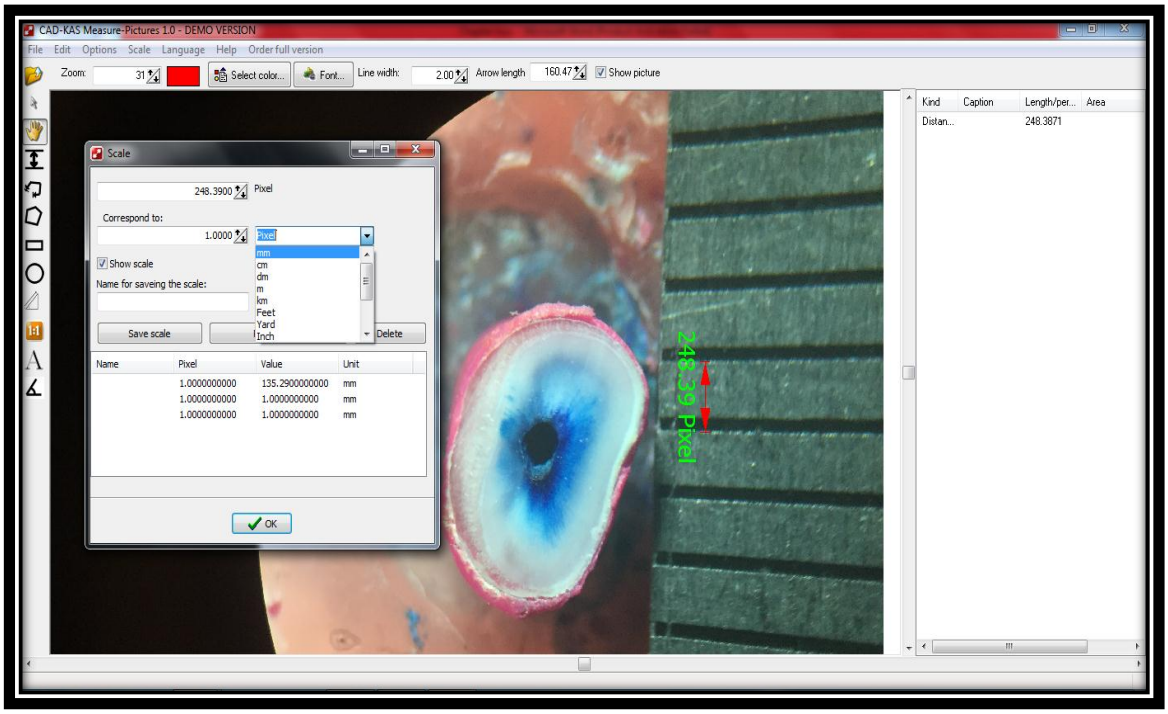
(Figure 2-18), **A**: cutting of sample for permeability test, **B**: cross sections of the root corresponding to the root thirds.

Figure (2-19) stereomicroscope.

2.2.6.2 Radicular dentin permeability measurements and evaluation

The images were opened with measure pictures V 1.0 software (CAD-KAS Kassler Computer software GbR, Germany), for measuring of radicular dentin Permeability the dye penetration area and the total root section area were calculated then subtract the root canal hole area from both previously mentioned areas to get the real dye penetration area and root section area.

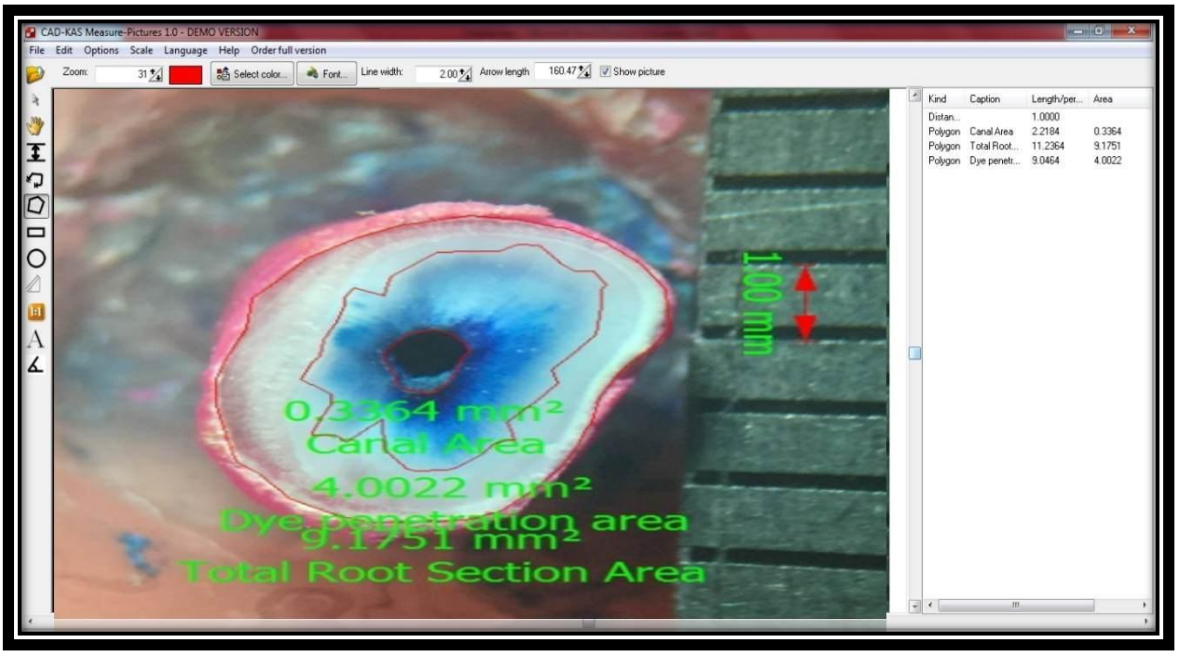
First, calibration was done by numerical scale to convert pixel unit into millimeter **(Figure 2-20).**



(Figure 2-20) Calibration to convert pixel unit into millimeter by using numerical scale.

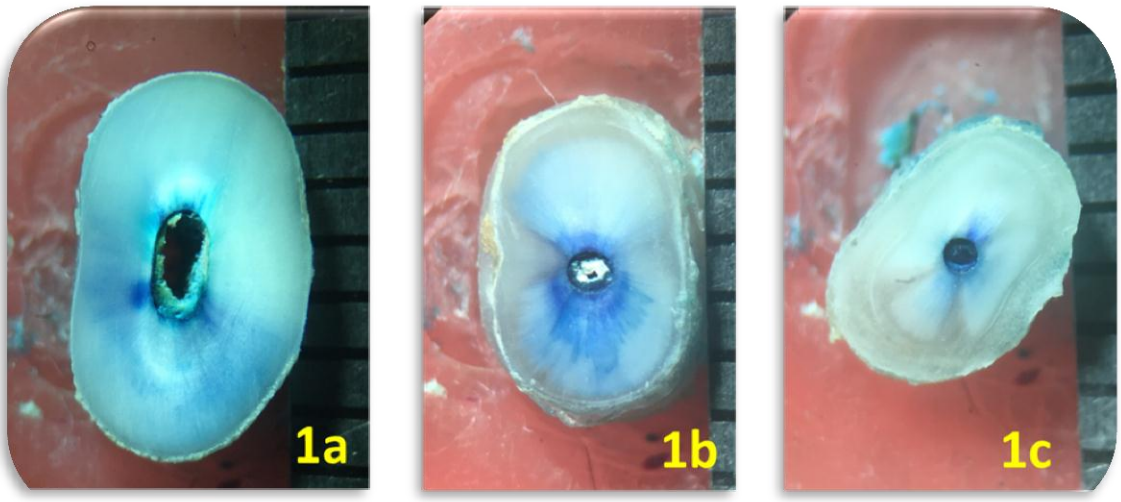
Subsequently, and after completion of measuring areas **(Figure 2-21)**, the dye-penetrated area was divided by the root third area, and multiplied by 100% resulting in the percentage of dye penetration in each root third; see the following equation:

Dye Penetration in Root Section = (Net dye penetration area /Net total root third area) × 100.

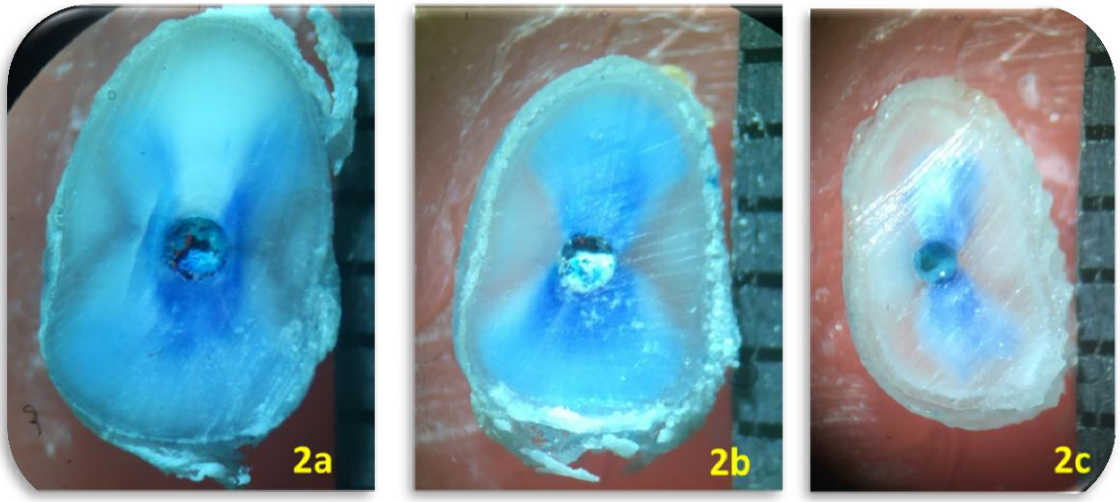


(Figure 2-21) measurement of dye penetration area in square millimeter unit

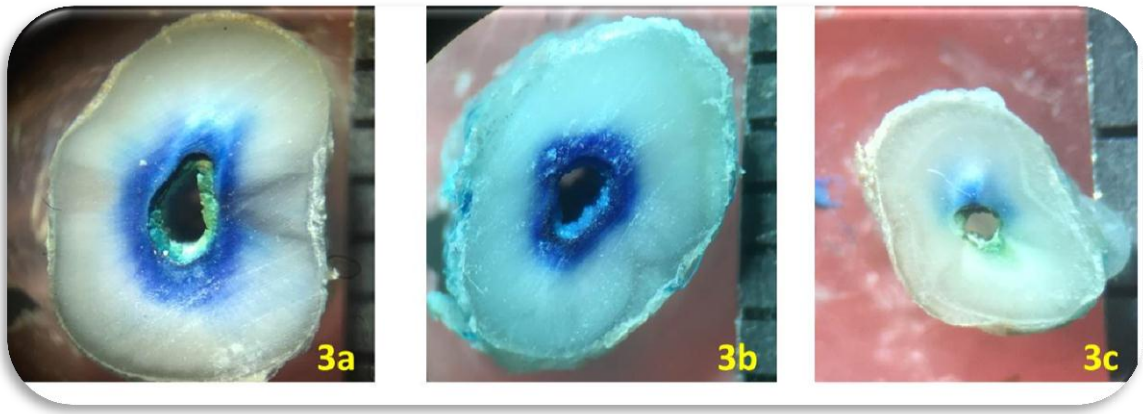
The dye penetration area would be shown in **figures (2-22), (2-23), (2-24), (2-25) and figure (2-26)** as follow:



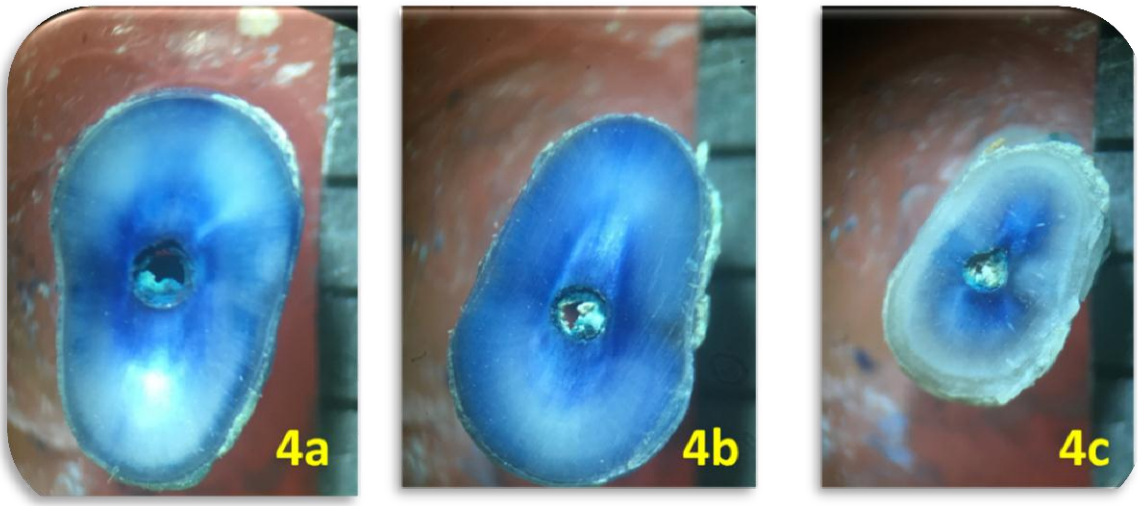
(Figure 2-22) Stereomicroscope image after transversal cuts and dye solution penetration for control group, the number (1) in the figure correspond to the group number, and the letters (a), (b) and (c) represent coronal, middle, and apical thirds respectively.



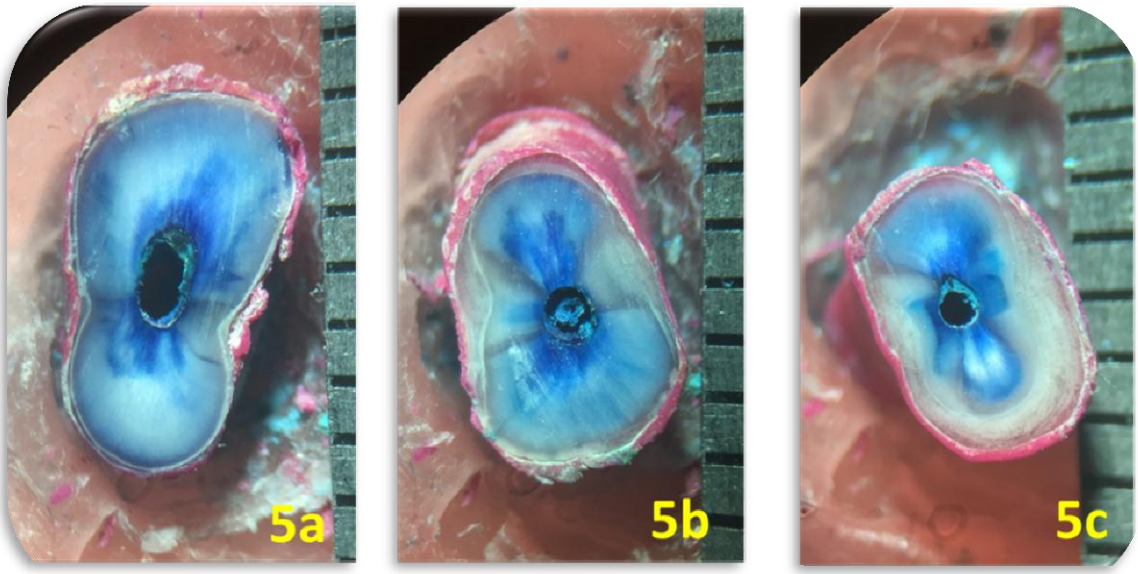
(Figure 2-23) Stereomicroscope image after transversal cuts and dye solution penetration for Endoactivator group, the number (2) in the figure correspond to the group number, and the letters (a), (b) and (c) represent coronal, middle, and apical thirds respectively.



(Figure 2-24) Stereomicroscope image after transversal cuts and dye solution penetration for XP-endo finisher group, the number (3) in the figure correspond to the group number, and the letters (a), (b) and (c) represent coronal, middle, and apical thirds respectively.



(Figure 2-25) Stereomicroscope image after transversal cuts and dye solution penetration for Erbium laser group, the number (4) in the figure correspond to the group number, and the letters (a), (b) and (c) represent coronal, middle, and apical thirds respectively.



(Figure 2-26) Stereomicroscope image after transversal cuts and dye solution penetration for Diode laser group, the number (5) in the figure correspond to the group number, and the letters (a), (b) and (c) represent coronal, middle, and apical thirds respectively.

2.2.7 Pilot Study

A pilot study has been made before preparing the research at hand to evaluate:

• The parameters that were employed to assess the tested devices and to test the temperature elevation at root surface during laser irradiation.

• To practice the preparation of longitudinal grooves on the root surface from buccal and palatal without invading the root canal and also about the method of root splitting with the surgical blade and mallet.

2.2.8 Statistical Analysis

Descriptive statistics including: minimum (Min.), maximum (Max.), mean, median, mean rank and standard deviation (SD) were calculated for the percentage of dye penetration area for each group. The data were collected and statistically analyzed using the Statistical Package for the Social Sciences (SPSS,version 21). Shapiro-wilk test: test the normality distribution of quantitative variables.

Kruskal-Wallis test non-parametric test were done to test whether there is a statistical difference among the groups regardless the level and among the groups and within group at different levels. Following multiple comparisons is Dunn's post hoc test.

Level of significance:

$P>0.05$ (Non-Significant)

$P\leq0.05$ (Significant)

$P<0.01$ (Highly Significant).

Keselman, and Penfield (akp.effect) effect size were used which was based on Cohen's d as 0.2(small), 0.5(medium), 0.8(large).

Chapter Three

Results, Discussion and Conclusion

Chapter three Results, Discussion and Conclusion

3.1 Results:

Permeability test:

As it was mentioned in methodology, roots were sectioned transversely into three parts representing apical, middle and coronal area of the root. Then the area of dye penetration and the total root section area were calculated, then subtract both of them from the root canal area to get the net dye penetration area and root section area. Afterward the dye-penetrated area was then multiplied by 100% and divided by the root third area, resulting in the percentage of dye penetration in each root third [17].

Dye Penetration in Root Section =

(Net Dye Penetration Area /Net Total Root Third Area) × 100

Data that represent permeability of root canal dentin expressed as percentage of dye penetrating area at three level of root canal are displayed in the appendices.

The summary of descriptive and statistical test for the percentage of dye penetrating area among control and experimental groups are shown in **Table (3-1).**

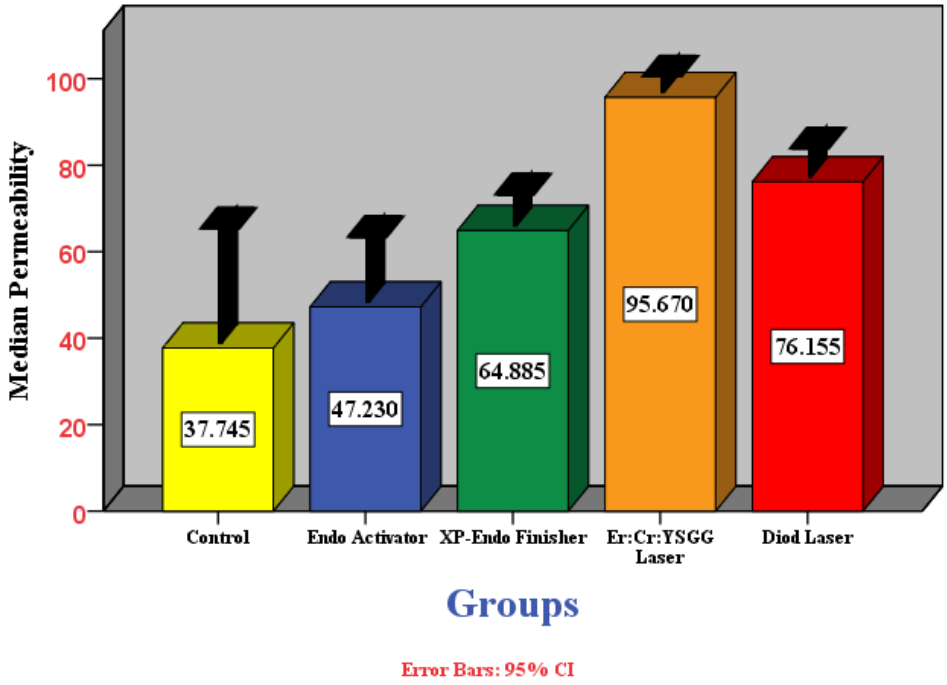
Table (3-1): descriptive and statistical test of Permeability among groups

Groups	Mean	±SD	Median	Mean Rank	Chi-square	df	Sig.
Control	46.535	33.048	37.745	58.80	26.935	4	0.000 HS
EndoActivator	48.354	31.905	47.230	59.77			
XP-endo Finisher	51.590	31.876	64.885	64.65			
Er:Cr:YSGG Laser	79.420	29.466	95.670	104.10			
Diod Laser	71.605	22.513	76.155	90.18			

HS=Highly significant at P<0.01.

Among groups as seen in a table above the highest median and mean rank percentage were presented in Erbium laser group followed by Diode laser group, and the lowest median and mean rank percentage were appeared in control group with highly significant difference among groups.

In **(Figure 3-1)** the median values of the percentage of dye penetration area among all five groups were shown:



(Figure3-1): Bar chart showing median percentage of dye penetration area

From **Figure (3-1)**, both the highest and lowest median values for percentage of dye penetration area in root canal dentin among all five groups regardless the site were seen in Er:Cr:YSGG laser group and control group respectively. The rest of median values for the other groups were fluctuating between these two values with highly significant difference between them using kruskal-wallis test.

3.1.1 The comparison of root canal dentin permeability among all groups regardless the level of the root

To compare among all groups regardless the level, multiple Mann-Whitney U test adjusted by DUNN-Bonferroni method; non-parametric test was performed to identify the presence of statistically significant difference for the percentage of dye penetration area in root canal dentin. The results were as shown in **Table (3-2).**

Table (3-2) Adjusted Multiple Mann-Whitney U test for multiple comparisons of Permeability between groups.

Groups	**Groups**	**Z**	**ES**	**Sig.**	
Control	EndoActivator	0.087	0.06	1.00	NS
Control	XP-endo Finisher	0.524	0.27	1.00	NS
Control	Er:Cr:YSGG Laser	4.059	1.45	0.000	HS
Control	Diod Laser	2.812	0.866	0.049	Sig.
EndoActivator	XP-endo Finisher	0.438	0.239	1.00	NS
EndoActivator	Er:Cr:YSGG Laser	3.972	1.621	0.001	HS
EndoActivator	Diod Laser	2.725	0.918	0.064	NS
XP-endo Finisher	Er:Cr:YSGG Laser	3.535	1.021	0.004	HS
XP-endo Finisher	Diod Laser	2.288	0.503	0.222	NS
Erbium Laser	Diod Laser	1.247	0.685	1.00	NS

NS=not significant at P>0.05, Sig. =Significant at P<0.05, HS=highly significant at P<0.01

As shown in **table (3-2)**, the highly clinical significant difference P< 0.01, can be shown between Er:Cr:YSGG laser group with control, EndoActivator, and XP-endo Finisher groups. Also there is a significant difference P< 0.05 between Diode laser group with control group. The rest comparisons between other groups there are no significant difference P> 0.05. In addition; the practical values (ES) were shown a small effect between control group with both Endoactivator and XP-endo finisher groups, where it was shown a large effect between control group with both Erbium laser and Diode laser groups.

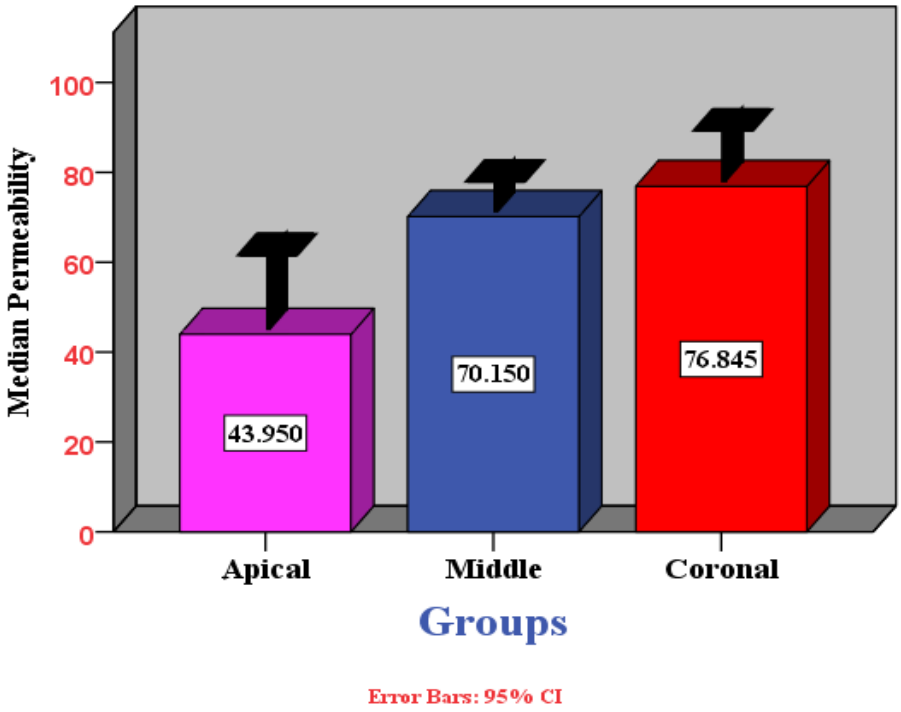
The descriptive statistical test among three levels (apical, middle and coronal) regardless the groups were shown in **Table (3-3).**

Table (3-3) Descriptive and statistical test of Permeability among sites of roots

Groups	Mean	±SD	Median	Mean Rank	Chi-square	df	Sig.
Apical	42.024	33.940	43.950	58.80	22.627	2	0.000 HS
Middle	63.165	29.740	70.150	59.77			
Coronal	73.313	25.642	76.845	64.65			

HS=highly significant at P<0.01

Comparisons were done among the three different regions, apical, middle, and coronal. The median and mean rank percentage of dye penetration were lower in the apical third section for all experimental groups compared to cervical and middle third as shown in the table above with highly significant difference between them. The median values among sites regardless the groups were shown in **figure (3-2)**:



(Figure3-2): Bar chart that represents the median percentage of dentin permeability among three sites regardless the groups.

Multiple comparisons of dentin permeability among three sites shown in **Table (3-4)**:

Table (3-4) multiple comparisons of Permeability between levels

Groups	**Groups**	**Z**	**ES**	**Sig.**	
Apical	Middle	3.11	0.645	0.006	HS
Apical	Coronal	4.672	1.051	0.000	HS
Middle	Coronal	1.560	0.360	0.356	NS
NS=not significant at P>0.05, HS=highly significant at P<0.01					

From **Table (3-4)** we can see highly clinical significant difference P<0.01 between apical with middle thirds, and also between apical with

coronal thirds, but in comparison of middle with coronal third there is no significant difference P>0.05. In addition to the practical values (ES) that were shown a medium effect between apical and middle thirds, large effect between apical and coronal thirds and small effect between middle and coronal thirds.

3.1.2: Descriptive statistics of permeability among groups within each site:-

The summary of descriptive statistical analysis among all five groups within each site (apical, middle, and coronal) shown in **Table (3-5).**

Table (3-5) Descriptive and statistical test of permeability among groups within sites

Site	Groups	Mean	±SD	Median	MR	Kruskal-Wallis#	
						Chi-square	Sig.
Apical	Control	33.216	35.348	18.785	22.200	7.856	0.097 NS
	EndoActivator	27.519	32.779	25.570	19.000		
	XP-endo Finisher	32.008	31.797	24.450	21.450		
	Er:Cr:YSGG Laser	59.118	34.324	66.955	32.450		
	Diod Laser	58.258	26.633	52.055	32.400		
Middle	Control	45.072	32.490	36.000	17.200	13.522	0.009 HS
	EndoActivator	58.339	27.750	56.985	22.300		
	XP-endo Finisher	54.560	28.446	70.215	21.100		
	Er:Cr:YSGG Laser	87.125	28.090	100.000	38.900		
	Diod Laser	70.727	14.774	73.820	28.000		
Coronal	Control	61.317	27.781	69.170	19.550	13.557	0.009 HS
	EndoActivator	59.203	26.676	55.620	17.000		
	XP-endo Finisher	68.202	26.672	75.140	22.400		
	Er:Cr:YSGG Laser	92.016	11.413	100.000	36.200		
	Diod Laser	85.829	16.791	91.990	32.350		

Df=4, NS=not significant at P>0.05, HS=Highly significant at P<0.01

The table above showed that the descriptive statistical analysis among all groups within sites, the highly median and mean rank percentage

in apical third were shown in Erbium laser and Diode laser groups respectively, and the lowest median and mean rank percentage were shown in control group, and there was no significant difference P>0.05. Consequently, in the middle and coronal thirds there is highly significant difference P<0.01 and the highly median and mean rank percentage were shown in Erbium laser and Diode laser groups. The lowest median and mean rank values were shown in control group.

3.1.2.1 Multiple comparisons of groups in middle third:-

As in apical third the clinical (p value) and practical (ES value) values would be explained in **table (3-6):**

Table (3-6) multiple comparisons of groups in the middle third.

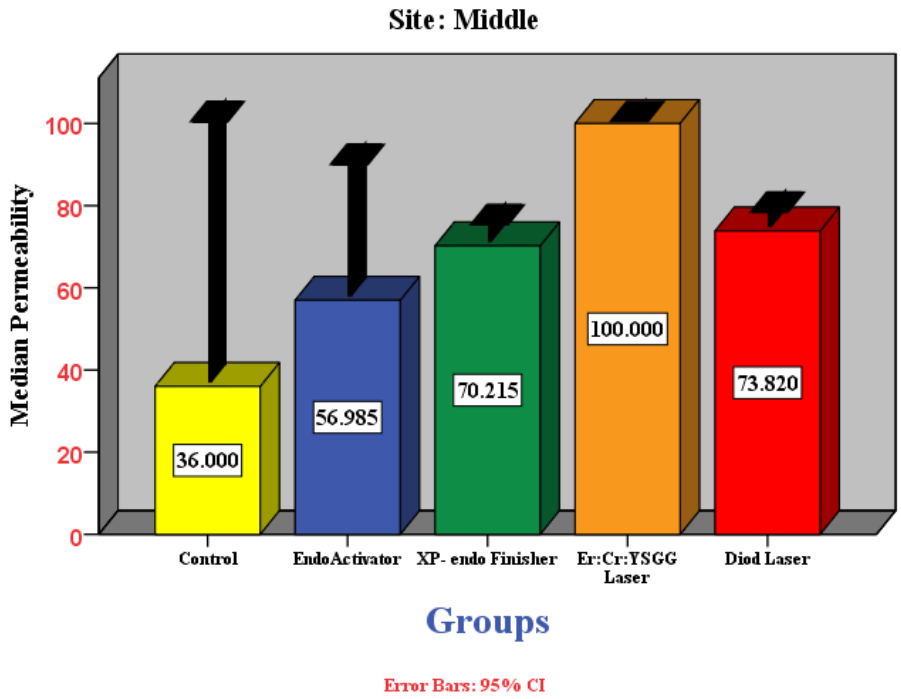
Groups	Groups	Z	ES	Sig.	
Control	EndoActivator	0.786	0.715	1.00	NS
Control	XP-endo Finisher	0.601	0.739	1.00	NS
Control	Er:Cr:YSGG Laser	3.346	3.325	0.008	HS
Control	Diod Laser	1.665	1.818	0.958	NS
EndoActivator	XP-endo Finisher	0.185	0.101	1.00	NS
EndoActivator	Er:Cr:YSGG Laser	2.560	1.571	0.105	NS
EndoActivator	Diod Laser	0.879	0.515	1.00	NS
XP-endo Finisher	Er:Cr:YSGG Laser	2.745	1.208	0.061	NS
XP-endo Finisher	Diod Laser	1.064	0.314	1.00	NS
Er:Cr:YSGG Laser	Diod Laser	1.681	1.976	0.928	NS

NS=not significan at P>0.05,HS=highly significant at P<0.01

At the middle third and from the table above, the clinical p values were shown a non-significant difference between all groups except for control group with Erbium laser group were shown a highly significant difference. While for practical values (ES) a medium effect was presented between control with both Endoactivator and XP-endo finisher groups while, there was a small effect size between Endoactivator and XP-endo

finisher groups. In addition; it was shown a large effect between the Erbium laser group and all other groups. Also the (ES) value was shown a medium effect between Endoactivator with Diode laser groups, and a small effect between XP-endo finisher with Diode laser groups.

The median values of percentage of dye penetration area at the middle third were shown in **figure (3-3).**



(Figure3-3): Bar chart that represent the median percentage of dentin permeability in middle third.

3.1.2.2 Multiple comparisons of groups in coronal third:-

Multiple comparisons of groups in coronal third would be shown in **table (3-7):**

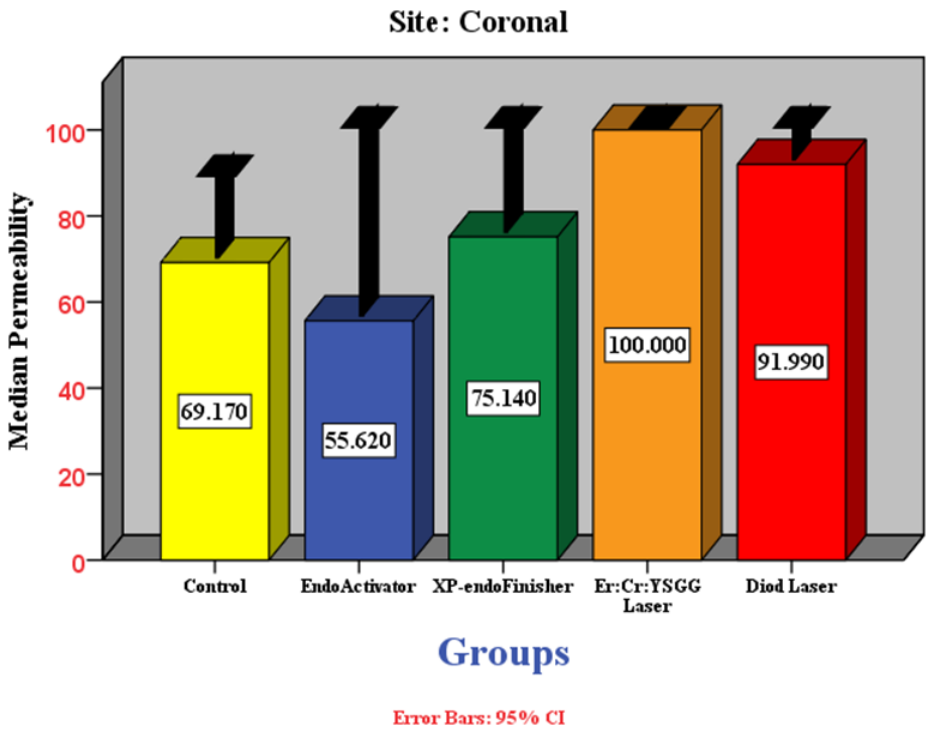
Table (3-7) multiple comparisons of groups in the Coronal third

Groups	Groups	Z	ES	Sig.	
Control	EndoActivator	0.398	0.144	1.00	NS
Control	XP-endo Finisher	0.444	0.377	1.00	NS
Control	Er:Cr:YSGG Laser	2.597	1.222	0.094	NS
Control	Diod Laser	1.996	0.907	0.459	NS
EndoActivator	XP-endo Finisher	0.842	0.829	1.00	NS
EndoActivator	Er:Cr:YSGG Laser	2.994	2.216	0.027	Sig.
EndoActivator	Diod Laser	2.394	1.491	0.167	NS
XP-endo Finisher	Er:Cr:YSGG Laser	2.152	1.579	0.314	NS
XP-endo Finisher	Diod Laser	1.552	0.875	1.00	NS
Er:Cr:YSGG Laser	Diod Laser	0.600	0.329	1.00	NS

NS=not significant at P>0.05, Sig.= significant at P<0.05.

In coronal third in contrary with other thirds there was a large (ES) value between Endoactivator and XP-endo finisher groups as shown in table (3-7). Also a large effect size (ES) between control, Endoactivator, XP-endo finisher groups (all these groups) with Erbium and Diode lasers groups. That's about the practical ES value. Now and regarding the clinical p value, there was a significant difference between Endoactivator and Erbium laser groups; while, all other groups recorded a non-significant difference.

The median values of percentage of dye penetration area at the coronal third were shown in **figure (3-4).**

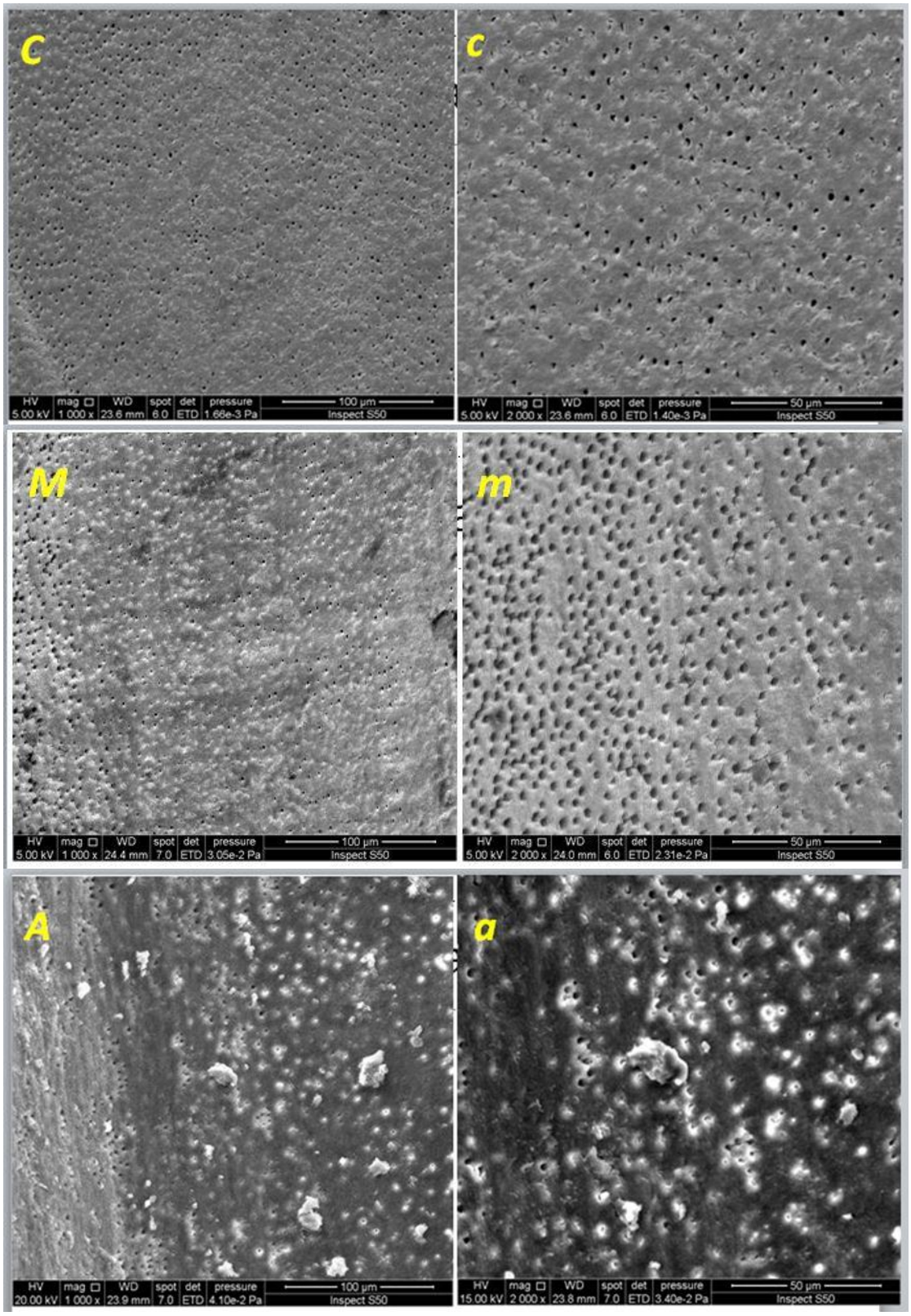


(Figure3-4): Bar chart that represent the median percentage of dentin permeability in coronal third.

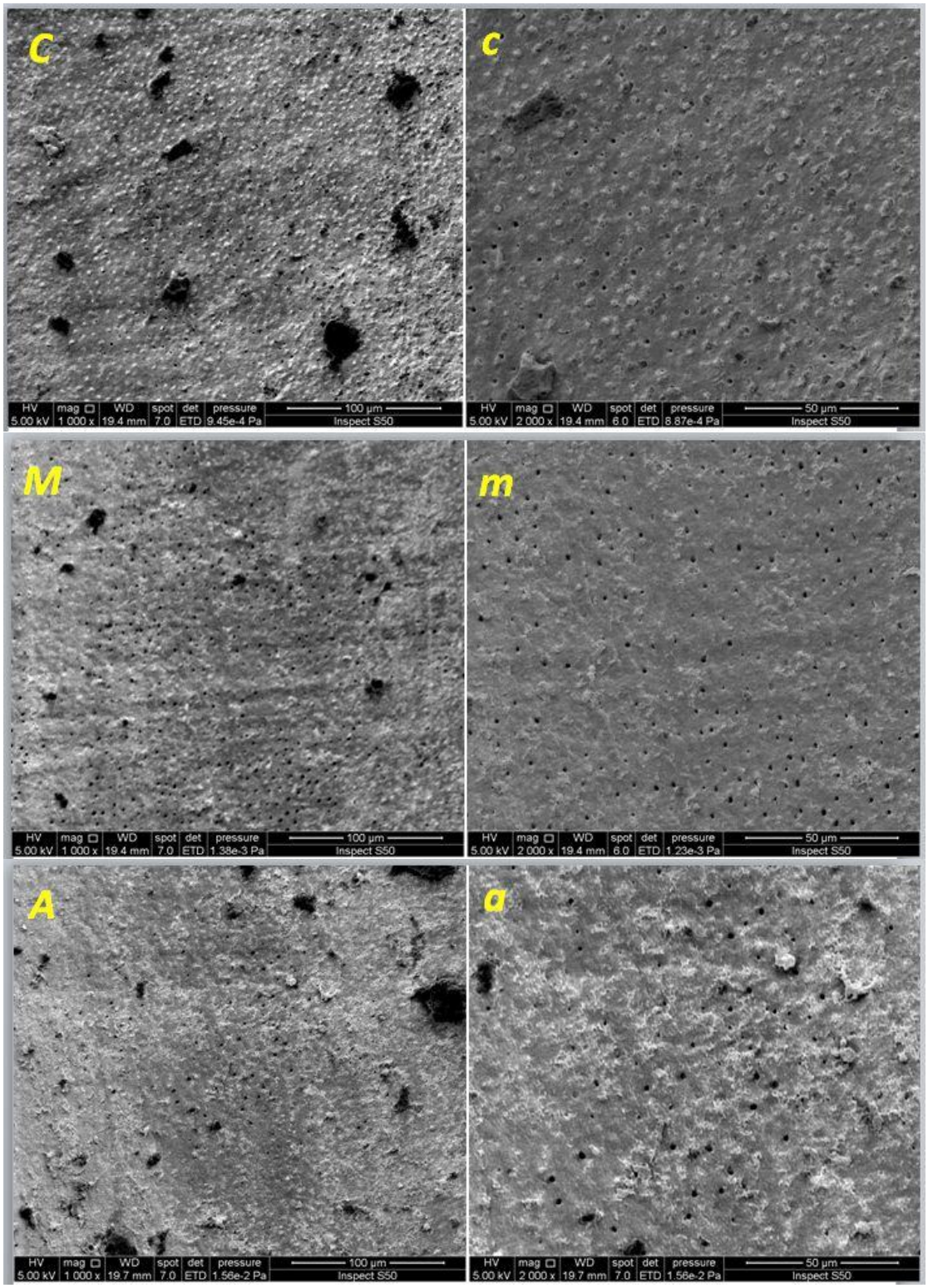
3.1.3 SEM images:

For SEM findings; The SEM findings varied in different portions of root canal, and in different groups. In control group, dentinal tubules were partially opened and clusters of smear layer were found distributed in some areas of whole tooth root especially in apical and coronal thirds and in fewer amounts in middle third. For dentin debris there is scattered remaining debris especially in apical third and in little amounts in both middle and coronal thirds. In this group the effect of EDTA was clear in removing smear layer and opening dentinal tubules partially most often in middle third rather than other thirds **(Figure 3-5).** In Endoactivator group the results were similar as in the control group, the presence of clusters of smear layer and debris especially in apical third was obvious and the dentinal tubules were partially opened as seen in **(Figure 3-6).** In group three (G3) in which the XP-endo finisher file was used a better removal of smear layer and debris can be noticed and also increase in number of

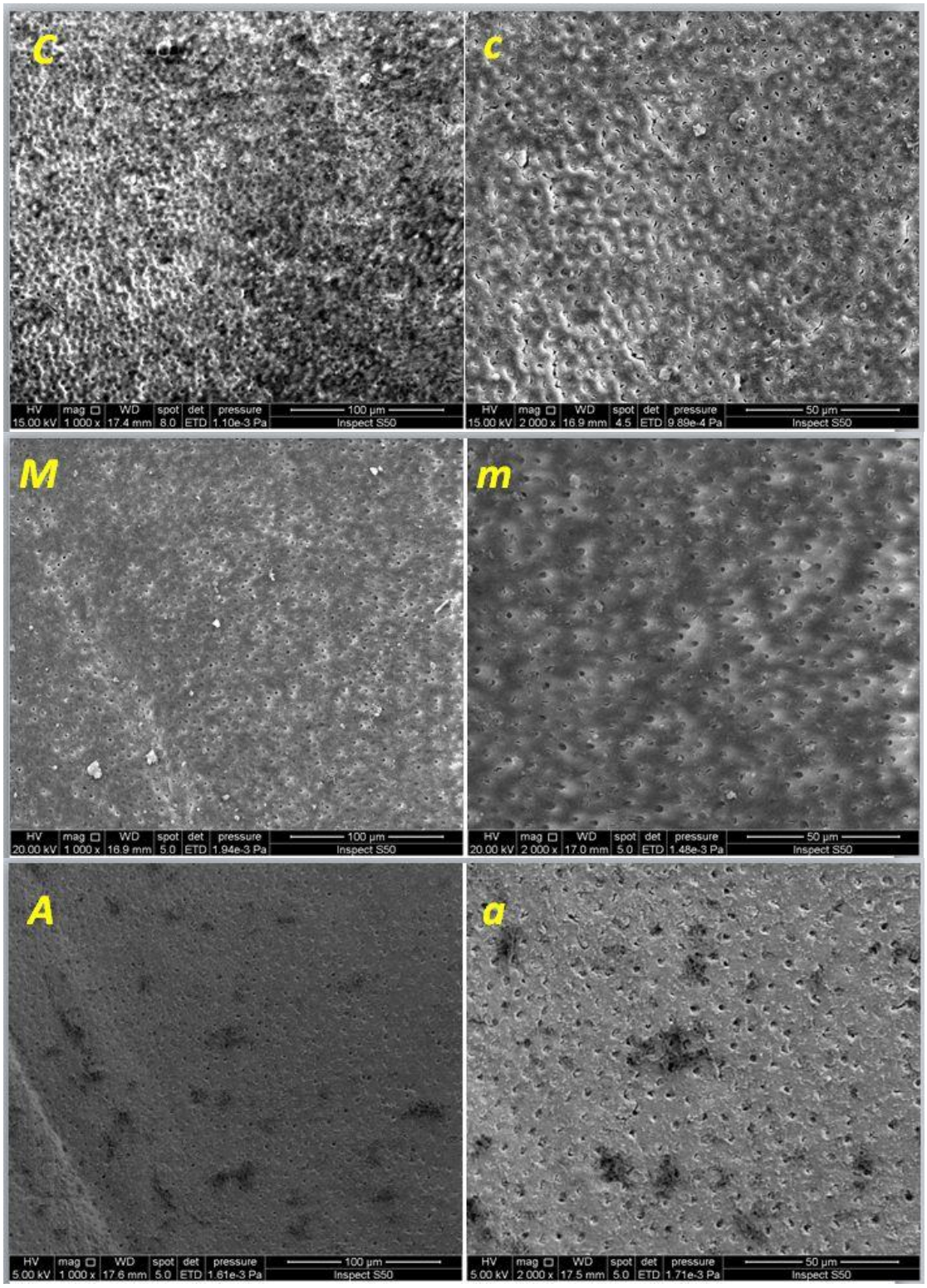
opened dentinal tubules specially in middle third but also the semilunar shape of the most of the dentinal tubules was clearly detected which mean that, they are partially occluded specially in apical and coronal thirds **(Figure 3-7).** For Erbium laser group **(G4)** the smear layer was ablated and removed at the whole root regions specifically in middle third although at the apical third the root canal dentin suffering ablation more than other areas while in the coronal third still there are some of the dentinal tubules were closed **(Figure 3-8).** For Diode laser group it was obviously seen complete smear layer removal and presence of annular shape of dentin at the whole root thirds and an obvious increase in number of opened dentinal tubules **(Figure 3-9).**



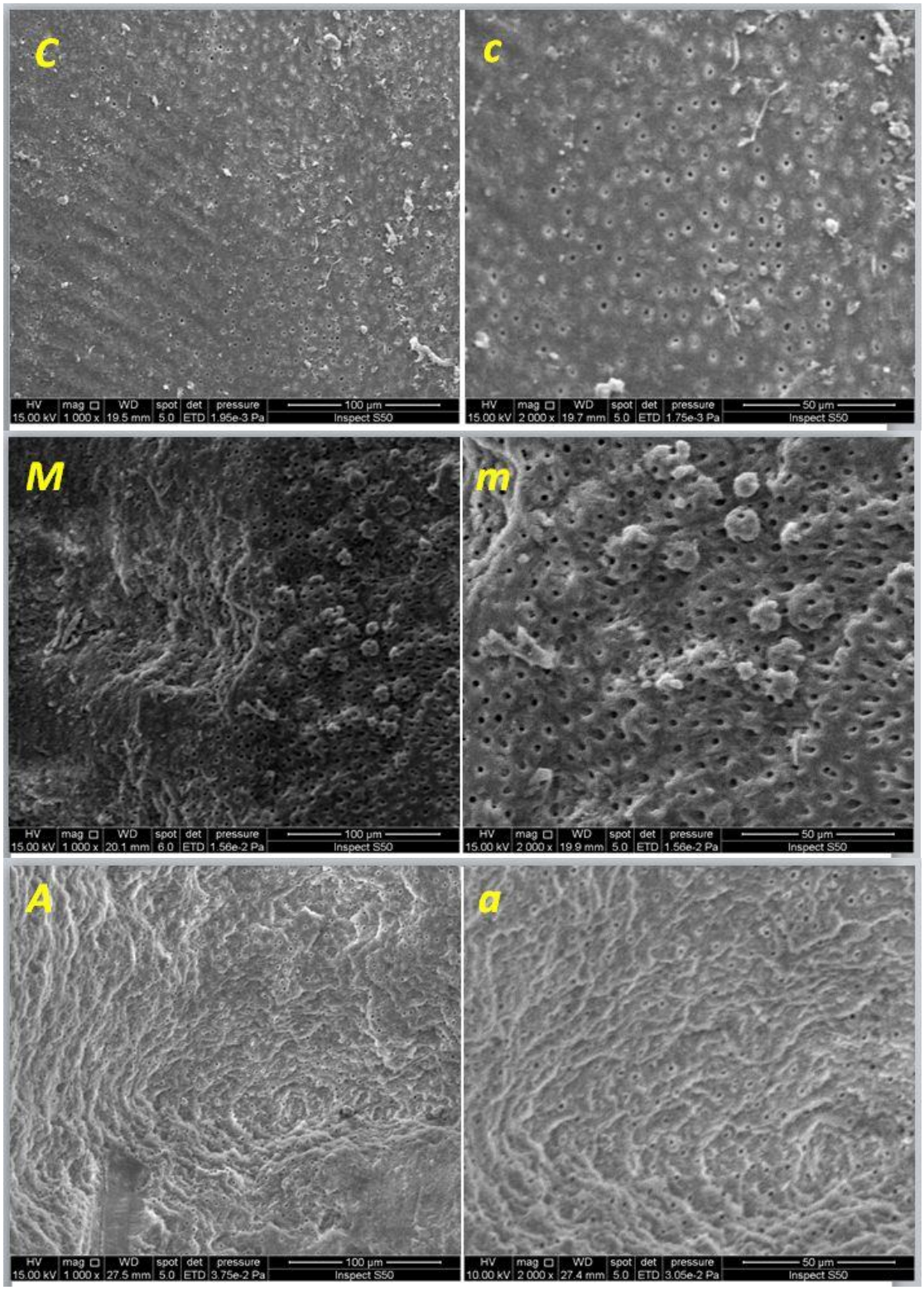
(Figure3-5) SEM images of control group C/c: coronal third at magnifying power 1000X, 2000X respectively; M/m: middle third at 1000X, 2000X magnifying power respectively; A/a apical third at same magnifying power mentioned above.



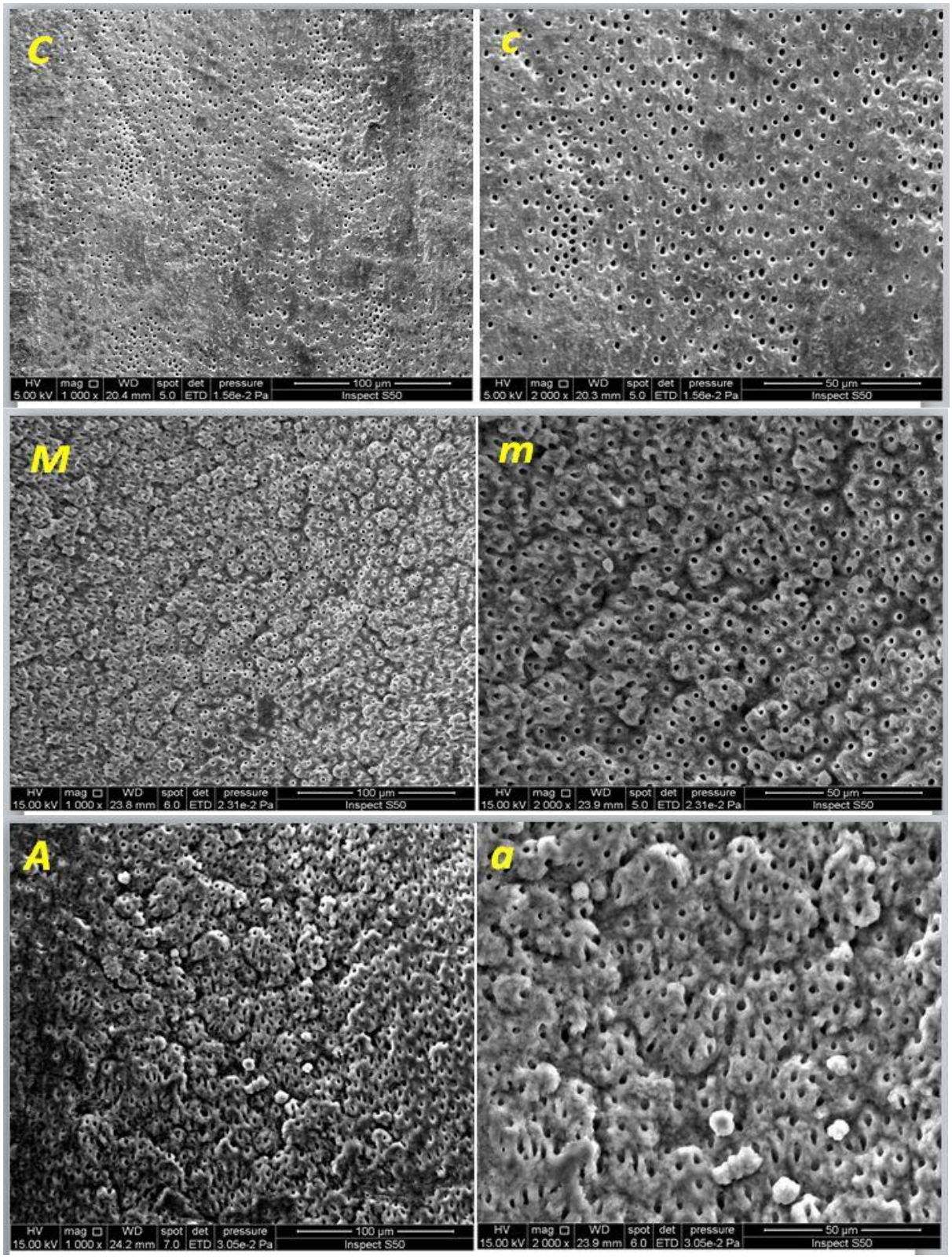
(Figure3-6) SEM images of EndoActivator group C/c coronal third at magnifying power 1000X, 2000X respectively; M/m: middle third at magnifying power 1000 X, 2000 X respectively; A/a apical third at same magnifying power mentioned above.



(Figure3-7) SEM images of XP-endo Finisher group C/c coronal third at magnifying power 1000X, 2000X respectively; M/m: middle third at magnifying power 1000 X,2000 X respectively; A/ a: apical third at same magnifying power mentioned above.



(Figure3-8) SEM images of Er:Cr:YSGG laser group C/c coronal third at magnifying power 1000X, 2000X respectively; M/m: middle third at magnifying power 1000 X,2000 X respectively; A/ a: apical third at same magnifying power mentioned above.



(Figure3-9) SEM images of 940 nm Diode laser group C/c coronal third at magnifying power **1000X**, 2000X respectively; M/m: middle third at magnifying power 1000 X, 2000 X respectively; A/ a: apical third at same magnifying power mentioned above.

3.2 Discussion:

A major goal in the treatment of infected root canal is the removal of the inner layer of contaminated dentin, by mechanical scraping of the walls of this anatomical space. Conversely, dentin surfaces may remain untouched after endodontic preparation[113, 114], so this disinfection must be achieved by the action of irrigating solutions [115].

During instrumentation, there is the production of dentin shavings, which if left in the root canal, these remnants of the necrotic tissues and microorganisms, may lead to the dispersion of infection and generation of an adverse endodontic treatment prognosis [116]. It has been demonstrated that debris accumulation and smear layer formation is a potential side effect of root canal instrumentation, and have a negative impact on the sealing ability of root canal fillings [113, 117].The smear layer which is an amorphous and irregular layer is formed on root canal walls after instrumentation. Potential detrimental effects may happen if the smear layer is not removed throughout root canal treatment [118].In cases of infected root canals, remaining debris and smear layer harbor microorganisms and their byproducts [119].

Irrigation is an important phase of endodontic treatment. In addition to antimicrobial effects and tissue dissolution, microorganisms and debris are flushed out of the root canal by the washing action of the irrigant. It has been shown that 35% or more of the canal system is untouched by endodontic instruments .Irrigants must be brought into direct contact with the entire canal area and especially with the apical portions of narrow root canals for optimal effectiveness. The penetration and flushing action of the irrigant depend not only on the anatomy of the root canal system but also on the system of delivery, the volume and fluid properties of the irrigant, and the size, type, and insertion depth of the irrigation needle [120]. It has been reported that the smear layer hindered the intracanal disinfectants and

sealers from diffusion into dentinal tubules and has the possibility of diminishing the seal of the root canal filling [121, 122]. Syringe irrigation is a typical method for root canal irrigation; however, Peeters et al. [123] in 2011 stated that, this method is not effective in the apical third of the root canal. It is difficult to entirely eliminate the remaining smear layer, especially in the apical third due to the smaller size of the apical third compared with the other regions hinders the circulation and action of the irrigating solutions [124].

As a result of all the above mentioned reasons; in this study, different irrigation systems (EndoActivator (sonic activation) and XP-endo finisher (rotary activation)) and lasers (Er:Cr:YSGG laser and Diode laser 940 nm) were compared for their effect on radicular dentin permeability and removing of smear layer. All systems were compared with the conventional irrigation method by using 5 ml syringe attached to 29 gauge irrigation needle. The systems were EndoActivator system, which depend on sonic technology for irrigation, the XP-endo finisher, Er:Cr:YSGG laser2780 nm, and Diode laser940 nm.

Root canal anatomy has many geometrical possibilities in cross section; for example: round, oval, long oval, flattened or irregular [125]. These anatomic complexities might represent physical constraints that pose a serious challenge to adequate root canal instrumentation and disinfection [126-128]. For this reason; the freshly extracted human mandibular premolar teeth were used in this study, to reduce variables through the study so the effect of different irrigation systems and lasers will be more obvious. Since most of the enlarging instruments result in circular carving motion [129], the roots were sectioned at the fourteen millimeter length perpendicular to the long axis of the root for easy handling and to facilitate straight line access for canal instrumentation and disinfection, since if the

crown is present in each tooth, it would have its own access design and to get a flat reference point for measurements [130].

Moreover, many researches stated an increase in the permeability of dentin after exposure to diode laser. These findings were mainly resulted from combining a chemical irrigant like EDTA or NaOCl with diode laser, taking into account when water was set as an irrigant solution with diode laser dye penetration that was much lower [104, 131, 132].

Because of its practical application and potential applicability, the 980-nm diode laser has been evaluated in Endodontic field [133-135]**.** The diode laser device had both CW and chopped or gated mode.

In the CW, laser energy is delivered to the tissue in an uninterrupted way, while in the chopped mode; there is a time interval among pulses that dissipates the heat [136]. When the diode laser is used in the chopped mode, the amount of energy settled in dental tissue is approximately half of the energy of the continuous way [137-139].

The dentine surface was covered by the smear layer, slightly adhered to the surface, with larger inorganic content [140], which absorbed part of the laser energy and modify the surface topography. Conversely, when the specimens treated with EDTA, the laser energy was delivered and transformed to thermal energy directly in the dentin matrix that presented a low mineral content due to the action of EDTA [141]. So that, the laser mode that was chosen for this study was CW diode laser mode 940 nm. Previous reports stated that the laser irradiation was enhanced the effect of EDTA (60 s) of treatment with laser activated irrigation plus EDTA may increase the risk of dentin erosion or damage [123, 142, 143]. It has been reported that dentin can be eroded or damaged when it was in contact with EDTA for more than 60 s. [144], for that reason, in this study the EDTA was applied for 60 s without any activation and the irrigant that received the activation method was the NaOcl only.

Er,Cr:YSGG laser recently used in endodontic treatment to shape, and clean the canal created clean dentin surface as a result of its high affinity to (–OH) in water molecules, this wavelength ablates intertubular dentin more than peritubular dentin due to lower mineral content with absence of cracking, melting, or resoldification [102, 145].

Laser energy is delivered throughout the radial firing tip (RFT) in a unique pattern and ensures more homogenous removal of smear layer, allowing better removal of smear layer compared to bare end fibers [146]. The possibility of shockwave generation with dental lasers inside the root canals and its role in smear layer removal was recently been suggested [59, 64, 147].

To avoid possible irrigant extrusion, Matsuoka et al. [148] proposed that 200- or 320-μm fibers should be kept 2–3 mm away from the anatomic apex to hinder eradication of the apical constriction, so that the laser fiber tip was applied 2 mm away from the anatomic apex.

For the evaluation of postoperative root canal cleanliness, the standard technique is the investigation of the root segments under the SEM. Several different protocols have been described for this purpose. Some of these studies are only descriptive in nature, while others use predefined scores. These scoring systems may include three scores, four scores, five scores, or even seven. Certain observer biases may occur when working under higher magnifications, as only a very small area of the canal wall can be observed [149]. The presence of debris and smear layer is evaluated from images at 200x and 1000x, respectively [119]. This study is depending on descriptive analysis of smear layer removal at 1000x and 2000x.

Permeability is an innate characteristic of dentin resulted from the presence of a large number of dentinal tubules, spreading along the whole width of dentine in both crown and root portion of the tooth. As a

sequence, dentin permeability is based on the number and dimension of tubules. Changes in dentin permeability might occur during endodontic therapy, depending on the treatment protocol applied [150].

3.2.1 Scanning electron microscope analysis and permeability evaluation at the apical and middle third:

For this study, SEM results for diode laser group, the images showed an increase in the number of the opened dentinal tubules in middle and apical parts **(Fig 3-9)** of the root when irradiated with 36 s of diode laser. These results came in accordance with Arslan et al. [151] SEM micrographs; which showed an increase in the number of the opened dentinal tubules in middle and apical parts of the root when irradiated with 20 s of diode laser.

The mechanism for the laser activation of irrigating solutions originates from the absorption of laser energy, the formation of vapor bubbles, the collapse of the bubbles, acoustic streaming, and finally cavitation. Current study results came in accordance also with the results of Wang [152] who reported that diode lasers clean the apical third more effectively than middle third due to the narrow space and melting of the smear layer. while it disagreed with Parirokh et al. [153] who stated that in apical part of the root, most of the dentinal tubules were closed due to dentine melting in the narrow canal. The different wavelength and power settings and irradiation duration might explain the difference between the two studies. This wavelength (940 nm) irradiation was done in a speed of 1 mm/s to irradiate a whole root and the results showed that laser activation removed more smear layer than other groups, which means, agitation of irrigant during root canal treatment is important to facilitate mechanical efficacy of irrigation and the removal of the smear layer.

Current study results also came in agreement with Saraswathi [154] who noticed a better removal of smear layer when agitated NaOCl with laser.

In this wavelength limit, some of the energy is absorbed by the mineral structures of dentine such as phosphate and carbonate, the laser thermal ablation caused disturbance of its crystal arrangement which appear as melting of smear layer. This became more clear when laser power increased[155]

For dentin permeability results of diode laser group, there was an increase in median and mean rank in the middle and apical thirds compared with the control, EndoActivator, and XP-endo groups. The increase in dentin permeability may facilitate the penetration of chemical solutions and improve the treatment success rate.

The SEM results come in along with Alfredo's work [155], and also with Saraswathi [154]. In SEM images, the control group where roots were not activated, the least number of dentinal tubules was opened and the some areas were covered with smear layer although the EDTA has the ability to remove the inorganic material of smear layer and has limited bactericidal action on the surface [156, 157].

It seems to be difficult to completely remove smear layer, particularly in the apical third of the root because the smaller size of the apical third (compared with the other thirds) hinders the circulation and action of the irrigating solutions and vapor lock formation [151]. Clinically, the root is enclosed by the bone socket, and the canal behaves as a closed-end channel. This situation results in gas entrainment at the end of this region, producing a vapor lock effect during conventional irrigation procedure. In the present study, all groups treated with EDTA exhibited smear layer removal in some areas of the canal mainly in the middle third, regardless of the agitation technique used.

The findings in this study regarding the results of XP-endo Finisher file in smear layer removal can be attributed to its metallurgy. The development and manufacture of XP-endo Finisher files are dependent on the shape-memory principles of the NiTi alloy. The file is straight in its martensitic phase which is formed when it is cooled. When the file is subjected to the body temperature (the canal) it will convert its shape because of its shape-memory to the austenitic phase. It has been claimed by the manufacturer that the austenitic phase shape in the rotation mode permits the file to contact and clean areas that are otherwise difficult to reach with regular instruments[58]. Even though in current study, neither the smear layer was completely removed nor the dentinal tubules opened clearly compared to the cavitational effect formed by laser activated irrigation. For SEM images of XP-endo finisher group the dentinal tubules were appeared in sickle shape at the apical and middle thirds **(Fig. 3-7)**.

For EndoActivator group the reduced cleaning efficiency of the EndoActivator compared with the laser activation in this study is supported by the results obtained by Jiang L et al. [158]. When EndoActivator tip is placed in the apical level, there is a certain amount of dampening happens when there is contact with the canal walls. This inhibits the free oscillation of the sonic tip, reducing the efficient streaming of the irrigant **(Fig. 3-6)**.

These results was achieved more via statistical results of percentage of net dye penetration area and confirmed by SEM images. Even with reduced cleaning efficiency of EndoActivator group compared with XP-endo finisher group but statistically there is no significant difference between them, these results came in accordance with Elnaghy et al., 2017 [108], who found that there is no statistically significant difference between the two systems in debris and smear layer removal.

For Erbium laser group vapor bubbles form when laser energy is absorbed by irrigant solution, which can cause a volume expansion that is

1600 times the original volume and then collapse and cause an acoustic streaming which in order, causes the cavitation effect [159].

3.2.2 Scanning electron microscope analysis and permeability evaluation at the coronal third:

In general the coronal third SEM images show less number of open dentinal tubules compared with the middle third as a result of wide area and a decrease in the effect of the irrigation systems on the dentin. However for permeability experiment the coronal third showed the highly mean and median percentage regardless the group, the results explanation according to Teixeira study [160], in coronal and middle parts, the size of the dentinal orifices is larger than in apical part; this may permit the entrance of the methylene blue dye more easily inside the tubules even with few number of DT.

For the diode laser group the presence of flat dentin surface indicated that the less effect of laser radiation but also, can be noticed that, the presence of clean dentin surface and opened dentinal tubules in a little difference with middle third. For Erbium laser group, the same as for the diode laser group, it seems to have weak effect at the coronal level, may be due to the large area of the pulp chamber so that, the least number of opened dentinal tubules were appeared compared with middle third of the same group.

For XP-endo finisher and EndoActivator groups at the coronal level, the results were stunning mostly closed dentinal tubules or partially opened this may be due to reentering the debris and dentin fragments inside when the tip was in contact with the root canal wall instead of flushing them out.

3.3 Conclusion

Under the condition of this proposed methodology and based on the findings of this study, the following conclusions could be obtained:

1. Regarding a smear layer removal depending on SEM findings:

a- Diode laser group revealed a unique pattern of radicular dentin free of smear layer, with preservation of dentinal tubules morphology and absence of any thermal side effects.

b- Direct laser irradiation accompanied with cavitation effect done by laser activation of irrigants (diode laser or Er:Cr:YSGG laser) was the most effective protocol in removing smear layer from the entire root canal wall.

c- Mechanical devices (Endoactivator or XP-endo finisher) achieved more effective smear layer removal and more homogenous distribution of the irrigants than control group with breakup of the vapor lock action.

2. Regarding dye penetration:

a- Maximum percentage of dye penetration was observed in Erbium laser group due to laser ablative effect.

b- The percentages of dye penetration of the other experimental groups (diode laser, XP-endo finisher and endoactivator) groups were close to each other. Statistically there was no significant difference; this means that all the used activation protocols led to increase dentin permeability and their effect were clear mainly in the middle third.

3.4 Suggestions for Future Studies

1. Further study for the conjugation of laser with different irrigants like hydrogen peroxide and phosphoric acid.
2. Studying the temperature elevation inside the canal and on the surface using Erbium and Diode laser assisted root canal treatment.
3. Studying the bacterial interaction with the use of the same devices and protocol for all groups.
4. Studying the amount of extruded materials through the apical foramen by using the same devices and protocol for all groups.
5. Research work to determine laser dosage in laser assisted endodontic treatment.
6. Further long-term clinical studies are required to assess the applicability of using these lasers in vivo.

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Appendices

Appendices

Appendix 1: Calculation procedure for the ratio of dye penetration area of the control group, a: coronal third; b: middle third; and c: apical third.

	G1 a					
No.	**total**	**dye**	**canal**	**tot-can**	**dye-can**	**ratio**
1	2	2	1	1	1	100
2	14.6409	13.1483	1.3526	13.2883	11.7957	88.77
3	16.0338	13.425	1.0148	15.019	12.4102	82.63
4	21.6118	7.7382	1.5186	20.0932	6.2196	30.95
5	19.9513	14.2417	1.7158	18.2355	12.5259	68.69
6	18.4925	7.455	0.8513	17.6412	6.6037	37.43
7	17.9607	6.7591	1.5354	16.4253	5.2237	31.80
8	22.5849	16.6221	2.9408	19.6441	13.6813	69.65
9	17.1147	13.9924	1.7992	15.3155	12.1932	79.61
10	18.8878	5.6272	1.5222	17.3656	4.105	23.64
						61.32

	G1 b					
No.	**total**	**dye**	**canal**	**tot-can**	**dye-can**	**ratio**
1	2	2	1	1	1	100
2	10.4164	5.8216	0.5351	9.8813	5.2865	53.50
3	10.6731	1.0061	0.5803	10.0928	0.4258	4.22
4	14.0339	5.8071	0.7529	13.281	5.0542	38.06
5	13.2537	4.4494	0.4149	12.8388	4.0345	31.42
6	18.3219	4.7133	0.8799	17.442	3.8334	21.98
7	20.8903	4.5445	1.2491	19.6412	3.2954	16.78
8	16.2364	9.0463	1.6166	14.6198	7.4297	50.82
9	2	2	1	1	1	100.00
10	11.9845	4.4569	0.5894	11.3951	3.8675	33.94
						45.07

	G1 c					
No.	**total**	**dye**	**canal**	**tot-can**	**dye-can**	**ratio**
1	8.7334	5.5058	0.3135	8.4199	5.1923	61.67
2	6.4259	0.4721	0.2077	6.2182	0.2644	4.25
3	2	1	1	1	0	0.00
4	6.8371	4.1509	0.4377	6.3994	3.7132	58.02
5	11.8533	0.9267	0.2511	11.6022	0.6756	5.82
6	26.1472	3.6508	1.1042	25.0430	2.5466	10.17
7	2	1	1	1	0	0.00
8	11.5714	7.863	1.0277	10.5437	6.8353	64.83
9	2	2	1	1	1	100.00
10	8.4541	2.5396	0.3076	8.1465	2.2320	27.40
						33.22

Appendix 2: Calculation procedure for the ratio of dye penetration area of the Endoactivator group, a: coronal third; b: middle third; and c: apical third.

	G2 a					
No.	**total**	**dye**	**canal**	**tot-can**	**dye-can**	**ratio**
1	2	2	1	1	1	100.00
2	7.9652	6.0081	0.3587	7.6065	5.6494	74.27
3	10.5715	6.3007	1.0081	9.5634	5.2926	55.34
4	9.8262	6.268	0.4626	9.3636	5.8054	62.00
5	22.8064	11.5257	2.9101	19.8963	8.6156	43.30
6	2	2	1	1	1	100.00
7	22.5445	7.3885	1.5574	20.9871	5.8311	27.78
8	20.3941	11.692	0.6631	19.731	11.0289	55.90
9	19.3911	4.9851	1.3987	17.9924	3.5864	19.93
10	21.563	12.426	1.9087	19.6543	10.5173	53.51
						59.20

	G2 b					
No.	**total**	**dye**	**canal**	**tot-can**	**dye-can**	**ratio**
1	1.4575	1.2756	0.06	1.3975	1.2156	86.98
2	6.1716	3.9808	0.2695	5.9021	3.7113	62.88
3	8.2656	3.9234	0.5975	7.6681	3.3259	43.37
4	4.9588	4.4665	0.2492	4.7096	4.2173	89.55
5	13.9117	7.6751	1.1604	12.7513	6.5147	51.09
6	2	2	1	1	1	100.00
7	18.3592	4.129	1.5154	16.8438	2.6136	15.52
8	14.1753	5.7573	0.5014	13.6739	5.2559	38.44
9	11.3713	3.726	0.4894	10.8819	3.2366	29.74
10	13.9216	9.3595	0.5731	13.3485	8.7864	65.82
						58.34

	G2 c					
No.	**total**	**dye**	**canal**	**tot-can**	**dye-can**	**ratio**
1	1	1	1	0	0	0.00
2	1	1	1	0	0	0.00
3	4.6507	3.1232	0.3494	4.3013	2.7738	64.49
4	1	1	1	0	0	0.00
5	8.9502	2.8065	0.8087	8.1415	1.9978	24.54
6	2	2	1	1	1	100.00
7	9.2435	3.1088	0.5703	8.6732	2.5385	29.27
8	10.9975	3.5421	0.3033	10.6942	3.2388	30.29
9	1	1	1	0.0000	0.0000	0.00
10	8.6581	2.5354	0.3164	8.3417	2.2190	26.60
						27.52

Appendix 3: Calculation procedure for the ratio of dye penetration area of the XP-endo finisher group, a: coronal third; b: middle third; and c: apical third.

	G3 a					
No.	**total**	**dye**	**canal**	**tot-can**	**dye-can**	**ratio**
1	2.932	2.2981	0.2388	2.6932	2.0593	76.46
2	19.1644	6.3407	1.3025	17.8619	5.0382	28.21
3	2	2	1	1	1	100.00
4	4.6778	3.5907	0.5254	4.1524	3.0653	73.82
5	26.1573	6.6392	1.6937	24.4636	4.9455	20.22
6	4.0171	2.6787	0.338	3.6791	2.3407	63.62
7	2	2	1	1	1	100.00
8	15.6889	12.4427	1.4349	14.254	11.0078	77.23
9	24.104	20.3268	2.4083	21.6957	17.9185	82.59
10	16.3752	10.1946	0.9746	15.4006	9.22	59.87
						68.20

	G3 b					
No.	**total**	**dye**	**canal**	**tot-can**	**dye-can**	**ratio**
1	2.3408	1.7355	0.1578	2.183	1.5777	72.27
2	16.694	2.476	0.822	15.872	1.654	10.42
3	14.5929	11.5325	0.7161	13.8768	10.8164	77.95
4	2.4723	1.7839	0.2474	2.2249	1.5365	69.06
5	20.3558	4.71	1.0838	19.272	3.6262	18.82
6	3.0476	0.5147	0.1741	2.8735	0.3406	11.85
7	18.4753	13.571	1.3475	17.1278	12.2235	71.37
8	10.9968	8.4956	1.0502	9.9466	7.4454	74.85
9	7.7481	5.3586	0.6566	7.0915	4.702	66.30
10	8.3422	6.1949	0.4733	7.8689	5.7216	72.71
						54.56

	G3 c					
No.	**total**	**dye**	**canal**	**tot-can**	**dye-can**	**ratio**
1	1.1864	0.1752	0.0493	1.1371	0.1259	11.07
2	2	1	1	1	0	0.00
3	2	1	1	1	0	0.00
4	1.1537	0.4964	0.0965	1.0572	0.3999	37.83
5	13.8506	1.7976	0.7663	13.0843	1.0313	7.88
6	2	1	1	1	0	0.00
7	10.4474	6.7558	0.8805	9.5669	5.8753	61.41
8	6.8008	5.6686	0.6946	6.1062	4.9740	81.46
9	5.5314	3.1509	0.3244	5.2070	2.8265	54.28
10	5.3048	3.578	0.203	5.1018	3.3750	66.15
						32.01

Appendix 4: Calculation procedure for the ratio of dye penetration area of the Erbium laser group, a: coronal third; b: middle third; and c: apical third.

	G4 a					
No.	**total**	**dye**	**canal**	**tot-can**	**dye-can**	**ratio**
1	2	2	1	1	1	100.00
2	2	2	1	1	1	100.00
3	21.0175	16.3278	1.8132	19.2043	14.5146	75.58
4	9.1322	6.8048	0.8583	8.2739	5.9465	71.87
5	2	2	1	1	1	100.00
6	2	2	1	1	1	100.00
7	9.0408	7.5791	1.193	7.8478	6.3861	81.37
8	2	2	1.0000	1	1	100.00
9	2	2	1	1	1	100.00
10	24.9603	22.9588	1.8438	23.1165	21.115	91.34
						92.02

	G4 b					
No.	**total**	**dye**	**canal**	**tot-can**	**dye-can**	**ratio**
1	2	2	1	1	1	100.00
2	2	2	1	1	1	100.00
3	15.4262	12.3286	1.6315	13.7947	10.6971	77.54
4	2	2	1	1	1	100.00
5	2	2	1	1	1	100.00
6	2	2	1	1	1	100.00
7	2	2	1	1	1	100.00
8	2	2	1.0000	1	1	100.00
9	2.502	2.0904	0.0875	2.4145	2.0029	82.95
10	14.689	2.1554	0.6444	14.0446	1.511	10.76
						87.13

	G4 c					
No.	**total**	**dye**	**canal**	**tot-can**	**dye-can**	**ratio**
1	2	2	1	1	1	100.00
2	2.7039	2.0236	0.1147	2.5892	1.9089	73.73
3	8.3465	5.4733	0.9771	7.3694	4.4962	61.01
4	2.5411	2.1031	0.1892	2.3519	1.9139	81.38
5	1	0	1	0	-1	0.00
6	10.4641	5.4419	0.96	9.5041	4.4819	47.16
7	2	2	1	1	1	100.00
8	6.8227	5.0717	0.3619	6.4608	4.7098	72.90
9	1.8641	0.8947	0.0527	1.8114	0.8420	46.48
10	9.9825	1.303	0.4943	9.4882	0.8087	8.52
						59.12

Appendix 5: Calculation procedure for the ratio of dye penetration area of the Diode laser group, a: coronal third; b: middle third; and c: apical third.

	G5 a					
No.	**total**	**dye**	**canal**	**tot-can**	**dye-can**	**ratio**
1	2	2	1	1	1	100.00
2	19.1279	12.9722	1.835	17.2929	11.1372	64.40
3	2	2	1	1	1	100.00
4	2	2	1	1	1	100.00
5	2	2	1	1	1	100.00
6	8.9996	6.4093	0.8002	8.1994	5.6091	68.41
7	2	2	1	1	1	100.00
8	11.2588	9.5742	0.7406	10.5182	8.8336	83.98
9	20.7357	17.4885	1.3449	19.3908	16.1436	83.25
10	20.6652	12.7361	1.6749	18.9903	11.0612	58.25
						85.83

	G5 b					
No.	**total**	**dye**	**canal**	**tot-can**	**dye-can**	**ratio**
1	2	2	1	1	1	100.00
2	13.5347	8.4289	1.3636	12.1711	7.0653	58.05
3	12.7382	6.2917	0.5033	12.2349	5.7884	47.31
4	11.598	9.0326	0.666	10.932	8.3666	76.53
5	15.6533	12.349	1.0382	14.6151	11.3108	77.39
6	10.5714	7.7831	0.8776	9.6938	6.9055	71.24
7	15.2122	11.802	0.7633	14.4489	11.0387	76.40
8	9.7592	7.6982	0.4195	9.3397	7.2787	77.93
9	15.1663	10.2944	0.643	14.5233	9.6514	66.45
10	15.1847	8.8947	0.8993	14.2854	7.9954	55.97
						70.73

	G5 c					
No.	**total**	**dye**	**canal**	**tot-can**	**dye-can**	**ratio**
1	8.2258	7.0913	0.7265	7.4993	6.3648	84.87
2	9.5883	5.8492	0.9319	8.6564	4.9173	56.81
3	16.1881	4.1534	0.5428	15.6453	3.6106	23.08
4	5.9421	2.7993	0.4742	5.4679	2.3251	42.52
5	2	2	1	1	1	100.00
6	5.9954	4.6768	0.5222	5.4732	4.1546	75.91
7	11.8337	5.8317	0.4453	11.3884	5.3864	47.30
8	8.618	7.2567	0.4360	8.1820	6.8207	83.36
9	8.2254	2.1414	0.2878	7.9376	1.8536	23.35
10	9.7698	4.6646	0.4228	9.3470	4.2418	45.38
						58.26

وزارة التعليم العالي والبحث العلمي

جامعة بغداد

معهد الليزر للدراسات العليا

تأثير ليزرات (٩٤٠ نانومتر و ٢٧٨٠ نانومتر) و بعض أجهزة تفعيل مادة سقي قناة الجذرعلى نفاذية العاج وازالة طبقة اللطاخة (دراسة مختبرية)

رسالة مقدمة الى

معهد الليزر للدراسات العليا /جامعة بغداد /لاستكمال متطلبات نيل شهادة ماجستير علوم في الليزر/ طب الاسنان

من قبل

رؤى محمد فاضل المفرجي

بكالوريوس طب وجراحة الفم والاسنان ٢٠٠٩

بإشراف

الأستاذ المساعد الدكتور لطفي غلام عوازلي

١٤٣٩هـ **٢٠١٧م**

الخلاصة

مقدمة: تنظيف وتنظيم شكل قناة جذر السن يعتبر خطوة مهمة في اجراء علاج عصب السن، وبما ان التنظيف الميكانيكي ينتج عنه مخلفات عاج السن والتي تسمى "بطبقة اللطاخة" التي تعيق تخلخل مادة السقي الى داخل قنوات السن وبذلك تحد من عملية التعقيم وبالتالي التصاق مادة الحشوة مع عاج السن، وعليه الكثير من الدراسات اشارت الى ضرورة ازالة "طبقة اللطاخة".

الهدف: هدف هذه الدراسة هو لأختبار ومقارنة تأثير كل من ليزر الاربيوم ذو الطول الموجي ٢٧٨٠ نانومتر، و ليزر الدايود ذو الطول الموجي ٩٤٠ نانومتر، و جهاز الاهتزاز الصوتي اندواكتفيتر، واخيرا الفايل الدوار XP على ازالة طبقة اللطاخة عن طريق فحص نفاذية العاج الجذري و فحص المجهر الالكتروني الماسح.

الطريقة: مجموعة عددها (٧٠) سبعين سن احادي الجذر من الضواحك السفليه للانسان، سليمة خالية من التسوس، قلعت لاغراض التقويم. حضرت قنوات جذور الاسنان ميكانيكاً وقسمت الى خمسة مجاميع حسب طريقة السقي كل مجموعة مكونة من اربعة عشر (١٤) عينة. المجكوعة الضابطة واربعة مجاميع تجريبية طريقة سقيها بالاجهزة على التوالي: الاهتزاز الصوتي "اندو اكتفيتر"، الفايل الدوار XP، ليزر الاربيوم، وليزر الدايود. بعد ذلك عزلت العينات من الخارج بطلاء الاظافر واغلقت فتحة ذروة الجذر بواسطة الشمع، ثم قطعت عرضيا الى ثلاثة اقسام و فحصت بواسطة المجهر وتم تحليل الصور بالبرنامج الالكتروني، اضافة الى ذلك خضعت اربعة عينات من كل مجموعة لفحص المجهر الالكتروني الماسح.

النتائج: أظهرت النتائج اختلافا احصائيا واضحا بين مجموعة ليزر الاربيوم وباقي المجاميع ماعدا مجموعة ليزر الدايود حيث لم يظهر بينها وبين مجموعة الاربيوم اختلافاً احصائياً واضحاً. بالنسبة لصور المجهر الالكتروني الماسح، حيث اظهرت مجموعة الدايود ازالة واضحة لطبقة اللطاخة.

الاستنتاجات: اعتمادا على نتائج هذه الدراسة المخبرية تم استنتاج ذلك، ان استخدام ليزر الدايود ذو الطول الموجي ٩٤٠ نانومتر وبقوة ١.٧ واط وبسرعة ١ ملم/ثانية لغرض تحفيز السقي داخل قناة الجذر، كان فعالا في ازالة "طبقة اللطاخة" من دون ظهور علامات تدل على اذابة تركيب الجذر، اما ليزر الاربيوم فقد قام بازالة طبقة اللطاخة عن طريق استئصال اجزاء من عاج السن. من جهة اخرى فان كل مجموعات الاختبار كانت افضل من المجوعة الضابطة في ازالة طبقة اللطاخة مما يدل على ان استخدام اجهزة تحفيز السقي في علاج العصب أساسي.