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Endodontic Therapy Using Er,Cr:YSGG Laser: Clinical and Confocal Laser Microscope Study

A thesis Submitted

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By

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بسم الله الرحمن الرحيم

﴿ يَرْفَعِ اللَّهُ الَّذِينَ آمَنُوا مِنكُمْ وَالَّذِينَ أُوتُوا الْعِلْمَ دَرَجَاتٍ وَاللَّهُ بِمَا تَعْمَلُونَ خَبِيرٌ ﴾

صدق الله العلي العظيم

سورة المجادلة الآية رقم 11

Certification

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Dedication

To my darling parents who taught me & show me the road of success

To my lovely wife who push me for glory

To my kids, the joy of my life

With deep love and regards

Ali

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Abstract

The prime objective of endodontic therapy is to eradicate bacteria and other microorganisms from radicular dentine. Many studies have been done and different armamentariums are employed to serve this purpose but still further researches are required to approximate perfection. The ErCr:YSGG laser is proved in earlier vitro studies of being a promised apparatus on the part of removal the smearlayer and root canal disinfection. Till now there is no rigid clinical study of statistical significance results enhance the use of Er,Cr:YSGG laser in minimally invasive endodontic. The aim of the study is to enhance endodontic treatment for patients who are diagnosed with different Apical diagnoses by using ErCr:YSGG laser and minimally invasive technique in single visit root canal treatment, assisted by confocal laser microscope study.

The samples used for confocal laser microscope investigation are composed of 30 extracted-human teeth of single root which were decrownated at the CEJ. Root canal treatment was performed for all samples using ProTaper Next rotary instruments. The apical size of all the specimens was instrumented up to X4. The samples were divided into six groups, smear layer was removed in four groups by either Er,Cr:YSGG Laser or EDTA and the remaining two group act like a control. Then, all the samples were obturated by one or the other techniques (carrier-based ,lateral compaction). AH plus sealer was used which was mixed with Rhodamine B fluorescence dye. After performing confocal laser microscope study, the clinical study was conducted and the EDTA was no longer used in the clinical study.

The study group was composed of 40 patients who were indicated for root canal treatment and diagnosed having apical periodontitis. An

informed-consent form was signed by all patients before being involved into the study. The selected patient teeth were permanent first molars. Cleaning and shaping started according to minimal invasive endodontic by using ProTaper Next instruments. The ‘push-pull’ preparation technique was used up to X2 for mesial or bucall root canals and X3 for distal or palatal canals with 5% NaOCl irrigation. Subsequently, Smear layer was removed for all persons by using Er,Cr:YSGG laser at 2780 nm wavelength with a radial firing tips RFT2 and RFT3. The running parameters were: 1.25 W average power, 20 Hz pulse repletion rate, 60μs pulse duration; 30%Air; 10%Water. After laser irradiation, a final irrigation was done with 5ml of Saline solution. Then, laser disinfection was done using Tip: RFT2, 1 W average power, 20 Hz pulse repletion rate, 60μs pulse duration; 10%Air; and without Water. The subjects were divided into two groups; the first one was obturated with carrier-based technique, while in second group, cold-lateral compaction was used. AH-Plus sealer was the sealer for both groups. Healing of the different apical periodontitis cases was evaluated clinically and radiographically along six months period. The clinical part of estimation depends on the signs and symptoms. While, the other part builds upon Periapical index (PAI) scoring.

Conforming to Confocal laser microscopy study, significantly found that the depth of the sealer-penetration in the bucco-lingual direction was greater than the mesio-distal one in all groups. In overall statistical comparison between all groups, significant-differences were noticed in G1 with all groups (at $P \leq .01$), and between G2 and G4,G5,G6, indicating that smear layer removal by laser at fluence 7.96 J/Cm^2 was correlated to maximum sealer-penetration (1234.25μm) specially with carrier based obturation-technique.

According to ErCr:YSGG laser assisted minimally invasive endodontic therapy, the prognosis of healing rates was compared temporally for all patients who were followed up at three recall periods at 1month, 3months, and 6months after endodontic therapy. The success of root canal treatment for these periods was 67.5%, 82.5%, and 97.5%, respectively. Form the first month after endodontic treatment, the prognosis of treatment was promised.

In conclusion, The using of confocal laser microscope assists and improve the efficacy of ErCr:YSGG laser in removing the smear layer, depending on clear and highly-contrast fluorescence images of labeled sealer which penetrate the dentinal tubules.

The minimally invasive endodontic therapy with the smear layer removal and disinfection of the ErCr:YSGG laser of 7.96 J/Cm^2 fluence delivered by radial-firing-tips can enhance the treatment of patients who diagnosed with different apical diagnoses in single visit root canal treatment.

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List of Abbreviations

Abbreviations	Term
Er,Cr,:YSGG	Erbium, chromium:yttrium–scandium–gallium–garnet
CO_2	Carbon dioxide
CW	Continuous wave
°C	Degree Celsius (unit of temperature)
E	Energy
Er:YAG	Erbium-doped:Yttrium, Aluminum, and Gernet
ArF	Argon fluoride
KTP	Potassium titanyl phosphate
He-Ne	Helium Neon
Ho:YAG	Holmium-doped:Yttrium, Aluminum, and Gernet
Hz	Hertz (unit of frequency)
J/cm^2	Joule per square centimeter (unit of energy density)
LITT	Laser induced interstitial thermotherapy
M	Mass in kg.
mJ	Milli Joule (unit of energy)
mW	Milli Watt (unit of power)
Ns	Nanosecond
µJ	Micro joule (unit of energy)
µm	Micrometer (=10^{-6} m)
µW	Micro Watt (unit of power)
Nd:YAG	Neodymium doped Yttrium –Aluminum Garnet
Nm	Nanometer (= 10^{-9} m)
PRR	Pulse Repetition Rate
SEM	Scanning electron microscope
CLSM	Confocal Laser Scanning Microscope
kHz	Kilo hertz
W/cm^2	Watt per square centimeter (unit of power density)

EDTA	ethylene diamine tetraacetic acid
PIPS	photon-induced photoacoustic streaming
RFT	radial firing tip
NiTi	Nickel Titanium
MIE	minimally invasive endodontics
NaOCl	Sodium hypochlorite
CMCP	Camphorated monoparachloro phenol
PCP	Parachlorophenol
CPC	Camphoratedparachlorophenol
MTA	mineral trioxide aggregate
TEM	Transverse-Electromagnetic-Modes
Q-switched	Quality factor swirched
LED	Light Emitted Diode
Mid-IR	Middle Infrared
LLLT	Low Level Laser Therapy
UV	Ultraviolet
aPDT	antimicrobial-photodynamic-therapy
PAD	photo activated disinfection
Nd:YAP	Neodymium: yttrium, aluminum, and perovskite
3-D	Three Dimensions
FDA	Food and Drug Administration
HA	Hydroxyapatite
I_0	Incident Intensity
Λ	Wavelength
EM	Electromagnetic
AlGaAs	Aluminum Gallium Arsenide
CHX	Chlorhexidine
DEJ	Dentinenamel Junction
PAI	Periapical index scoring

Chapter One

Introduction

&

Basic Concepts

Chapter One

Introduction and Basic Concept

1-1 Introduction

The prime objectives of endodontic therapy are to eradicate bacteria and other microorganisms from radicular dentine and to make a sterile root canal field and to obturate root canals with a hermic seal (1). After root canal instrumentation, a smear layer will be formed which compose of integrated dentine, organic materials, and bacteria. This layer attaches to the internal canal wall and occludes the dentinal tubules (2,3). Most of earlier studies about the smear layer are directed on removing this layer to get appropriate root canal disinfection (4**)**. The smear layer acts like a barrier that impedes the infusion of irrigation solutions and prevents the penetration of sealer materials inside the dentinal tubules (4–8). Currently, some of irrigants and chelating agents can perform this removal like; MTAD, EDTA, Citric acid, and Phosphoric acid. These solutions present some unsatisfied outcomes owing to inability to approach all areas along the canal wall (9).

The evaluation of dentine- guttapercha interface and penetration of sealer into dentinal tubules can be performed using one of the investigation method such as; stereomicroscope, scanning-electron microscope, and confocal laser microscope. The confocal laser microscope is preferred due to the ability to investigate the sealer-dentine status at multilayers on the whole circumferential border of the root with highly-contrast seen depending on fluorescence-phenomena (10-13). Principally, the protocol of using confocal laser microscope requires flurochromophores that should be blended with and dissolved in the investigated material. Rhodamine B molecules are considered water insoluble and can be dissolved in organic-solving like sealer; primer; and coupling agent. The labeled sealer like; Ah-plus sealer can be detected and identified inside the dentinal tubules with confocal laser microscope (14).

A lot of invented armamentariums were used to improve the cleaning and shaping phase of endodontic therapy. Among of these irrigation techniques, negative pressure, sonic, ultrasonic, photon-induced photoacoustic streaming (PIPS), and laser applications (15,16). Since the invention of the first laser, dentistry has been a function of laser development which considered a progress in endodontic. One of these important applications is clearing away smear layer from radicular dentine(17,18) and getting deep radicular sterilization(19,20) . many lasers types have been adopted for these applications, comprising the argon-fluoride (ArF) and other exc-imer lasers(21), argon-ion laser(21), KTP lasers(22), diode-laser, Nd YAG-laser(23,24), Ho:YAG-laser(25), Er:YAG-laser(26,27), and Er,Cr:YSGG-laser(28,29).

Erbium, chromium:yttrium–scandium–gallium–garnet (Er,Cr:YSGG) laser(2.78μm), has been exhibited qualified smear layer removal(30) and better endodontic disinfection than some traditional ways(31) without any hazards to adjacent tissues (32,33). However, there is still no clinical evidence stating the efficacy of the Er,Cr:YSGG laser-assisted endodontic treatment. In the present work this laser was used in both confocal and clinical studies with high penetration depth and successful rate respectively. Besides that, the using of radial firing tips (RFT) guarantees even distribution of light along the canal walls. These tips have been a profitable tool for smear layer removal using water concomitantly to root canal disinfection in dry conditions(34). Previous studies about using this laser necessitate multivisit treatment, and appropriate cleaning and shaping is required for decent result by increasing in the diameter size of the root canal(35).

ProTaper Next is one of the recent systems which used in this study. This system has highest cyclic fatigue resistance which may be belonged to the strengthened NiTi, M-Wire and off-centred cross section which brings about a swaggering movement during rotation thereby decreasing binding to the dentinal wall(36). On the other hand, the durability of endodontically treated tooth is a crucial parameter. Concerning this concept, minimally invasive endodontics (MIE) can be utilized for ultimate conservation of healthy dental structure during root canal treatment. To get a rewarding result, there should be a balancing between preservation and removing of dentine during instrumentation(37). Thus, the minimally invasive endodontic was employed in the clinical study to preserve the tooth structures. While, laser action push the optimum cleaning and disinfection which demand larger apical diameter.

After good instrumentation and efficient debridement of the root-canal, optimum obturations are required. One of the obturation techniques is cold lateral compaction which considered as a reliable and simple way to fill the root canal very well with less complexity(38). Another obturation technique, carrier-based techniques, was used which is a warm gutta-percha on a cross-linked gutta percha core. For Example: Guttacore which achieved a better fill and adaptation in the critical apical third of working length than cold lateral or warm vertical techniques(39). In this research, the cold lateral and carrier based obturation techniques were compared in both confocal and clinical studies.

There are a lot of different composition root canal sealers which are aiding to close the voids or to fill irregularities in the root canal and to occupy the space between the gutta-percha cones and between the core material and the root canal. AH plus is an epoxy resin–based sealer. It is widely used sealer and characterized by good handling and superior physical properties(40). Therefore, this sealer was used in the present work.

Currently, various dental-lasers like Nd YAG, CO_2, and Erbium family lasers have been employed to remove smear-layer and other remnant debris that formed or primarily exist inside the root-canal(41-46). Various researches have presented the superiority of Er,Cr:YSGG laser in performing these tasks. Additionally, many lasers with various spectrums have been used for disinfection or initiation of other disinfective materials. However, the ability of laser to access the entire root canal system whiles other irrigants and disinfectant does not. Till now there is no obvious clinical study of statistical significance results enhance the use of Er,Cr:YSGG laser in minimally invasive endodontic for patient suffered from apical periodontitis.

1.1.1 Aim of Study

The study intends to enhance the endodontic treatment for patients who are diagnosed with different Apical Diagnoses by using ErCr:YSGG laser and minimally invasive technique in single visit root canal treatment, assisted by confocal laser microscope study.

These objects can be gained when performing the followings:

1. Vitro study that using confocal laser microscopy to investigate the AHplus sealer penetration into dentinal tubule following smear layer removal by either use of ErCr:YSGG laser or EDTA.and compare between cold lateral and carrier based obturation techniques
2. Er,Cr:YSGG laser assisted root canal treatment for patients diagnosed of having apical periodontitis. Then, monitoring the healing percentages for six-month duration after clinical endodontic treatment and put a hypothesis that the healing percentage will be not affected.

1.2 Endodontic Therapy

The key of success of root canal treatment includes: reach out the appropriate diagnosis accompanied by a completed plan for treatment; knowing of the teeth morphology and dental anatomy; and total debride, disinfect, and obturate the radicular space. Previous researchers have found that the missing of one of these concomitant factors can leads to endodontic failures(47). Deficient obturation, incomplete cleaning, improper shaping, and insufficient disinfection could be decreasing the success to failure ratio as a group or individually. However, bad obturation is intimately attached to inappropriate cleaning and shaping, and belonged to short term failure (48).

On the other hand, it was found that what evacuated from root-canal system are of paramount importance comparing to what filled inside. Therefore, eradication of the pulp remnant, debris, and microorganisms are of great importance. Hermic seal after optimum endodontic cleaning and shaping will embalm the organisms if any, and will forbid root canal and /or periradicular contamination again. (49)

1.2.1 Cleaning and Shaping

Generally, endodontic treatment of vital dentition has a higher chance of success comparing to necrotic dentition with peri radicular involvement. This is may be due to persistent of necrotic debris, and the difficulty in removing bacteria and the bacterial byproducts. To achieve a better result files should contact all walls planes of the root. There are a lot of morphological challenges like; lateral canals, root curve, fins, Culde sacs, and isthmuses. Consequently the major role of cleaning phase is the reduction of irritations as far as possible (50).

Till now no decent way is available for cleaning assessment. The assessment is depending mainly on, the achieving of clear dentine during instrumentation, the irrigants colour, enlarging the canal using three sequenced files after the initial gauged file, and getting glazed plane surface; however, there is no correlation between these ways and debridement (51).

On the other hand, the scope of shaping is to simplify the cleaning phase and produce adequate zone for obturation phase. Shaping aimed to sustain and promote the steady funnel shape form the coronal to apical parts of canal-system. It can imply a procedure facility especially in apical instrumentation. Obturation technique could determine how much enlargement is needed. For example, in lateral compaction technique the enlargement should be sufficient for allowing spreader application to 1-2mm of the determined working length (52,53). While in warm vertical compaction technique the canal is enlarged coronally to allow the plugger introduction 3-5 mm of the determined working length (54,55).

General knowledge of dental anatomy and teeth morphology could help in determining the degree of apical enlargement, in spite of individual teeth differences (56-58). Other factors are involved in such instance like canal shape and diameter. As a result of morphological variations, enlargement cannot be regulated specially at the apical part. Minimum apical instrumentation decreases the procedural errors as well as reduces cleaning procedure adequacy (58-61).

One of the results of inadequate apical cleaning is that irrigants solutions cannot be arrived apically if the apical size smaller than 0.35mm.(62) some researches engorges this fact, the increase of the apical part size of the canal signify the irrigation procedure along with adequate debris removal (63). Therefore enlargement protocol is in direct correlation with cleaning efficiency (64) and microorganism devaluation (65,66). Minimal invasive technique is conflicted with these requirements for good cleaning and disinfection techniques (67,68).

The invasion of bacteria in necrotic tooth with a pathosis can reach the dentinal tubules of radicular dentine (69). Bacteria colonies cannot be removed by instrumentation and/or by irrigation (70). The initial method for decreasing their count is by enlarging the apical preparation. However it is difficult to access to deep located bacteria. It was described a direct relationship between these counts and the depth of tubular penetration (71).

1-2-2Endodontic Dis-infection

The endodontic disinfection depends mainly on the chemical action of the irrigation solutions and intra-canal medicaments.

1-2-2-1 Irrigants

The endodontic disinfection depends mainly on irrigation solution. Generally these solutions should have the following properties: dissolve organic tissue, soften inorganic tissue, having reduced surface tension, showing no toxicity, lubricate the canal walls, and have broad antimicrobial activity (72). Till now no one of the available irrigation solutions encounter all these properties (73).

1- Sodium Hypo-chlorite

Sodiumhypochlorite is considered as extremely powerful and reliable root canal solution (74). It has some properties making it widely used in root canal treatment like; organic tissue solvent, anti-microbial (75), and good lubricant (76). Beside that it is low-priced and handy.

The action of this solution mainly depends on the formation of free chlorine which has the ability to degrade the organic tissue. The recommended concentrations of sodium hypochlorite for endodontic therapy are 0.5- 5.25 percent (77). The lower concentration of irrigant can be refunded by using more solution volume (78). Warming up the irrigants can participate in increasing its affectivity (79).

2. Chlorhexidine

This solution has an extensive anti-microbial action along with a substantivity and low toxicity (80,81). chlorheaxadine of 2% concentration is acting as strong anti-microbial as 5.25 percent hypochlorite (82) , but it is more active against *E. faecalis* (83) the major drawback of this irrigant is concerning with inefficiency in removing of smear layer.

3. EDTA

The ethylene diamine tetraacetic acid major action is removing of the smear layer after cleaning and shaping (84). The recommended way of such removal is performed by rinsing with 17 percent EDTA for 1 minute then irrigation by sodium hypochlorite (85). The EDTA action is for removal of inorganic materials, while hypochlorite removes the remaining organic substances.

The chelating agent remove the plug and smearlayer along with enlarging of dentinal tubules (86,87). These effects affect the root canal at the coronal two thirds more than apical one (88). This may be due to the differences in size along the canal length (89) , or due to the diversity in anatomy like sclerotic or irregular tubules (90).

1-2-2-2 Intra-canal Medicaments

Multi visit endodontic treatment requires dressing material used intracanally to maintain the level of disinfection. The objectives of these medicaments are to: decrease the pain between sessions, act as antibacterial. There are a lot of intra canal medicaments such as: Phenolics, Eugenol, Camphoratedmonoparachlorophenol(CMCP), Parachlorophenol(PCP), Camphoratedparachlorophenol(CPC), Metacresylacetate(Cresatin), Cresoll, Creosotte(beechwood), Thymol, Aldehydes, and calcium hydroxide (91).

1. Phenols and aldehydes

Most of these medicaments possess nonspecific activity. They can impair microbial structure along with the adjacent tissues (92). They are considered as toxic-material. Aldehyde medicament is used for soft tissue fixation (93). Studies have showed controversy of usage of these medicaments clinically (94,95).

2. Calcium hydroxide

Calcium hydroxide is one of the strongest materials that applied intracanally to prevent the growth of microbes (96). This ability is render to the high alkalinity which effect on bacteria and their product and dissolve necrotic substances (97). It is widely recommended to be applied for necrotic teeth with pathosis. However it is of low interest in vital teeth.

The high effect of this material can be got when it is placed deep and dense inside the root canal space. As a result of this application there will be a difficulty in removing especially at the apical third (98).

1-2-2-3 Disinfection Devices and Techniques

1. Syringe Delivery

Advantages of using needle and syringe as an irrigant carrier are: permitting appropriate placing, restocking of out solution, washing out large particle, as well as providing of direct contact to microbes (99).

2. Manually Activated Irrigation

The master apical cone can be used in frequent filing motion inside the root canal to activate the irrigant solution. This dynamic movement of gutta-percha must be in short strokes (100).

3. Sonically Activated Irrigation

The sonic activation system (figure 1.1) has been designed for irrigant activation producing hydrodynamic action (101). This method is considered more safe and better effect than ultrasonically method. Previous studies showed that Endo-Activator has the ability for smear layer removal, debridement of untouched wall portions of the root canal, and force out bacterial colony inside tiny and greatly curved root canals (102).

Fig. 1.1 The sonic activation system(102)

4. Passive Ultrasonic Irrigation

Generally, this system possesses the ability for mechanical root canal preparation and debridement. The frequencies of oscillation of driven-files are 25–30 kHz. They are running in a transverse oscillation, presents with nodes-antinodes frequency across its vibration (103). This technology activates irrigant by acoustic energy which transmitted through the vibrating file. Ultrasonic waves act as a means for energy transmission the absorbed energy can produce acoustic streaming and cavitation of the irrigant (104). As shown in Figure 1.2

Fig. 1.2 Passive Ultrasonic Irrigation(103)

5. Negative Apical Pressure

Endo-Vac system (Figure 1.3) consists of three components: MasterDeliveryTip, Macro Cannula, and Micro Cannula. The first component acts as irrigants vehicle (connected to a syringe) and evacuator (connected to the high-speed suction) concurrently. The suction of irrigation solution is performed by the macro-cannula from the middle and coronal part of the canal (105).

Fig. 1.3 Setup of the EndoVac system(105)

6. Safety-Irrigator

The RinsEndo system is used for endodontic irrigation utilizing pressure suction method. This system is composed of hand-piece, cannula with a 7millimeter outlet, and a syringe that transmit irrigation solution. The hand-piece of the system is connected to a dental-compressor and it can perform irrigation at 6.2 milliliter per minute. The used irrigation volume is 65 mL which oscillate at 1.6 Hz (106) .(Figure 1.4)

Fig 1.4 The RinsEndo system(107)

7. Gentle Wave System

This system is composed of a console and a Treatment Instrument. It is considered a novel-approach used for cleaning and disinfection the root canal (108). Studies have presented the cleaning efficiency of Gentle-Wave System; it is eight times more efficient than other irrigation systems (109).

Fig. 1.5 Gentle Wave System(110)

8. Laser-Activated Irrigation

Modern researches have been directed on laser induction in irrigation process (111-113). The mechanism of action of this system depends on absorption of laser energy by the irrigant and formation of explosive-vapor bubble with a collateral cavitation action. This activation technology is very powerful in removing the smear layer.

Photon induced photoacoustic streaming (PIPS) is considered an innovative procedure in which Er:YAG Laser activates irrigation solution. The laser parameters used for PIPS procedure adopts low laser energy and relatively short pulsewidth of 50 microsecond to produce high peakpower. The generated photo-acoustic shock wave permit a 3D flowing of irrigant solution (114).as shown in Figure 1.6

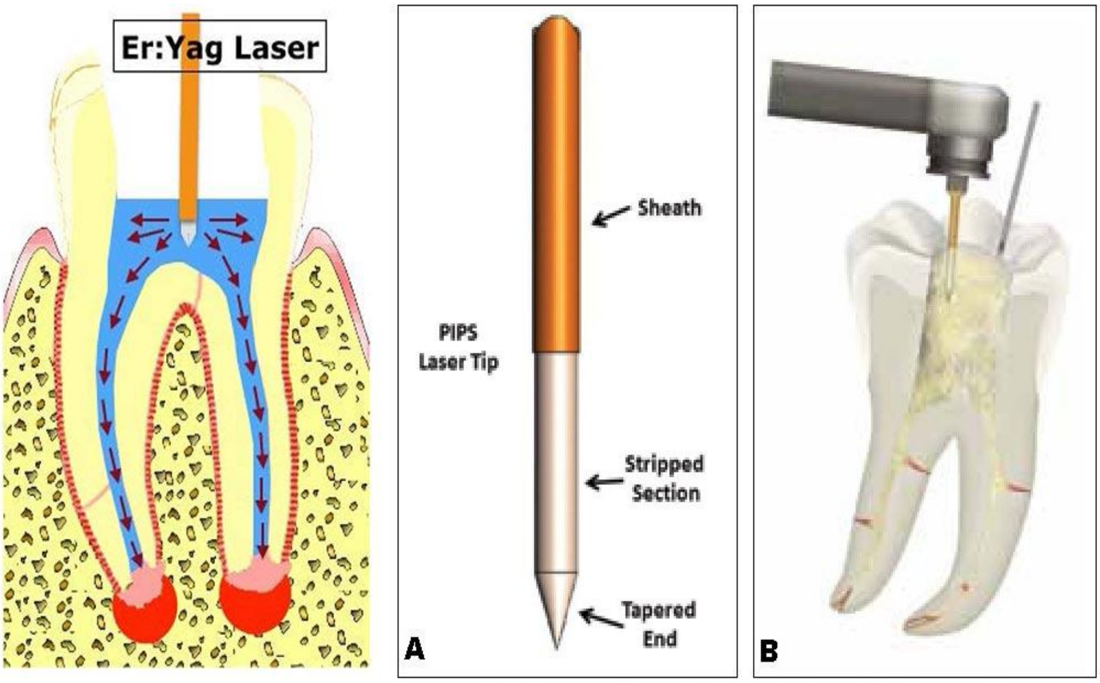


Fig. 1.6 Photon-induced-photo-acoustic-streaming A) Er:YAG laser tip B) the laser tip is placed in the pulp chamber(114)

9. Photo-activation Dis-infection

This technology recently has got a lot of endodontic researches due to its antibacterial activity in attacking the residual-bacteria intra canally. this technique utilize a nontoxic photosensitizer dye, low-intensity visiblelight , and with the presence of O_2, react to generate cyto-toxic collections (115). Photoactivated disinfection is competent against other microorganisms including virus, fungi, and spores (116). (Figure 1.7)

Fig. 1.7 Photoactivated disinfection using tolonium chloride(116)

1-2-3 Root Canal Obturation

Endodontic treatment objects to prevent or treat the periapical pathosis though fulfilling its sequenced steps; by cleaning, disinfection, as well as a good root canal obturation. From the time of 1965, the microbes and their byproducts are considered one the most innovative factors that causing apical-periodontitis (117). So, the eradication or reduction of these factors are of primitive requirement for success (118,119).

Throughout obturation phase, the debrided and disinfected root canal must be filled and sealed from the canal-orifice to cementodentinal junction (47). This obturation should provide a fluid tight barricade and prevent the reinfection of peri-radicular area (48).

1-2-3-1 Timing of Obturation

The decision about the time of making obturation involved with the treatment schedule whether it's single or multivisit. At the obturation time the root canal; should be debrided very well by previous step of chemomechanical cleaning (120) , and must be dry. Endodontic treatment of one session is preferred if all requirements are fulfilled (121). Unless, multi sessions endodontic therapy and inter appointment intra canal medication should be performed (122).

1-2-3-2 Current Material for Obturation

Generally the currently available obturation materials are composed of semisold core and sealer. Grosman (1978) put a criterion for optimal equity of obturation material (123). This criterion includes the following:

- Simple manipulation
- Perfect 3-D fitting inside the root canal system
- Dimensional stability

- No irritation
- No staining
- Anti-microbial
- Invulnerable & nonporous
- Resistant to tissue-fluid
- Radio-opaque
- Readily-removed

1. Guttapercha

It is a trans 1-4 poly isoprene which is the chemical form of natural rubber material. Traditionally, Guttapercha composed of 65% zinc-oxide, 20% guttapercha, 10%) radio-opacifier ,and 5%plasticiser. There are two crystalline-forms of Guttapercha : alpha and beta. Beta phase is available as gutta-percha points which can be converted to alpha phase when subjected for heating from 42to49° C (124).

Commercially, Guttapercha is provided in two forms cones and pellets. The cone form has different size ranges, including standardized(ISO) 2% taper and non-standardized in 4%, 6%, 8%, 10%, 12% taper (124).

2. Calcium silicate cements

They are a mineral trioxide aggregate (MTA)- derived dental- materials that used for obturating broad open-apices, perforation of roots and root-end filling. They showed less cytotoxicity than any other commercially-available materials (125). It has been reported that if these materials surfaces comes incontact with synthetic body-fluids, it will form hydroxyl-apatite (126-130).

3. Sealers

Sealers are the material used to seal the interface between filling material and canal walls. Researchers reported that sealers possess the ability to positively effect on the result of endodontic therapy (131). Some of these materials have showed anti-bacterial properties against microorganism. According to Grossman, the optimal properties of root canal sealers are; provide a hermetic-seal, Dimensional stability and insolubility, no-discoloration, slow-setting-time, Antimicrobial, and Nonirritant (132). Sealers are categorized into a number of groups as the following: Zincoxideeugenol, Calciumhydroxide, Glassionomer, Resin based, Calcium-silicate, and Silicone based sealers (132).

AH-Plus sealer is a type of resin based material. It is different from its previous edition AH-26 in a matter of formaldehyde- release. It has high sealing-ability and adherence to radicular dentin beside its anti-microbial activity (133). This Sealer presents a not easy resorption when it extruded in the peri apical area and can elicit an inflammatory-reaction. However, this reaction will be subsided within few weeks and the sealer can be tolerated (134).

1-2-3-3 Techniques of Obturation

Generally, there is a lot of obturation techniques used to fill the root canal system. Each one of them has its indications, advantages, and drawbacks (135).

1. Cold lateral compaction

It is contemplated a gold standard obturation against which other techniques can be estimated. Cold lateral compaction is comparatively simple to perform with satisfying apical management and acceptable cost (136).

2. Warm lateral compaction using ultrasonics

Warm lateral compaction is a modified technique of the previous one. The used armamentariums for this technique are; a peizo-electric ultra sonic device, adaptor of file, and a k-type file. It has some superiority against cold-lateral technique; the guttapercha can be flowed to fill lateral canals or defects that formed due to internal-resorption (137).

3. Warm vertical compaction

This technique is used since 1967, it was invented by Schildder and then it was modified to continuous/ interrupted -wave compaction-technique (Figure 1.8) it has an advantage of ability to fill lateral canals and root canal irregularity by recruiting thermo plasticized guttapercha. Despite that it has some drawbacks; difficulty in controlling the length and relatively high price of equipment (138).

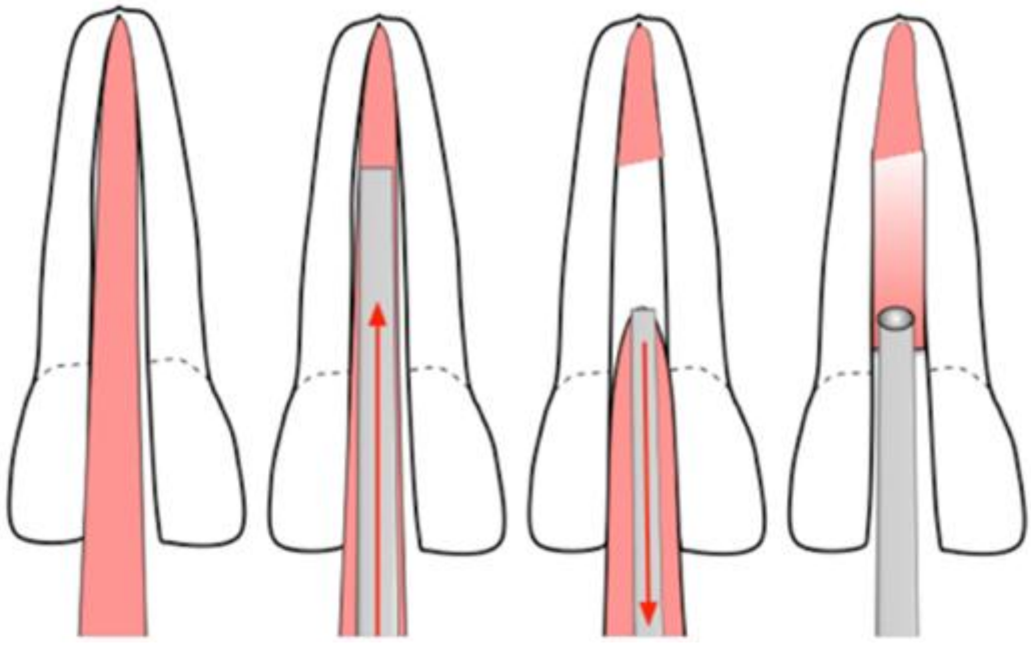


Fig. 1.8 continuous wave compaction-technique(138)

4. Apical-fill in open apex cases

The ideal material that fit for open apices is calcium-silicates cements. This material if it was handling properly it can promote the success outcome of endodontic treatment. Mostly they are available in powder-liquid-form (139).

5. Thermo-mechanical compaction

The mechanism of thermo-mechanical technique (Figure 1.9) depends on the generated heat from the frictional movement of reverse H-files when packing the guttapercha inside the canal (140). Thermo-mechanical compaction has the ability to obdurate irregularities and defects (141).

Fig. 1.9 Thermo-mechanical compaction(140)

6. Carrier-based

This technique composed of a rigid core and coating guttapercha. There are three types of guttapercha based on carrier material, ThermafilI guttapercha have titanium and stainless steel carriers, ThermafilII contain plastic core, and GuttaCore (Figure 1.10,A) which composed of cross linked guttapercha.. In carrier-based technique, a verifier was advanced inside root-canals down to the working-length for size verification. Then, GuttaCore were heated by GuttaCore oven Thermaprep (Figure 1.10,B) before insertion inside the root canal. (Dentsply Maillefer, Ballagues, Switzerland) (39).

Fig 1.10 A) GuttaCore B) Thermaprep 2 oven(39)

7. Single cone

Principally, filling the root canal system by a standardized single cone and sealer is controversy, because it cannot permit for 3-D filling. However, a Smart-seal which is an example of this technique, has the ability to fill expand and improve the 3-D obturation of the root canal system (142).

1-3 Laser

The LASER stands for Light Amplification by Stimulated Emission of Radiation. It is considered one of the utmost imperative appliances in medical and factorial applications. It produces light beam of characteristics not seen in other naturally produced lights. Some lasers can generate power till 10^{20} W for short times with excellent spatial characteristic. The handy applicable lasers present with wavelength from ultraviolet to the far infrared. All laser types share same main component like; active-medium, pumping source, and resonator as shown in Figure1.11. Also, cooling-systems, control panel, and optical fibers (143).

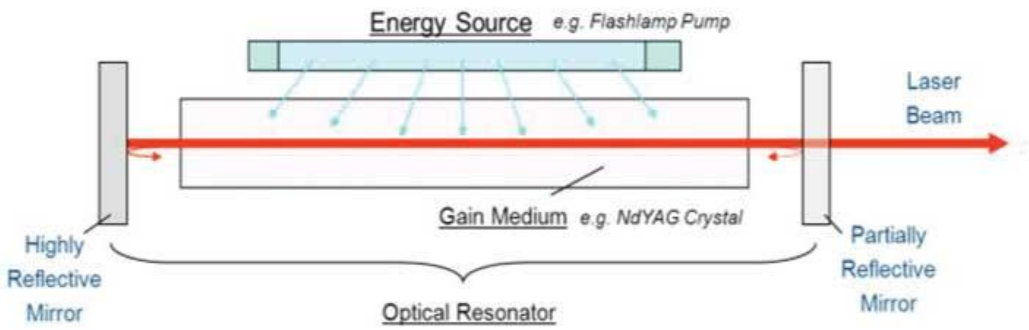


Fig.1.11 component of laser(144)

1-3-1 properties of the laser light

A- Coherence:-

Laser system generates light waves of special properties which contains photons having same phase difference. The coherence is a special laser feature that not available in other light sources. The laser waves have spatial and temporal coherence. Temporal coherence is the phase approximation in different fractions of laserfrequency band width. While, spatial coherence is the phase approximation in various spatial fractions of laser beam when propagated to specific length (145).

B- focusability:-

Generally, lasers have the ability to be strictly concentrated to a tiny spot-size. Laser beam can be nearly focused to the size of the laser-wavelength if considering a single transverse-mode TEM_{00} was got from the laser (145).

C- Monocromaticity:-

This property describes the purity of the laser beam color that means how narrow the laser beam frequency-bandwidth is. Laser light is quasi-monochromatic .i.e. one color; which means that all the photons have close wavelengths values (145).

D- Collimation:

The parallel rays of Laser light can travel to specific direction and remain parallel to each other. The laser emitted light beam of least divergence in the world. Therefore the laser light can travel for a far distance with relatively low divergence (145).

E- Brightness:-

The brightness is referred to the laser intensity or the power density. Mathematically, it is the quotient of the laser power divided by the transverse area of the laser beam. As a result the measuring unit is W/cm^2. The laser brightness is an exceptional property of laser light that having greater intensity than other light sources of the same power. The secret behind laser brightness is the parallism of laser rays each one to others as it moves through space giving rise to concentrated laser energy especially if the laser beam confined to smaller point (145).

1.3.2 The characteristic of laser beam

The output characteristic of laser beam involve: the temporal (time domain) and the spatial (space) characteristics.

1.3.2.1 Temporal characteristic of the laser beam

Lasers can be categorized into two types according to the emission modes: continuous-wave (CW) lasers, and pulsed modes lasers as depicted in Figure 1.12. Cw lasers can be modified into gated pulse emission. This modification is performed after generation of the Cw laser beam (146).

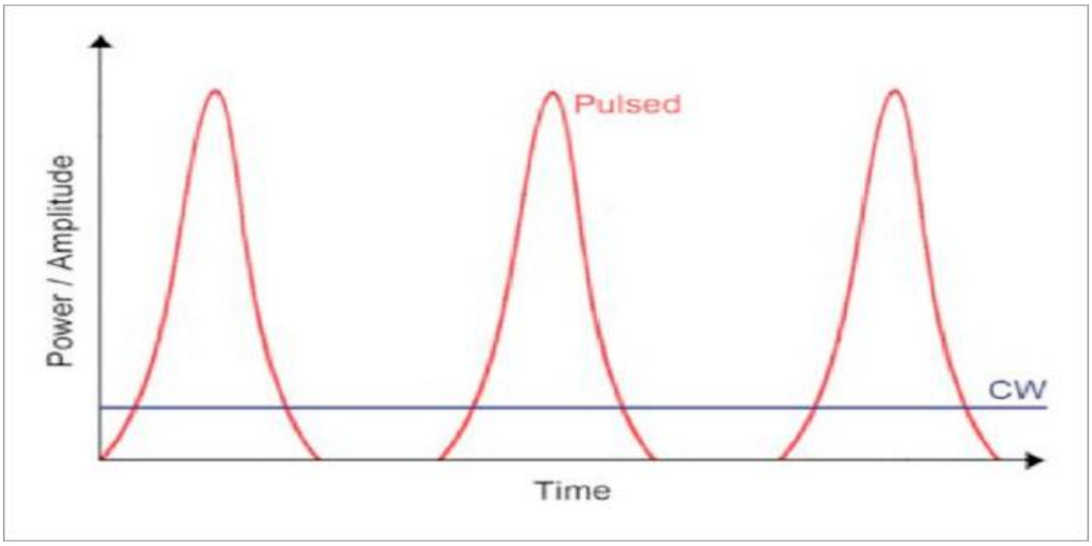


Fig.1.12 CW Vs. pulse lasers(146)

1- **Continuous Wave**

Continuous-wave lasers include lasers that generate laser power continuously and almost constantly after switching the laser device on. They are pumped by electrical direct current which in turn must be continuous and constant for example; diode laser (146).

2- Gated Pulsed Mode

Some types of CW lasers can be modified and supplied with shutters that help in production pulses with higher peak power. The duration of these pulses is ranging from millisecond to microsecond. Such gated shutters can be seen in diode and CO_2 lasers which operate originally in CW mode (146).

3- Free-Running Pulse

The Free running lasers include lasers that produce laser energy with a short pulse width and high peak power. These lasers are free from any intra cavity components. The pumping mechanism should supply these lasers with enough energy in very short time. Usually, the pulse width of these lasers is accounted in the micro second with longer pulse intervals. For example of free running laser: Er,CrYSGG, ErYAG, NdYAG, and Nd:YAP (146).

4- Q-switched Mode

Q-switched laser generates short pulses in nanosecond scale. It is called Q-switching, in which the rate of population inversion is modulated while the pumping is continuing in providing energy. Thus a shorter pulse with a very high energy will be emitted in short time (146).

5- Mode locked Laser

Another method of production a very short pulse in pico or femto second range with giant pulse energy can be done using an acousto-optic modulator in mode-locking technique. This modulator is fixed inside the resonator with main function of production constructive interferences between phases of emitted modes (146). Till now, there is no laser used for dentistry has utilized Q-switching or mode locking techniques (147).

1.3.2.2 Spatial characteristics of the laser beam

These characteristics are related to the transverse crosssection of the laser beam and beam divergence. The transverse cross section has power densities of different distribution and pattern with central area of higher intensity than the periphery. These intensity patterns are called Transverse-Electromagnetic-Modes (TEM). Generally, the transvers modes are labeled by 3-indexes (TEMplq) which mark each mode. The letter p is refered to the number of radial zero fields, letter l is the number of angular zero fields, and letter q is the number of longitudinal fields. The first two indexes are usually used to specify a TEM mode, like TEM00, TEM10, etc. it is obvious that when the transverse modes get higher order, it will be difficult to confine laser beam to a smaller point. That is why some times TEM_{00} mode or Gaussian beam is favored (Figure 1.13). Additionally, these fundamental modes: are smoothly handled physically, have circular symmetry, possess the highest power density of the whole other transverse modes, and are considered stable and conserve their shape as they propagate (145).

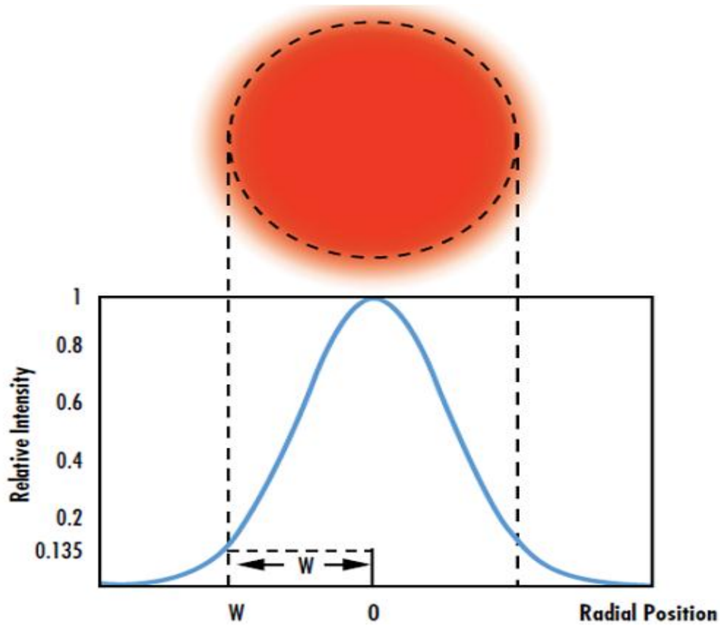


Fig. 1.13 TEM_{00} mode or Gaussian beam(145)

The other spatial characteristic is the divergence of laser beam which determine the diffusion of laser beam after crossing a distance. The divergence of laser beam is fully dependent on the divergence angle, wavelength of the incident laser, and on the shape and size of the aperture that exist the laser light. The laser beam diameter will become larger as it is crossed longer distance or when the divergence angle is bigger (145).

1-3-3 Laser Delivery Systems

The laser delivery system is playing a crucial role in transmitting the laser energy to the operation site whatever in contact or non-contact modes. The mainly used delivery systems in dentistry are: optical fiber, hollow waveguide, and articulated arm.(Figure 1.14) (144)

1-3-3-1 Optical Fiber

Optical-fiber generally designed from quartz silica. The optical fibers consist of a core and cladding with different refractive indices surrounded by; slim poly-amide-coating, and flexible denser sheath covers. The fiber-core acts like a transmission media for laser light while the coating layers protect this core and confine the light inside it. The fiber is connected to the laser device though specific connector and connects from the other side with handpiece (144).

1-3-3-2 Hollow Waveguide

The wave-guide is a coated pliable hollow tube. This tube is lined by silver-iodide material which acts like a reflector. The hollow tube covered by a numbers of coating covers which protect the tube. The waveguide is connected to the laser device though specific connector and connects from the other side with hand-piece (144).

1-3-3-3 Articulated Arm

It composes of sequences of hollow-tubes connected to each other by fulcrum mirrored-joints. It has a counter-weight to permit easy movement. Articulated arm is connected to the laser device though specific connector and connects from the other side with hand-piece (144).

A B C

Fig. 3.14 A) optical fiber B) Hollow waveguide C) Articulated arm(144)

1-3-3-4 Contact and Noncontact Procedures

Principally all traditional instruments used in dentistry are coming in contact with the treated site which gives a tactile sense to the operator. The application of lasers in dentistry can be performed in contact and noncontact procedures. The contact application of laser permits a simple access of dental tissue, for example the application of fiber-tip inserted into a periodontal-pocket to clear away inaccessible granulation-tissue. In this procedure the laser beam spot will be at focal-point which presents maximum intensity and allows for precise surgical application. On the other hand, in non-contact application the hand-piece is moved away from the target tissue with some distance between them. The advantages of this procedure are; suiting different oral tissue surfaces, acting on a wider area with less intensity (144).

1-3-3-5 Aiming Beam

Most of lasers wavelengths used in dentistry are in the infrared region (invisible region). So, they must be supplied with a visible aiming beam that helps in controlling the application of these lasers. The aiming beams can be other visible laser or LED or ordinary focused light (144).

1-3-4 Laser Systems in Dentistry

Mostly, the wavelengths of major dental laser systems are located at visible and infra-red zones of electro-magnetic spectrum. Mid-IR lasers like Er family lasers can perform hard and soft-tissue applications. While, visible, and the remaining IR lasers represent the soft tissue lasers, and also used for caries-detection and bio-stimulation (LLLT). In general, two basic types of dental lasers can be distinguished: semi-conductor lasers which is compacted in size like diode lasers, the other lasers types have definite parts that take up a bigger hoofprint. All lasers types have the same components; active-medium, pumping-source, resonator. As well as, they comprise: cooling-system, control-panel, and delivery-system (148).

1.3.4.1 Classification of Dental Laser

Lasers can be classified conforming to their clinical application into soft tissue laser, hard tissue laser, and all tissue lasers. As shown in table 1.1

Table 1.1 Classification of dental lasers concerning their clinical uses(148)

Dental Laser	Wavelength	Type of Laser according to application
Diode	445 nm	Softtissue lasers
KTP	532 nm	
Diode	810, 940, 970, 1,064 nm	
Nd:YAG	1,064 nm	
Nd:YAP	1,340 nm	
CO 2	10,600nm	
Er,Cr:YSGG	2,780nm	Hard and softtissue lasers
Er:YAG	2,940nm	
KTP	532 nm	Low level laser treatment
Diode	635–675 nm	
Diode	810, 940, 970, 1,064 nm	
Diode	405 nm	Laser for caries detection
Diode	655 nm	

On the other hand, lasers can be classified in consonance with electromagnetic spectrum that their wavelengths belong.

1.3.4.2 Most commonly used lasers systems in dentistry

1. **Lasers in the Ultraviolet spectrum**

The UV zone of electromagnetic spectrum (0.3- 0.4μm) includes in the excimer-family lasers. These lasers are used mainly for ophthalmologic application. Earlier experiments were performed in endodontic using excimer laser (308 nm). This laser is currently not applied for dental procedures (148).

2. **Lasers in the Visible Spectrum**

Lasers in this group emit laser light in the visible region such as; argon lasers which are emitting blue laser at 488 nm and green laser at 514 nm however these lasers are stopped for dental application. While, the KTP green laser at 532 nm and diode blue laser at 445 nm are still used in dentistry. In the red region, another diode-lasers are introduced which emitting lasers at range of 635- 675 nm, these lasers are mainly performed the low level laser-therapy and photo-dynamic therapy (148).

KTP laser (Second Harmonic)

KTP laser was imported for dental application since the beginning 1990. It has a high affection with hemoglobin making it ideal for bleeding control and coagulation. This laser composes of Nd:YAG and KTiOPO4 crystals. The first crystal is responsible for laser generation at 1064 nm wavelength while the second one act for frequency duplication leading to a production of laser light with a half wavelength of the generated laser at 532 nm.

Generally, the lasers in the visible-light region when incident on the tissue are undergoes optical phenomenon; absorption and diffusion which happened with equaled percentages. Therefore the laser tissue interaction would be safe and of less penetration depth. It is specially to noticed that there are substances, called “photosensitizers,” which have the ability to absorb visible lights ranged between 630 and 675nm to become a strong germicidal. At this moment, the lasertherapy is predominantly termed as antimicrobialphotodynamic therapy (aPDT) or photo activated disinfection (PAD). Different chromophores are added for certain bleachinggel optimized for such wavelengths. For example; Rhodamine, is a purple colored stain reciprocal to 532 nm wavelength of KTP laser(148).

3. NearInfrared Laser

The near infra-red area is ranging from 800 to 1500 nm. It includes lasers that mainly used; for endodontics and periodontal disinfection and for oral-surgery such as diode lasers (810-1064nm), NdYAGlaser (1064nm), and NdYAPlaser (1340nm) (148).

Diode laser

The Diode laser was used in dentistry since 1980. It composes of Gallium-arsenide doped with aluminum-atoms, or gallium-arsenide doped with indium-atoms semiconductors active-medium. The diode laser was further developed and reduced in size to be a multilayer wafer-like construction. This design permits one and only emission pattern with near infra-red wavelengths. The continuous wave emission of diode laser can be modified by mechanical-system giving rise a chopped or gated pulse emission by bisecting the linear emission into intervals equals to the opening time of the shutter. The duration time of this chopped laser is ranged from micro seconds to few ms, beside inconstant-frequency up to 20,000 Hz (148).

Nd:YAG and Nd:YAP lasers

The active media of Nd:YAG laser is a solid crystal of yttrium-aluminum-garnet, doped with neodymium atoms, a metal of the group of rare earth elements. The pumping of Nd:YAG crystal is performed using a strong flashlamp (freerunning pulsemode). As a result, this laser system emit laser light in a pulse mode with a fast starting and ending of each pulse followed by an interval of inactivity. The control panel with installed software allow for controlling laser parameters such as the pulse repetition rate and other parameters. The neodymium:YAP laser has a crystal of yttrium, aluminum, and perovskite, doped with neodymium as active medium. The laser energy of near-IR wavelength is transferred by means of bendable optical fibers with various radius and end up with contact hand piece (148).

4. **Medium-Infrared Laser**

Lasers in this range have high absorption in water molecule. holmium:YAG of 2,100 nm is used in medical application. Er:YAG of 2940nm and Er,Cr:YSGG of 2780 nm wavelengths have a lot of applications in dentistry (148).

Er: YAG

The Er: YAG laser is considered the first laser used for cavity drilling. It was popularized for dental use since the last decade of the 20^{th} century as a substitution of conventional drilling instrument. The active medium of this laser is a crystal of yttrium, aluminum, and garnet which doped with erbium atoms. The emission spectrum of the active medium is in the middle infrared at 2.94 µm which coincide with the absorbtion peak of water molecule. it energized by optical pumping source resembled by free running pulses of potent flash-lamp. The erbium laser is running in a pulse mode with a microsecond pulse width. The properties of this system together with the software controlling giving rise a thermal interaction with different tissue types and below the tissue thermal relaxation time. The delivery system of this laser consists of tissue contact handpiece and sapphire tips connected to optical fiber or articulated arms. The erbium laser can be used for both soft and hard tissues (148).

Er,Cr:YSGG

The Er,Cr:YSGG laser is a unique all tissue laser system that incorporates the laser action with the water jet. The water spray aid in cooling the tissue and increase the absorption of laser inside tissue giving rise to a safe and an effective cutting, shaving, contouring, and resecting of oral hard-tissue. In addition, it can perform a unique soft tissue laser applications such as; incision, excision, ablation and coagulation. The Er,Cr:YSGG laser has a promised application in dentistry especially in specific endodontic and periodontal applications (148).

The energy of laser is conveyed to the target through laser tips of handpiece that connected to an optical fiber which in turn connected to the laser device. The laser aiming beam is a red laser light which is emitted from the hand piece and used as a laser guide. The laser system contains programmed software that can control the laser parameters and the application procedures (144).

This laser system is classified as class 4 that generate relatively high output power. These lasers are able to cause; hazardous effect to operators eye or skin, and potentially fire risk. High protection measures are recommended. The active medium is a crystal of Yttrium, Scandium,Gallium, and Garnet which doped with Erbium and Chromium. The Er,Cr:YSGG laser device emit laserlight in the mid infra-red region at 2.78 μm with microsecond pulse duration and energy of maximum 600 mJ (144).

One of the imperative accessories of this laser system is the radial-firing-tips (RFT) which permits laser distribution all around the tip in the apico-lateral direction as shown in Figure (1-15). It is used in Endodontic therapy to remove the smear layer and doing root canal disinfection.

There are two size of RFT 2 and 3 which have diameter of 200um and 320 um respectively (144).

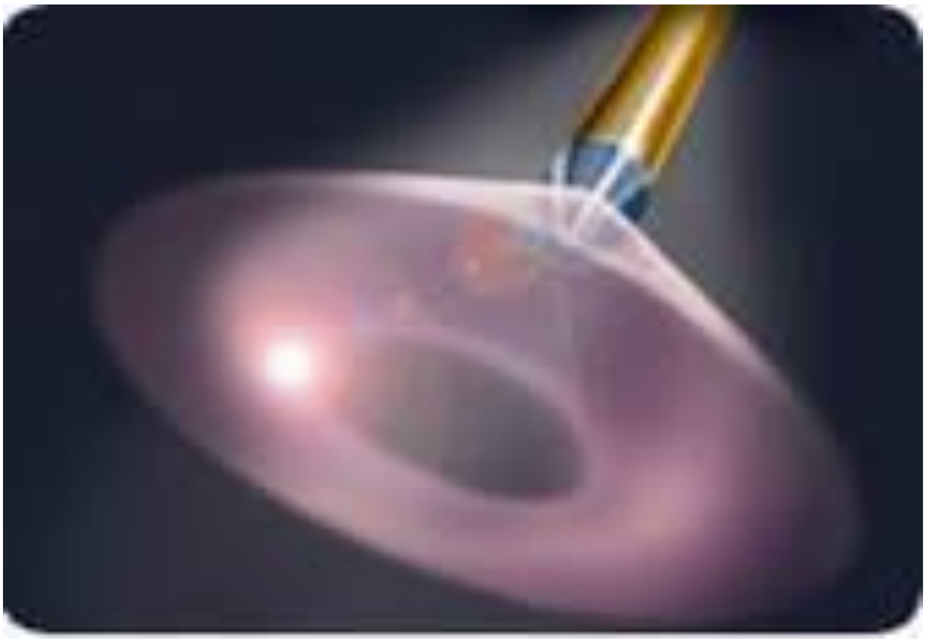


Fig. 1-15 radial Firing Tip(144)

5. **Far-Infrared Laser**

CO_2 laser of different wavelengths; 9.3, 9.6 and 10.6 µm is located in the far-IR region. This laser is used mainly for oral surgery and in caries prevention. Not long ago CO_2 laser of 9.3 µm was suggested for both soft and hard tissue applications (148).

CO_2

The carbon dioxide laser (CO_2) is emitting laser light in the far infrared spectral region at three strong lines 10.6, 9.6, and 9.3 µm. CO_2 laser is considered one of the most high power lasers in the world that producing power of more than one hundred thousand watt and pulsed energies of up to ten thousand joule, it is also available in smaller form of more than 100 W powers (144).

The water molecules can absorb this laser very well. Therefore, Co_2 laser is applied mainly for soft tissue application like frenectomy, gingivectomy, biopsies, and removal of benign and malignant lesions. As well as used for the therapy of apthous ulcer, accelerate extraction sites coagulation, debride sulcular epithelium and intraoral soft tissue surgeries (144).

The active media of CO_2 laser is composed of gas mixtures (Carbon dioxide, nitrogen, hydrogen, xenon, helium) in a sealed champer. It generates laser light in the far infrared region. The original CO_2 lasers were continuous wave or gated with pulse width of 0.5 sec to 50 milisecond (148).

1.3.5 Confocal laser microscopy

The Confocal-laser-scanning-microscopy(CLSM) is an optical-imaging technique that utilizing a spatial pin hole to shut off or confine focus-light and laser in image-generation of a small object. The micrographs of confocal laser microscope have better optical resolution and contrast than images of other microscopes (149). In addition, the CLSM has the ability of performing optical sectioning within an object by taking multi 2-D photographs at different-depths in a specimen giving rise to 3-D designs. The confocal microscope is used for scientific and industrial investigations and typically applied for Bio-science, semi-conductor examination and materials-sciences (150).

1.3.5.1 Principle

The technique of confocal microscope depends on fluorescence like others wide-field microscopes. The difference between the two microscopes is in the illumination procedure, the sample in confocal microscopy is illuminated by focused laser light at certain depth rather than illumination of the whole sample as done in wide-field microscope. The outcome of such excitation is emission of fluorescent light at specifically point of focused laser light inside the sample. A spatial filter is putted in the light path to block out rays except focused light, thus permitting only the fluorescence light for entering the light-detector. (Figure1-16) (151).

The three dimensional images can be get by employing a special microscope soft ware (z-stack) which stack several optical planes each plane is scanned independently in a raster-pattern. The confocal laser microscopy can do analysis for multi color immune fluorescence stains by using several lasers and emission/excitation filters (150).

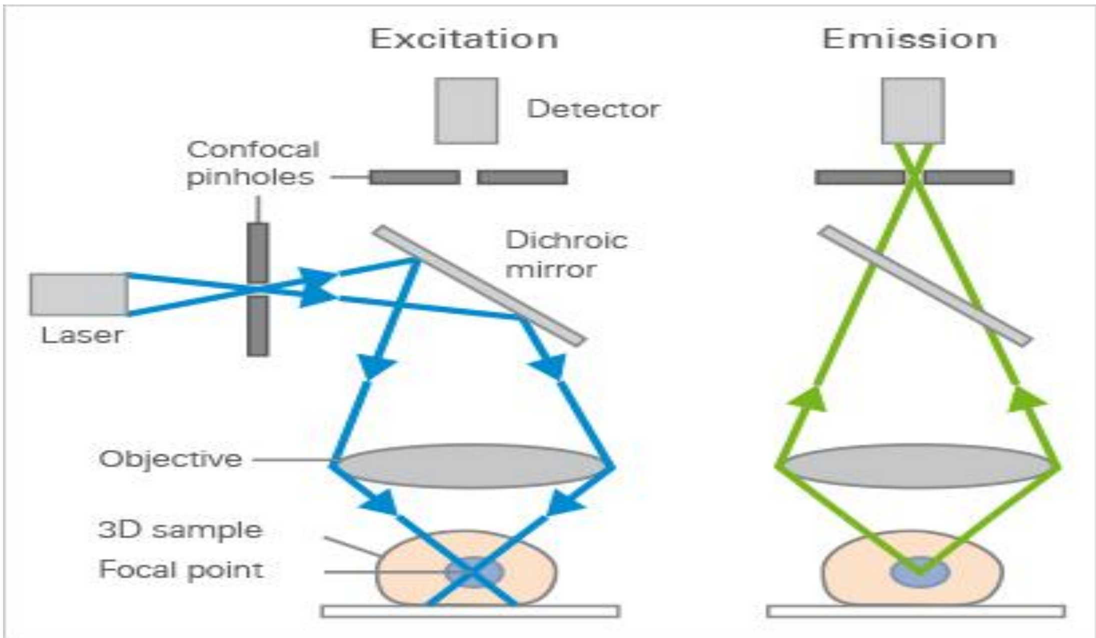


Fig 1.16 Excitation and emission light pathways in a basic confocal microscope configuration.(151)

1.3.5.2 Applications

The Confocal laser microscopy is widely used to determine the fine details of certain objects at cellular level. A lot of living cells, tissues, and other tiny objects can be visualized in high-resolution after being labeled by fluorechromophores stains. A special property of confocal laser microscopes is a production of sharp photograph at the exact point of focusing without dehiscence from background fluorescence (150).

For that reason, substructures inside bulky object can be smoothly envision by means of CLSM. In addition, assemblage of multi photo of various optical planes, a three dimensional structure can be analyzed (Figure1.17). The CLSM has been used in dental researches like; in oral microbiology, in operative dentistry, and in in endodontic. One of favorable ways for investigation of the dentin/sealer interface is the using of confocal laser microscopy which provides affording detailed information about the presence and distribution of sealers inside dentinal tubules (151).

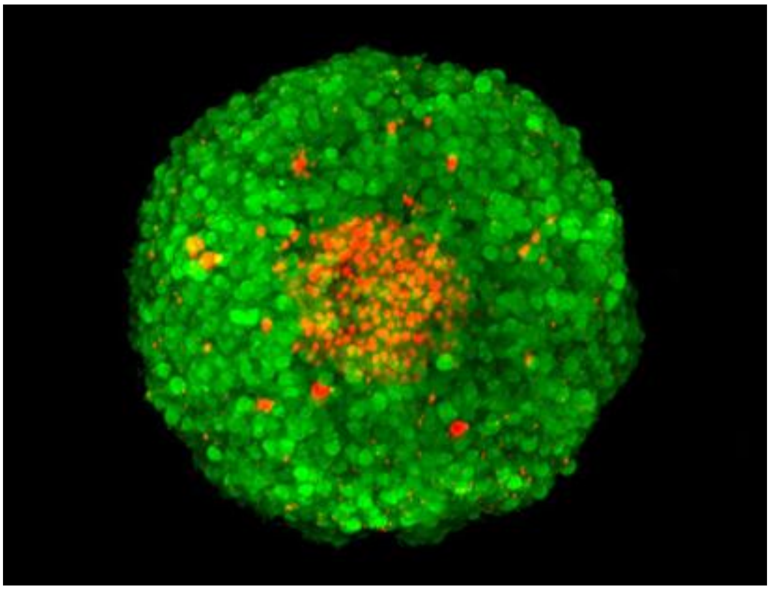


Fig. 1.17 Green: FDA-stained living cells. Red: PI-stained dead cells in the necrotic center of the spheroid.(151)

1.4 Laser–Tissue Interaction

The human dentitions are formed of different hard tissue like; enamel, dentine, and cementum. All these tissues as well as the bone tissue are made up of particular ratio of hydroxyl-apatite, H_2O, and collagenmatrix. On an optical point of view, the above-mentioned constituents are describe as chromophoress, beside that they possess a particular have specific affection with mid-IR lasers, like Er, Cr:YSGGLaser and Er:YAGLaser. as shown in Figure 1.18 (152).

The diversity in chromophores percentage of different oral tissue explains the diversity in optical propertiess of these tissues. Consequently, the coefficient of absorption and the ablations-thresholds of various tissues are different and various laser parameters are required. For instance the dental caries contain more water than normal dentine therefore the mid IR laser can selectively remove the carious dentine. In addition, the cooling by water jet in ablation of tissue by mid IR all tissue laser aid in increasing the absorption of laser and in cleaning and cooling activity which boost the condition of the ablations of the hardtissues (152).

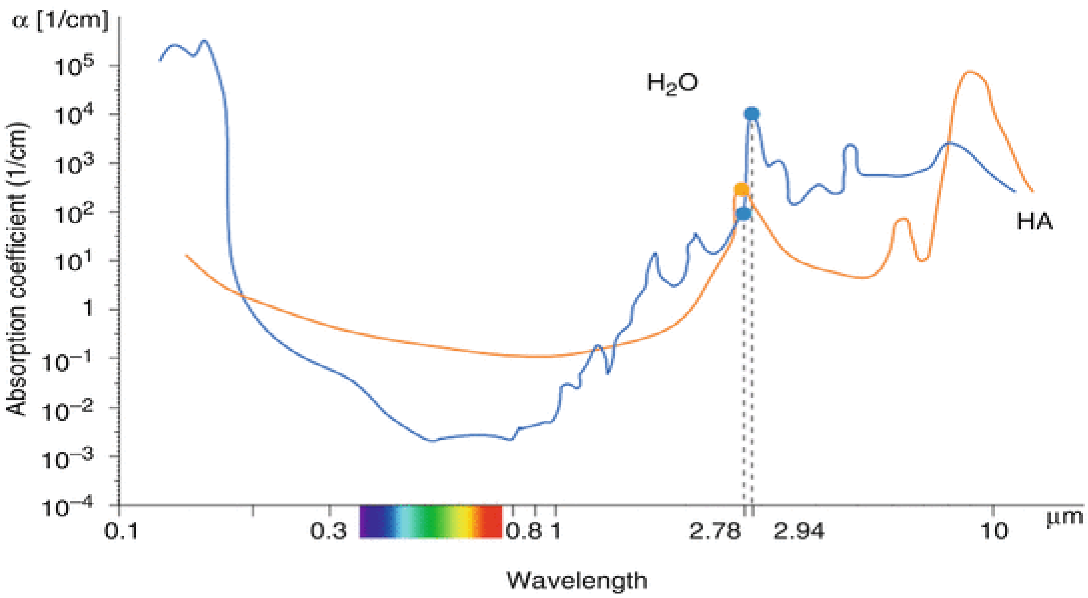


Fig. 1.18 the absorption spectrum of water and hydroxyapatite(152).

1.4.1 Actions of tissue on light

Generally, the specific application of laser in dentistry depends mainly on the selection of appropriate wavelength and parameters that best fit the interaction with human oral tissue. The laser-tissue-interaction pursue physically in optics order: the incident laser light can be undergoes reflection, absorption, scattering, and transmission as shown in Figure 1.19. (153).

As much as the wavelength of the incident beam is coinciding with the absorption peak of the tissue spectrum, the greater light will be absorbed; otherwise the incident beam can be reflected and/or transmitted (153).

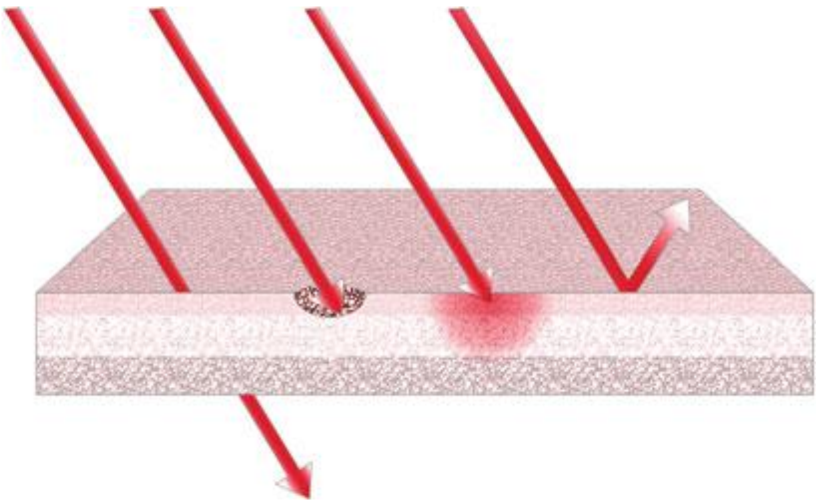


Fig. 1.19 effect of the tissue on light (153).

1. **Reflection**

Reflection is the returning back of incident beam to the same medium when hit the physical boundary of other medium with different index of refraction like air and tissue. This optical event results due to loss of sympathy of the incident- light with the tissue. Generally, the amount of reflected laser radiation is small and around 5% of the emitted laser. This proportion symbolizes the laser hazard that concerns the safety-measures.

Laser emission is actually having a potential harmful effect on ocular structures such as; retina, cornea, lens, and aqueous-humor (153).

Under the law of reflection, the wave normal of the incident and reflected beams and the normal of the reflecting surface to lie within one plane, called the plane of incidence. The specular reflection is happened on smooth surface which is pretended to be relatively smooth, despite of the surface-irregularities that considered small compared to the wavelength of the laser light. On the other hand, the diffuse reflection is occurred when the surface irregularities are as large as or larger than the wavelength of the laser light. At this moment, several beams can be reflected and do not necessitate to be lying within the plane of incidence.

Because of the roughness of most oral tissues surfaces and have not highly polished-surfaces such as optical mirrors the diffuse-reflection is encountered more commonly. The specular reflection can overcome diffuse reflection when the tissue becomes wet (153).

2. Absorption

Absorption expresses the great affection between the matter and the incident light which will be attenuated inside the matter (Figure 1.20). The quantity of absorbed laserenergy inside the tissue represents the bulk of laser therapy by eliciting the various forms of laser-tissue interaction such as: photo chemical, photo thermal, and photo mechanical–photoacoustic energy, determined by the laser wavelength, laser-parameters, and the temporal characteristic of the laser beam (153).

The intensity of the incident-light is decreased by absorption as the light is tramping the matter. The absorbance is the ratio of absorbed-intensity to incident-intensity. If some medium is a totally transparent for specific wavelengths, it will allow the passing of light with no absorption.

Therefore, the amount of incident light energy will equal the amount of transmitted light energy. Examples for this medium in human body are cornea and lens which are designed as a transparent medium for visible light. On the other hand, when some medium is a perfectly opaque for specific wavelength, it will forbid the light passage. As a result the absorbance will be approximately 1 due to the total absorption of incident light (153).

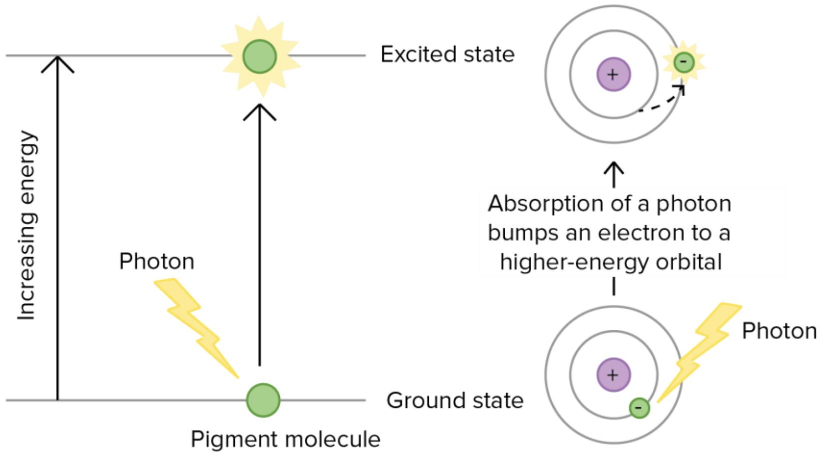


Fig. 1.20 the absorption process(148)

The absorbance of any matter to any electromagnetic radiation is depending on the following factors: electrons structure of each atoms and molecules that forming up the matter, incident-light wavelength, materials-thickness, beside matter temperature and concentration. The absorption length measures the distance z in which the intensity I(z) has dropped to 1/e of its incident value I_0. (153).

Generally, each matter is composed of structural elements (chromophores) different from other matter, So that the interaction with photonic energy is also different depending on the absorption potential to the incident light. These chromophores are described as chemically-structured elements which have the ability to interact with particular photonic energy of specific wavelength giving raise a pigmentation of its matter. However, the photonic spectrum contain invisible light zones, some of these chromophores have been described as invisible too like, water (148).

In oral tissue, the hard/soft tissues of the oral cavity are complex, heterogenous, anisotropic, and have variable thickness. The chromophores of these tissues are usually of different absorption coefficients. They include; collagen, keratin, melanin, hemoglobin hydroxyapatite, and water. These chromophores are considered the key factors that determine the starting and type of interaction (148).

3. Scattering

The scattering is defined as a multidirectional spreading of light in depth of matter. The amount of scattered laser energy inside the tissues can produce photochemical and/or photo-thermal interaction mechanisms which are responsible for the deep laser therapeutic action like bio-stimulation and disinfection (153).

Understanding the phenomenon of scattering depends on the understanding of absorption. When an electromagnetic field is incident on elastically bound charged particles, the particles will be oscillated by the electric field. If the frequency of the incident light is equivalent to normal frequency of free vibrations of a molecule, resonance exist which followed by a reasonable quantity of absorption (153).

In different circumstances, Scattering is happened at frequencies different from that of normal frequencies of molecules and the produced vibration is established by forced vibration. Generally, this oscillation will share the same propagation and frequency of incident radiation but with a very little energy comparing to the case of resonance. However, there will be a phase dismatch between the forced oscillation and the incident oscillation which leads to photons slow down when penetrating into a thicker material. Thus, the scattering can be considered as the fundamental basis of dispersion, two types of scattering can be identified. Elastic and inelastic scattering are built upon whether part of the incident photon energy is transformed during the process of scattering.(Figure 1.21) (153).

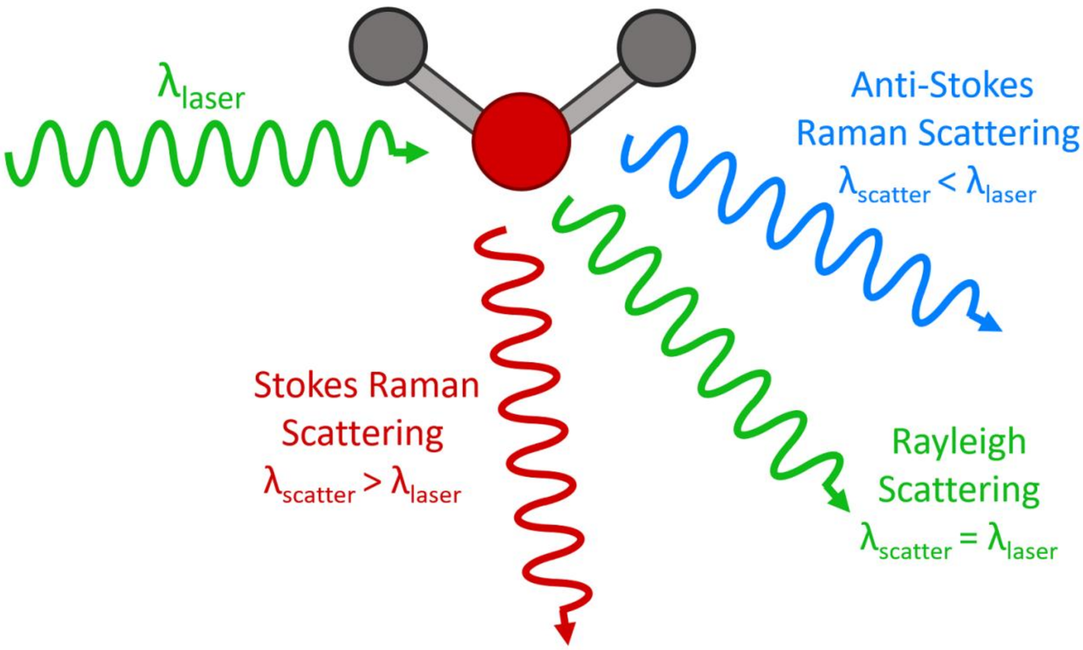


Fig. 1.21 Elastic and inelastic scattering(152)

4. Transmission

This term is defined as the passing of electromagnetic energy throughout a matter without interaction and does not elicit any physical or biological effects (153).

1.4.2 Action of light on the tissue

The action of laser on the tissue can be understood by the interaction which can be occurred in different mechanisms when the electromagnetic wave incident on the bio-tissues. The applied laser parameters, the optical properties of the tissue and other thermal properties determine the type of interaction. The optical properties of the tissue like the coefficients of reflection, absorption, and scattering. Perform an essential function in the interaction mechanism and govern the total amount of laser transmittance throughout the tissue at a specific wavelength (153).

Under other conditions, the most important laser parameters includes: laser-wavelengths, exposuretime, laser-energy, spotsize, fluence, and the laser intensity. The most effective parameter in determining the interaction mechanism is the exposure time. Since 1960, the time of invention of the first laser by Maiman, many researchers had investigated the effects of potential-interaction employing many laser-systems and biologic tissues. They have conducted five categories of the interaction mechanisms. These are photochemical interactions, photothermal interactions, photoablation, plasma-induced ablation, and photodisruption (153).

All mentioned above clearly divert interaction mechanisms have the same familiar fact: the distinctive energy-density is starting at around 1 J/cm^2 upto 1000 J/cm^2. This is remarkable, since the intensity itself differs over fifteen orders of magnitude. In this manner, one parameter characterizes and principally curbs the interaction mechanisms: the exposure-time which is primarily corresponding to the interaction-time itself.

1. Photochemical Interaction

This interaction is happened when the applied laser light has the ability to produce chemical reactions inside macromolecules or tissues. In medical and biological applications, the photochemical interaction is considered the basis of photodynamic therapy (PDT). Additionally, bio-stimulation is also connected to this interactions mechanism, despite the fact that is not dependably confirmed. The Photochemical mechanism takes place at typically low intensities about $1W/cm^2$ with a relatively long exposure times from few seconds to continuous wave. Accurate choice of laser-parameters should performed to produce scattered light diffuse throughout the tissue. The most used lasers for photochemical interaction are lasers with visible wavelengths, like; Rhodamine dye lasers at 630 nm. These lasers have high efficiency and long optical penetration depths which is of importance if deeper tissue structures are to be reached (153).

Since the beginning of the 20th century, some dyes have been able to produce photosensitizing effect. One of the most important examples, some types of porphyrins has a long clearance period in tumor cells. When the laser applied to these photosensitizers it could be transferred to a toxic state and the tumor cells could be preferentially treated. Now days, the concept of photo dynamic therapy has develop into a particular pillars in the new treatment of cancer (153).

On the other hand, the bio-stimulation is also connected to photochemical mechanism which occurred at extremely low energy densities ranging between 1 and 10 J/cm^2. The healing of wounds and some antiinflammatory properties has been documented by using red or near infrared lasers like; heliumneon laser and diode-laser (153).

2. **thermal Interaction**

The photothermal mechanism is the base of broad-interactions types, where the predominant factor is the tissue temperatures rise. The temperature changes of the tissue can be generated by Continuous wave or pulsed-laser irradiation. Different thermal effect on the tissue can be distinguished contingent upon the duration and peak value of the tissue temperature reached. In consideration of the conception of photo thermal interaction of any surgical dental laser with the oral soft tissues, there will be a series of effects that may be happened due to thermal rise. The thermal effect includes: heating, coagulation, vaporization, carbonization, and photoacoustic effect. (Figure 1.22) (153).

- Tissue heating: the heating of the tissue is induced to a low level below the destruction threshold; this simple elevation of temperature is the bases of photobiostimulation phenomena.
- Tissue coagulation: the heating of the soft tissue ≥ 45 °C for a duration of time leads to overcome the destruction threshold and the tissue will be permanently damaged. Above 50 °C the wall of bacteria can be destructed, while at 60 °C the protein of the tissue will be denaturation. As a result the wall of circulatory small vessels in the heated tissue area will be structurally changed and giving raise to blood coagulation
- Vaporization: under normal atmosphere the vaporization temperature of water is 100 °C. Inside the biological tissue the water vaporization is accompanied with protein denaturation which might present at lesser temperatures. Beside that a volumetric change and expansion will be happened especially when the applied laser wavelengths were in the visible and near IR spectrum.

In contrast, the vaporization induced by middle infrared lasers (erbium family) will be different due to little absorption of these lasers in visible chromophores,

- Carbonization: is occurred after prolonged laser application on soft tissue which may cause last stage of molecular damage and formation of carbonated structure. It was reported that the temperature is raised to 200 °C or higher. This undesired outcome can be happened due to inappropriate laser parameters or increased exposure time. Clinically, it is appeared as black-slag around the rims of incised soft tissue which has advantageous absorption to the incident beam especially IR lasers and this may signify the hazardous effect.

- Photoacoustic effect: this effect is happened as consequence of photothermal action on water molecule which will be undergoing transformation to vapor. This transition of matter status leads to volumetric changes and cavitation action inside the tissue giving rise to a shock wave. In addition, there will be an energy conversion to sound wave, and this might be noticed in middle infrared laser application (148).

Generally, there are binary conceptions of ablation can be accounted; ablation facade which is the area of irreversibly changed tissue that removed by ablation, secondly, the thermal facade which is effect on the underlying layer due to the thermal rise (153).

Thermal relaxation time is the time that treated tissue takes to deplete around 63% of the laser induced thermal-energy. This time can be determined by mathematical calculations. The relaxation time is depending on the tissue-irradiated zone, thermal-diffusivity, and the tissue thickness (148).

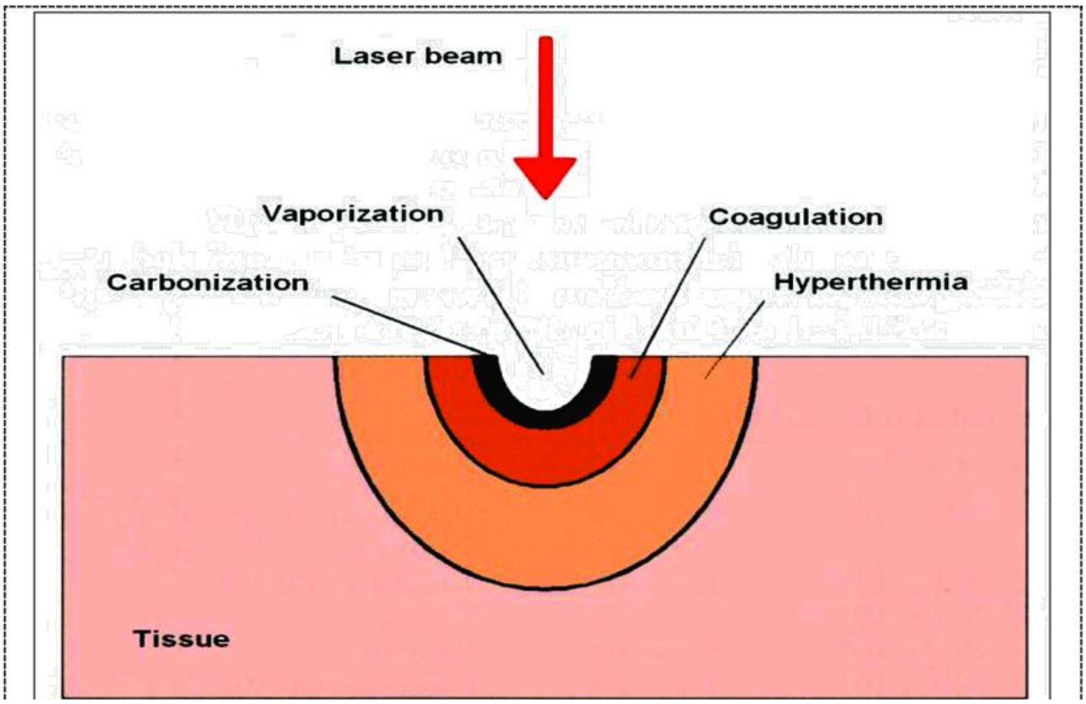


Fig. 1.22 laser thermal effect on tissue(148)

3. Photoablation

Photo-ablation can be described as ablative photo decomposition which is the decomposition of the material subjected to highly intensive laser irradiation. Typically, the power densities of lasers that induce this interaction should pass a threshold of 10^7–10^8 W/cm^2 with nanosecond pulsedurations. The ablation-depth, the depth of tissue removal per pulse, is governed by the pulse-energy up to specific saturation limit. The geometrical pattern of photoablation is defined and described by the spatial characteristic of the laser beam. The superiority of this interaction mechanism sits in the consistency of the engraving action, its exceptional uniformity, and the absence of thermaldamage to adjacent-tissue (153).

4. Plasma-Induced Ablation

At extremely high intensities more than 10^{11} W/cm^2 applied on solids and fluids, or more than 10^{14} W/cm^2 applied on air, a phenomenon known as optical-breakdown can be induced. If mode-locked and amplified Nd:YLF laser with picosecond pulse duration is propagated on an extracted human-tooth, A glowing plasma-spark will be obviously seen which is directed against the laser-light outlet. When a train of pulses of laser light are applied, a regular sparking-noise is noted which is synchronized with pulse frequency. It is obvious that the ablation of this technique caused a highly clean and precise removal of tissue with no proof of thermal or mechanical casualty which can be obtained when selecting suitable laser criterion (153).

5. Photodisruption

Generally, the physical effects connected to optical-breakdown are plasma formation and shock wave generation. On the occasion that optical-breakdown present inside soft tissues or fluids, cavitation and jet formation could be also happened. At extremely high pulse energies which lead to tremendous plasma energies, shock-waves and other mechanical drawbacks become more obvious and may even rule the overall effect consequent to the tissue. Principally, all these are happened because of the actuality that mechanical effects proportion linearly with the absorbed energy. As a result, due to this mechanical impact, the term disruption (from Latin: ruptus = ruptured) is more accurate (153).

1-5 Laser-Assisted Endodontics

The prime objectives of endodontic therapy are to eradicate bacteria and other microorganisms from radicular dentine and to make a sterile root canal field. Dental-Lasers have been considered an important tool in modern endodontic dentistry; they can help in the diagnosis and detection of residual bacteria, and act like a potent method in microorganism eradication and disinfection. In addition, laser has a superior action over traditional ways in reaching distant zone inside the radicular dentinal tubules. Laser application in endodontics is not considered as substitution for traditional rotary or hand cleaning and shaping but instead it complete and support the conventional procedures that giving rise to dramatic outcomes (148).

1-5-1 Laser Application in Diagnosis

1-5-1-1 Laser-Doppler Flow metry

The previous pulp testing procedures are depending on the pain reflex due to electrical, cold, or hot stimuli. These methods are technique sensitive and may give rise to false positive result. The sensory response of the pulp cannot always gives the real status of the pulp for example; teeth subjected to trauma or inappropriate orthodontic movement can elicit pain reflex and in fact may have bloods supply problems (154).

Laser Doppler flowmetry has the ability to estimate the blood supply which gives raise the vitality status of the pulp. It is action depends on the laser light which is transmitted across the dental tissue toward the pulp. the flowing erythrocyte will scattered the laser light with longer wavelength while the static blood will reflect the laser with the same wavelength (155).(Figure 1.23)

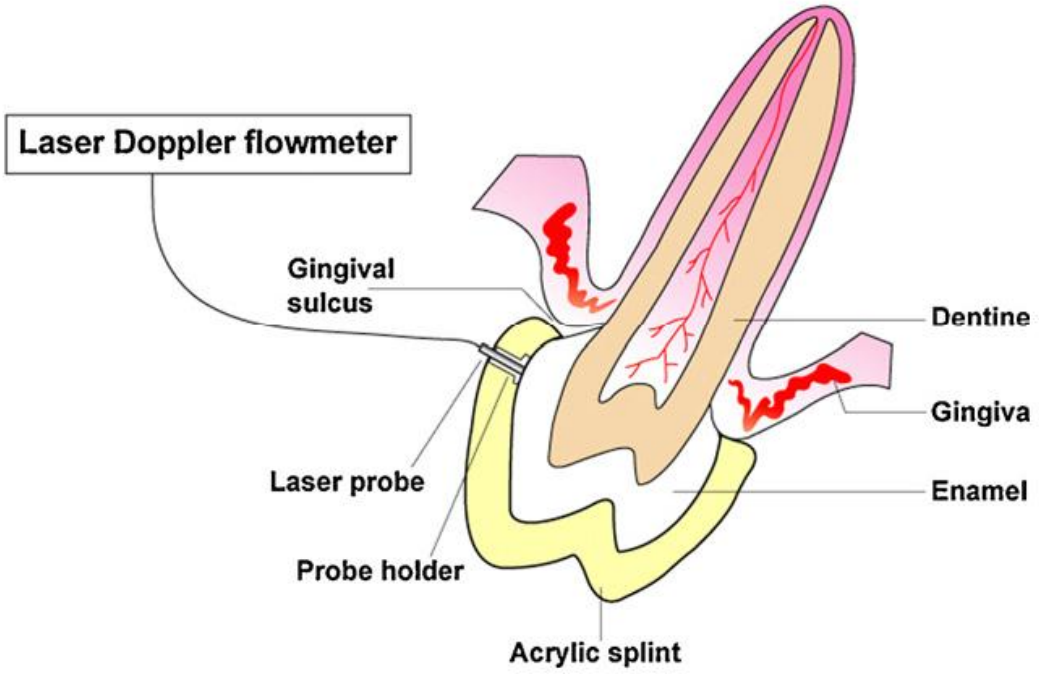


Figure 1.23 Laser-Doppler Flowmetry(155)

1-5-1-2 Endodontic Diagnosis of by Fluorescence

The conventional culture test for determining microorganisms existence of different form in the root canal system are complex and not precise method. Laser fluorescence device can help in diagnosis of the root canal by giving an instant estimation about the planktonic and biofilm forms of microorganism (156).

the Dignodent device (Figure 1.24) is an elegant example of laser fluorescence application. The mechanism of action of this device is depending on propagating red laser light of 655 nm on the dental tissue which evoke fluorescent emitted near-IR beam which can be detected and transformed to digital reading on a scale of 100 (157).

Fig. 1.24 Dignodent device(157)

1-5-2 Laser-Assisted Widening of the Root Canal

Many previous studies have been performed about the widening of the root canal by laser. They used water coolant- Nd : YAG laser to enlarge the apical diameter of the canal from 0.2mm to approximately 0.35 mm. The fiber tip was introduced inside the root canal and moved in in circumferential-sweeping-action accompanied by laterally pressured pulling. The employed parameters were 300 mJ with 1 Hz for 1 min. other authors have used Ho:YAG laser with 245 μm fiber tip to widen the canal from 0.25mm to 0.4mm.(158).

Er,Cr:YSGGlasers were used with different size fiber tips to shape the canal from the crown down to the apex. However, this laser has a great ability to shape radicular dentine and remove smear layer, endodontic mishaps like; ledge, zip, elbow, or perforation have been reported (159). Despite of the fact that lasers have a capability to enlarge the root canal, it cannot meet all the mechanical objectives of cleaning and shaping of the root canal system (160).

1.5.3 Smear Layer Removal

Several sorts of dental lasers have been employed to remove the smear-layer from the radicular dentine. These lasers are comprising; argon-fluoride(161), argon-ion (162), KTP (163), diode (164), NdYAG (165), Ho:YAG (166), ErYAG (167,168), Er,Cr:YSGG (169), and CO_2 lasers (170).

The most reliable, convenient, and low-priced dental laser is the diode laser. It emitted laser radiation at a range from 810 to 980 nm which has a high penetration depth and disincentive properties. These properties make diode laser a profitable device for root canal disinfection as well as for smear layer removal. It has been reported some drawbacks concerning thermal rise from the application of diode laser in removing the smear layer especially with high fluence (171,172)

Another potent laser in root canal disinfection is Nd:YAG laser which shows less potential in smear layer removal than Er family lasers (173). Researches about using Nd:YAG laser in endodontic dentistry has discovered that the application of this laser with black ink will signify the removal action of smear layer (174). In spite that other studies reported a disadvantage related to tissue destruction due to heating (175).

Er family lasers like; Er YAG and Er,Cr YSGG have high absorption in water that make them the most powerful lasers used for smear layer removal beside their disinfection abilities (176). A previous comparison has been made between EDTA and three lasers; argon ion laser, Nd:YAG laser, and Er:YAG laser with laser parameters (50mJ, 1W, 5Hz), (200mJ, 2W, 20Hz), and(100mJ, 1W, 10Hz) respectively. It was found that all of the three lasers have greater action in removing the smear-layer than EDTA, beside that Er:YAG lasers were the best (172).

1-5-4 Disinfection

1-5-4-1 Photo-thermal Disinfection

Generally, the applications of laser for disinfection procedure are present superiority over conventional methods because of laser ability of reaching the entire root canal system (177). The mechanism of disinfection is depending on the photo-thermolysis of the target chromophores. In mid-far IR laser application the targeted chromophore is water molecule which make up the main containent of microorganism. While, in visible-near IR laser application the spotted molecules are; porphyries, melaninn, and pigment (178-180).

To minimizing the collateral damage associated with temperature increasing more than 7 degrees, the laser is preferred to apply in pulsed mode or with low duty cycle (181). In addition, the development of specially designed laser tips have promote the affectivity of laser application and it confined to the root canal walls as well as prevent the apical laser hazard. For example; conical-tip, side firing tip, and radial firing tips are develoved (182).

Now a days, the most common applied lasers with photo thermal disinfective properties are; NdYAG, KTP and diode lasers. These lasers present much greater anti-microbial activity with higher penetration inside the tissue than does other lasers(183).

1-5-4-2 Photo-dynamic Disinfection

The Photodynamic disinfection can be defined as the disinfection that induced by laser as a result of laser-photosensitizer interaction. The photosensitizers are comprise; endogenous sensitizer like porphyrins which is an intracellular component of bacteria, and exogenous dyes like methylene blue that is incorporated to bacterial cell wall after its application. The outcome of laser-photosensitizer interaction is the formation of active-oxygen that destroy the bacterial cell wall, causing leaking of the cellular contents and denaturing of bacterial-protein and DNA (184).

The photodynamic disinfection can be utilized in endodontic therapy especially to treat cases with persistent bacterial infection that cannot be treated conventionally. Additionally, this disinfection method doesn’t produce temperature rise to the radicular dentine or adjacent tissues (185-188).

1-5-5 Endodontic Debridement

The dental lasers have presented a relevant improvement in debriding the root-canal. Unlike laser technologies, the traditional cleaning and shaping procedures does not completely debride the entire root canal system and may leave some walls untouched, especially in oval canals. Additionally, conventional instrumentation may enlarge the canal to undesired limit and alters the normal anatomy and angulation of the canal, leading to transportation. These mishaps are rarely seen if the debridement has been done by appropriately selected laser parameters (189).

Besides that, the using of rotary or hand files in root canal instrumentation can yield smear-layer. The formation of smear layer can further complicate the root canal treatment procedure, it necessitate the usage of interspersing irrigants like, sodium- hypochlorite and EDTA. While, laser doesn't produce this layer and smoothly remove the existing one (189).

1-5-5-1 Fluid Agitation

As previously mentioned, Sodium-hypo-chlorite is considered the most commonly used irigant in root canal treatment due to its potent activity. However it is weak in removing the smear layer, the irrigation protocol must be supported by EDTA (190). The action of these irrigation solutions can be increased by agitation. The commonly used agitation methods are sonic or ultra-sonic agitation methods that are preferably applied throughout final irrigation step (191).

As presented previously Er:YAG and Er,Cr:YSGG lasers have a great affinity for interaction with water that make them perfectly fitted for irrigant agitation. This fluid agitation has two advantages; firstly the photothermal action of laser will warm up the irrigant to a degree that promote its chemical affectivity, secondly the cavitation action of these lasers can improve the flushing rinsing of irrigation solutions and release the trapped air bubbles (192).

Another modification of fluid agitation by laser has been discovered, photoninduced photo-acoustic streaming (PIPS). The PIPS technique is introduced to enhance the root canal disinfection in accompany with sodium hypochlorite (193-197).

1-5-5-2 Cavitation

The flow of irrigation solution in normal irrigation procedure is relatively slow and confined to very short distance beyond the needle tip. Besides that, the surface tension of the irrigation solution can limit the diffusion of solution especially in limited small canal space (198). Additionally, the delivery of the irrigant inside the root canal may be accompanied by bubbles entanglement apically to the enforced fluid (199).as a result of these encountering difficulties, fluid agitation is essential throughout irrigation protocol.

The laser induced-cavitation can agitate the fluid inside the root canal by producing disturbance to the irrigation solution. Unlike conventional irrigation procedure that entail placement of irrigation needle 1mm from the working length, the laser tip can be placed in static coronal position or withdrawn from the middle to coronal third of the root canal (199,200).

The induced-fluid motion by laser cavitation can beat bubbles entanglement inside the root canal. As a result of streaming that is happened due to inflation and consequent rupture of the laser-caused bubble and the due to the generated pressure at the walls of the root canal, the possibility of removing the smear layer will be highly increased (201,202).

1-5-6 Laser Induced Analgesia and Photo-biomodulation

Since 1990, researches about laser biostimulation action have showed NdYAG laser in pulsed-mode has the ability to desensitize the cervical tooth sensitivity due to laser interaction with mediators that lye deep inside the dental tissue. Consequent animal study has presented the relation of Nd:YAG and Er:YAG lasers radiations with the induced analgesia, it was found that after laser irradiation on teeth the pain threshold was increased due to laser effect on neural conduction action. However, this action was very obvious few minutes after treatment and decreased within quarter hour, it has a dramatic effect on delayed neurogenic-inflammation. That is what noticed clinically during cavity preparation by Er laser family (203-207).

The outcomes of laser induced analgesia and photbiomodulation are now used in dental therapy especially in oral surgery, operative procedures, and endodontic therapy. According to clinical findings, the short irradiation time will selectively block the de-polarization A-fiber rather than C-fiber (208).

The pain therapy can be promoted by; pulsed or Cw-mode diode laser, NdYAG laser in pulsed mode, Er:YAG laser, and Er,Cr:YSGG laser. The most important parameters that affect the potential effect of therapy are; laser-wavelength, fluence, energy of the energy, and the time repetition rate (209-212).

1-5-7 Laser Pulpotomy

The pulpatomy treatment of deciduous dentitions has been performed using tricresol formalin for long periods. As a result of this compound has present a toxic and carcinogenic effects on biologic tissue, its uses have been limited. Others substitutions are relatively coasty like mineral trioxide aggregate, therefore it is recommended to find a reliable method. Laser application in endodontics has been developed a lot, that engorge the researcher to find a way of using lasers in pulpatomy procedures. These lasers include; NdYAG, ErYAG, CO_2 and semiconductor lasers.

The main advantages of laser pupatomy are; lower procedure time, easyer technique, little discomfort postoperatively, and profited results when compared with conventional methods. These elegant outcomes belong to laser ability to disinfect the operation site and the photobiostimulative action (213-216).

1-5-8 Safety Issues Related to the Use of Lasers in Endodontics

The modern endodontic therapy directed to use magnifying optics like microscope to increase the precision of the treatment. The using of dental lasers with these treatment modalities can increase the laser eye hazard, so it is recommended to wear eye protecting goggle and add filter for the microscope. However, lasers with wavelengths more than 2 micron can be considered relatively safe, it can be absorbed by microscope optics (148).

1-5-8-1 Prevention of Transmitted Infection by Contact

The multi-use laser accessory that used for endodontic treatment might be considered a source of transmission of infection between patients if not well sterilized. However, insubstantial tips and others disposable accessory have been used in some laser-devices, a lot of laser systems have a multiuse accessory and tips that can be sterilized (217). The pertinent recommended methods for prevention of transmission of infection are as the following:

1. The water supply, which acts like a coolant during laser application on the tissue, should be hygienic.

2. The volatile debris and ablated particles may be attached to the tip surface and leading to decrease the power density, therefore it is recommended to clean the laser tip immediately during and after the operation.

3. Generally, laser accessory like handpiece, optical fiber, and tips have to be cleaned thoroughly and sterilized after every usage (218).

1-5-8-2 Temperature Effects of Lasers on the Dental Pulp

Most of dental lasers used in endodontic therapy have relatively high power that induce thermal rise in dental tissue to a degree might affect tissue vitality. However, it was reported that the temperature changing whether increasing or decreasing can leads to minimize blood flow of the pulp as determined by Doppler-flowmetry (219). The tissue absorbance and reflectance of the incident beam spectrum will determine the pulp reactivity. In Previous study, pulp necrosis is accounted when a thermal load of 150 centigrade is applied on the surface of enamel for a half minute (220). Another study has concluded the thermal rise to more than 5.5 °C can induce pulp necrosis in about 15 percent of patients, at the same time the thermal rise to 17 °C can produce pulp necrosis in all patients (221).

The appropriate selection of laser parameters for dental laser application which accompanied by sufficient water cooling can minimize the collateral damage to the pulp. It has been proved that water /air coolant can decrease the thermal elevation that result from photothermal ablation beside it can clear away the ablated tissue and deposit (221).

1-5-8-3 Temperature-Effect of Lasers on Periodontal Tissues.

The preservation of periodontal tissue is of ultra-most importance in successful of endodontic therapy. However, the conventionally employed endodontic instrument does not generate thermal rise on periradicular area (222), researches have presented some instrumentation and obturation modalities can produce thermal rise to periodontium (223-228). On the other hand, the Er lasers application on dental hard tissue is causing water-evaporation inside the hydroxyapatite crystal, leading to cooling down the temperature of the tissue.

The photothermal action of lasers on the periodontium and adjacent bone structure has been studied (229,230). These tissues have shown a slight response to temperature rise of 47 °C, complete pause of blood flow and bone necrosis can be encountering when the temperature increased to 60 °C (231). Conversely, the temperature decrease down to 5° Celsius does not affect the periodontium and surrounding bone (232).

Several studies have been done concerning the Er:YAG laser application on dental hard tissue (233), it was concluded that the maximum thermal rise on the periradicular area <6 °C apically and <3 °C middly. Another study on the same laser has presented a temperature rise <7 °C at the middle root area (234). If the water cooling is employed the thermal rise will decrase to <2 °C (235). As a result, the cooling systems of laser devices is quiet sufficient to overcome the photothermal action of laser on soft and hard periradicular tissue (236,237).

1-6 Laser Safety

The laser light is considered as a powerful source of coherent electro-magnetic radiation which if collimated on living tissue will be absorbed partially or totally to produce a molecular changed to that tissue. Most of dental Lasers wavelengths are located in the infrared range that means most of the absorbed energy will convert to heat inside the target tissue. This photothermal effect might cause an elevation in tissue temperature to a level which leads to protein denaturation or water evaporation(238).

The valuable knowledge and acquired experience in manipulation of laser energy can give rise to wonderful result for laser-treated tissue. On the other hand, clumsiness and inappropriate application of laser energy or effect on surrounding and adjacent tissue might show irreversible damage to these tissues. This side effect can be seen, during oral laser application, around the mouth and in the skin of the face or in retinal tissue (238).

Due to the high demands of using laser in dentistry, laser safety must take a high issue during laser application. Protection the adjacent tissues and safeguard the eye by goggle are the primary requirements of laser safety (238). According to previous studies concerning to dental laser-hazards, it was presented that application-hazards belonged to dental laser usage persist unwell implied and unexplained. The main probably happened problems include eye involvement, skin injury, burns, electrical shocks, and to little degree air contamination by laser plume (239).

1-6-1 Laser Classification

The classification of lasers is performed according to the possibility of laser to produce potential eye or skin damage. The real benefit of this classification is to alarm the operators from the relative risk attached to laser systems. The main laser parameters that were taken in account are; the output power, laser-energy, wave-lengths, exposure-time, and the laser beam spot diameter. There are four main classified lasers groups starting from class I ascending to more hazardous class IV (240).

Class I : this group includes lasers systems which are cleared from radiation threat during normal usage.

Class II : it encompass laser systems that generate low output power less than one miliwatt in the visible light range.

Class IIIA : this group comprise lasers with moderate output power. Some precaution measures should be employed.

Class IIIB : it includes lasers system with intermediate output power. Dealing with this lasers group requires specific caution measure.

Class IV : encompass laser system that generate relatively high output power. These lasers are able to cause; hazardous effect to operators eye or skin, and potentially fire risk. High protection measures are recommended (241).

Recently this classification has been developed and subjected to modification due to the increased worldliness of laser usage. In addition, the development of magnification ways in dentistry like; microscope or loupes is signifying the laser hazard. This classification includes the following laser groups (242).

Class 1: these lasers group are considered safe at all. They present no hazard to eye or skin of operators despite them using magnifying means.

Class 1M: principally, this lasers group encompasses lasers presenting no risk, but they can be risky when viewed by magnifying optics. However, they are still considered relatively safe due to the beam divergence with large spot diameter.

Class 1C: this class takes its letter c from contact or conditional (243). Generally these lasers are designed for skin or underlying tissue treatments which come in contact or close to target tissue with relative safety for the eye.

Class 2: this group resemble Class 2 group in the previously mention classification. Lasers in this group are considered safe due to the blinking reflex of the eye will diminish the exposure time. These laser include pointers and measuring devices.

Class 2M: generally, it has the same power and wavelength range of class 2 but, they can be hazardous when viewed by magnifying optics, like microscope or telescope. As mentioned previously in class1M, class 2 M has large spot size and divergent beam.

Class 3R: these intermediate powered visible lasers are considered safe if used correctly, with viewed beam restriction. Class 3R lasers radiation hazard can exceed the maximum permutable exposure for the eye(244).

Class 3B: lasers of this class showing a wider wavelengths range from 0.3 μm to far infra red region. Forthright-exposure to eye or skin is considered hazard so goggle must be used for protection. On the other hand, diffuse scattering is relatively considered safe.

Class 4: includes lasers with greatest hazard of any other classes. These lasers produce high output power, more than 500 mW. They have the ability of causing skin burning or permanently eye damage wherever subjected to direct or scattered radiation. These systems should be supplied with a key switch and a safety inter-lock (243).

.

1-6-2 Hazards of Laser Beams

The laser-induced hazard can be described as the effect that could cause; physically harmful-damage, physiological malfunction, unfortunate surgical-result (245).

Laser beam hazard can be estimated with concerning to: wave-length, power-density, optical-compromises, non-target oral tissue, non-target skin, inhalation, and laser plume endangers

1. laser-wavelength: most of dental lasers wavelengths lies within (0.37-10.6 um) that means they are non-ionizing radiation. The interaction of these lasers with tissue mainly is wavelength dependent photo-thermal interaction. According to wavelength dependent interaction the incident laser beam is; absorbed, transmitted, scattered, or reflected by the tissue. All These four interaction might be happened simultaneously and can produce hazard.

2. The power of the irradiation: this power is associated to the energy per time with spot dimension of the incident beam which giving raise how

much the tissue received power density. According to the values of the power density, tissue can be treated, irritated or permanently damaged.

3. Optical risks: it was reported several cases were presented with eye comprises due to laser radiation hazard. The wearing of protecting goggle for the patient and operators is of great importance for safety procedure[246-248]. One of the physiological responses of eye to the visible laser spectrum is blanking the eye which considered natural protection against lasers class I and II. However, the closure time of the eye laid is in the order of two tenths of the second and the eye must not receive radiation more than that permitted. As a result laser with higher intensity can affect the eye and induce injury faster than the protecting blinking reflex of the eyelid (249).

4. Non-target oral tissue: laser procedure inside the oral cavity might show some challenges concerning the accessibility and intentional in-voluntary movement of the cheek, lip, and tongue of the patient. Therefore, a special care must be taken when reflecting these structures and controlling the laser handpiece before the starting of the treatment. Additional possible risk of using laser in oral cavity is the collateral damage to adjacent tissue and this might happen because the inhomogeneous turbid oral tissue nature especially when the absorption of adjacent tissue is greater than the accused one (250).

Another hazard is accounting for the reflection process which may affect or harm tissue other than the target one. Direct or specular reflection can be happened on mirrors; metal instruments used in dentistry, amalgam restoration if any, and even moisture of the oral surfaces (251).

5. Non-target skin: generally, skin hazard is low, during laser application in dentistry. As a result, the required protection of skin hazard would be

not as that recommended for facial plastic and dermal laser processes (252).

6. Inhalation and laser-plume risks: it is produced as a byproduct of ablation of oral tissue by laser radiation. The inhalation of this plume is considered a real hazard to patient and operators so that, room ventilation and face musk should be equipped. The laser plume is composed of water-vapor, CO and CO_2 gases, in addition to metal-fume, particulate organic and inorganic-matter, and microorganism (253-256). The hazardous effects of laser plume can cause: irritant eyes, nausea, difficulty in breathing, and cross infection (257,258).

1.7 Literature review

Year by year, several studies have been performed about endodontic branch of dentistry. Some of them focused on cleaning and shaping phase such as using different rotary techniques (37,50,51), increasing irrigant effect, removing of smear layer by different techniques (99-115), and root canal disinfection (19-22). The Er,Cr:YSGG laser has a part of all proceeding researches. Other studies evaluate the obturation phase, assessing the adaptation and penetration of different sealer types by means of many investigation techniques like: scanning electron microscope, micro CT, and confocal laser microscopy (150,151).

In 2013, Martins et al studied the Efficacy of Er,Cr:YSGG laser with endodontical radial firing tips on the outcome of endodontic treatment. They concluded that the Er,Cr:YSGG laser group is exhibiting statistically significant decreases in PAI scores (259). In 2014, again

Martins et al studied the outcome of Er,Cr:YSGG laser-assisted treatment of teeth with apical periodontitis and they found for single-rooted and premolar teeth, this laser-assisted protocol can achieve predictable endodontic outcomes, comparable to conventional strategies in 1 year of follow-up (260).

In 2014, Astrit Kuci et al used the confocal laser scanning microscopic to evaluate the sealer penetration into dentinal tubules in the presence or absence of smear layer. They found the removal of the smear layer increased the penetration depth of MTA Fillapex used with the cold lateral compaction technique with maximum sealer penetration of 980um at the middle third (261).

In 2015, Licata et al studied the effectiveness of a new method of disinfecting the root canal, using Er, Cr:YSGG laser to kill Enterococcus faecalis in an infected tooth model, they found that results indicated a bactericidal effect of Er, Cr:YSGG laser irradiation at the settings used in this study. The highest bactericidal effect of this laser was observed at 60 s of irradiation time, using an energy pulse of 75 mJ (262).

Lopez-Jimenez et al at 2015 used Atomic force microscopy to visualize the injuries in Enterococcus faecalis surface caused by Er,Cr:YSGG and diode lasers. Laser irradiation was achieving significant bactericidal effects deeper than conventional chemical solutions (263).

In 2016, Asgeir et al studied the healing rates after Endodontic Therapy using the novel gentlewave system and monitored the cases for 1 year, they found that the cumulative success of endodontic therapy was 97.3%. The success rates of necrotic and irreversible pulpitis were 92.9% and 98.4%, respectively (264).

In 2016, Another study has been done about Root surface temperature changes during root canal laser irradiation with dual wavelength laser (940 and 2780 nm), Haidary et al combine the alternating pulses of Er,Cr:YSGG and 940-nm diode lasers, emitted through one radial firing tip (265).

In 2017, Martins et al presented two case reports using a double-wavelength (940 nm + 2780 nm) laser in endodontics, The results of both clinical cases show the immediate remission of symptoms, absence of clinical complications and complete radiographic healing. However the canal is enlarged relatively at the apical area (266).

In 2017, Sarika Chaudhry et al used the confocal microscope to investigate the action of endo activator and Er,Cr:YSGG laser activation of Qmixirrigant, on sealer penetration. They concluded that the maximum sealer penetration was recorded for Er,Cr:YSGG laser activated group (267).

In 2018, Paloma et al performed a comparative study of debris and smear layer removal with EDTA and Er,Cr:YSGG laser. They concluded that in the middle third, Er,Cr:YSGG laser showed a better cleanliness with statistically significance differences compared to 17% EDTA (268).

In 2019, Paulina et al, review the effect of laser radiation in removing the smear layer. They conclude that, the application of laser system can be a more effective way to remove the smear layer than other conventional activation (269).

In 2020, Ayca Yilmaz et al have studied the effectiveness of various final irrigation techniques on sealer penetration by using a confocal laser scanning microscopy. They found that all the experimental groups exhibited significantly higher penetration rates than the control group with maximum penetration depth of 652um (270).

Various preceding researches have presented the superiority of Er,Cr:YSGG laser in performing smear layer removal and root canal disinfection . In the present study this laser was used in clinical and confocal laser microscopy studies, for smear layer removal and root canal disinfection preceded by minimally invasive endodontic technique.

Chapter Two

Materials

&

Methods

Chapter Two
Materials and Methods

This chapter includes a description of the patient selection, sample preparation, grouping, irradiation procedure, material, and equipment used in the present study with method(s) used to perform the study and the statistical analysis.

2-1 Materials:

-2 % lidocaine with1:100,000 epinephrine (Septodont - Lignospan Standard)

- Sodium hypochloride 5.25% (NaOCl) exp. Date 2021

- normal saline (bioneer, exp. 2022)

- EDTA 17% (prevest DentPro)

- AH plus sealer (Dentsply DeTrey, Konstanz, Germany)

- paperpoint (Dentsply Maillefer, Ballagues, Switzerland).

- Guttapercha cones preotaper next (Dentsply Maillefer, Ballagues, Switzerland).

- Guttacore (Dentsply Maillefer, Ballagues, Switzerland).

- Temporary filling

- light cured composite (3M P60 , USA)

- flowable composite (3M , USA)

- bonding agent (3M, Universal ,USA)

- Acid etchant

- Glass Ionomer-Cement (Kavitan-Plus, Prague, Czech)

- Rhodamine B (Alfa Aesar, Karlsruhe, Germany)

- Thymol crystals (BDH Lab. reagents / England)

2.2 Equipment:

- Er,Cr:YSGG laser (Waterlase i-plus, Biolase-Technology, Inc, San Clement, CA)

- syringe (Monoject, Sherwood Medical)

- X-ray Films

- Rubber Dam

- Thermaprep (Dentsply Maillefer, Ballagues, Switzerland)

- incubator (Memmert / Germany)

- Microtome (Mecatome T210 A; Presi, Tavernoles, France)

- sandpaper discs(P 1000)

- Mecapol (P230, Presi, France)

- Confocal Laser scanning Microscope (Leica DMi8; JH technology, Germany)

-Scissor (Thackeray, England)**-**

- Mirrors, sharp probes, and tweezers (Derfla, Germany).**-**

- Graduated Endodontic ruler.

- Electronic balance 0000 (Model HR-200, Made in Japan).**-**

- Finger Spreader (Dentsply Maillefer, Ballagues, Switzerland)

- K-Files #06,08,10,15,20,25(Dentsply Maillefer, Ballagues, Switzerland)

- plugger (Dentsply Maillefer, Ballagues, Switzerland)

- Cover slab

- Microscope Sildes

- Apex Locator (Root ZX mini, Morita, Japan)

- X-ray Device (runyes dental x ray unit, china)

2.3 Er,Cr:YSGG laser

The Er ,Cr :YSGG laser, Water-Lase iPlus device, is a unique all tissue laser system that incorporates the laser action with the water jet. This laser was used in the present study for smear layer removal and intra-canal disinfection. The smear layer and disinfection parameters were chosen carefully without causing collateral thermal damage to periradicular area. The smear layer removal parameters were 1.25 W average power, 20Hz pulse repletion rate, 60µs pulse duration; 30%Air; 10%Water. The radial firing tips were used for this procedure: RFT2 and RFT3 with diameters 200 µm and 320 µm respectively. On the other hand, the disinfection parameters were 1 W, 20 Hz; 60 µs; 10%Air, and without water. The laser device and its specification is depicted in Figure and Table (2.1)

Fig. 2-1 the Er ,Cr :YSGG Laser device

Table 2.1 Er , Cr:YSGG (Water-Lase iPlus-Laser) specifications(271)

ELECTRICAL	
Type	(Class I) Medical-Electrical-Equipment
Operating-Voltage	100 VAC ± 10 % // 230 VAC ± 10 %
Frequency,	50/60 Hz
Current-rating	5 A/8 A
Main-control	Circuit-breaker
On/Offcontrol	Key switch
Remote-interruption	Remote-interlock-connector
AIR& WATER-OUTPUT	
Water-type	Distilled-water /Deionized
External-air-source	5.5-8.2bar
Water.	0–100 %
Air,	0–100 %
Interaction-zone	0.5-5mm (Hand piece-tip – target**)**
OPTICAL,	
Laser-classification	Four
ActiveMedium	Er,Cr:YSGG (Erbium, Chromium :Yttrium, Scandium,Gallium, Garnet)
Wavelengths	2780 nm
Frequency.	5–100Hz
Average-power	0.1–10W
Power-accuracy	±20 %
Pulse-energy	0–600mJ
Pulse-duration for“H”-mode	60µs
Pulse-duration for“S”-mode	700µs
Hand piece head-angles	70°contraangle
Gold HP Tip diameter-range	200–1200µm
Turbo Tip focal diameter-range	500-1100µm
Output-divergence	≥8°perside
Mode,	Multi mode
• AimingBeam:	635 nm red-laser, 1 mW max
• Water-Level Sensor-Beam,	635 nm redlaser, 1mW max
• Nominal-Ocular Hazard=Distance	5 cm
Maximum-Permissible-Exposure (MPE):	$3.5x10^5$ W/m^2

2-4 Confocal Laser Microscopic Study

The confocal laser microscopy study was implemented prior to the clinical study. The confocal study was performed in Sharif University of Technology- Tehran-Iran. In this study confocal laser microscopy (Table 2.2) was used to investigate the AHplus sealer penetration into dentinal tubule following smear layer removal by either use of ErCr:YSGG laser or EDTA.

Table 2.2 specification of a confocal laser scanning microscope (Leica DMi8; JH technology, Germany)(272)

Power supply	Internal
Display	6 or 12 LEDs
Focus	Manual 2-gear
objective turret	6-fold M32 coded
reflector turret	• 2 fold-reflectorturret-coded • 6 fold-reflectorturret-coded • 6fold-reflectorturret-uncoded
Reflectedlight-axis	Manual: • iris incl centerablefield & aperture-iris • dia-phragm & manualUC-3Dillumination • slot for polarizer & additional filterslider
Contrast-technique • Incidentlight (IL) • Transmittedlight (TL)	 BF , UC 3D, HDF, DIC , Pol, Fluorescence BF, Pol, Ph, DIC , DF
Magnification-changer	Active on front port, manualcoded : 1.5× or 2.0×
Stages	• Fixedstage with different-inserts and object-guide • Manual 3plate stage with differentinserts • Glidingstage

2-4-1 Samples

The samples used are composed of 30 extracted-humanteeth of single root. Teeth were extracted from patient aged between 12-60 years old for orthodontic or periodontics purposes. The teeth were examined clinically and radiograghically to ensure that there is no root fracture, open apex, and/or root resorption. The entire samples were conserved in 0.1% thymol crystalsolution until the stating of the experiment. Then, samples were decrownated at the CEJ by using a high speed fissure-bur with water-cooling, as shown in Figure 2.2.

These samples were used for confocal laser microscopic analysis to investigate the AHplus sealer penetration into dentinal tubule following smear layer removal by either use of ErCr:YSGG laser or EDTA.

Figure 2.2 decrownated teeth

2-4-2 Experimental Design

Root canal treatment was performed for all samples. The working length was estimated by using K-file #10 which introduced inside the canal and pushed down to be just seen passed the apical foramen, this measurement was used after subtracting 1 mm. The root canal was negotiated with size 8 or 10 file up to get canal-patency at the apical area. Then, they were shaped with ProTaper Next rotary instruments. The apical size of all the specimens were instrumented up to X4 (0.4 mm tip with 6 % taper). They were copiously irrigated between changing each file with 2 mL 5% NaOCl delivered by 27G needle with 3-mL syringe

All samples were split into three-groups, every group has ten roots. The first one was irradiated by 2.780 µm Er ,Cr:YSGG laser for smear-layer-eradication with a radial firing tips RFT2 and RFT3 [diameter 200 µm for apical and middle third and 320 µm for coronal third respectively]. The used parameters were: 1.25 W, 20Hz, 60µs; Air 30; Water 10. The RFT was inserted down to the root canal 1mm shorter than the determined-length. At the time of laser application, it was withdrawn circularly against walls of the canal. This action has been done again three times at a rate of 1-2mm/second. Second group was irrigated with 17%EDTA (2 mL for 3minutes) to eliminate the smear-layer, after that lastly flushed by two milliliter sodium hypochlorite. Third group has been used as control, so no smear layer was removed.

All specimens of all groups were obturated with AH plus sealer. The sealer was prepared as reported by the instructions of the manufacturer. Despite that, before being investigated by the confocal-laser microscope, it has been mixed with fluorescent dyes. The used dye was Rhodamine B which was added at weight percentage of 0.001. The sealer was applied inside the canal by means of paper point. After that, the samples without exception were subdivided into 2groups; first group was obturated with carrier-based method while in second group cold lateral compaction was used.

In carrier-based technique, X4 GuttaCore was used with the GuttaCore oven Thermaprep. After the heating period of the Thermaprep has ended, the Guttacore is thoughtfully withdrawn from the oven holder. Then, a locking cotton pliers was used to grasp the GuttaCore just above the calibration ring that marks the working length and inserted precisely into the orifice, and slip to length without stirring the axial walls.

While in the second group, cold lateral technique group, the selected master cone was X4. After insertion and fitting of the master cone, finger-spreader has been used with labeled length of 1-2 mm shorter than the determined-length. Then, extra guttapercha with 0.02 tapering were implanted till the entire root-canal was obturated. For obturation assessment, radiographs were taken from two aspects buccally and mesially. Then, coronal seal of the roots samples was performed using glassionomer-cement. After that, the samples were conserved for 48 hours inside an incubator with 37 C temperature and complete humidity.

In summery, this study consists of six groups assembled by letter G from 1-6 as showed bellow where each group has five teeth:

G1: smear layer removed by Laser and obturated with carrier-based technique.

G2: smear layer removed by Laser and obturated with lateral compaction technique.

G3: EDTA for smearlayer removal , obturated by carrier-based technique.

G4: EDTA for smearlayer removal , obturated by lateral compaction technique.

G5: smear layer was not removed , obtureated carrier-based technique.

G6: smear layer was not removed , obturated with lateral compaction technique.

2-4-3 Roots Sectioning and Preparation for Confocal-Laser-Microscopy

The samples were mounted in polyester resin as depicted in Figure 2.3.a. Then, horizontal sectioning was performed for each root at 3, 6, and 9 millimeters lengths away from apex. Diamond saw of 500 rpm spinning speed was used for sectioning with continual water-jet, as showed in Figure 2.3 b and c. After that sand paper disc (P1000) mounted on polishing device were used to polish the surfaces of samples.

a b c

Figure 2.3 a) polyester resin b) sectioned root c) (Mecatome T210

The sectioned root slices were inspected under a confocal laser scanning microscope (figure 2.4) at 532 nm wavelength, whereas the depth of sealer penetration measured at each slice on four distinct location (buccal, lingual, mesial, and distal). The used magnification was 10X and 40X. The seen rows have been chosen 7.5 micron underneath the sample surface. The scanning-thickness of dentine was 92.5 micron with 7.5micron step-size. The image resolution of the scanned samples was 1,024X1,024 pixels.

The photograph examination and calculation were done using Photo-shop 7.0 (Abode System, Sann Jose, CA). The maximum depth of sealer penetration in the dentinal tubules, starting from the canal wall, was measured and documented on 10 different lines in each sites.

a **b**

Fig. 2.4 a) a confocal laser scanning microscope (Leica DMi8; JH technology, Germany) b) root slices fixed on slides

2-5 Clinical Study

2-5-1 Study Cohorts

The study group was composed of 40 patients who were indicated for root canal treatment and diagnosed having apical periodontitis. The clinical research was conducted according to the Declaration of Helsinki. The project of the study was discussed with the involved subjects and an informed-consentform was signed by all patients before being involved into the study. The patient's selection for this study was subjected to inclusion/exclusion-criteria.

2-5-2 Inclusion/ Exclusion Criteria

The included persons were aged from 12-60 years old. They were treated by minmaly invasive non surgical endodontic therapy. The whole cases have been diagnosed of having apical periodontitis according to clinical and radiographical finding. The selected patient teeth were permanent first molars.

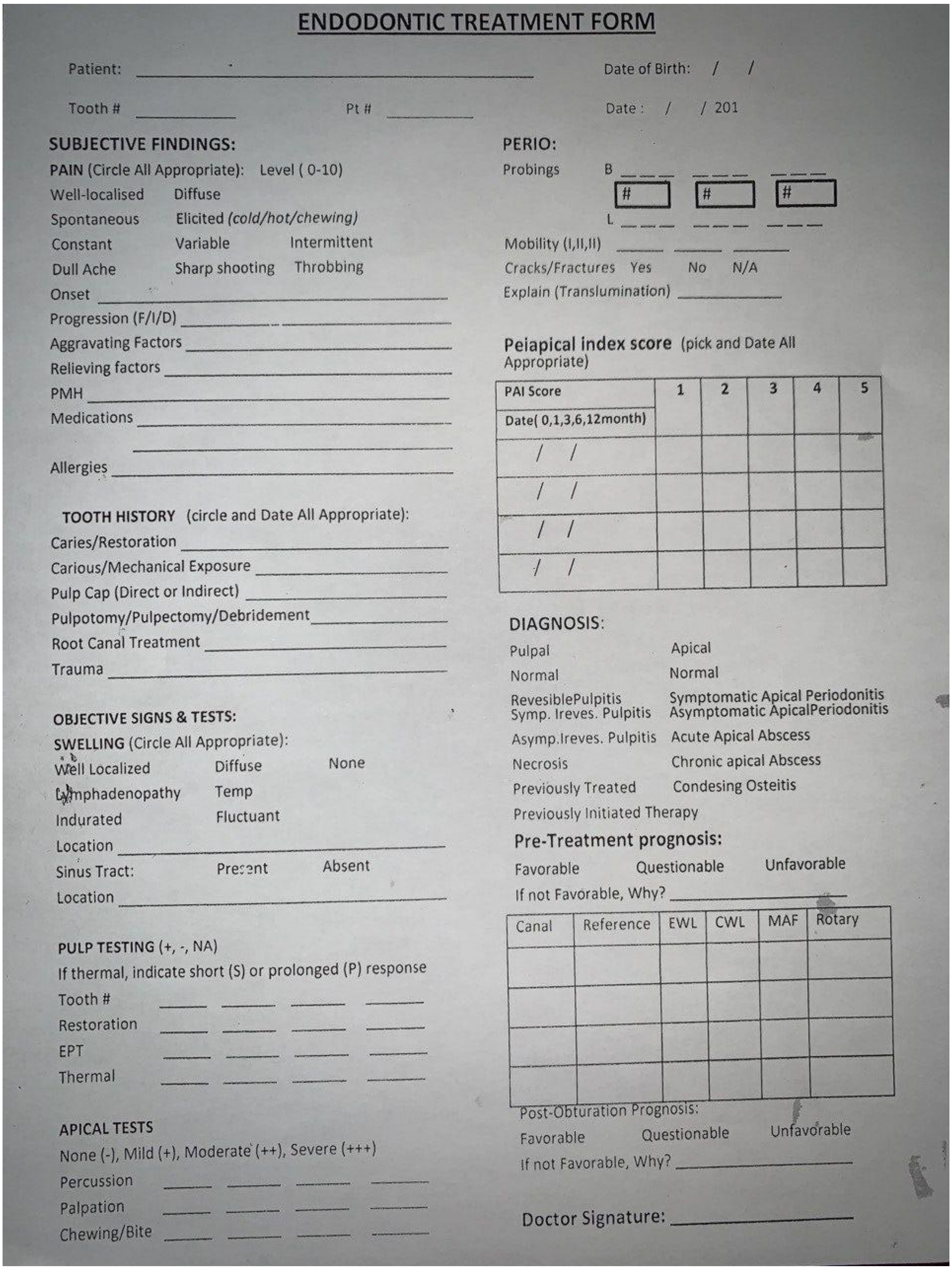
Patients were excluded if they have had endodontic therapy (for the selected tooth of the study). Teeth with periodontal problems were also excluded such as; mobile teeth with score of more than 2, teeth have more than 6 mm pocket-depth, and teeth presented openapices. Additionally, patients were excluded who under medicine regime that could interrupt the bone-metabolism like; hormones intake, immune suppressive medications, cortico-steroids pills, selective serotonin reuptake inhibitor, tumornecrosis factors, intra venous bisphosphonates, and anti resorptive medicine.

2-5-3 Preoperative Data Collection

A thorough preoperative clinical examination was performed for each patient and supported by radiographic records. This examination includes a patient's medical history and previous dental work, in addition to an intraoral assessment which encompassed the mobility testing, calculation of the periodontal pocket depths. Also the swelling, softtissue-lesion if any, percussion, and palpation were recorded. After that, pulp status and peri radicular diagnostic case was concluded and documented (figure 2.5). The parallel peri apical radiographic technique was employed and the radiographs analyzed according to periapical index score (272).

A coded data sheets were used, these sheets contain edited radiographic and clinical data belonging to each accused tooth at different periods:

before (preoperative), after (postoperative), after one month, and at 3-month intervals form the date of obturation up to 6 months.



ENDODONTIC TREATMENT FORM

Patient: ______________ Date of Birth: / /

Tooth # ________ Pt # ________ Date : / / 201

SUBJECTIVE FINDINGS:

PAIN (Circle All Appropriate): Level (0-10)

Well-localised Diffuse

Spontaneous Elicited *(cold/hot/chewing)*

Constant Variable Intermittent

Dull Ache Sharp shooting Throbbing

Onset ______________

Progression (F/I/D) ______________

Aggravating Factors ______________

Relieving factors ______________

PMH ______________

Medications ______________

Allergies ______________

TOOTH HISTORY (circle and Date All Appropriate):

Caries/Restoration ______________

Carious/Mechanical Exposure ______________

Pulp Cap (Direct or Indirect) ______________

Pulpotomy/Pulpectomy/Debridement ______________

Root Canal Treatment ______________

Trauma ______________

OBJECTIVE SIGNS & TESTS:

SWELLING (Circle All Appropriate):

Well Localized Diffuse None

Lymphadenopathy Temp

Indurated Fluctuant

Location ______________

Sinus Tract: Present Absent

Location ______________

PULP TESTING (+, -, NA)

If thermal, indicate short (S) or prolonged (P) response

Tooth # ____ ____ ____ ____

Restoration ____ ____ ____ ____

EPT ____ ____ ____ ____

Thermal ____ ____ ____ ____

APICAL TESTS

None (-), Mild (+), Moderate (++), Severe (+++)

Percussion ____ ____ ____ ____

Palpation ____ ____ ____ ____

Chewing/Bite ____ ____ ____ ____

PERIO:

Probings B ___ ___ ___ # # # L ___ ___ ___

Mobility (I,II,II) ____ ____ ____

Cracks/Fractures Yes No N/A

Explain (Translumination) ________

Peiapical index score (pick and Date All Appropriate)

PAI Score	1	2	3	4	5
Date(0,1,3,6,12month)					
/ /					
/ /					
/ /					
/ /					

DIAGNOSIS:

Pulpal: Normal; RevesiblePulpitis; Symp. Ireves. Pulpitis; Asymp.Ireves. Pulpitis; Necrosis; Previously Treated; Previously Initiated Therapy

Apical: Normal; Symptomatic Apical Periodonitis; Asymptomatic ApicalPeriodonitis; Acute Apical Abscess; Chronic apical Abscess; Condesing Osteitis

Pre-Treatment prognosis:

Favorable Questionable Unfavorable

If not Favorable, Why? ________

Canal	Reference	EWL	CWL	MAF	Rotary

Post-Obturation Prognosis:

Favorable Questionable Unfavorable

If not Favorable, Why? ________

Doctor Signature: ________

Fig. 2.5 endodontic treatment form

2-5-4 Treatment Procedure

First of all, 2% lidocaine anesthetic solution with 1:100,000 epinephrine was given for patients to be more comfortable. A rubber dam was used to isolate the first molar tooth which will be treated as shown in Figure 2.6. After removing of decay and broken filling, the tooth was built up to get four wall straight access cavity. Then, #10 K- file was used to negotiate the root canals and check the canal patency. After that, radiographs, and apex locator were used to determine the working length.

Fig. 2.6 rubber dam isolation of tooth #36

Glide paths reproduction were done by employing hand and rotary files # 10 K-file and Proglider file respectively and without coronal flaring. Then, cleaning and shaping started according to minimal invasive endodontic by using ProTaper Next instruments. The ‘push-pull’ preparation technique was used up to, X2 (0.25 mm tip with 6 % taper) for mesial and bucall root canals of lower and upper first molars ,and X3 (0.3 mm tip with 6% taper) for distal and palatal canals. Copious irrigation was performed with 2 mL 5% NaOCl following each protaper file with a recapitulation by #10 K-file.

Subsequently, smear layer removal was done for all patients. Smear layer was removed for all persons by using Er ,Cr:YSGG laser. The laser application for smear layer removal was done by using Er ,Cr:YSGG laserdevice (Figure 2.7) at 2,780 nm wavelength with a radial firing tips RFT2 and RFT3 [diameter 200 µm for apical and middle third and 320 µm for coronal third respectively]. The running parameters were: 1.25 W average power, 20 Hz pulse repletion rate, 60µs pulse duration; 30%Air; 10%Water. The firing-tip was advanced inside the canal lumen 1mm shorter than the determined working length. Then, at the time of irradiation it would be withdrawn in a circular motion against the dentinal walls of the root. This operation was re-performed three times at a rate of 1-2mm/second.

After laser irradiation, a final irrigation was done with 5ml of Saline solution. Then, disinfection for the root canal was done with the same laser device, the same Steps were repeated in each canal but with disinfection settings; Tip: RFT2, 1 W average power, 20 Hz pulse repletion rate, 60µs pulse duration; 10%Air; and withoutWater.

The subjects were divided into two groups; the first one was obturated with carrier-based technique, while in second group, cold-lateral compaction was used. AH-Plus sealer was the sealer for both groups. In carrier-based technique, X2 or X3 Guttacore verifier were advanced inside rootcanal down to the determined-length for size verification. Then, X2, X3 GuttaCore were used with the GuttaCore oven Thermaprep. Whereas, in second group, X2 or X3 master gutta-percha cone was used with extra cones of 2% tapering.

After completing obturation procedure, sealing of the pulp chamber floor was done using light-cured composite. Then, a final restoration for patients has been done.

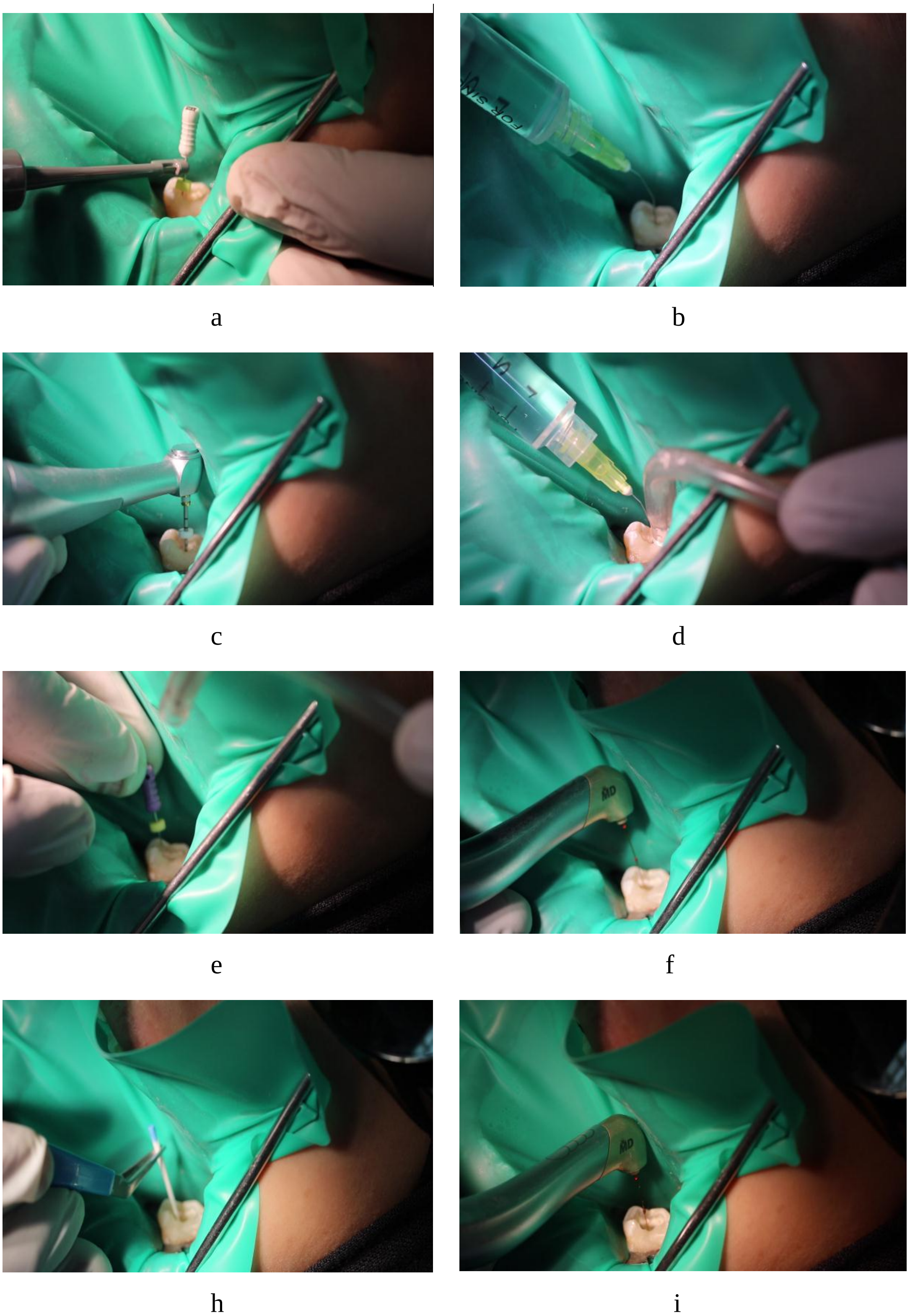


Fig. 2.7 treatment procedure using Er ,Cr:YSGG laser

2-5-5 Outcome Measures and Criteria

Healing of the different apical periodontitis cases was evaluated clinically and radiographically along six months period. The clinical part of estimation depends on the signs and symptoms. While, the other part builds upon Periapical index (PAI) scoring. This scores graded from normal periradicular tissue which assembled by score 1 to severe apicalperiodontitis of exacerbating sign and symptoms which assembled by score5 (273).

According to the above evaluation, three conditions of the study cases could be distinguished: healed, healing, or diseased (274). These conditions can be explained as the following:

A. Healed: normal status clinically, no tenderness to percussion, and the periapical index score 1 or 2 (assessed radiographically).

B. Healing: normal status clinically, no tenderness to percussion, and there is a size reduction in the apical periodontitis lesion and accompanied shifting of PAI score to smaller value.

C. Diseased: signs and symptoms present clinically, and the periapical index score 3 or more or there is an increased lesion-size or hiking in the PAI-score

In summery, successes cases include healed or healing conditions which accompanied the success of root canal treatment.

2-5-6 Evaluating Radiographs

The evaluation of the coded radiographic films of randomized different patients was performed blindly by two skillful endodontists. First of all, a

PAI score was given for every root which could be seen on the radiographic film. Then, the maximum index score of all tooth's roots was given for this tooth. The sum of these PAI scores of all teeth at different follow up periods was further statistically evaluated.

2-6 Statistical Analysis

SPSS version 21, was used to evaluate differences as the following:

1) In confocal study: differences were evaluated between studied groups by using ONE WAY ANOVA test; differences within groups were inspected by using multiple comparison method (L.S.D.). Differences between variables were setting as significant at 5 % ($P \leq 0.05$) and highly-significant at 1 % ($P \leq 0.01$).

2) In clinical study: two variables comparisons via independent t-test, three and more variables comparisons via Univariate (ONE WAY ANOVA) test were used. Pearson coefficient was performed to determine association of therapy outcome with studied variables. Detection of predictors was observed by using Logistic regression. Differences between variables were setting as significant at 5 % ($P \leq 0.05$) and highly-significant at 1 % ($P \leq 0.01$).

Chapter Three

Results,
Discussion
&
Conclusions

Chapter Three
Results and Discussion and Conclusions

3-1 Results

The results of this chapter are composed of confocal laser microscope images, sealer penetration depth calculations, radiographic findings, and clinical outcome. They were presented, evaluated, and discussed consequently.

3-1-1 Confocal laser microscope results

First of all, the data from confocal laser microscope were collected. Then, Image analysis was done by means of Adube Photo-shop V7 (AdobeSystem, Inc, SanJose, C A) . Utmost penetration-depth of the sealer into dentinal-tubules, starting from the canal wall, was measured and documented on 10 different lines in each sites. as shown in Figure 3.1

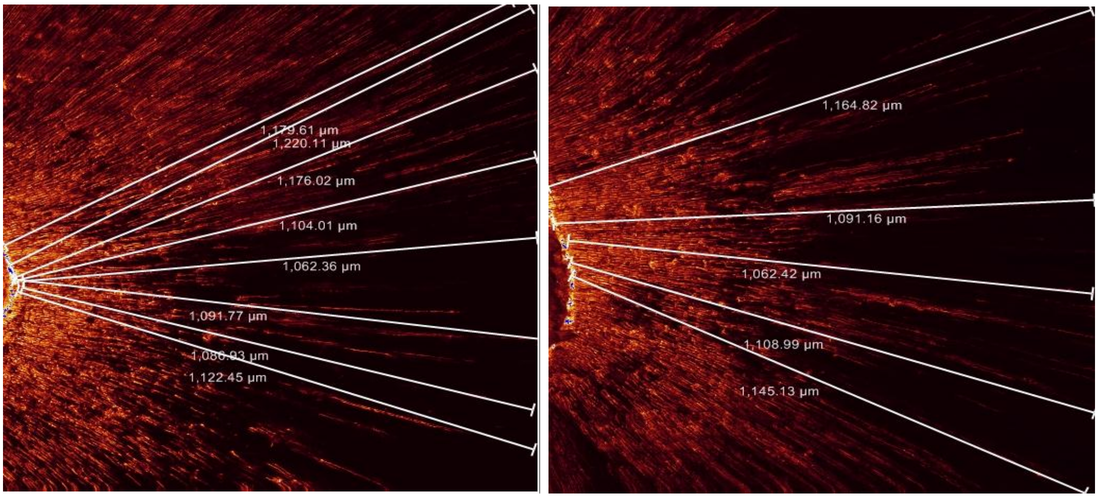


Fig. 3.1 calculation of the utmost penetration-depth of the sealer into dentinal-tubules

The following tables (3.1-18) display the penetration depth of all study groups in four direction (buccal, lingual, mesial, distal) of different sections (coronal, middle, apical)

Table 3.1 sealer penetrations (in µm) in G1 apical third

Buccal	Mesial	Lingual	Distal
1164..82	1115.88	1058.27	761.25
1091.16	1126.51	1117.76	757.18
1062.42	1020.29	1168.64	758
1108.99	1118.02	1015.4	806.36
1135.12	1015.2	1128.87	765.36
1145.43	818.67	1082.54	742
1124.1	962.2	1065	873.42
1099.5	1092.95	1023.23	789.5
1167.62	1022.3	1028.31	807.72
1110.25	953.1	1062.25	785.36

Table 3.2 sealer penetrations (in µm) in G1 middle third

Buccal	Mesial	Lingual	Distal
1122.45	955.26	983.64	1075.66
1220.11	925.09	995.31	1076.71
1176.02	886.42	1056.61	1120.74
1104.01	1013.78	1019.04	1034.79
1062.36	985.27	1023.34	1043.85
1091.77	1020.9	1056.45	1113
1086.93	963.28	990.56	1099.84
1122.45	945.38	1065.74	1003.7
1210.65	1001	1095.21	1121.86
1219.36	1010.98	989.96	1062.68

Table 3.3 sealer penetrations (in µm) in G1 coronal third

Buccal	Mesial	Lingual	Distal
1053.18	863.65	777.96	735.01
1048.88	882.65	734.6	650.29
986.9	822.84	679.89	749.34
1008.73	927.95	897.13	694.95
1066.2	1023.88	1014.53	772.85
1150.16	996.74	1114.89	802.45
1171.44	896.39	1087.6	796.87
1111.75	100288	1020.15	899.65
1203.24	964.85	952.35	899.45
1234.25	987.56	1110.36	756.34

Table 3.4 sealer penetrations (in µm) in G2 apical third

Buccal	Mesial	Lingual	Distal
981.82	204.52	539.1	157.71
975.45	172.94	526.68	146.2
963.81	120.77	523.72	165.35
900.94	114.49	495.53	155
902.59	132.38	587.23	159.1
992.21	253.27	574.95	270.84
956.32	245.24	561.5	267.69
961.2	261.39	551.76	295.9
926.32	238.39	582.36	311.71
946.16	260.77	542.21	219.25

Table 3.5 sealer penetrations (in µm) in G2 middle third

Buccal	Mesial	Lingual	Distal
1061.43	911.16	1151.99	764.19
1048.04	992.59	1092.25	684.52
1006.49	932.48	1087.62	756.49
1023.54	857.91	1045.67	839.91
1046.37	865.85	1099	766.9
1097.12	808.17	1025.89	753.31
1080.18	951.08	965.07	726.9
1039.37	988.9	911.79	683.78
1098.8	1065.5	776.52	714.59
1123.02	1016.84	759.83	745.31

Table 3.6 sealer penetrations (in µm) in G2 coronal third

Buccal	Mesial	Lingual	Distal
1115.2	1033.85	1083.61	1027
1131.65	1027.25	1080.18	1039.16
1140.2	1028.6	1034.51	1025.97
1176.66	1038.5	1086.88	972.85
1228.1	1028.84	1141.77	936.08
1123.01	1157.53	1051.42	945.89
1076.52	1086.94	1047.04	978.09
1035.69	1061.35	1045.94	980.87
1044.66	1060.94	1097.26	1015.34
1081.44	1075.51	1015.09	1079.02

Table 3.7 sealer penetrations (in µm) in G3 apical third

Buccal	Mesial	Lingual	Distal
820.64	543.39	953.64	862.3
1028.32	255.38	881.19	819.61
994.14	197.2	945.51	921.54
1004.6	474.07	990.47	917.4
1104.38	537.25	1047.53	926.75
1029.2	462.23	895.14	885.5
993.5	296.84	878.29	915.69
895.78	532.3	1025.17	869.41
1102.3	294.27	996.96	875
939.5	249	872.19	903.5

Table 3.8 sealer penetrations (in µm) in G3 middle third

Buccal	Mesial	Lingual	Distal
1068.31	743.34	624.2	545.07
1045.94	870.01	463.1	642.55
1021.53	937.59	692.64	64.68
1050.3	770.16	835.62	774.65
1086.74	628.3	888.76	622.09
1061.5	911.61	655.27	965.27
1007	925.99	775.86	978.03
1005.7	929.11	869.9	779.69
1080.8	969.24	1000.87	951.39
1006.45	1016.1	1011.44	1024.69

Table 3.9 sealer penetrations (in µm) in G3 coronal third

Buccal	Mesial	Lingual	Distal
1077.75	985.16	913.77	347.91
1036.36	987.14	917.32	389.92
1088.74	944.58	995.19	228.67
1068.36	948.65	964.85	223.15
1081.07	989.54	962.18	247.92
1075.04	986.02	968.04	268.88
1063.04	989.55	985.6	265.9
1069.88	975.25	976.25	278.11
1074.7	997.48	984.76	455.93
1034.01	993.54	986.24	248.36

Table 3.10 sealer penetrations (in µm) in G4 apical third

Buccal	Mesial	Lingual	Distal
1107.51	899	624.13	355.56
978.4	1060.65	509.13	668.52
1024.69	1049.34	843.01	716
1040.6	1056.8	933.19	509.77
899.72	1087.35	977.57	500.38
473.62	445.73	309.68	321.5
456.21	473.09	411.29	337.94
562.17	443.67	346.05	333.54
482.1	452.12	323.42	346.99
494.8	485.65	328.1	325.16

Table 3.11 sealer penetrations (in µm) in G4 middle third

Buccal	Mesial	Lingual	Distal
1054.31	667.27	925.34	542.47
878.4	824.57	869.82	736.59
901.65	665.27	938.97	722.3
878.5	689.06	878.6	607.71
886.24	478.65	834.18	752.34
901.95	625.36	843.65	603.36
1006.9	542.84	845.32	751.36
845.36	785.2	901.54	654.95
912.36	495.75	963.15	596.31
862.74	657.15	865.15	639.15

Table 3.12 sealer penetrations (in µm) in G4 coronal third

Buccal	Mesial	Lingual	Distal
807.72	804.87	566.99	707.11
916.34	780.35	548.65	748.1
937.07	833.88	790.46	711.73
935.21	844.91	758.34	715.89
885.49	762.18	707.97	641.71
865.15	753.62	700.25	631.27
842.99	865.24	654.64	704.36
871.26	862.14	673.15	715.39
912.64	756.21	509.89	694.28
934.66	741.01	506.5	700.6

Table 3.13 sealer penetrations (in µm) in G5 apical third

Buccal	Mesial	Lingual	Distal
52.56	39.59	32.67	42.59
42.08	26.2	40.39	35.52
49.98	15.27	83	25.3
35.32	22.25	58.64	33.45
34.11	18.32	38.5	37.21
51.46	28.96	75.21	40.25
37.41	16.63	36.2	24.35
49.38	17.52	34.3	27.21
53.2	26.18	34.89	33.69
44.89	26.1	33.13	40.36

Table 3.14 sealer penetrations (in µm) in G5 middle third

Buccal	Mesial	Lingual	Distal
768.1	485.22	246.2	346.02
892.03	350.36	328.74	369.75
655.17	261.27	403.94	231.87
685.42	511.74	732.49	44871
676.91	892.04	517.57	661.13
654.95	496.14	509.14	352.41
635.18	368.88	263.74	360.2
624.39	275.2	359.5	254.96
730.25	790.06	457.65	423.78
680.36	492.35	621.64	625.28

Table 3.15 sealer penetrations (in µm) in G5 coronal third

Buccal	Mesial	Lingual	Distal
681.36	437.25	245.02	265.35
648.25	456.15	365.36	248.36
632.33	487.21	377.98	445.36
607.14	479.36	246.48	485.14
652.39	394.85	425.62	365.96
684.14	347.25	485.99	315.02
625.02	390.01	487.15	532.63
671.36	413.65	321.21	518.14
658.22	426.22	307.03	536.02
614.36	343.33	455.21	425.99

Table 3.16 sealer penetrations (in µm) in G6 apical third

Buccal	Mesial	Lingual	Distal
64.16	13.61	32.53	31.42
111.51	9.28	44.37	47
105.36	11.5	101.71	33.2
50.25	12.14	18.28	25.2
42.3	8.5	15.25	10.4
32.3	11.65	54.64	24.7
38.3	8.99	15.33	12.65
40	9.47	19.77	24.21
62.21	12.4	54.21	33.27
46.25	11.4	25.78	29.66

Table 3.17 sealer penetrations (in µm) in G6 middle third

Buccal	Mesial	Lingual	Distal
1044.12	584.78	16.27	379.45
1003.88	570.67	47.78	316.18
984.77	690.45	35.37	152.46
992.47	970.07	12.56	504.61
1080.32	807.78	17.21	658.83
736.25	573.56	25.03	265.95
799.32	582.32	15.23	156.25
845.89	695.21	26.47	178.32
845.65	809.32	26.12	296.47
856.25	890.78	12.36	231.56

Table 3.18 sealer penetrations (in µm) in G6 coronal third

Buccal	Mesial	Lingual	Distal
736.19	420.64	566.26	538.12
741.32	485.24	523.6	539.24
363.09	529.98	500.6	481.29
765.53	548.02	639.81	475.36
862.75	550.94	525.86	654.92
462.38	648.88	514.23	648.94
463.58	624.32	596.35	566.29
746.36	634.19	621.08	554.85
795.05	624.02	506.31	559.46
657.15	485.01	501.36	519.35

3-1-1-1 sealer penetration into buccal, mesial, lingual, distal sites

Comparison between sites was performed for each third of each group. It was significantly found that the depth of the sealer-penetration in the bucco-lingual direction was greater than the mesio-distal one. These comparisons were presented in the following tables and figures describing the study-group from G1-G6.

In G1 group, there is a significant difference between mesial and buccal, and between distal and the other sites within the apical third at $p<0.01$.

At the middle third the significance is seen between: the buccal and the others, distal and the others, and between mesial and lingual. While, at the coronal third the differences were significant between the buccal and the other sites, and between the distal and the others. as shown in Table 3.19 and Figure 3.2

Table 3.19 comparison in respect to sites within G1

Sub-Groups	Buccal	Mesial	Lingual	Distal	P value
Apical third	1120.94±33.24	1024.51±96.40 a	1075.03±50.01	784.62±38.17 a,b,c	<0.01**
Middle third	1141.61±59.68	970.74±43.78 a	1027.59±38.81 a,b	1075.28±39.69 a,b,c	<0.01**
Coronal third	1103.47±83.92	936.94±68.22 a	938.95±160.37 a	775.72±79.46 a,b,c	<0.01**

letter (a) referred to significant differences from bucall site, letter (b) referred to significant differences from mesial site, letter (c) referred to significant differences from lingual site,

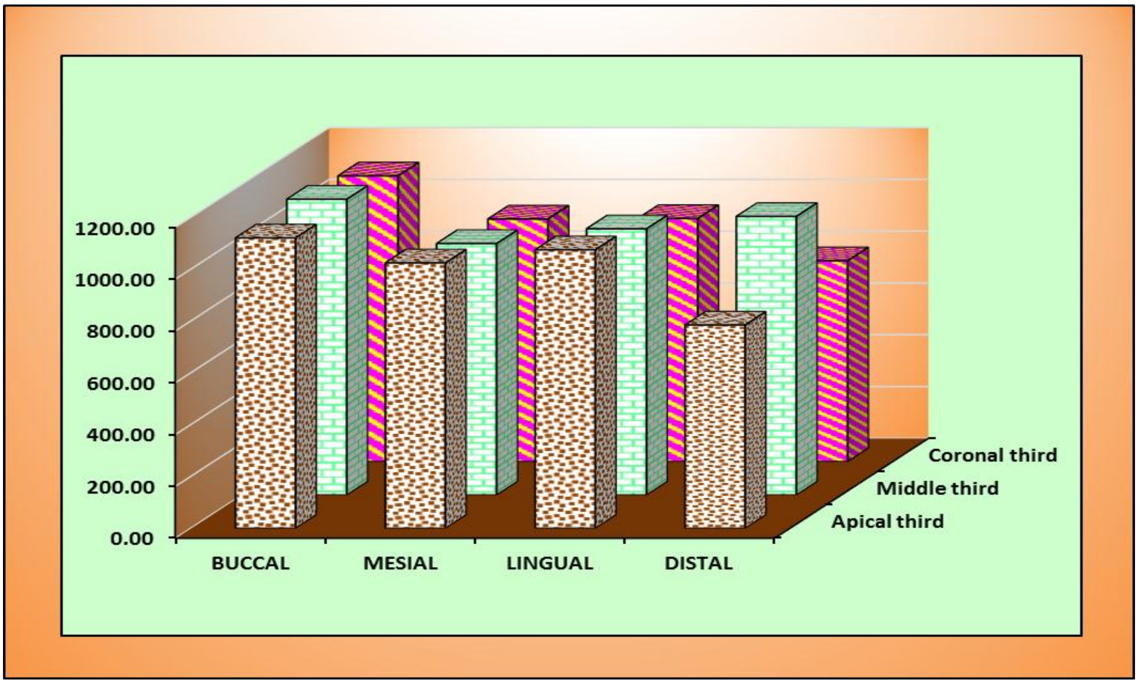


Fig. 3.2 Mean value in respect to site of G1

Table 3.20 and Figure 3.3 show the comparison within G2 group. Significant differences were found as the following: Apically; (the buccal and the other sites, between mesial and lingual, and between distal and the lingual site), Middly; (mesial and buccal, distal and others), Coronally; (buccal and the other sites, distal and others).

Table 3.20 Comparison in respect to sites within G2

Sub-Groups	Buccal	Mesial	Lingual	Distal	P value
Apical third	950.68±31.66	200.42±60.31 a	548.50±28.96 a,b	214.88±65.84 a, ,c	<0.01**
Middle third	1062.44±36.75	939.05±79.88 a	991.56±136.53	743.59±45.58 a,b,c	<0.01**
Coronal third	1115.31±59.08	1059.93±40.35 a	1068.37±36.77 a	1000.03±44.74 a,b,c	<0.01**

letter (a) referred to significant differences from bucall site, letter (b) referred to significant differences from mesial site, letter (c) referred to significant differences from lingual site,

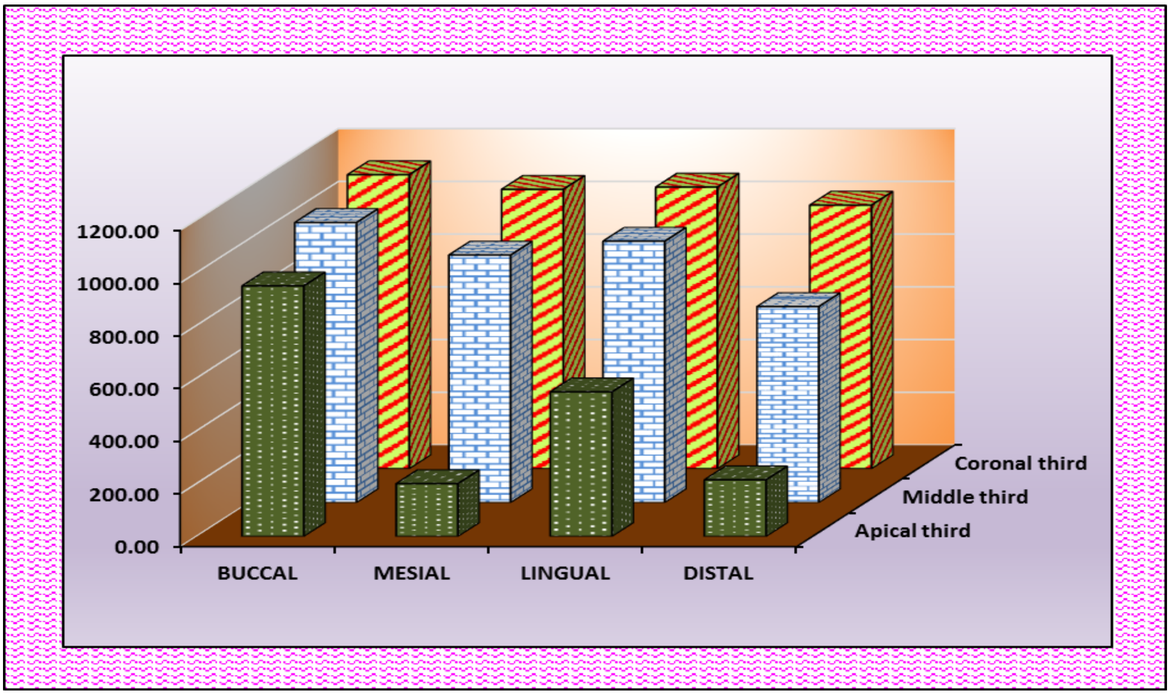


Fig. 3.3 Mean value in respect to site of G2

Table 3.21 displays the differences within G3 which were significant at the apical third, between mesial and buccal, Lingual and mesial, distal and others except lingual site. As well as significant difference was seen between buccal and others at the middle third. Coronally; between buccal and the other sites, distal and others, as depicted in Figure 3.4

Table 3.21 Comparison in respect to sites within G3

Sub-Groups	Buccal	Mesial	Lingual	Distal	P value
Apical third	991.24±87.58	384.19±137.61 a	948.61±64.95 b	889.67±33.88 a, ,b	<0.01**
Middle third	1043.43±31.39	870.15±119.51 a	781.77±174.24 a	734.81±289.27 A	<0.01**
Coronal third	1066.90±18.14	979.69±18.39 a	965.42±28.32 a	295.48±77.08 a,b,c	<0.01**

letter (a) referred to significant differences from bucall site, letter (b) referred to significant differences from mesial site, letter (c) referred to significant differences from lingual site,

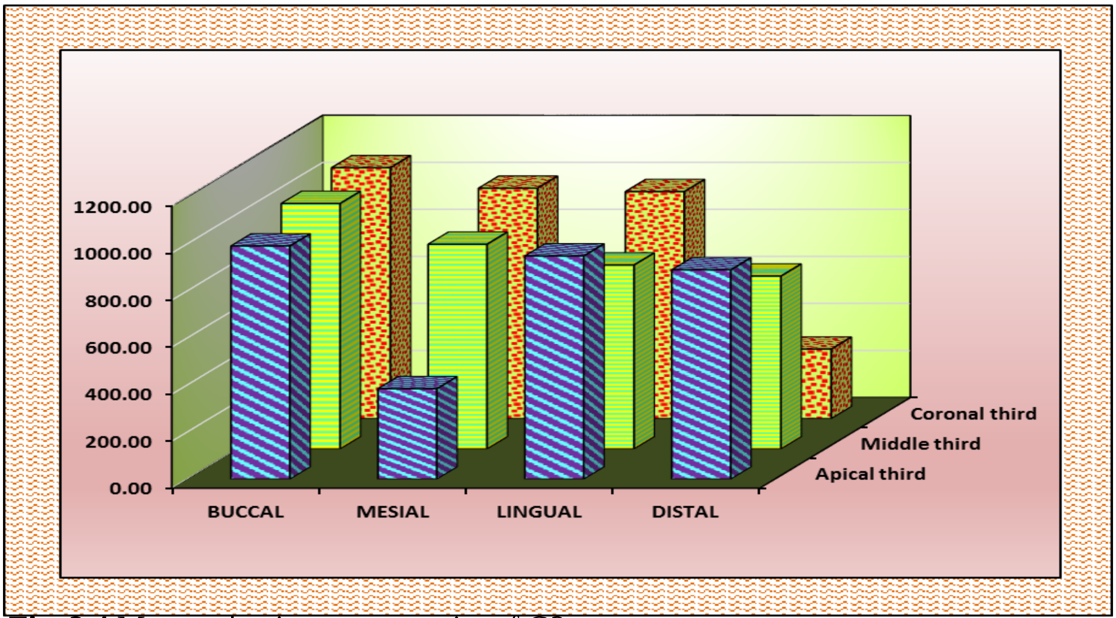


Fig. 3.4 Mean value in respect to site of G3

In G4 group (table 3.22, Figure 3.5), there is a significant difference between mesial and distal, and between distal and buccal site within the apical third. At the middle third the significant difference is seen between: the buccal and others except lingual, distal and the others except mesial, and between mesial and lingual. While, at the coronal third the differences were significant between the buccal and the other sites, and between the distal and the others except lingual.

Table 3.22 Comparison in respect to sites within G4

Sub-Groups	Buccal	Mesial	Lingual	Distal	P value
Apical third	751.98±278.32	745.34±305.09	560.56±266.82	441.54±149.68 a ,b	0.026*
Middle third	912.84±66.03	643.11±113.35 a	886.57±44.01 b	660.65±75.20 a ,c	<0.01**
Coronal third	890.85±44.00	800.44±47.92 a	641.68±102.53 a, b	697.04±35.08 a, b,	<0.01**

letter (a) referred to significant differences from bucall site, letter (b) referred to significant differences from mesial site, letter (c) referred to significant differences from lingual site,

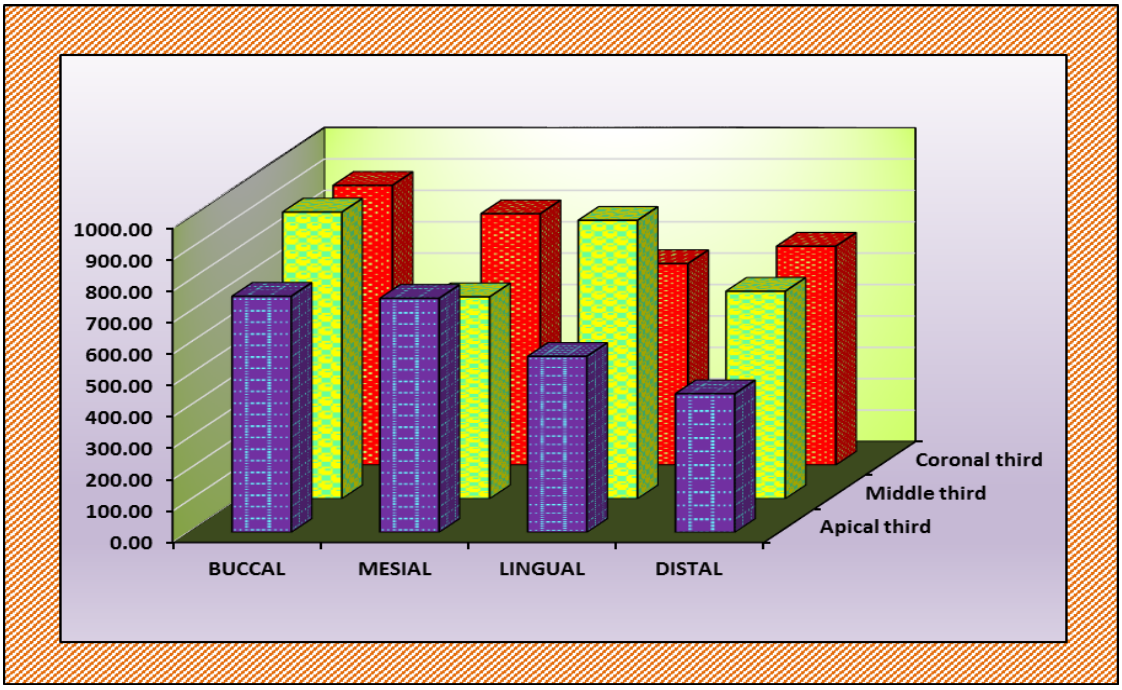


Fig. 3.5 Mean value in respect to site of G4

In G5 group, there is a significant difference between the buccal and the others in all thirds. In addition, a significant difference between mesial and lingual, and between distal and the others is seen in apical third. As shown in Table 3.23 and in figure 3.6

Table 3.23 comparison in respect to sites within G5

Sub-Groups	Buccal	Mesial	Lingual	Distal	P value
Apical third	45.04±7.37	23.70±7.37 a	46.69±18.75 b	33.99±6.51 a ,b,c	0.026*
Middle third	700.28±79.94	492.32±206.77 a	444.06±155.73 a	407.41±140.75 a	<0.01**
Coronal third	647.46±27.20	417.53±49.85 a	371.71±91.17 a	413.80±109.36 a	<0.01**
letter (a) referred to significant differences from bucall site, letter (b) referred to significant differences from mesial site, letter (c) referred to significant differences from lingual site,					

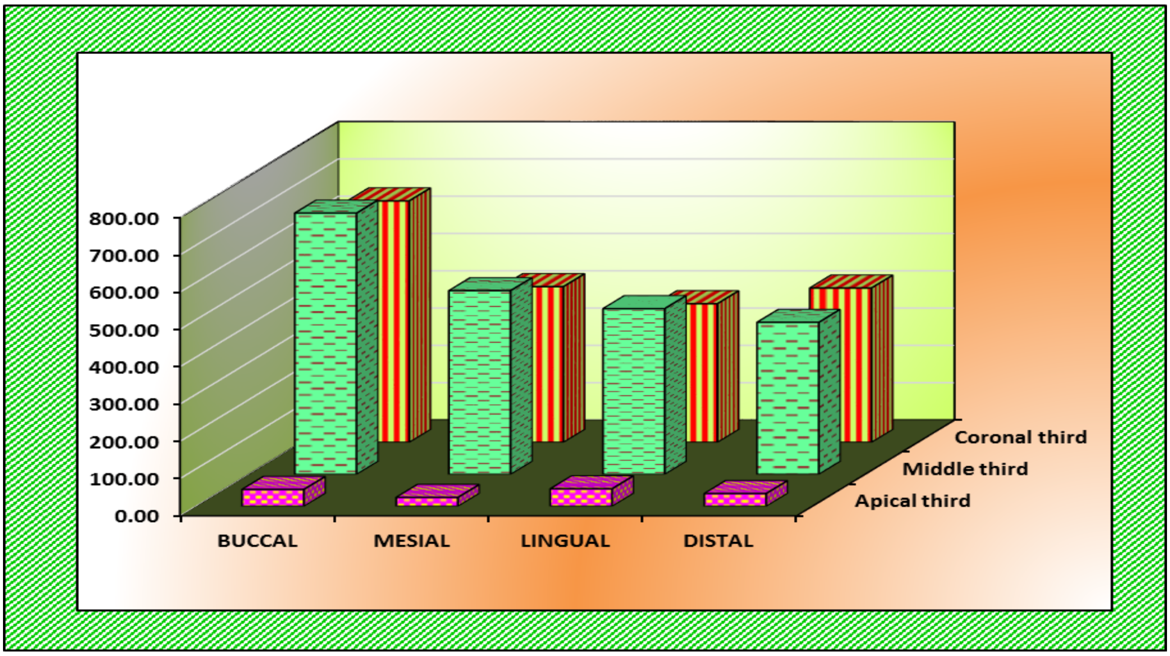


Fig. 3.6 Mean value in respect to site of G5

Table 3.24 , figure 3.7 show the comparison within G6 group. Significant differences were found as the following: Apically; (the buccal and the other sites, between mesial and lingual), Middly; (the buccal and the other sites, between mesial and lingual, distal and others), Coronally; (buccal and the other sites).

Table 3.24 comparison in respect to sites within G6

Sub-Groups	Buccal	Mesial	Lingual	Distal	P value
Apical third	59.26±27.82	10.89±1.71 a	38.19±27.02 a, b	27.17±10.55 a	0.026*
Middle third	918.89±115.95	717.49±145.22 a	23.44±11.32 a,b	314.01±162.73 a,b,c	<0.01**
Coronal third	659.34±168.70	555.12±76.86 a	549.55±52.50 a	553.78±60.11 A	0.054NS

letter (a) referred to significant differences from bucall site, letter (b) referred to significant differences from mesial site, letter (c) referred to significant differences from lingual site,

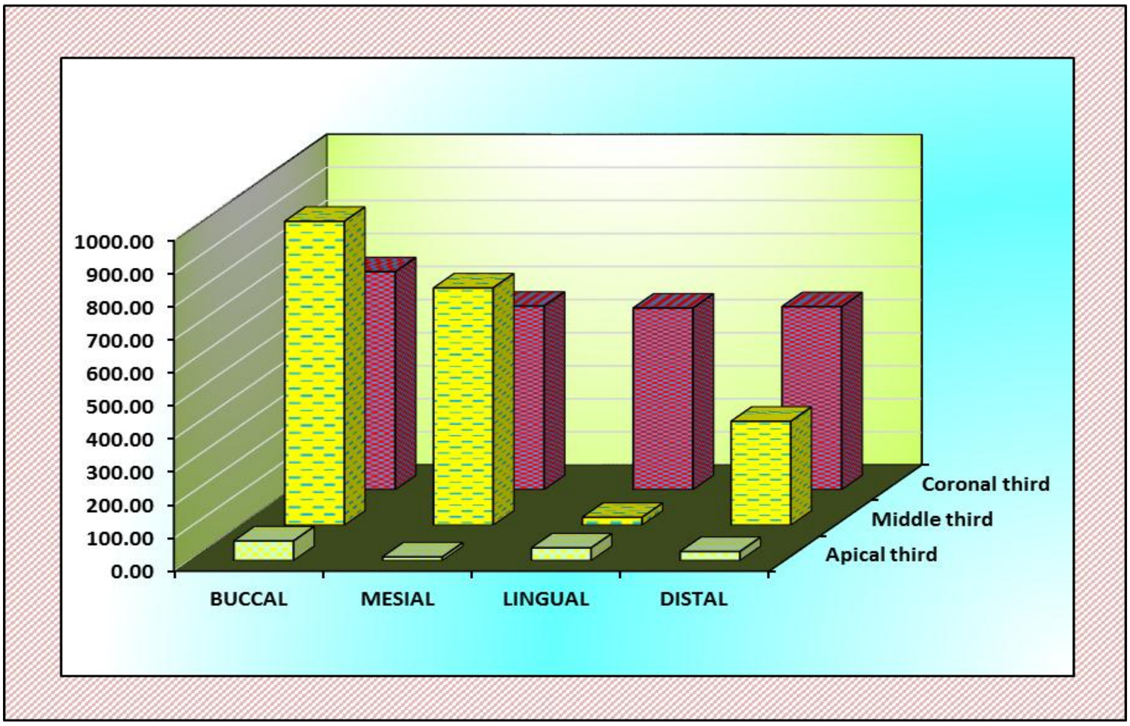


Fig. 3.7 Mean value in respect to site of G6

3-1-1-2 Sealer penetration in the apical, middle, and coronal-sections

The mean, minimum, maximum sealer penetration depth of all study groups were described at apical, middle, and coronal sections. The means of the study groups were compared at each section

Table 3.25 and figure 3.8 present a significant difference between G1 group and all other groups at the apical section. Also there is a significant difference between; G 2 and groups G 3 to G 6, and between G3 and G 4, G 5, G 6. Beside that significant difference is seen between G4 and G5, G6 with no significance between G5 and G6.

Table3.25: Apical Third comparison between studied groups

Groups	Mean±SD	Minimum	Maximum	P value
G1	1001.27±143.36	742.00	1168.64	<0.01**
G2	478.62±313.59 A	114.49	992.21	
G3	803.43±262.29 a,b	197.20	1104.38	
G4	624.85±280.17 a,b,c	309.68	1107.51	
G5	37.36±14.28 a,b,c,d	15.27	83.00	
G6	33.88±26.27 a,b,c,d	8.50	111.51	

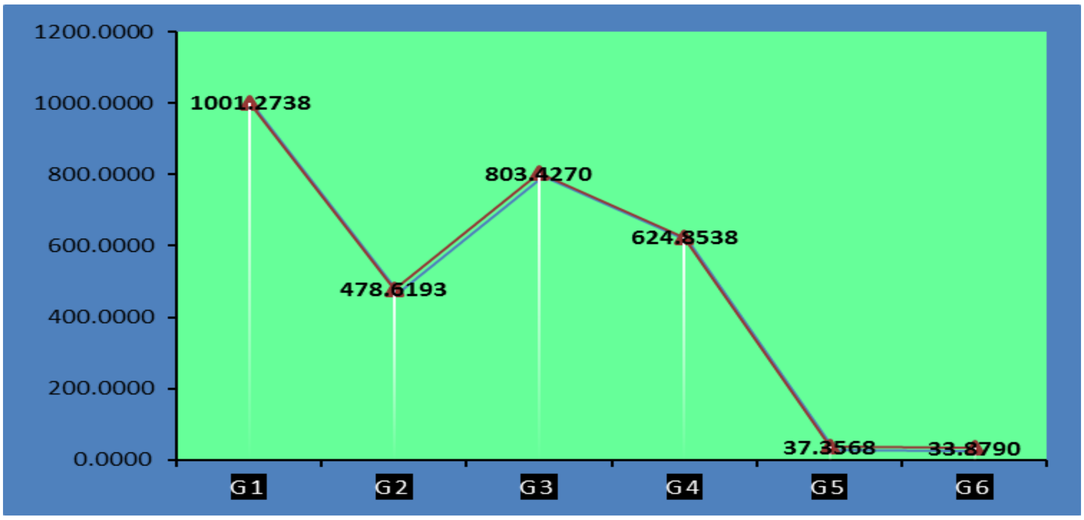


Fig. 3.8 Mean value of apical third of studied groups

At the middle third, (Table 3.26, Figure 3.9) a significant discrepancy was seen within G1 group and all group. In addition, significant difference was occurred between; (G.2 and G.4, G.5, G 6), (G.3 and G.5, G.6), and (G.4 and G.5, G.6). Beside that no significance is presented between; (G2 and G3), (G3 and G4), (G5 and G6).

Table 3.26: Middle Third comparison between studied groups

Groups	Mean±SD	Minimum	Maximum	P value
G1	1053.80±77.56	886.42	1220.11	<0.01**
G2	934.16±144.73 A	683.78	1151.99	
G3	857.54±209.94 A	64.68	1086.74	
G4	775.79±146.96 a,b	478.65	1054.31	
G5	511.02±186.24 a,b,c,d,	231.87	892.04	
G6	493.46±371.87 a,b,c,d,	12.36	1080.32	

Fig. 3.9 Mean value of Middle third of studied groups

At Coronal third section, (Table 3.27, Figure 3.10) a significant discrepancy was seen within G1 group and all-groups. As well as, a significant difference was occurred between; (G2 and G.3, G.4, G.5, G.6), (G.3 and G.5, G.6), (G.4 and G.5, G.6) and (G.5 and G.6). Beside that, no significance is presented between G3 and G4.

Table 3.27: Coronal third comparison between studied groups

Groups	Mean±SD	Minimum	Maximum	P value
1	938.77±154.48	650.29	1234.25	<0.01**
2	1060.91±60.65 A	936.08	1228.10	
3	826.87±315.91 a, b	223.15	1088.74	
4	757.51±114.44 a,b	506.50	937.07	
5	462.62±132.04 a,b,c,d,	245.02	684.14	
6	579.45±107.65 a,b,c,d,e	363.09	862.75	

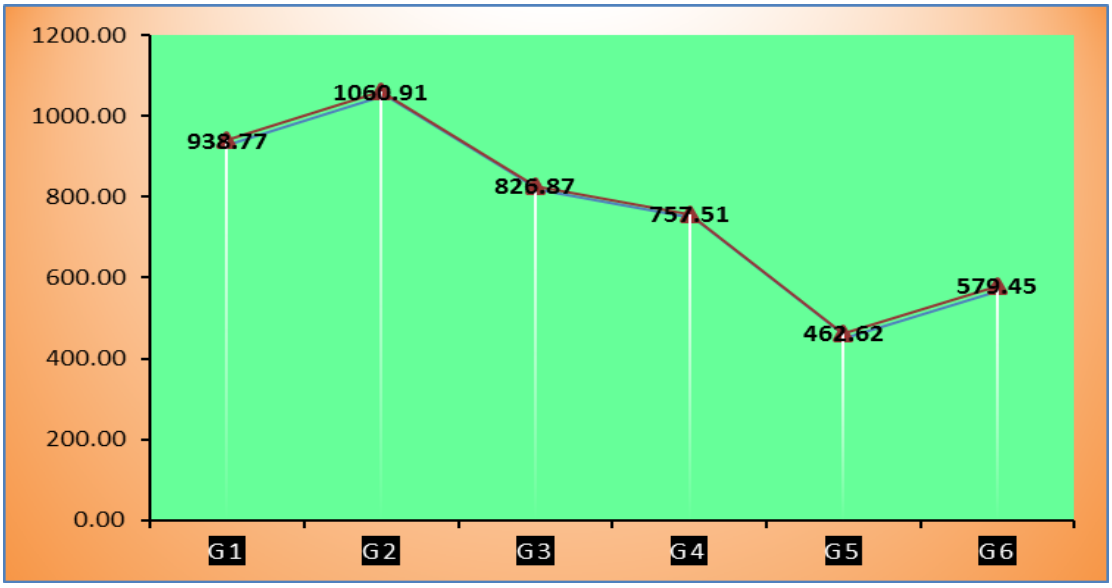


Fig. 3.10 Mean value of Coronal third of studied groups

3-1-1-3 Over all Sealer penetration

In over all statistical comparison between all groups (Table 3.28), significant-differences were noticed in G1 with all groups (at P $\leq$. 01),and between G2 and G4,G5,G6, indicating that smear layer removal by laser was correlated to maximum sealer-penetration specially with carrier based obturation-technique. Further Significant difference was presented in groups G3,G4 and G5,G6, indicating that smear layer removal by EDTA , regardless the obturation technique,was associated with greater selear pentration as shown in Figure 3.11and 3.12

Table3.28 Statistically Compared experimental Groups G 1-6 (mean ± standard-deviation in µm)

Groups	Sections			
	Coronal	Middle	Apical	Overall
G1	938.77±154.48	1053.80±77.56	1001.27±143.36	997.95±136.96
G2	1060.91±60.65 A	934.16±144.73 a	478.62±313.59 A	824.56±321.47 a
G3	826.87±315.91 a,b	857.54±209.94 a	803.43±262.29 a,b	829.28±264.94 a
G4	757.51±114.44 a,b	775.79±146.96 a,b	624.85±280.17 a,b,c	719.38±204.10 a,b,c
G5	462.62±132.04 a.b.c.d	511.02±186.24 a,b,c,d	37.36±14.28 a,b,c,d	337.00±250.62 a,b,c,d
G6	579.45±107.65 a,b,c,d,e	493.46±371.87 a,b,c,d	33.88±26.27 a,b,c,d	368.93±327.40 a,b,c,d

Overall significant differences (P≤0.01) were observed between studied groups, however letter (a) referred to significant differences from group 1, letter (b) referred to significant differences from group 2, letter (c) referred to significant differences from group 3, letter (d) referred to significant differences from group 4, and letter (e) referred to significant differences from group 5.

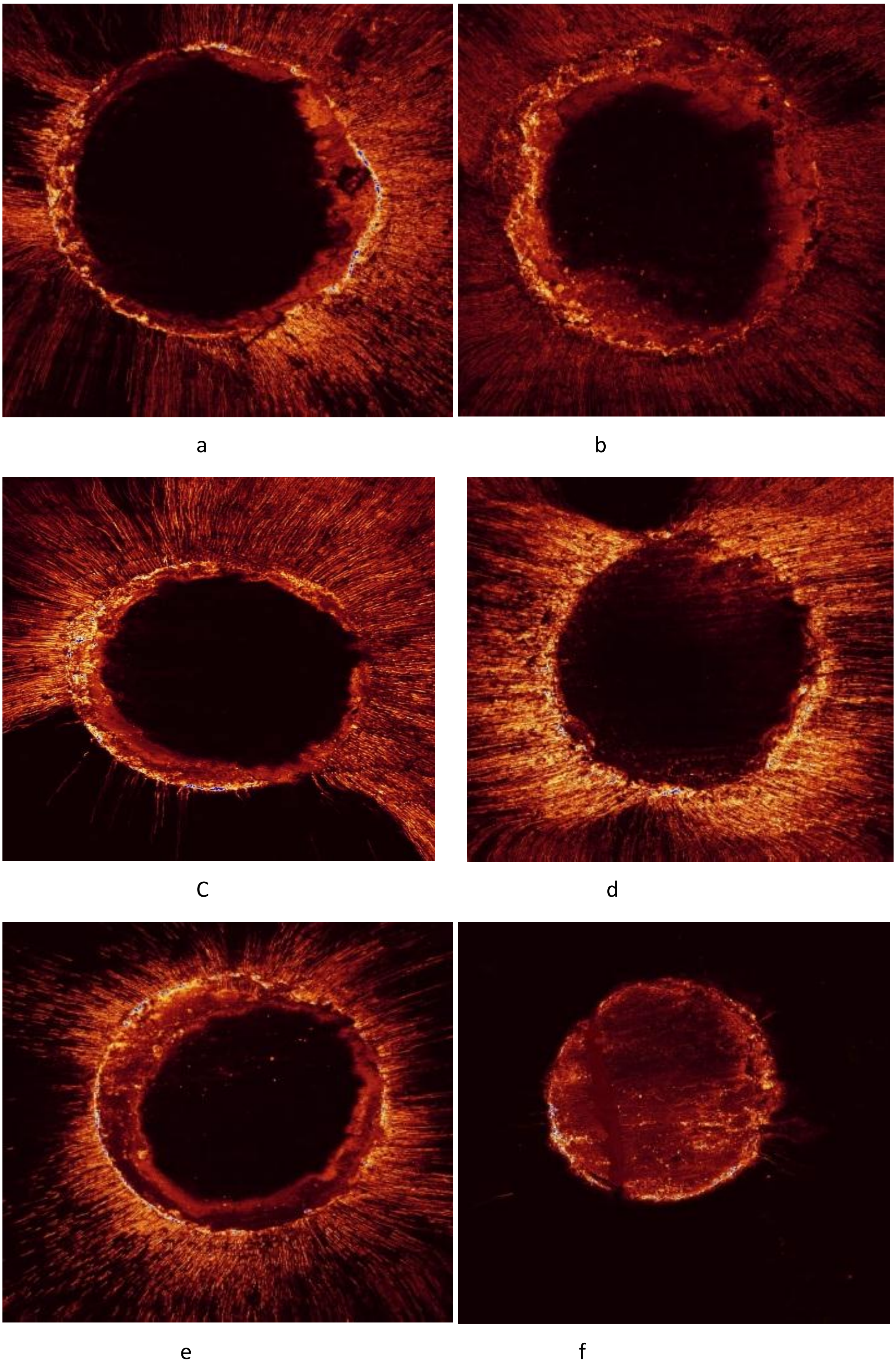
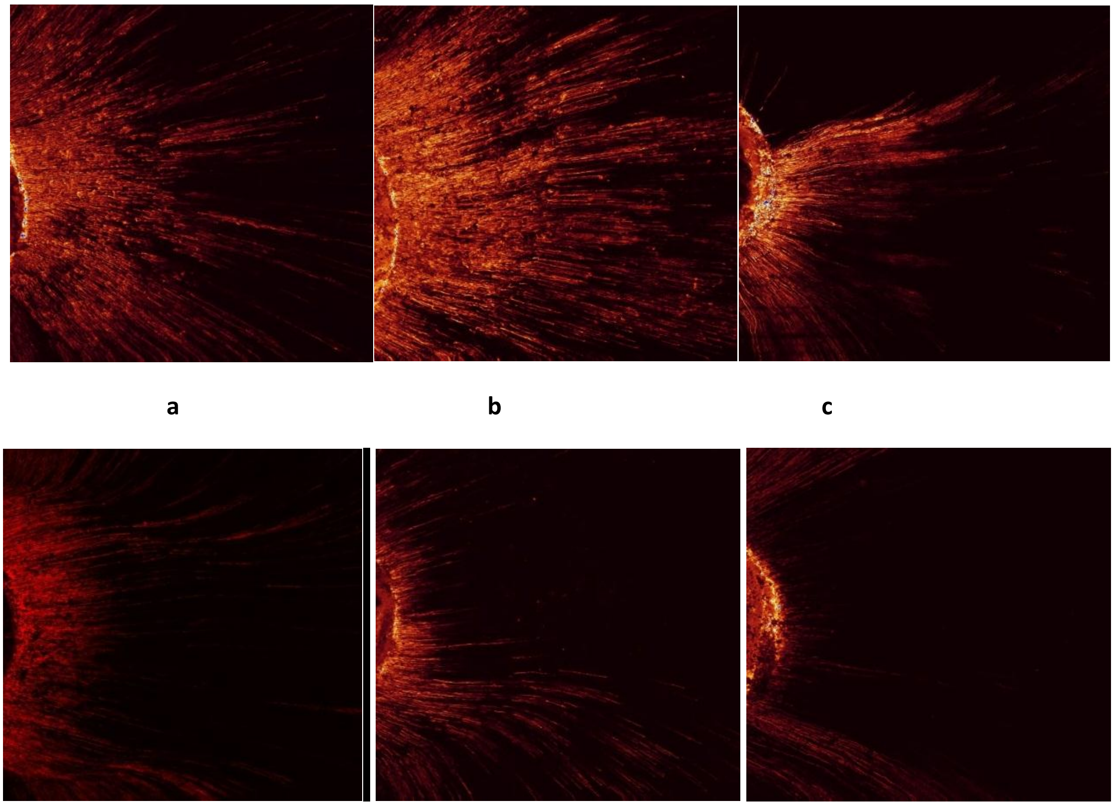


Fig. 3.11 Confocal-laser- microscopic photographs presenting sealer-penetration into dentinal-tubules of an AHplus -filled canal (middle third). a) G.1, b) G.2, c) G.3, d) G.4, e) G.5, f) G.6. Magnification X10.



a b c

d e f

Fig.3-12 Confocal-laser-microscopic photographs presenting the sealer-penetration into dentinal-tubules of an AHplus -filled canal (apical third, buccal side). A) G.1, b) G.2, c) G.3, d) G.4, e) G.5, f) G.6. Magnification 40X.

Another Overall comparison was made regarding the means of sealer penetration in the coronal, middle, and apical sections. Significant differences were presented in coronal with apical and in middle with apical sections, but not between coronal and middle sections. As shown in Table(3-29) and Figure(3-13)

Table3.29: Overall correlation between studied groups in respect to location

Location	Mean ± SD	Minimum	Maximum	P value
Apical	497.57±419.41	8.50	1168.64	<0.01**
Middle	770.96±294.35 A	12.36	1220.11	
Coronal	771.02±262.75 A	223.15	1234.25	

** Significant differences at 1%, letter (a) means there is a significance with apical third

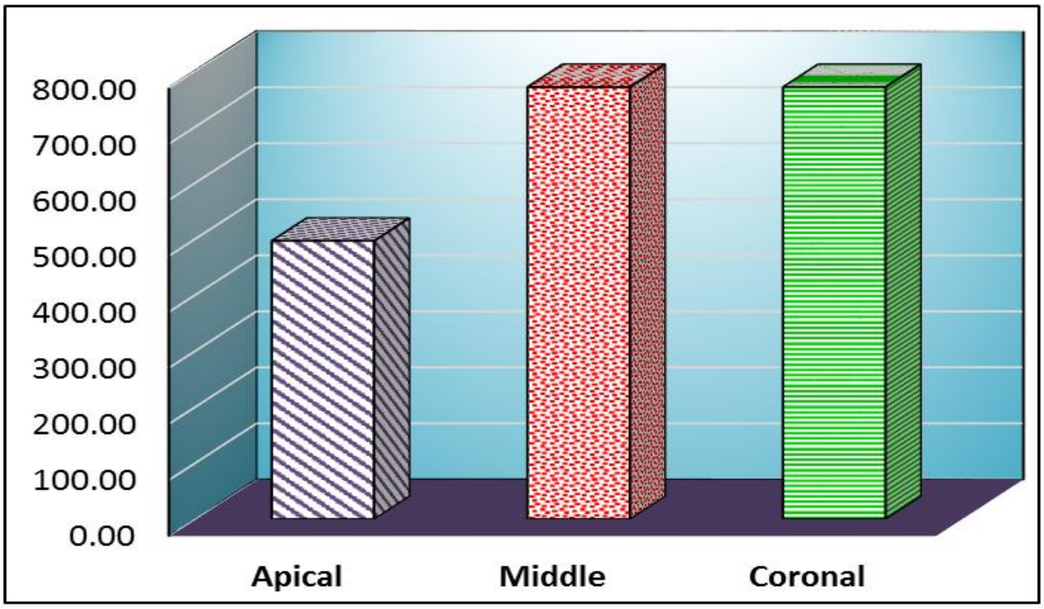


Fig. 3.13 Mean value in respect to location

3-1-2 clinical study results

The results of the clinical study include all the patients who treated with minimally invasive Endodontics therapy using Er, Cr: YSGG-laser. The description of the treated patient concerning: age, gender, oral hygiene, periapical diagnosis, and the periapical score for six months period is displayed in the following Tables.(3.30-39)

Table 3.30 Description of the study cohort and the periapical scores for 6 months duration part 1

Patient name	Hadeel Shabaan	Mariem Ali	Amal Ghali	Ali Ahmed
Treated tooth	36	46	46	46
Age	18	12	37	24
Gender	F	F	F	M
Oral hygiene	Fair	Fair	Fair	Fair
Diabetic	No	No	No	No
Periradicular diagnosis	Asymptomatic Apical Perio-dontitis	Chronic Abscess	Symptomatic Apical Perio-dontitis	Asymptomatic Apical Perio-dontitis
Sealer extrusion	No	Yes	Yes	Yes
Obturation technique	Cold lateral	Carrier based	Cold lateral	Carrier based
PAI score before treatment	5	5	5	4
PAI score After 1 month	4	4	4	3
PAI score After 3 month	3	3	3	2
PAI score After 6 month	2	2	2	1

Table 3.31 Description of the study cohort and the periapical scores for 6 months duration part 2

Patient name	**Auday Latief**	**Yosif Mansor**	**Alaa Ali**	**Fatemaa Rasheed**
Treated tooth	26	46	36	46
Age	40	25	25	24
Gender	M	M	F	F
Oral hygiene	Good	Good	Fair	Good
Diabetic	No	No	No	No
Periradicular diagnosis	Asymptomatic Apical Perio-dontitis	Chronic-- Abscess	Chronic Abscess	Asymptomatic Apical periodontitis
Sealer extrusion	Yes	Yes	Yes	Yes
Obturation technique	Carrier based	Carrier based	Cold lateral	Cold lateral
PAI score before treatment	5	5	5	4
PAI score After 1 month	4	4	4	4
PAI score After 3 month	3	3	3	3
PAI score After 6 month	2	2	1	2

Table 3.32 Description of the study cohort and the periapical scores for 6 months duration part 3

Patient name	Nabaa Hussien	Zainab Zaghair	Jassim Ibrahiem	Narjes Qassim
Treated tooth	26	26	16	26
Age	14	45	60	18
Gender	F	F	M	F
Oral hygiene	Good	Fair	Fair	Fair
Diabetic	Yes	No	Yes	No
Periradicular diagnosis	Symptomatic Apical Perio-dontitis	Symptomatic Apical Perio-dontitis	Asymptomatic Apical Perio-dontitis	Asymptomatic Apical Perio-dontitis
Sealer extrusion	Yes	Yes	Yes	No
Obturation technique	ColdLateral	ColdLateral	ColdLateral	ColdLateral
PAI score before treatment	5	3	4	5
PAI score After 1 month	4	3	4	4
PAI score After 3 month	3	2	3	3
PAI score After 6 month	2	1	2	2

Table 3.33 Description of the study cohort and the periapical scores for 6 months duration part 4

Patient name	Batool sadek	Azraa Mohamed	Hameed Modhafer	Adel Abd Alhussien
Treated tooth	26	26	26	46
Age	17	37	32	35
Gender	F	F	M	M
Oral hygiene	Good	Good	Good	Fair
Diabetic	No	No	No	No
Periradicular diagnosis	Symptomatic Apical Perio-dontitis	Acute Abscess	Asymptomatic Apical Perio-dontitis	Asymptomatic Apical Perio-dontitis
Sealer extrusion	No	Yes	Yes	No
Obturation technique	Cold lateral	Cold lateral	Carrier based	Carrier based
PAI score before treatment	4	5	5	4
PAI score After 1 month	3	4	4	4
PAI score After 3 month	2	4	3	3
PAI score After 6 month	1	3	2	2

Table 3.34 Description of the study cohort and the periapical scores for 6 months duration part 5

Patient name	Adel Abd Alhussien	Afraa Ali	Ibrahiem Kariem	Doaa Hussien
Treated tooth	36	46	36	26
Age	35	34	30	22
Gender	M	F	M	F
Oral hygiene	Fair	Fair	Fair	Good
Diabetic	No	No	No	Yes
Periradicular diagnosis	Acute Abscess	Chronic Abscess	Acute Abscess	Asymptomatic Apical periodontitis
Sealer extrusion	No	Yes	Yes	No
Obturation technique	Cold lateral	Cold lateral	Carrier based	Cold lateral
PAI score before treatment	5	5	4	3
PAI score After 1 month	4	4	4	3
PAI score After 3 month	3	3	3	2
PAI score After 6 month	2	2	2	1

Table 3.35 Description of the study cohort and the periapical scores for 6 months duration part 6

Patient name	Mahmood Rasheed	Amna sadek	Mohamed Abd Alreza	Kauther Hammed
Treated tooth	46	46	46	16
Age	59	23	15	21
Gender	M	F	M	F
Oral hygiene	Fair	Good	Good	Good
Diabetic	No	No	No	No
Periradicular dia gnosis	Asymptomatic Apical Perio-dontitis	Asymptomatic Apical Perio-dontitis	Symptomatic Apical Perio-dontitis	Chronic abscess
Sealer extrusion	No	No	No	No
Obturation technique	Carrierbased	Carrierbased	Carrierbased	Carrierbased
PAI score before treatment	4	4	4	5
PAI score After 1 month	3	3	3	4
PAI score After 3 month	2	2	2	3
PAI score After 6 month	1	1	1	2

Table 3.36 Description of the study cohort and the periapical scores for 6 months duration part 7

Patient name	Esraa Saad	Sabaa Mohamed	Hazem Saeed	Ali Abd Alkareem
Treated tooth	46	16	36	46
Age	34	19	35	29
Gender	F	F	M	M
Oral hygiene	Fair	Fair	Fair	Fair
Diabetic	No	Yes	No	No
Periradicular diagnosis	Acute abscess	Chronic Abscess	Chronic Abscess	Symptomatic Apical
Sealer extrusion	Yes	No	No	No
Obturation technique	Cold Lateral	Cold Lateral	Carrier based	Carrier based
PAI score before treatment	4	5	5	5
PAI score After 1 month	4	4	4	3
PAI score After 3 month	3	3	4	2
PAI score After 6 month	2	3	3	2

Table 3.37 Description of the study cohort and the periapical scores for 6 months duration part 8

Patient name	Suha Aied	Firas Saadi Mousa	Hassan Kadhban	Jassim Ali
Treated tooth	26	46	46	36
Age	34	52	16	45
Gender	F	M	M	M
Oral hygiene	Fair	Fair	Good	Fair
Diabetic	No	Yes	No	No
Periradicular diagnosis	Acute Abscess	Chronic Abscess	Symptomatic Apical periodontitis	Chronic Abscess
Sealer extrusion	No	No	No	No
Obturation technique	Cold Lateral	Carrier based	Carrier based	Cold Lateral
PAI score before treatment	5	5	3	5
PAI score After 1 month	4	4	3	4
PAI score After 3 month	3	4	2	4
PAI score After 6 month	2	3	2	3

Table 3.38 Description of the study cohort and the periapical scores for 6 months duration part 9

Patient name	Weaam Abd Alameer	Abbas Falah	Nibrass Hassan	Fatema Ali
Treated tooth	16	46	26	26
Age	29	44	33	25
Gender	F	M	F	F
Oral hygiene	Good	Good	Good	Fair
Diabetic	No	No	No	No
Periradicular diagnosis	Asymptomatic Apical Perio-dontitis	Chronic - Abscess	Symptomatic Apical Perio-dontitis	Acute - Abscess
Sealer extrusion	No	Yes	No	No
Obturation technique	Carrierbased	Carrierbased	Carrierbased	Carrierbased
PAI score before treatment	4	5	3	3
PAI score After 1 month	4	4	3	3
PAI score After 3 month	3	4	2	2
PAI score After 6 month	2	3	2	1

Table 3.39 Description of the study cohort and the periapical scores for 6 months duration part 10

Patient name	Sahar Zamel	Salam Haleem	Noor Ali	Hassan Abbas
Treated tooth	36	16	16	46
Age	56	41	21	16
Gender	F	M	F	M
Oral hygiene	Fair	Fair	Good	Good
Diabetic	Yes	No	No	No
Periradicular diagnosis	Chronic Abscess	Chronic Abscess	Asymptomatic Apical periodontitis	Asymptomatic Apical periodontitis
Sealer extrusion	Yes	Yes	No	No
Obturation technique	Cold Lateral	Cold Lateral	Cold Lateral	Carrier based
PAI score before treatment	5	5	4	5
PAI score After 1 month	4	4	4	4
PAI score After 3 month	4	4	3	3
PAI score After 6 month	3	3	2	2

The frequency, percentage, and the P-value of variables were tested. Among the forty participants in this study, 45% and 55% were male and female respectively, without statistically significant differences established between them. The percent of having a history of diabetes disease was 15%, with significant P-value (P< 1%).

No significant difference was found between the different status of oral hygiene, 42.5% of the subjects had good oral hygiene and 57.5% was fair. After six months follow up, 32 of treated cases considered as healed, 17 cases under healing process, and the remaining one case was diseased as showed in Table 3.40 .

Figures 3.14 , 3.15, and 3.16 present radiographs of an endodontic cases treated by Er ,Cr:YSGG laser. The healing of these lesions is revealed after 1 month, 3month, and 6 months afterwards endodontic therapy. In Figure 3.14 the preoperative radiograph shows distal root with a well localized periapical lesion.

Figure 3.15 presents lower right first molar with chronic abscess, the periapical and periradicular radiolucency is obvious around the roots. Figure 3.16 shows apical radio-lucency over apical third of the roots in lower left firstmolar with acute abscess.

Table 3.40 Domains and sub-domains variables of study and their criteria of comparison.

Variables	Criteria	n (%)	P value
Age	≤35	29(72.5)	0.000**
Gender	Male	18(45)	0.988ns
Oral hygiene	Good	17(42.5)	0.613ns
Molar	upperleft	11(27.5)	0.439ns
	upperright	6(15.0)	
	lowerleft	7(17.5)	
	lowerright	16(40.0)	
Diabetic	Yes	6(15)	0.000**
Periradicular diagnosis	Asymptomatic Apical	14(35)	0.065ns
	symptomatic Apical	8(20)	
	Acute Abscess	7(17.5)	
	Chronic Abscess	11(27.5)	
Sealer extrusion	Yes	18(45)	0.988
Obturation type	Cold Lateral	20(50)	1.00ns
	Guttacore	20(50)	
Number of Visit	Single	40(100)	
PAI score	≥3	40(100)	
PAI after one month	≥3	40(100)	
PAI after three month	≥3	29(72.7)	0.000**
PAI after six month	≥3	8(20)	0.000**
Healing rate	Success	39(97.5)	
	Healed	32(80)	
	Healing	17(17.5)	
	Diseased	1(2.5)	

ns= not significant, ** Significant differences at 1%,

a) Pre Treatment

b) Post treatment

c) After 1month

d) After 3months

e) After 6months

Fig. 3.14 Radiographic films showing the roots of tooth #36. a) preoperative radiograph present a periapical lesion for both roots b)The mesial and distal roots were obturated with Gutta-core X2 andX3 respectively and AH Plus sealer. c,d,e) reveals the healing of the lesions at 1month, 3months, and 6months after minimally invasive Endodontics therapy using Er,Cr:YSGG laser.

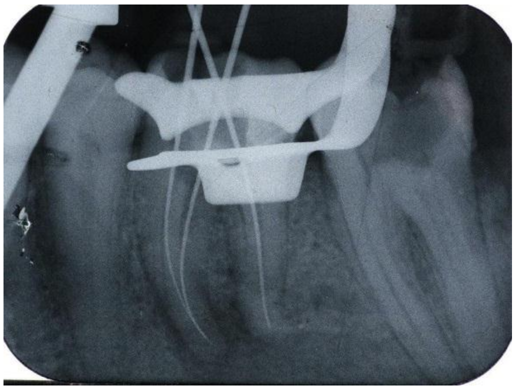
a) Pre Treatment **b) Post treatment**

c) After 1 month **d) After 3 months**

e) After 6 months

Fig. 3.15 Radiographic films showing the roots of tooth #46. a) preoperative radiograph present apical rediolucency around the apical and radicular area b)The mesial and distal roots were obturated with Gutta-core X2 andX3 respectively and AH Plus sealer. c,d,e) reveals the healing of the lesions at 1month, 3months, and 6months after minimally invasive Endodontics therapy using Er,Cr:YSGG laser.

a) Pre Treatment



b) Estimation of working length

c) Post treatment

d) After 1 month

e) After 3 months

f) **After 6 months**

Fig. 3.16 Radiographic films showing the roots of tooth #36 diagnosed with acute abscess. a) preoperative radiograph present periapical radiolucency roots b) determination of the working length c)The mesial and distal roots were obturated with Gutta-core X2 andX3 respectively and AH Plus sealer.d,e,f) reveals the healing of the lesions at 1month, 3months, and 6months after minimally invasive Endodontics therapy using Er,Cr:YSGG laser.

Moreover, as dipicted in Table 3.41, concerning the Pearson correlations there is a highly correlation between the healing and the preoperative PAI score (r =0.543 highly significant).

Table 3.41 Association of variables with the outcome

Variables	No	% Success	95% CI	Pearson correlation
Age			0.912-1.994	0.124ns
≤35	29	96.5		
>35	11	100		
Gender			-0.670 – 0.175	-0.189ns
Male	18	100		
Female	12	95.5		
Preoperative PAI score (≥3)	40	100	0.237- 0.726	0.543**
Obturation type			-0.670 – 0.170	-0.192
Cold Lateral	20	95		
Guttacore	20	100		

IC= confidence intervals, ns= not significant, * Significant differences at 5%, **Significant differences at 1%

The prognosis of healing rates was compared Temporally as shown in Figure 3.17 Forty patients were followed up at three recall periods at 1month, 3months, and 6months after endodontic therapy. The success of root canal treatment for these periods was 67.5%, 82.5%, and 97.5%, respectively.

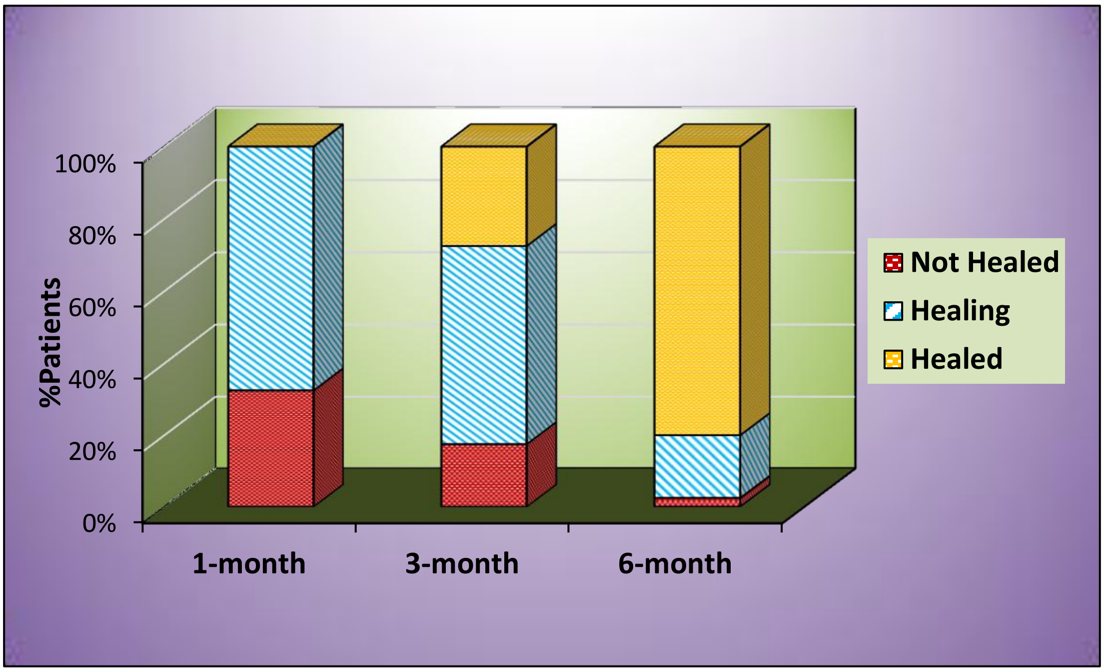


Fig. 3.17 the success of therapy at 1-month, 3-month and 6-month follow-up time

Figure 3.18 shows some of different cases treated during this study treated by minimally endodontic therapy using Er,Cr:YSGG laser. Preoperative radiographs present a periapical lesion for roots. Figure 3.18 B), and D) obturated with Gutta-core X2 for mesial roots andX3 for distal roots and AH Plus sealer. whereas A), C), and E) obturated with cold lateral compaction.

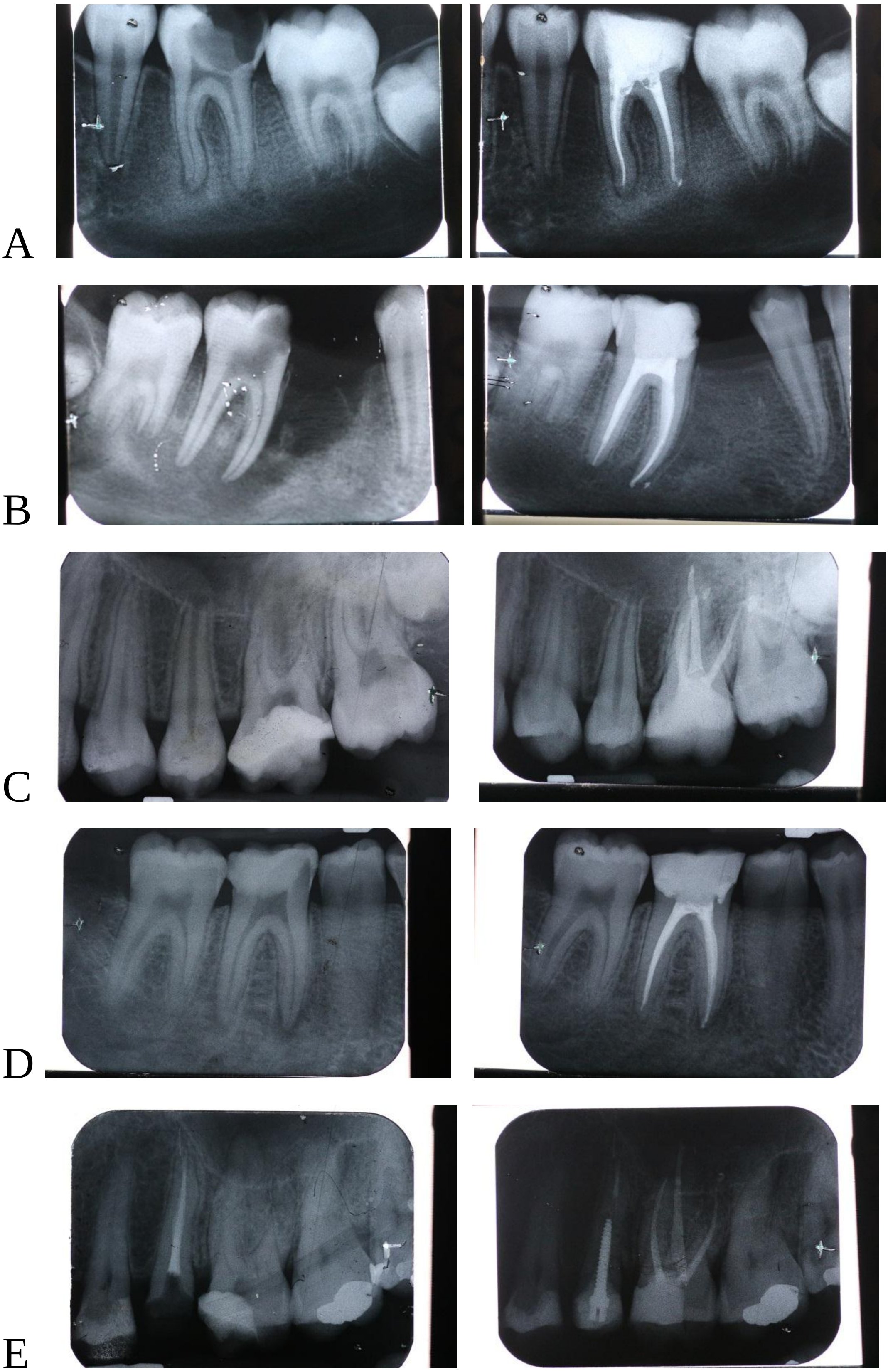


Fig.3.18 radio-graphs of some cases of clinical study a) tooth #36 b) tooth #46 c) tooth #26 d) tooth #46 e) tooth #26

3-2 Discussion

In this thesis, the confocal laser microscope study has been performed prior to the clinical study and to support their outcomes. The outcomes of the vitro study have been filtered and the best methodology of the study groups is transferred to be tested and evaluated clinically. The evaluation of dentine- guttapercha interface and penetration of Ah-plus sealer into dentinal tubules have been done in the confocal study stage. However, there is other investigation methods can be used for sealer –dentine evaluation, like stereomicroscope, scanning electron microscope.

The confocal laser microscope was preferred due to the ability to investigate the sealer-dentine status at multilayers on the whole circumferential border of the root with highly-contrast seen depending on fluorescence-phenomena (10-12). In previous study, they concluded that the using of confocal laser microscope have presented superiority because the capability of investigation the sample thickness from the surface to the underling layers without any artifact (13).

Principally, the protocol of using confocal laser microscope requires flurochromophores that should be blended with and dissolved in the investigated material. The selected flurochromophores was Rhodamine B which has electro balance undetached-molecules. This molecule is considered water insoluble and can be dissolved in organic-solving like sealer; primer; and coupling agent. The labeled sealer can be detected and identified inside the dentinal tubules with confocal laser microscope (14). In order to conserve the physical properties of the sealer material, the flurochromophores must be added in concentration of less than 0.002 (275).

Tables (3.1-18) explain the sealer penetration of G1 and G2 is more obvious in the buccal direction followed by lingual, mesial, and distal directions respectively. While the sealer penetrations into different directions of G3, G4, G5, and G6 are as the following: buccal, mesial, lingual, and distal. These sealer penetration variations between different directions at different sectional level of various groups are depending on many factors. The affecting factors are including: the physical properties of the sealer, the size of the dentinal-tubules, percentage of inter-tubular dentine, the presence of smear layer, the obturation techniques, and the presence of butterfly effect (132).

The butterfly effect is an optical circumstance observed in root-cross section of some teeth and is linked with dentinal-tubules order and density. It has been seen in some teeth that showing greater density of radicular-dentinal-tubules at the buccolingual direction related to mesiodistal direction (276). Unfortunately, the dentition that presented with this effect are more reliable to vertical root fracture in the bucco-lingual direction because of lesser inter tubular dentine and hardness in this direction compared to mesio-distal direction (277). Generally, the butterfly effect affects the sealer penetration status inside the dentinal tubules. In addition, it may disrupt the mechanical inter locking of resin tag with radicular dentine in some resin sealer like Ah-plus sealer (276).

Figure 3.11 showed some sides without even penetration of the sealer. This may be associated with density and direction of dentinal-tubule at these sites which may have greater hardness. The other possible causes is that the air bubble entrapment specifically in G3 and G4 groups(Figure 3.11,c and d) which leads to untouched area with EDTA solution. On the other hand, in G1 and G2 groups(Figure 3.11,a and b), the laser ablation of smear layer may be not completely performed due to the ejected particles, the evaporated smear layer contents, scattered the laser beam away from the smear layer especially when the hand withdrawal speed of laser tips is get slower.

The removal of smear layer has signified the sealer penetration depth as seen in G1, G2, G3, G4 groups compared to G5, G6 groups as depicted in Figure 3.12. This result is in a good agreement with earlier studies that estimated the relationship of the occurrence of smearlayer and penetrationdepth of the sealer (278-282). Wherever the smear-layer is removed the sealer penetration will be higher.

The Conventional way of removing the smear layer using EDTA is preferable to be applied in butterfly-presented teeth at the starting and finishing of instrumentation to minimize the fracture susceptibility due to file torque pressure (277). Figure (3.2-7) present the result of G1 G2 groups that treated by Er,Cr:YSGG laser which have more sealer penetration in the bucco-lingual direction than the meso-distal direction and that may be due to the selective absorption of the laser in peri-tubular dentine of less hardness is higher than that of the other direction. This selectivity in absorption is a matter of safety and perfection of laser in expelling the smearlayer only. While, action of the EDTA was inharmonious, the mesial site penetration depth was greater than the lingual site which means the action of EDTA was on smearlayer as well as on intact radicular dentin.

It is clear that the prime data of the present study was that higher sealer penetration was established when the ErCr:YSGG laser was employed for smear layer removal with Carrier-based technique. Another meaningful data were that the deportation of smearlayer in general and the obturation technique further enhanced the entrance of AH-plus sealer into dentinal tubules.

The flow of a sealer and its penetration depth determine how good obturation will get, that fill inconsistency on the dentine walls, and distances among the core obturation materials. AH-plus sealer was characterized as pseudoplastic material when subjected to compaction a decline in viscosity with a rise in flow will happened due to an increase in the shear rate (283,284). In the present study, the flowability of AH-plus is affected when exposed to a compaction pressure as a result of the wedging of the spreader or due to the hydraulic pressure of the Guttacore obturator.

In addition, the elevated temperatures accompanied the obturation of Guttacore leads to reduce in the viscosity of the AH-plus sealer(55,283). And that explain the higher sealer penetration when used with the carrier-based technique. Beside that the obturators advance warm gutta-percha 3-dimensionally into the dentinal walls generate the hydraulic force bunched warm gutta-percha flowing uniformly in 3-dimensions which affect the penetration depth of the sealer as shown in Figure 3.11 a and c.

Many studies about the communication of smear layer with the penetration-measure of sealers into dentinal tubule have displayed controversy consequences; despite the fact a groups of investigators have declared that no penetration of sealer appear when there is a smear layer (285,286) , others have reported that the presence of smear layer diminish sealer-penetration to a some degree but doesn't absolutely cease it (287), and another groups in-vivo study have disclosed that the sealer penetration is happened markedly even though of presence of smear layer (288).

In our study, the outcomes are somewhat in agree with second group of studies (287) by reason of the smear layer removal by ErCr: YSGG laser as in (G1,G2) or by EDTA (G3,G4) expanded the sealer penetration when compared with control groups(G5,G6).

The effect of smear layer removal by ErCr: YSGG laser is obviously clear over that by EDTA on sealer penetration, this owing to the deeper clearness of dentinal tubules by laser as it can advance deeper into dentinal tubules (289) without being dicey to neighboring tissues(290) .In addition, the using of modified radial-firing-tips (RFT) boost the distribution of light in root canal system, and have been displaying to be a commodity means for smearlayer elimination adopting water mutually to rootcanal sterilization in moistureless condition (291).

The laser parameters used for smear layer removal was 1.25 W, 20 Hz, 60 μm, 10 water, 30 air. The selection of laser parameters based on removing the smear layer efficiently without affecting intact root dentine, does not produce temperature rise above the accepted limit. The dose of the laser with fluence (7.96 J/cm^2) in the current work was exceeding the ablation threshold of dentine by Er,Cr:YSGG laser . The laser fluence was applied with 60us pulse duration giving rise to cold ablation of smear layer without affected heat. One of the important factors that affect the dynamic of ablation process is the debris-screening of the ejected particle, which can absorb and scatter the laser energy. The degree of debris-shield builds upon on the debris's compactness of which is powerful with large Laser tissue number. Because of this compactness rely upon laser- power density; it is favorable to obtain laser tissue number above one with relatively long pulse-duration (292).

Previous study has been performed about the thermal effect of ErCr: YSGG laser on dentinal wall irradiated with powers ranging from 1 to 6W. Output power of more than 4 W can produce crack and carbonization when applied on radicular dentine10. However, the laser irradiation of 1W can also produce the same thermal effect when applied without coolant10. Another study has been conducted, it was found that the calcium phosphate ratio of the radicular dentine is not changed when irradiated with 3W Er,Cr:YSGG laser.11 despite that , the thermal damage has been reported which present as carbonization, limited area of melted dentinal tubules, leading to occluded opening of dentinal tubules. According to these finding, Er ,Cr:YSGG laser of average-power more than 1.5 W not only produces thermal changes but never clear away smearlayer completely (293-295).

When looking at Tables (3.25,26,27) it will be found that the penetration of sealer is deeper at the coronal, middle parts related to apical part. The result is in a good agreement of that of preceding researches which have certified the correlation of sealer with filing technique (296-298). That may be due to the size of dentinaltubule openings are closer and bigger in the coronal and middle parts compared to apical part of the root which permit smoother penetration of sealers. Beside, higher compressive-effort may exercise in obturation at the coronal two third.

Figure 3.8 represents the mean value of sealer penetration of all groups at the apical third. The unexpected drop of the figure curve may be due to the used obturation technique. In cold lateral technique the spreader is inserted within 1-2mm of determined-length which may affect the lateral pressure on the sealer penetration at the apical third.

The advantages of deep penetration of root canal sealer are enhancing the micromechanical interlocking of AH-plus sealer with radicular dentine (290,299). Also, it acts like a blocking-factor that may conflict with microorganism colonization and prohibit their regrowth inside the canal wall. Sealer inside dentinal tubules produces a physical-barrier that restricts microbial micro leakage and secondary endodontic infection (290). In addition, the bactericidal effect of sealer will still active after penetration that may promote the healing process of peri apical lesion and sustain normal status (300,301).

After the supportive results of confocal laser microscope study, the clinical study was conducted which clarified the outcome of an endodontic treatment for 6-months follow-up. The best result of the confocal laser microscopic study was found when the laser was used. Therefore the conventional method for removing the smear layer does not reused in the clinical study. The clinical study was objected to declare the healing of necrotic teeth with various apical periodontitis category.

One of the crucial factors that affect the prognosis of the endodontic therapy is the existence of apical-periodontitis which may conflict with the treatment-prognosis and may decrease the successful rate (22,50,264). In view of actuality that there is not a fulfilled clinical-guideline concerning the treatment of apical periodontitis cases, as a result farther studies are continually required to establish which are the protocol-related factors that can interact with the root canal treatment results (291).

Table 3.40 shows the possible predictive factors like; age, sex, tooth-form, oral hygiene and periradicular diagnosis which have no significant effect these finding are coincide with a previous study (264). The successful rate of endodontic therapy is directly proportional to the eradication of the bacteria and other microbes as well as to the host-response and the coronal-sealing of the treated teeth (264,266,270).

The Er ,Cr:YSGG laser can perform smear layer elimination and eradication of bacteria inside the root-canal systems. Moreover, the cleaning and shaping were performed according to minimally invasive technique to preserve the root structure. The apical enlargement was from 0.25 mm to 0.3 mm with 6 % tapering, further decreasing of the apical diameter conflicts with the requirements of the obturation techniques.

Carrier based and lateral compaction obturation techniques were adopted for root canal obturation afterwards laser application. Earlier in vitro studies were using Er,Cr:YSGG laser after multiple appointments endodontic treatment, but the canals instrumented to a larger apical diameter (302,303). Their results depending on enlarging the canal size provide freely movement of laser tip inside the root canal space.

Furthermore, there is no dependable confirmation that healing improvement affected by number of sessions, whatever it is single or multiple sessions with calcium hydroxide intracanal medication (304).

One of the objectives of endodontic treatment is to survive the involved tooth to the finest viable case without surgical intervention (303,304). Some studies advocate that teeth with partial healing prognosis must be subsequent to prolong time duration. Despite that, another study (305) presents about 95% of the cases with long period follow up could be anticipated at shorter period. In addition, loss of patient's susceptibility over long period follow-ups will be increased. So that, some of researchers directed to choose briefer follow up duration, while others recommended simpler but definite proxy endpoints (306,307). In this study, the patients were observed for 6 months period. However , the case with poorly prognosis in this study may accounted for delayed healing process which may be due to the huge apical radiolucency with chronic abscess in the periradicular area beside that the patient was diabetic and presented with bad oral hygiene.

In the present study, 97.5% healing rate at 6 months period was displayed. This result of high endodontic success is rejecting the guesstimated hypothesis that the healing percentage checked at 6 months will be decreased. Earlier clinical researches (308-310) were done using other endodontic supported techniques. They present different healing percentage at the same endpoint period, after six months. One study present 70.6% healing percent of the lesion after root canal treatment (311). Other study (312) revealed healing percent around 67% of the treated cases. Another one showed 83.33 % healing rate after using of Er,Cr:YSGG laser (313). A 92.9% healing rate had been accounted in previous study that using gentle wave system in necrotic teeth (264).

The prognosis of healing rates was compared Temporally as shown in Figure 3.15 Forty patients were followed up at three recall periods at 1-month, 3-month, and 6-month after treatment. The success of root canal treatment for these periods was 67.5%, 82.5%, and 97.5%, respectively. Form the first month after endodontic treatment, the prognosis of treatment was promised.

The progress of the treatment prognosis is owing to the laser effect in clear away smear layer and endodontic disinfections. It's worth mentioning, the scattering of the laser radiation inside the root canal system may have photo-biostimulative action which may increase the healing process (314) . In addition, the scattered laser energy falls in the therapeutic window of the biostimulation 1- 10 J/cm^2. The power density of the used laser was 1.3 x 10^5 W/cm^2, the probability of Raman scattering is relatively low of all scattered radiation and because the wavelength of laser fall in the IR region so the possibility of Raman scattering is increased. Previous study had conducted that Er , Cr: YSGG laser probably induce pocket reduction and bone regeneration (282,283). Guesstimating possible mechanism of this petition appears arguable just before satisfying confirmation. More investigations are recommended to assess the theoretical efficacy of Er ,Cr:YSGG Laser in enhancing bone-regeneration in clinical efforts.

In traditional endodontic-treatment, it is popular that the disinfection of root-canal system especially at the apical third could be promoted utilizing ultrasonic tips (315). In the present study, the displayed result of 97.5% healing percentage is signifying a valuable laser elimination of the smear layer from dentinal wall. The mechanism behind smear layer removal by laser is the photothermal ablation.

When the water molecules in the smear layer absorb the mid IR laser energy, they will be suddenly vaporized. This rapid vaporization is combined with a pressure gradient. Small micro explosion is responsible for the detachment and ejection of smearlayer. In addition, the water spray aid in cooling the tissue and increase the absorption of laser inside tissue giving rise to a safe and an effective laser removal action.

The other encountered laser action is an efficient and thorough disinfection laser action underneath dentinal tubules. The mechanism of disinfection is depending on the photo-thermolysis of the target chromophores. For ErCr:YSGG laser application the targeted chromophore is water molecule which make up the main continent of microorganism.

One of the crucial factors that connected directly to the treatment success is the conservation of tooth dentine as much as possible (316-318). In the present study, it is noticeable that this issue is taken into account through using minimal invasive endodontics. The dentin structure is preserved during access preparation and root canal shaping.

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3-3 Conclusion

1. The promising use of confocal laser microscope assists and improve the efficacy of ErCr:YSGG Laser in eliminating the smear-layer, depending on clear, highly-contrast fluorescence images of labeled sealer which penetrate the dentinal tubules.
2. Considering the confocal laser microscopy study, the using of ErCr:YSGG laser for smear layer removal propose for larger dentinal tubule penetration of the Ah plus sealer comparing to EDTA and normal groups.
3. The carrier based technique is better than cold lateral compaction technique in adaptation and forcing the sealer farther inside the dentinal tubules.
4. The minimally invasive endodontic therapy with the smear layer removal and disinfection of the ErCr:YSGG laser of 7.96 J/Cm^2 fluence can enhance the treatment of patients who diagnosed with different apical diagnoses in single visit root canal treatment.
5. The clinical use of radial-firing-tips (RFT) allow for even distribution of laser that irradiate the entire root canal walls for smear layer elimination adopting water mutually to root canal sterilization in moistureless condition.
6. It is shown a tremendous degree of success (97.5%) of root canal treatment in a period of 6 months after treatment. The hypothesis that the healing percentage will be not affected is disregarded
7. Er,Cr:YSGG Laser of 1.25W, 20Hz, 60µs permit for rapid rate of healing with a predictable outcome taking into account minimally invasive technique in single visit root canal treatment

3-4 Suggestion for future work

1. Study the biostimulation effect of the scattered laser radiation.
2. Compare between Er,Cr:YSGG and diode lasers in endodontics disinfection
3. Compare between different sealer types in dentinal tubules penetration ability after smear layer removal
4. Study the Er,Cr:YSGGLaser stress effect ahead of resiliency of dentine.

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بالتوافق مع دراسة الفحص المجهري بالليزر البؤري ، وجد بشكل كبير أن عمق اختراق السدادة في الاتجاه اللساني كان أكبر من المتوسط الوسطي القاصي في جميع المجموعات. في المقارنة الإحصائية الإجمالية بين جميع المجموعات ، لوحظت فروق ذات دلالة إحصائية في G1 مع جميع المجموعات (عند P 01. 01) ، وبين G2 و G4، G5، G6 ، مما يشير إلى أن إزالة طبقة اللطاخة بالليزر عند الطلاقة 7.96 جول/سم^2 كان مرتبط بأقصى اختراق للسدادة (1234.25 ميكرون) خصيصًا باستخدام تقنية الحامل القائمة على الحامل.

وفقًا لـ ErCr: YSGG بالليزر بمساعدة المعالجة اللبية طفيفة التوغل ، تمت مقارنة تشخيص معدلات الشفاء مؤقتًا لجميع المرضى الذين تمت متابعتهم في ثلاث فترات استدعاء في الشهر 1 و 3 أشهر و 6 أشهر بعد العلاج اللبي. كان نجاح علاج قناة الجذر لهذه الفترات 67.5٪ و 82.5٪ و 97.5٪ على التوالي. ومن الشهر الأول بعد علاج اللبية كانت النتائج واعدة.

في الختام ، يساعد استخدام مجهر الليزر البؤري على اثبات فعالية ErCr: YSGG ليزر في إزالة طبقة اللطاخة ، اعتمادًا على صور اضحة ومتباينة للغاية من السدادة المسمى التي تخترق الأنابيب العاجية.

العلاج اللبي الأقل بضعاً بإزالة طبقة اللطاخة وتطهير ليزر ErCr: YSGG بتدفق 7.96 جول/سم^2 التي يتم تقديمها من خلال الوسائل الشعاعية يمكن أن يعزز علاج المرضى الذين تم تشخيصهم بتشخيص قمي مختلف في علاج قناة الجذر ذات الزيارة الواحدة

الخلاصة

الهدف الأساسي من علاج اللب هو القضاء على البكتيريا والكائنات الدقيقة الأخرى من العاج الجذري. العديد من الدراسات قد اجريت ومختلف الادوات قد وظفت لخدمة هذا الغرض ولكن لا تزال هناك حاجة لمزيد من الأبحاث للوصول للدقة. أثبت في دراسات مخبرية سابقة أنه جهاز Er,Cr:YSGG مفيد من جانب إزالة الطبقة الصبغية و كمطهر للقناة الجذرية. حتى الآن لا توجد دراسة سريرية واضحة لنتائج ذات دلالة إحصائية تعزز استخدام الليزر مع حشوات جذور تحفظية. الهدف من الدراسة هو تحسين علاج اللبية للمرضى الذين تم تشخيصهم بتشخيصات ذروية مختلفة باستخدام بالليزر وتقنية الحد الأدنى من التدخل في علاج قناة الجذر ذات الزيارة الواحدة ، بمساعدة دراسة مجهر ليزر متحد البؤر.

تتكون العينات المستخدمة في الفحص المجهري بالليزر البؤري من 30 سن بشري ذات جذر واحد تم قطعها في منطقة التقاء المينا مع طبقة السمنت. تم إجراء علاج قناة الجذر لجميع العينات باستخدام الأدوات الدوارة ProTaper Next. تم قياس الحجم القمي لجميع العينات حتى X4. تم تقسيم العينات إلى ست مجموعات ، وتمت إزالة طبقة اللطخة في أربع مجموعات إما بـEr Cr: YSGG Laser أو EDTA والمجموعتان المتبقيتان للمقارنة. بعد ذلك ، تم حشو جميع العينات بواسطة تقنية الضغط الجانبي أو القائم على الناقل. تم استخدام AH plus sealer الذي تم مزجه مع صبغة Rhodamine B الفلورية. بعد إجراء دراسة مجهر ليزر متحد البؤر ، أجريت الدراسة السريرية ولم يعد يستخدم EDTA في الدراسة السريرية.

تكونت مجموعة الدراسة السريرية من 40 مريضاً تم تحديدهم لعلاج قناة الجذر وتم تشخيص إصابتهم بالتهاب اللثة القمي. تم التوقيع على استمارة الموافقة المستنيرة من قبل جميع المرضى قبل المشاركة في الدراسة. أسنان المريض المختارة كانت الأضراس الأولى الدائمة. بدأ التنظيف والتشكيل وفقًا للمحافظة على الانسجة السنية باستخدام أدوات ProTaper Next. تم استخدام تقنية تحضير "الدفع والسحب" حتى X2 لقنوات الجذر المتوسطة أو البوقية و X3 للقنوات البعيدة أو الحنكية مع 5٪ من الري NaOCl. بعد ذلك ، تمت إزالة طبقة اللطاخة لجميع الأشخاص باستخدام ، Er Cr: YSGالليزر على طول موجة 2780 نانومتر بواسطة وسائل إطلاق شعاعية RFT2 و RFT3. كانت معلمات التشغيل: 1.25 واط متوسط القدرة ، 20 هرتز معدل استنفاد النبض ، مدة النبضة 60 ثانية ؛ 30٪ هواء ؛ 10٪ ماء. بعد التشعيع بالليزر ، تم إجراء الري النهائي باستخدام 5 مل من محلول ملحي. بعد ذلك ، تم إجراء تعقيم بالليزر باستخدام: RFT2 ، متوسط قدرة 1 واط ، معدل استنفاد النبضة 20 هرتز ، مدة النبضة 60 ثانية ؛ 10٪ هواء ؛ وبدون ماء. تم تقسيم االاشخاص إلى مجموعتين. تم حشو جذور المجموعة الأولى باستخدام تقنية تعتمد على الناقل ، بينما في المجموعة الثانية ، تم استخدام الضغط البارد الجانبي. كان سيلر AH-Plus هو السدادة لكلا المجموعتين. تم تقييم الشفاء من حالات التهاب اللثة القمية المختلفة سريريًا وبالأشعة على طول فترة ستة أشهر. يعتمد الجزء السريري من التقدير على العلامات والأعراض. بينما يبني الجزء الآخر على مؤشر Periapical index ((PAI).

جمهورية العراق
وزارة التعليم العالي والبحث العلمي
جامعة بغداد

حشوات الجذور بأستخدام Er,Cr:YSGG ليزر
دراسة سريرية ومجهرية بواسطة مجهر ليزري متحد البؤر

رسالة

مقدمة الى معهد الليزر للدراسات العليا كجزء من متطلبات نيل درجة

دكتوراه فلسفة في الليزر / طب الأسنان

من قبل

علي عباس شهيد

بأشراف

الأستاذ الدكتور حسين علي جواد

1441هـ **2020م**