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A Comparison between Er,Cr:YSGG Laser (2780 nm) and Bur in Root End Preparation:- An in Vitro Study

A Thesis Submitted to the Institute of Laser for Postgraduate Studies, University of Baghdad in partial fulfillment of the requirements for the degree of Master of Science in Laser / Dentistry

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Dedication

I dedicate this work to those who share the same dreams of mine, but they prefer to tell the earth with their blood

None of this would happen without their sacred sacrifices and endless devotion.

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Abstract

Background : Root end surgery is the treatment of choice when non-surgical endodontic treatment continuously failed or can't be achieved. Various techniques with different instruments used to perform this procedure which affect the treatment success and outcomes; therefore, many studies were carried out to compare between them in order to determine the preferable technique and instruments.

The aim of this study was to compare between Er,Cr:YSGG laser 2780 nm and bur in root end surgery (root end resection and retrograde cavity preparation) regarding the characteristic and microscopical variations, temperature changes and the duration of the procedures.

Material and method: Forty extracted single rooted teeth endodontically treated, root canals were obturated and teeth were divided into four groups according to type of process. Teeth in group 1 were root-end resected using cross cut carbide bur while teeth in group 2 were root-end resected using Er,Cr:YSGG laser 2780 nm delivered through MGG6 sapphire tip of 600 µm diameter according to the manufacturer instruction (5 W, 25 Hz, 50% water, 80% air, 25.47 J/cm^2). Root end cavity preparation (retrograde cavity) in group 3 was prepared using carbide fissure bur while in group 4 was prepared using Er,Cr:YSGG laser 2780 nm delivered through MZ6 glass tip of 660 µm diameter according to the manufacturer instruction (3.75 W, 15 Hz, 30% water, 60% air,31.84 J/Cm^2). Temperature on external root surface and duration of procedures were recorded. Samples were prepared for scanning electron microscope and examined to evaluate characteristic and the morphological changes. Energy dispersive X-ray spectroscopy was performed to measure the mineral contents of dentin within group 4. For statistical Analysis**;** whenever required**,** X^2 test/Fisher's exact and Kruskal–Wallis test were used, the significant difference was set at $P \leq 0.05$.

Results: There was a significant difference between group 1 and group 2 regarding the number of intradentinal cracks as group 2 showed higher percentage of samples with intradentinal cracks, while there were no significant differences between them in terms of complete and incomplete cracks. Laser didn't cause cemental damage within the treated sample and the difference between group 1 and group 2 was highly statistically significant. Evaluation of surface roughness and duration of resection revealed statistically significant difference as laser resulted in rougher surface and longer time for resection process, while it was not significant in term of temperature measurements. On the other hand, laser revealed a higher value statistically compare to carbide bur during root end preparation in terms of dentinal crack, surface roughness, smear layer removal and opened dentinal tubules, temperature on the external root surface and the duration of cavity preparation ,while the difference between group 3 and group 4 in the term of quantitative assessment of opened dentinal tubules was very highly statistically significant.

Conclusion: Er,Cr:YSGG laser in root end resection process showed higher percentage of intradentinal cracks, no cemental damage, larger filling material – root canal wall gap area, rougher surface and longer time for cutting than bur. Er,Cr:YSGG laser in root end cavity preparation showed higher percentage of dentinal cracks, rougher dentinal surface, better smear layer removal, more opened DTs and longer time for preparation than bur. There is no elevation of temperature on external root surface of all groups. EDX showed no correlation between the weight % of Ca and P in dentin and the incidence of dentinal cracks. As a conclusion it is recommended to use bur for both root end resection and root end preparation and using Er,Cr:YSGG laser for smear layer removal. The root end preparation is necessary following root end resection.

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Abbreviations	**Term**
#	Size
IEC	International Electrotechnical Commission
ANSI	American National Standards Institute
max	maximum
CW	Continuous wave
DTs	Dentinal tubules
$Ca(OH)2$	Calcium Hydroxide
CRS	Conventional root end surgery
EMS	Endodontic microsurgery
ISO	International Organization for Standardization
TC	Tungsten Carbide
x	magnification
Er:YAG	Erbium-doped:Yttrium, Aluminum, and Gernet
Er,Cr:YSGG	Erbium Chromium:Yttrium, Scandium,Gallium and Gernet
Nd:YAG	Neodymium doped Yttrium –Aluminum Garnet
G1	Group 1
G2	Group 2
G3	Group 3

G4	Group 4
Hz	Hertz (unit of frequency)
J	Joule (Energy unit)
EDTA	Ethylenediamine tetraacetic acid
MTAD	A mixture of citric acid, tetracycline isomer and detergent
Nd:YAG	Neodymium:Yttrium Aluminium Garnet
ºC	Degree Celsius (unit of temperature)
rdg	an error factor of a digital tester
S.D	Standard Deviation
SEM	Scanning electron microscope
kV	kilo Volt
W	Watt (unit of power)
mW	Mill watt = 10^{-3} W
W/cm^2	Watt per centimeter square (unit of power density)
m	Meter (wavelength unit)
mm	Millimeter = 10^{-3} m
Mm^2	Square millimeter (unit of area)
µm	Micrometer =10^{-6} m
nm	Nanometer =10^{-9} m
RER	Root end resection

REP	Root end preparation (retrograde cavity preparation)
EDX	Energy dispersive X-ray spectroscopy

Chapter one

Introduction and Basic concepts

Chapter one : Introduction and Basic concepts

1.1 Introduction

"Endodontic Surgery" is a term that includes numerous surgical procedures performed to eliminate the predisposing agents of endodontic and periapical diseases and to rehabilitate the functional health of these tissues [1].

Endodontic surgery can be classified into the following [2]:

1. Fistulative surgery this involve many procedures such as incision and drainage, cortical trephination and decompression .

2. Corrective surgery include repair of root perforation which is either (mechanical or internal and external resorption) and periodontal management through either root resection or tooth resection ,and intentional replantation.

3. Periradicular surgery which includes curettage of the lesion, root end resection with or without retrograde cavity preparation (root end preparation) and retrograde filling. There are several indications and contraindications of periradicular surgery .

Periradicular surgery, considered as an extension of nonsurgical treatment, because the predisposing factors and the goals of treatment are the same: prevention or eradication of apical periodontal infections [3].
Indications for periradicular surgery had been updated by the ESE ″European Society of Endodontology, 2006″ including the following [4]:
(1) Radiological evidences of apical periodontal infection with or without symptoms of obstructed canal (the obstruction which can't be removed or displaced or there is a great risk of damage).

(2) Extrusion of filling material with evidence of apical periodontal infection clinically or radiographically with or without symptoms that persist over a prolonged period.
(3) Unresolved infection or that appear after endodontic treatment when retreatment is inapplicable.
(4) Perforation in the root or on the pulpal floor which is impossible to be treated from within the coronal cavity.

On the other hand, there are few contraindications for periradicular surgery; which involve general and local factors [5]:

A. General

Patient health condition includes psychological or physical status, e.g. bleeding disorders

B. Local

• Dental considerations include tooth restorability, length of root, periodontal and oral hygiene condition.

• Anatomical considerations include the proximity of nerves and blood vessels such as inferior alveolar and mental nerves during surgery of mandibular posterior teeth or palatal neurovascular bundles during surgeries in the maxilla.

• Accessibility of surgical site e.g: mouth opening, extension of the external oblique ridge associated with molars of apices that’s lingually positioned and large bony exostosis which interfere with flap incision and reflection.

1.2 Periapical lesion

One of the most common pathologies that occur within the alveolar bone is the periapical lesion. Bacteria and their by-products when access into the pulp will act as antigens that may trigger nonspecific inflammatory and specific immunological responses within the periradicular tissues which will result in periapical lesion [6, 7].

1.2.1 Etiology of periapical lesion

Microorganisms in the oral cavity invade dental hard tissues and cause demineralization of hydroxyapatite, this is either through cracks in the crown, opened dentinal tubules (DTs) with traumatized neurovascular bundles or the apical foramen in cases of severe periodontitis. The pulp contained in the enclosed space which is immunologically competent and able to resist infection; if this infection left untreated then it will result in necrosis of the pulp which is eventually arise by mean of proteolytic enzymes which is released by neutrophil granulocytes. This cause infection along the canal space, and induce host defense mechanism in the tissues surrounding the root apical end ″the periapex″ [8].

The magnitude of the host response is directly proportional to the number and the virulence of microorganism which affect the periradicular tissues. Bacteria damage tissue either by direct or indirect mechanisms. Direct mechanism occur when bacterial by-products (metabolites, enzymes and exotoxins) and its component elicit the development of immune mechanism which is capable of causing extreme tissue damage; as a results, chemical mediators (cytokines and prostaglandins) are released and those are responsible for the initiation of bone resorption which is ordinarily seen in chronic periradicular lesions. The immune mechanism is the most important factor that cause pus formation associated with acute periapical abscess as bacterial indirect effect is the most significant in the periradicular tissue destruction (acute and chronic perirapical lesions),the mechanism involve oxygen-derived free radicals formation with the release of lysosomal enzymes (elastase, collagenase and gelatinase) by polymorphonuclear neutrophils which will activate extracellular matrix destruction and results in pus formation. [9].

Another form of periapical lesion that occur due to non microbiological stimuli as a result of extrusion of filling material from the canal into the periradicular tissue (foreign body reaction) such as Gutta Percha, sealers, paper points, amalgam particles, silver, and calcic salts derived from the extruded $Ca(OH)_2$; those will induce an intensified localized reaction within the periradicular tissue, mediated by macrophages and giant multinucleated cells which will predispose periapical lesions [10].

Traumatic injuries are one of the serious unexpected events which can predispose periapical lesion which treated using apical surgery [11].

The structural content of a periradicular lesion determined according to the balance between the microbiological factors and the immune defenses [12]. Thus, when the infection reach the periapex, acute or abscess lesion occur which contains a dense aggregation of polymorphonuclear leukocytes, lined by granulomatous tissue contain macrophages, lymphocytes and plasmatic cells [13]. The periapical lesion may persist and give rise chronic lesions. The abscess may fully lined by epithelial cells and give rise to the radicular cyst [14].

1.2.2 Classification of periapical lesions

Periapical lesions are classified according to the etiology and the associated symptoms **(figure 1-1)**.

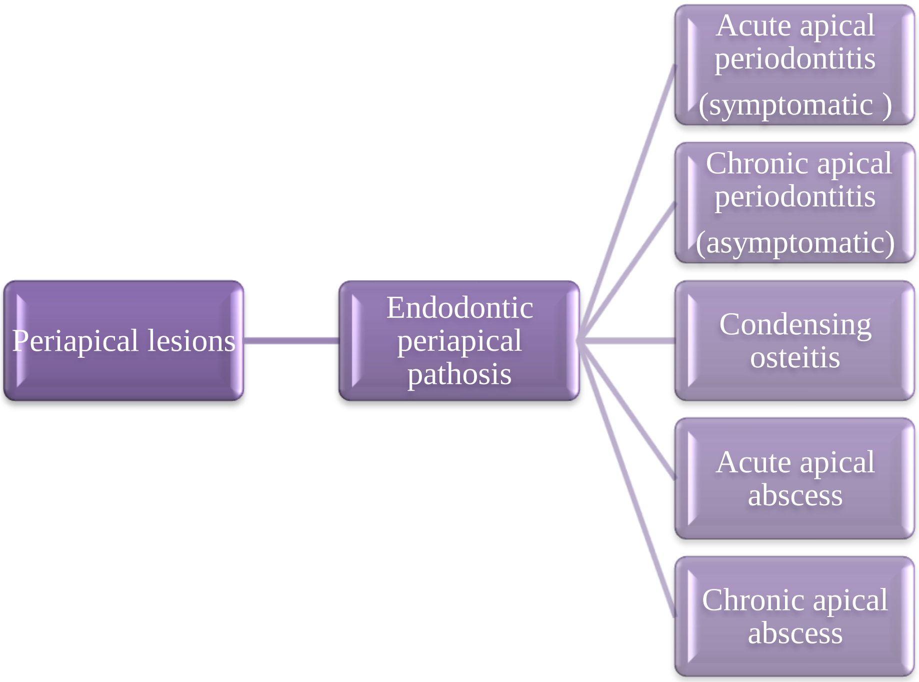


Figure (1-1): Classification of periapical lesions **[15]**.

1.3 Root end surgical procedure

The type of flap design depend on the periodontal status. At the beginning of the surgical procedure a surgical flap is elevated followed by an access to the cortical plate using a surgical handpiece and round bur. The lesion is excavated with a sharp bone and angled periodontal currete. The excavated lesion is kept in 10% formalin solution for histopathological examination. Root end resection (RER) is carried out perpendicular to the long axis of the root and about 2.5-3 mm of the apex is shaved away followed by root end cavity preparation (REP). Finally, filling the cavity with the appropriate retrograde filling material [16].

1.3.1 Rational for root-end resection

The following are common indications for RER during root end surgery [17]:

•Elimination of pathological processes such as fractured root apices associated with signs and symptoms, tenaciously attached pathological tissue to the apex, and eradication of foreign material in the apical third of the root canal.

• Elimination of anatomic variations which include inaccessible severe curves, apical canal bifurcation, apical deltas, lateral and accessory canals , canal calcification.

• Elimination of dentist errors in non surgical endodontic treatment such as root perforations, canal blockages, ledges, zips and separated instruments in the apical third of the canal.

•Ensure complete lesion removal, the RER provide accessibility to the deeply located tissue around root to ensure an adequate biopsy.

• When accessibility to the canal system is necessary this occur when the canal is blocked with a post core filling, and the apical third insufficiently biomechanically prepared and filled.

•Obtain an adequate apical seal: this is indicated when non-surgically endodontic treatment has already been carried out but RER may be necessary to obtain adequate apical seal .

• Decrease the fenestration of root apices of teeth especially maxillary teeth which may be related to orthodontics issues, anatomical anomalies, age, and traumatic causes.

1.3.2 Root end resection procedure

The favorable depth of root resection is 3 mm because lateral canals and apical ramifications are very common near the root end which can reduces the lateral canals by 93% and the apical ramifications by 98% [18]. First, The amount of resection depends on the rational for the resection process. In general, about 2 to 3 mm of the root end is resected which could be increased if necessary when a fracture instrument is lodged in the apical third; or decreased if this amount of resection would jeopardize the stability of short root [19].

Second, increasing the angle of resection will significantly increase the number of exposed DTs and consequently will increase their communication with the periapical region and the root canal system [20]. Tidmarsh and Arrowsmith showed that apex resection from 45° to 60° have about 28,000 tubules/mm^2 at a area adjacent to the root canal while there are average of 13,000 tubules/mm^2 at the cemental-dentin junction, which is an area which may communicate with the canal even if retrograde filling is present [21]; for this reason, increasing the resection angle will rise the probability that irritants from the canal will gain access to the healing tissues [3]. Finally, this will affect the success of root end surgery as it depends to a great extent on the obtaining an ideal apical seal [22].

Taking into consideration the biological and the biomechanical factors, the perpendicular plane during RER is preferable as apical bone rarefaction occurred in teeth at which their apex resected with certain angle; therefore, it is preferable to avoid any angle and chamfer at the apical portion level where the concentrated forces are able to induce osteolysis due to unwanted concentration of tensile stress [23]. Finally, extending the preparation depth of retrograde cavity is simpler if the apex resection is perpendicular to the long axis of the root [3].

1.3.3 Root end cavity preparation (retrograde cavity preparation)

After RER there are open DTs which may provide a route of communication between the canals and periradicular tissue which results in seepage of canal´s content to the later one, this emphasize the important role of the retrograde filling to seal the root canal and the opened DTs [24]. The retrograde cavity is prepared within the long axis of the root canal, in a parallelism of the anatomical outline of the root, owns adequate forms of retention, and enclose all the exposed openings of root canal system, thus all these factors should be considered during planning the retrograde cavity depth. The overall outline of the REP depend in the majority on the canal anatomy and the root outline in certain cases e.g. the shape of retrograde cavity in maxillary central incisors is round to oval while it is with very elongated and narrow in conjunction in premolar or molar teeth [25]. In order to sufficiently seal the apex, the preparation depth must be at least 1 mm deeper than the bevel´s length [19], as increasing the retrograde filling depth will decrease the apical leakage [26]. Therefore, if the teeth resected at 0 degree to the long access of root then filling of 1 mm depth is adequate while increasing the bevel will require filling of greater depth; for example ,the depth of retrograde filling should be 2.1 to 2.5 mm in root end resected with bevel of 30 to 45 degree respectively to obtain a similar apical seal, this is because of the shorter buccal wall of retrograde cavity of beveled root end resected [27]. Ideally, the REP depth should be 3 mm as more than this will not grant any greater advantages whereas lesser cavity depth may threaten the long-term success of the apical end seal [24]. Furthermore; preservation of remaining dentinal wall thickness of at least 2 mm around the retrograde cavity is also another requirement [28].

1.3.4 Techniques of root end preparation

There are several techniques for REP based on several conditions, those techniques involve the following [29]:

•Long axis cavity preparation

This is a class I cavity preparation in parallelism with the long axis of the root canal which is depend on accessibility to the root and also if appropriate instruments are available. This technique of REP requires the use of microhandpiece.

• Perpendicular cavity preparation to the cut root surface:

Its selection is determined by root anatomy, instruments ,accessibility and the experience of the surgeon. The preparation is performed at right angle to the buccal aspect of root. The depth of preparation is approximately 2-3 mm, encircling the entire visible outline of the canal system. The bur is lightly rocked in a mesial and distal direction to create undercuts.

• Preparation of vertical slot

A vertical cut of 5-7 mm is made from the labial (buccal) aspect, to the depth of the canal lingual wall using parallel crosscut fissure bur then a larger size round bur dropped in coronal direction to the base of the vertical cut then pulled out in a labial direction to create an supplementary retentive means. This technique enhance cavity retention (dovetailed cavity) also it provide access for placement of a reverse filling from either the labial (buccal) root surface or the resected apex.

• Preparation of transverse slot:

This preparation is made before the apex resection process, a preparation start from the proximal or buccal to the lingual wall, which is depend on the tooth and its position within the dental arch, the retention form is established internally with the same method performed in vertical slot preparation technique but with 90 degree rotation, this approach requires the removal of large amounts of labial bone.

•Reverse Canal Instrumentation

This technique used when coronal access to the root canal is inapplicable which preclude the canal biomechanical preparation. This technique can be performed with or without apex resection as K-files or Hedstrom files are bent at 90° bent and grasped with a hemostat .The accessible portion of the canal is biomechanically prepared and obturated with Gutta Percha and injected cement.

1.4 Outcome of various endodontic techniques

The success rates of apical surgery is inconsistent range from 44% to 90% prior to the introduction of microsurgery. Nowadays, there is improvement of the treatment outcome of root end surgery and the success rates raised to about 90% [30].

There are two techniques in endodontic surgery: conventional root end surgery (CRS) and endodontic microsurgery (EMS). There are several differences between those two techniques **(table 1-1)**. Setzer et al. suggested that the chances of EMS success was significantly higher than that of CRS [31] but the conventional technique is important to improve understanding of the possibility of success of modern root end surgery and therefore it is still used [32].

Many studies compared between the healing outcome between second-time endodontic surgery and that of first-time surgery. It was found that the healing outcome of second-time surgery is 7% - 27% lower than that of the first-time [30]. A success rate of 59% for second-times surgery compared to 86% for first-time surgery was found in 5 years longitudinal study [33].

A combined endo-perio lesions offer another challenges, particularly the absence of the bone plate buccally with a completely loss of support to root buccally [30]. Kim et al. reported that 77.5% of cases with combined endodontic–periodontal lesions were successfully treated compared to 95.2% cases with isolated endodontic lesion [34].

Table (1-1): Comparison between traditional and microsurgical technique [32, 35-38].

Traditional Technique	Microsurgical Technique
Large Osteotomy	Small Osteotomy
Greater loss of cortical bone	Less loss of cortical bone
Many exposed dentinal tubules	Few exposed dentinal tubules
Difficult evaluation of apices	Simple evaluation of apices
Difficulties in examination of the root resected surface (identification of microfractures)	Simple examination of the root resected surface (identification of microfractures)
Greater risk of lingual perforation of the root	Less risk of lingual perforation
Large regular instruments	Small microinstruments
Acute bevel angle	Shallow bevel angle
Difficulty of evaluation of root canal system and iatrogenic complication	Better evaluation and management of isthmi and accessory canals anatomic aberrations, iatrogenic complication (canal obstructions due to separated instruments) or canal calcifications and fractures within the root.

1.4.1 Healing criteria

There are several signs and symptoms that indicate clinical healing include absence of pain, extraoral and intraoral swellings, tenderness to palpation or percussion and sinus tract [30].

1.5 Root and periradicular structural composition and functions

Priradicular lesion and their surgical treatment affect periradicular tissue and root structure in several aspects depending on their composition and the limitation of their function.

1.5.1 Dentin

It forms the major part of mineralized tissues which is covered by enamel in coronal part while its covered by cementum in the radicular part, a structure involved in the teeth attachment to the alveolar socket [39]. Most of dentin is composed of hydroxylapatite, type I collagen fibrils ,a small amount of types III and IV collagen, noncollagen proteins and proteoglycans [40]. In other words, Dentin is a biological structure which is highly organized and composed of organized mineral components and complex protein aggregations which collectively form a rigid mineral-rich biocomposite [40]. Dentin include the minerals which is 70% in weight and 40–45% in volume while organic matrix is 20% in weight, 30% in volume, Water constituent 10% in weight and 20–25% in volume. On a weight basis, dentin is more mineralized than bone or cementum which is about 65% in weight but less mineralized than enamel which is 96% in weight [39].

Dentin is classified into primary, secondary and tertiary dentin at which primary dentin consist of mantle and circumpulpal components, secondary dentin secretion occur following root formation while secretion of tertiary dentin occur in response to various stimuli (e.g. carious attack and wear) following complete tooth formation. Dentin is composed of DTs of about 1–2 μm diameter surrounded by peritubular dentin (hypermineralized layer) and a softer intertubular matrix at which the organic materials is condensed [41]. The direction of DTs differ according to their location which is from the pulp to the dentinoenamel junction in the crown while their direction in the root is toward the cementodentinal junction . The basic dentin structure consist of calcified collagen fibrils of 50–100 μm average diameter which are orthogonal to the DTs and form the intertubular matrix [40]. The number of DTs about 45,000–65,000/mm^2 in the coronal part of dentinal layers close to the pulp which is higher than those of the outer dentin areas which is about 15,000–20,000/mm^2 . The diameter of DTs also differ according to their location as it is larger close to the pulp (3-4 μm) while it is smaller in diameter and about 1.7 μm (average diameter) in peripheral area and close to the DEJ. There are also exteremly thin collateral DTs ramifications of 1 μm diameter which is perpendicular to each other, divided and connected to the adjacent tubules via intertubular dentin, therefore it will form a three-dimensional network [40]. The DTs, which are interconnected by lateral tubules occupy about 20–30% of the dentin volume [42].All those previously mentioned dentinal components will affect the strength of the adhesive bonds between filling material and dentine, particularly the number of DTs/mm^2, diameter and the relative amount of intratubular and intertubular dentine considering their locations and the thickness of dentin in different parts of tooth [43].

1.5.2 The periradicular tissues

These consist of cementum, periodontal ligament and alveolar bone **(figure 1-2)** [42].

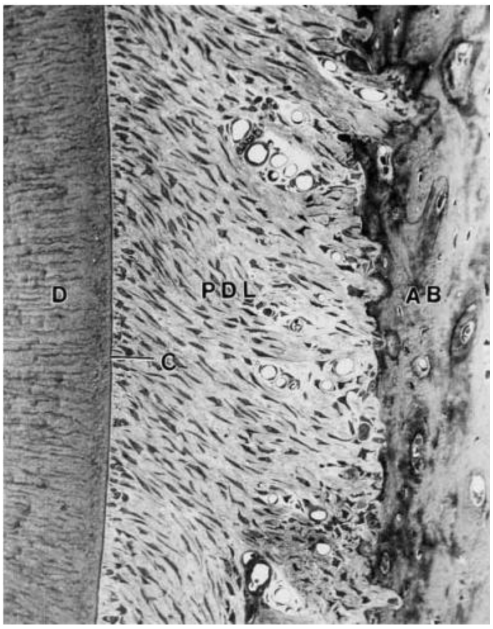


Figure (1-2):Histological section showing the periodontal ligament (PDL), dentin (D), cementum (C) and alveolar bone (AB) [44].

1.5.2.1 Cementum

Cementum is a thin layer of calcified tissue which covers the dentine in the root. The outer surface of cementum is contiguous with the periodontal ligament while its deep surface is firmly adherent to the dentin[45]. Cementum consist of 65% weight inorganic material and 23% weight of organic material and 12% weight of water [46]. Generally, cementum contains less mineral than dentin in the same tooth [47]. Its thickness vary according to its location within the root as it is thickest at the end of the root (200 µm even it may surpass 600 µm) while it is the thinnest in the cervical area (10-15 µm) [46]. There is always a thin layer of uncalcified matrix on the surface of the cellular variety of cementum of about (3–5 µm); this layer called precementum. Although, cementum is avascular and lack innervations but it is similar in its physical properties and chemical composition to bone [45].

Its essential role is to provide attachment to collagen fibres of the periodontal ligaments thus it is extremely responsive tissue, preserving the root integrity, aid in the maintenance of the tooth in its functional position within the oral cavity and it is part of repair and regeneration process of the tooth [45]. Cementum is crucial for convenient maturation of the periodontium and it is associated with the periodontal tissues development and regeneration [47].

Cementum classified into two main types considering inclusion or non-inclusion of cementocytes: cellular cementum forms thick layer covering the apical third of root and acellular cementum forms thin layer covering the cervical third of root [48].

Histologically, there three types of cementum [49]:

•**Acellular afibrillar cementum:** which is mostly found around the cemento-enamel junction and it also covers small areas of enamel. It is characterized by multiple layers of calcified non-homogenous matrix without collagen fibers .

•**Acellular extrinsic fiber cementum:** which constitutes large parts of the cementum. It is a mineralized tissue represented as thin layer extending along the coronal two-thirds of the root surface and reach the apical third of the root in anterior teeth .

•**Cellular mixed stratified cementum:** which is composed of multiple interposed layers of cellular intrinsic fiber cementum and acellular extrinsic fiber cementum. Mostly, it is found on the apical and in the furcation areas.

Cementum plays significant role in tooth support as it provide attachment for the principle fiber of periodontal ligament and thus suspend the tooth from the alveolar bone. Cementum deposit in response the occlusal tooth substance loss or wear. Furthermore, cementum has important physiological role in repairing the resorbed cementum and dentine. Any defect prohibits this normal mechanism may lead to external root resorption. One of the desirable outcomes of the successful endodontic treatment is the formation of cementum around the apical foramina [42].

1.5.2.2 The Cement–Dentine junction

The cemental fbirils appeared to blend with the dentinal fibrils only in specific places. The cemento-dentinal junction is a fibril-poor layer in both cellular and acellular cementum [50].

The cement–dentinal junction is biologically important because it connect two tissues of very different mineralization which are contemporarily developed and hold the periodontal ligament fibres to the dentine. The junction is also clinically important because of its role in preservation of tooth function whilst repairing root surface. It is considered as a permeable barrier that is a precursor for cementogenesis process. This junction is clinically significant during periodontal regeneration following the periodontal surgery [45].

1.5.2.3 Periodontal ligaments

The periodontal principal fibers are embedded as Sharpey's fibers within cementum and bone [44].

There are three regions of mature periodontal ligament including a region which is rich in cells and blood vessels (bone-related region), a region of dense well-ordered collagen bundles (cementum-related region) and a region which contains thinner collagen fibrils and fewer cells (middle zone) [51].

Periodontal ligaments have an important functions such as proprioception visco-elastic cushion effect by mean of its fibres and hydraulic fluid systems as well as responding to the functional overload by widening so as to alleviate the load on the tooth (an adaptive capacity) [42].

1.5.2.4 Alveolar bone

The alveolar process which contain the alveolar socket which consists of outer cortical plate (compact bone), a central spongy bone and bone lining the alveoli. The periodontal ligament fiber bundles attach to the bone lining of the socket. The bundle bone which composed of consecutive layers of intrinsic fiber bundles run in relatively parallel direction to the socket. Sharpey's fibers of the extrinsic collagen fiber bundles of the periodontal ligament are embedded within those bundle bone and almost at right angel to its surface [52].

Both bone formation and bone resorption are governed by osteoblasts and osteoclasts respectively. Bone forms and resorbs in response to the functional requirements (dynamic tissue), bone metabolism is under hormonal control and its resorption is affected by inflammatory mediators at either the perradicular or the marginal attachment [42].

The alveolar bone process anchor the root to the alveolus by the insertion of Sharpey's fibers into the alveolar bone proper thus it support the root and absorb then distribute the occlusal pressures which are generated during tooth contact [44].

1.5.3 Smear layer

Smear layer (SR) is an amorphous surface consist of organic and inorganic debris remained on the dentin and other surfaces after mechanical preparation of the canal [8], thus it may results in several problems affecting the endodontic filling [53]

The smear layer consists of two layers one is a superficial found on the canal surface wall of approximately 1-2 µm thickness and a deeper layer packed into the DTs to 40 µm depth [54].

The reasons which support smear layer removal are the following [55]:

1-It is of unpredictable volume and thickness because of its high water content.

2-It contains necrotic tissue as well as bacteria and their byproducts which may proliferate into the DTs.

3- Smear layer may block the DTs and prohibit the effects of irrigantion solution on bacteria which is located deep within those tubules.

4- It impair the sealing ability of filling materials as smear layer act as a barrier between the dentin and fillings.

5- Smear layer adhere loosely to that canal walls thus it considered as a potential threat for leakage and passage of bacterial contaminant between the dentinal walls and filling thus its removal enhance filling of the canal.

On the other hand, some researchers suggest that retaining the smear layer during canal preparation blocks the DTs thus it will prevent bacterial exchange by altering canal permeability (prevent bacterial migration into the DTs) [56].

Since smear layer contain debris, bacteria and endotoxins thus it could contribute to ongoing periradicular inflammation therefore, its complete removal is preferable. There are two methods used for this purpose which are either chemical or physical techniques. The chemical technique involves different chemical irrigants e.g. ethylenediamine tetraacetic acid (EDTA), sodium hypochlorite, organic acids, MTAD (a mixture of citric acid, tetracycline isomer and detergent [57]) and sometimes a combination of these irrigants is used to optimize smear layer removal. Physical techniques involve device that causes pressure waves and cavitations within the canal space, this includes ultrasonic tips (endosonics) and laser (pulsed middle infrared) [58].

Sodium hypochlorite (NaOCl) is an antimicrobial irrigant and can dissolve organic tissue thus it is one of the most common irrigants used during endodontic treatment [59]. However, NaOCl is toxic to the periradicular tissues (this is occur mostly in high concentrations) [60]. Since NaOCl only effective on organic particles thus its inefficient in complete smear layer removal from the dentinal walls [61].

Different chelating solutions used to remove smear layer such as citric acid and EDTA; their mechanism involve reducing the amount of calcium ions in dentin complex thus altering its permeability [62]. The drawback of these two chelating agents is that Citric acid causes crystals precipitation in the canal which might adversely affect the canal filling while EDTA causes dentin demineralization to about 20–30 µm depth in 5 min [56] .

The irrigation of the root canal with NaOCl followed by EDTA is recommended in order to remove both the organic and inorganic components of the smear layer effectively [63], mostly in the middle and cervical thirds [61] while the smear layer is incompletely removed in the apical third of the root canal. Raising temperature of sodium hypochlorite can enhance its efficacy [63].

It was found that the irrigant solutions can adversely affect the radicular dentin microhardness which provide indirect evidence for losing mineral substance in the dental hard tissues . The chelating action of EDTA soften the calcified components of dentin and reduce its microhardness while the NaOCl dissolve the collagen component of dentin (organic component) therefore the alternating irrigation with these irrigation solutions affects dentin hardness and weakening the root structure [64].

Several studies evaluate the effect of laser in smear layer removal, there are several controversies about the effectiveness of Nd:YAG laser on smear layer removal [65, 66] while diode laser showed evidences of debris removal [66]. Erbium lasers remove the smear layer through activation of water and the formation of vapor bubbles thus generate shock waves. The Er,Cr:YSGG laser of an of 1.5 W output power effectively reduced the smear layer in all wall sections of the root canal [67].

1.6 Basics of laser

The basic process of light amplification by stimulated emission of radiation giving the laser its name. Laser systems emit light of different wavelengths according to the type of the lasing media which include the ultraviolet region at about 200 nm till the infrared region (up to a wavelength of 10 µm) [68].

1.6.1 Laser design

Each laser consists of three main components **(figure 1-3)**, which are [69]:

•Lasing medium: three types of lasing medium which is either solid (crystals or semiconductors), liquid (organic dyes) or a gas (or gas mixture).

•Excitation (pumping) systems: these supply the lasing medium with the required energy to initiate the light amplification process. The excitation systems either optical (e.g. tungsten-filament lamps, continuous arc lamps , flash lamps, or other lasers), electrical (e.g. electric current in semiconductors , gas discharge tubes) or chemicals .

•Optical resonator: which consists of two mirrors arranged to allow feedback of photons along the lasing medium. One of them is fully reflected and the other is partially transparent to allow the laser beam to exit (output coupler) .

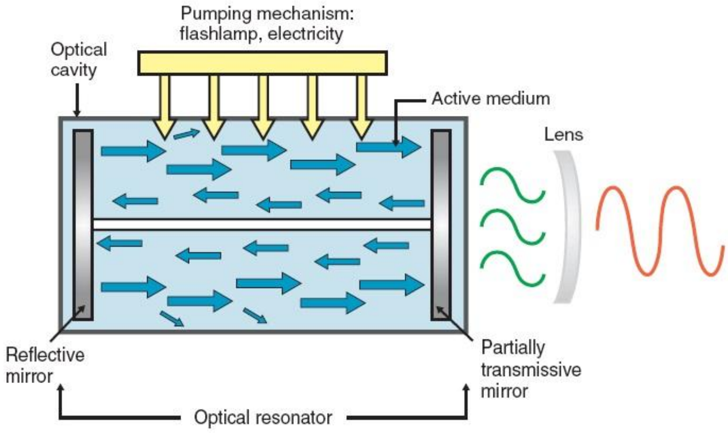


Figure (1-3):structural component of laser [70] .

1.6.2 Laser delivery systems

There are three types of available laser delivery systems [71]:

•Articulated arm (mirrors are place at the joints): this system used for all range of wavelength including ultraviolet, visible and infrared lasers .

• Hollow waveguides: it consist of flexible tube with internal reflecting surfaces, this system used for middle and far infrared lasers.

•Fiber optic: this system used for visible and near infrared lasers.

1.6.3 Properties of laser light

Laser light has specific characteristic which include [72]:

•Coherence: The stimulated emission process generate photons which are in phase with each other, equal and synchronized, this means in term of waves their crests and troughs are aligned both in space and time.

•Monochromaticity: the laser beam is a pure color which mean it is nearly monochromatic because as it consist of extremely narrow range of wavelengths.

•Directionality: laser light travel in a single direction and of very small divergence this is because laser light is more collimated than other sources.
•Brightness (intensity) : laser device can gain extremely high intensities because the output photons of a laser travel mainly in the same direction, therefore the power output of laser light is many times more efficient than that of the usual light source .

1.6.4 Emission modes

Dental laser devices can emit the energy in various emission modes [70]:
1. Continuous-wave mode: it mean that laser beam is emitted at only single power level as long as the operator press on the foot switch.
2. Gated-pulse mode: This mode can be achieved by placing a mechanical shutter in front of the beam path of a continuous emitted wave, opening and closing of this shutter will result in periodical alternations of the laser energy (similar to light blinking).
3. Free-running pulsed mode (true-pulsed mode): At which laser light of large peak energies emitted for microseconds and then laser is off for a relatively long time.

1.6.5 Laser effects on tissue

There are four effect of lasers when it hit the tissue **(figure 1-4)** [73]:

Transmission: the beam pass through the medium without interaction with it, then light will emerge out of the medium either distally, partially refracted or unchanged.

Scatter: The interaction is insufficient to attenuate the laser beam completely. the light energy undergoes some diminution with distance, distortion and at the same time rays travel in uncontrolled direction through the medium. Back scattering mainly occur when laser beam of short wavelengths hits the tissue.

Reflection: occur when the angle of incidence is less than the refractive angle which lead to a total reflection of the beam. At true reflection, the incident angle equal to the reflected angles. Some scatter may occur when the interface (medium) is rough or inhomogeneous.

Absorption: the medium attenuate the energy of the incident beam and transfer it into another form depending on the amount of the energy (heat or to biostimulation of receptor tissue sites).

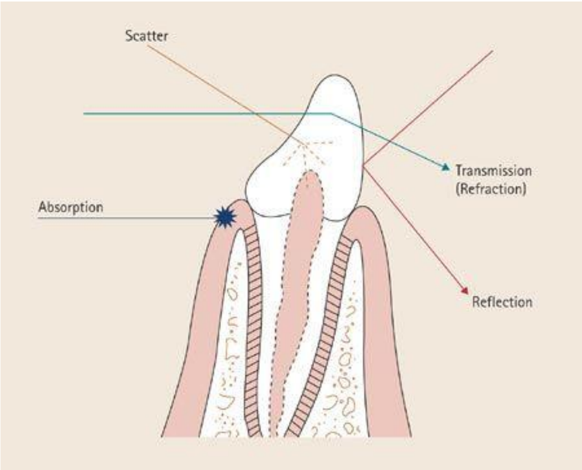


Figure (1-4): Laser effect on tissue [73].

The absorption of laser light by a target tissue depend on several factors (individually or collectively) [74]:

- Laser wavelength.
- The angle of incidence of laser beam.
- Exposure time.
- Contact versus non contact modes.
- Tissue composition

- Tissue thickness
- Surface wetness.

1.6.6 Laser-tissue interaction mechanisms

The various medical applications of lasers depend on the possibility to induce local necrosis, etching or fragmentation of tissues which will determined based on the laser beam and tissue characteristics [75].

laser light applied to the biological tissue and causes various interaction mechanisms, those are manifold into the following:

1.6.6.1 Wavelength dependent mechanism

I. Photochemical Interaction

Laser interact with macromolecules in tissue which induce chemical effects and reactions. Photochemical interaction mechanisms represented by photodynamic therapy (PDT) and biostimulation. Photochemical interactions occur when the power densities is very low (typically $1W/cm^2$) and the exposure times range from seconds to continuous (long exposure time) [76]. This mechanism use to cure composite resin restoration and to disinfect the periodontal pockets and root canals. The disinfection occurred by the breaking the chemical bonds as using photosensitive compounds exposed to laser energy can release a singlet oxygen radical which has antibacterial effect [70].

1. Potodynamic therapy

Photodynamic therapy (PDT) based on a photochemical reaction and depends on presence of three components: laser light for activation, sensitizers and molecular oxygen [77]. This begin with injecting the photosensitizer (e.g. porphyrins) into the body then using laser for their excitation. The stimulated sensitizer goes through series of intramolecular chemical reactions which lead to the oxidation of different cellular components (a cytotoxic process). Selective tumor eradication occur because specific photosensitizers persist for a longer period within the pathologic tumor tissue than a healthy one [68].

2 . Biostimulation

The photons energy absorbed in cells or tissue and causes several effects on metabolism and signaling pathways within the cells. Molecular target can be cytochrome c oxidase (the absorption is in the near infrared region) or photoactive porphyrin. The cellular target is mitochondria with the effects of increasing adenosine triphosphate production (ATP), reactive oxygen species(ROS) modulation and cellular signaling initiation which may cause increase in both cell proliferation and migration, increase tissue oxygenation, optimize healing of chronic wounds, improve injuries, reduce pain and also affect the nerve injury [77].

II. Thermal Interaction

Photothermal effects appear at power density of 1–10^6 W/cm^2 and exposure time of 1 msec–100 sec [68].The governing parameter of this interaction is the elevation of the local temperature. Laser radiation in both continuous or pulsed modes can induce thermal effects. The duration and peak value of the tissue temperature reached will determine different thermal effects like coagulation, vaporization, carbonization and melting [76] **(Table 1-2)**.

Table (1-2): The most important and significant tissue alterations are dependent on the temperature of the tissue after absorption of the laser radiation[78].

Temperature	Tissue changes
37°C	There is no obvious effect on tissue at this temperature or even if it exceed 5 °C above it .
42-50°C	The first is thermal effect can be contributed to changes of molecular conformation characterized by membrane alterations and bond destruction. This is called (hyperthermia) which lasts for several minutes and at this time necrosis occur in significant percentage of the tissue cells .
60°C	Elevation of temperature to this level will cause proteins and collagen denaturation which lead to tissue coagulation and cells necrosis; it is obvious macroscopically as visible tissue paling. There are numerous treatment techniques such as LITT require an elevation of temperatures to just above 60°C.
>80°C	Excessive increase in the permeability of the cell membrane which will destroy the maintained balance of chemical concentrations within cells.
100°C	Vaporization of water contained within tissues cause large increase in volume and gas bubbles formation which induce mechanical ruptures and thermal decomposition of tissue fragments
>150°C	This appear as blackening of the nearby tissue, smoking and charring (Carbonization) .
>300 °C	The tooth substance mostly consists of hydroxyapatite crystals (the chemical compound of calcium and phosphate ions) which undergo melting when the tissue temperature elevated to few hundred degrees Celsius.

III. Photoablation

Photoablation takes place at power density of 10^{4}-10^{10} W/cm^{2} and exposure time of 10^{-3}-10^{-10} sec but the typical power density threshold is 10^{7}-10^{8} W/cm^{2} and at pulse durations in the nanosecond range at which the material will be exposed to high intensity of laser irradiation and tissue decomposition will occur [78]. This ablation technique provides precise etching process without thermal damage to the adjacent tissue, therefore tissue removal with this technique is highly predictable [76].

1.6.6.2 Wavelength independent mechanism

I. Plasma-Induced Ablation

Optical breakdown occurs when power densities exceeding 10^{11} W/cm^2 in fluids and solids materials or 10^{14} W/cm^2 in air [76]. It occurs when electric fields are sufficiently strong to strip electrons from their atoms resulting in medium ionization and plasma formation [79]. Those processes can result in removal of tissue in a very clean and well defined fashion without any manifestation of thermal or mechanical damage as long as the appropriate parameters are used [76].

II.Photodisruption

Optical breakdown is associated with physical effects which are plasma formation and shock wave generation. Cavitation and jet formation take place when optical breakdown occurs within soft tissues or fluids, the tissue is split by mechanical forces [76]. Medical applications of this process use the ultrashort laser pulses of about 100 fs (e.g Ti:sapphire laser) which is used in ophthalmology for flaps cutting of the cornea, also in the soft and hard tissue removal as it provide a very precise but not efficient cutting [80].

1.7 Lasers in dentistry

Dental lasers divided into soft tissue lasers and hard tissue lasers according to their absorption by the tissue chromophores **(table 1-3 and figure 1-5)** :

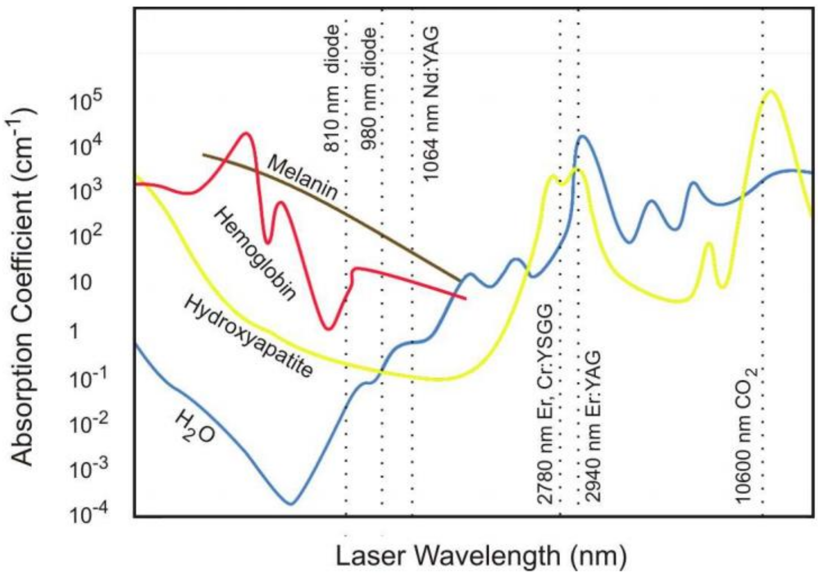


Figure (1-5): Absorption coefficients of various tissue chromophores relative to laser wavelength [81].

Table (1-3): Most common dental laser with their absorption and uses.[82-84].

Laser wavelength (nm)	Absorption	Dental use	Advantages	Disadvantages
Argon (488 nm and 514 nm)	Red pigments (melanin and haemoglobin) Camphoroquinon.	Soft tissue surgeries /curing of composite /power bleaching	• Excellent haemostatic ability. • It alter the surface chemistry of both enamel and root surfaces dentine, which reduces the probabilities of recurrent caries.	• Possibility of heat elevation in the pulp and on the adjacent tissues.
Diode * (810 nm,-830 nm and 980)	Pigment (melanin and haemoglobin).	Soft tissue procedures (periodontal and endodontic procedures) /power bleaching	• A reasonable haemostatic ability.	• Poorly absorbed by water and the hydroxyapatite which present in the enamel and dentin.
Nd:YAG * 1064 nm	Pigments (melanin and haemoglobin).	Soft tissue procedures (e.g. periodontal non-surgical sulcular debridement) and endodontic procedures.	•Highly absorbed by pigmented tissues (it is effective for cutting and coagulating of oral soft tissues). • Good hemostasis.	• High cost and large size.
Er,Cr:YSGG 2780 nm	Water	Hard tissue procedures / soft tissue procedures(with specific limitations).	• High affinity for hydroxyapatite and the highest absorption in water.	• High cost. • Marginally prolonged treatment time but with better results. • Poor haemostatic ability in soft tissue surgeries.
Er:YAG 2940 nm	Water (highest absorption).			
Carbon dioxide 10600 nm	Water	Soft tissue procedures (both major and minor surgical procedures).	•Its wavelength have high affinity for water thus rapid removal of soft tissue . • Rapid and excellent hemostasis with shallow penetration depth. • Optimize the mechanical retention of dental sealers.	• Its wavelength is of the highest absorbance than any laser but with greater thermal effect. • High cost and large size. • Greater destruction of hard tissues.

*0ther wavelength with the same media type is available.

1.8 Er,Cr:YSGG laser

The Er,Cr:YSGG laser is a pulsed laser system which delivered through fiber and sapphire or glass tips which is bathed in a mixture of water vapor and air. Laser energy interact with water at the tissue interface and cut hard tissue precisely; therefore, this device termed as hydrokinetic system which can be explained in another form as water droplets emitted from the handpiece will absorb the laser energy and a violent explosive forces (hydrokinetic effect) will take place within the hard tissue surface which will result in laser cuts with less damage to the prisms and the DTs without debris or smear layer when compared with the bur cuts [85]. Although numerous studies couldn't give any credence to the hydrokinetic effect as being the principle of how laser ablation work as it was revealed that even if the hydrokinetic effect exists, it will not work on the hard material which are void of water and it does not have any significant role in the enamel ablation. Erbium lasers ablation is primarily because laser initiate subsurface expansion of the interstitial water which is exist within the hard tissues [86].

During laser irradiation, water molecules and OH- groups in the hydroxyapetite crystal absorb the incident energy and cause rapid water vaporization, and expansion, followed by microexplosions which result in ejection of both inorganic and organic tissue particles at temperature lower than that of the melting point [80]. The ablation threshold of the Er,Cr:YSGG laser in human dental enamel is 4.93 to 5.66 J/cm^2 while in human dentin is 2.92 to 4.2 J/cm^2 [87], while the ablation threshold in bone tissue is 1.95±0.42 J/cm^2 [88]. The ablated surface appear microscopically in crater forms which differ from surface morphology instrumented by classical rotary tools. The minerals are dislocated at the crater edges which appeared visually as etched surface [80]; these microexplosions results in a surface which is rough, free of smear layer and with opened DTs [89, 90].

Er,Cr:YSGG laser associated with water spray not only reduce the temperature but also increases cutting efficiency [91].

Erbium lasers wavelengths are well absorbed in water, taking in consideration that the Er:YAG 2940 nm laser is somewhat more strongly absorbed than the Er,Cr:YSGG 2780 nm laser. The primary absorption for erbium wavelengths is in water due to a relatively broad water band around 3000 nm. There is a small percentage of laser absorption by hydroxyapetite because there is a small absorption at around 2800 nm by the hydroxyl group of the (carbonated) hydroxyapatite minerals within hard tissues, but this is far dominated by the water effects as water is naturally present among the hydroxyapetite crystals within the enamel, dentin, cementum and bone interstitially occupying any available space. The rate or the speed of the laser ablation is determined by several laser and tissue parameters including the incident laser energy, power density, wavelength, frequency, pulse duration, pulse shape, the thermal relaxation time of the tissue and the modes of laser emission (CW or pulsed mode). It is necessary to avoid the possibility of heat deposition within the tissue and heat conduction to the pulp and also to prevent charring and the accumulation of ablated products [92].

It had been found that Er,Cr:YSGG laser is effective in reduction the number of bacteria even at the lower output power of 1 W and there is certain degree of the laser's light conduction within the DTs which contribute to a higher penetration depth of laser [93]. It was observed that bacteria can be found at about 1,100 μm depth within the periluminal dentin, as long as the chemical irrigation can penetrate only 100 μm depth into the dentine which mean that the complete removal (or disinfection) of bacteria deep within the dentinal tubule is not possible. Irradiation using Er,Cr:YSGG laser will result in energy penetration and intratubular water expansion and water vapor collapse to a depth surpass 1000 μm (depending on the energy density) which is able to generate acoustic waves sufficiently strong to disrupt intratubular bacteria [94] .

The penetration depth of Er,Cr:YSGG laser differ according to the target tissue, and this will affect both the ablation process and speed; Er,Cr:YSGG laser wavelength penetrates 21 µm within the enamel, and 15 µm within the dentine. The longer the distance the laser pass within the tissue will result in heat dissipation in larger volume of tissue that mean it will take longer time for the specific tissue to reach the ablation temperature. Specifically, both the energy of the single pulse and the laser frequency (the number of times the energy of single pulse is repeatedly delivered to the specific spot area) will determine the speed of laser cutting [86].

1.9 Laser safety standard and hazard classification

Laser safety precautions such as protective eyewear, laser reflection, administrative control measures and flammability are governed by the laser classification.The manufacturer must determined the laser classification on both the device and aperture labels. The International Electrotechnical Commission (IEC) adopted certain classifications [95] which was established by American National Standards Institute (ANSI) Z136.1 [76]:

- Class 1: lasers are safe to be used under every reasonable circumstances .
- Class 1M: lasers are safe for viewing without magnification aids, but there is potential hazard if it viewed with optical aids (e.g. binoculars, microscopes, loupes and etc.)
- Class 2: include lasers with visible wavelengths (400-700 nm) considered safe if viewed for < 0.25 seconds
- Class 2M: lasers of visible wavelengths (400-700 nm) considered not safe if viewed with magnifications aids.

- Class 3R: considered marginally hazardous for intrabeam viewing when its diameter exceed 7 mm
- Class 3B: Those lasers considered hazardous for intrabeam viewing as it cause eye and skin injuries from direct viewing but unnecessarily from diffuse energy
- Class 4:include lasers with high power as it cause eye and skin injury from both direct and reflected energies.

1.10 Review of instruments used in root-end surgery

Several armamentarium have been used in root end surgery each one with several advantages and disadvantages and each one for specific situation.

I. Burs

Over decades numerous researches had been carried out to study the effect of various burs (different materials, shapes and configurations) as well as different speeds of handpiece on the root end resected surface, root end cavity walls, the adaptation of the retrograde filling material and the sensation of vibration. It was revealed that the #57 plain fissure bur with low-speed handpiece produce the smoothest surface and the least amount of Gutta Percha disruption while crosscut fissure burs in both high and low speed cutting produce the most uneven and the roughest surfaces. Both the plain fissure and crosscut burs which is used with the high speed handpiece result in Gutta Percha shred and tear. On the other hand, the cross cut fissure burs are commonly used in operative dentistry and oral surgery as it rapidly remove enamel, dentin and bone [96].

Weston et al. studied the effect of the direction of the burs rotation on the adaptation of filling material after RER and observed that when the handpiece moved in the reverse direction in relation to the direction of rotation of the bur, a great disruption of Gutta Percha can be observed but this is not occurred when the cut was in the forward direction using the same burs [97]. Morgan and Marshall use Multifunction burs one for cutting and the other for finishing which results in a relatively low levels of vibration with the most even and the smoothest resected root end surface with the least amount of shattering [98]. During REP using small round bur or inverted cone bur with the aid of angled micro-handpiece cause problems considering the direction and depth of the retrograde cavity [30].

II. Ultrasonic instruments

The ultrasonic instruments facilitates less destructive and proper REP compared to a cavity prepared with a bur. Ultrasonic allow a less angulated plane of RER [99] as long as ultrasound tips afford more accessibility to the apical end of the root canal which will facilitate root end resections in a perpendicular direction to the long axis of the root and this will preserve root structure and reduce the number of exposed DTs [100]. Those tips provide more parallel retrograde cavity walls and a greater depth for retention than that prepared with bur [101]. Ultrasonic tips are constructed with stainless steel with different lengths and diameters, these tips either are uncoated or coated with diamond or zirconium. The coating will enhance the efficiency of cutting which mean faster time of REP. For example, the diamond coating is the most aggressive but the fastest in preparation of a retrograde cavity. The number or types of fractures which occur at the root surface after REP is little affected by the type of the ultrasonic tip (coated or uncoated) [3]. Calzonetti et al. revealed that the use of ultrasonic tips for REP will not predispose microfractures within the root [102]. Another study suggested that cracks which are found on the resected root end surface after REP are caused by excessive tips vibration [103] and it is not possible to lower the power of ultrasonic device from medium to low intensity as an attempt to overcome this problem because this will result in more cracks [104].

III . Lasers in periapical surgery

Several studies compared between the conventional methods and several types of laser in root-end surgery.

1. Root-end resection

The rapid development of laser technologies and understanding of the properties of laser-tissue interactions encourages the introduction of laser in endodontic surgeries. Lasers show the ability to decrease the inflammation and the bacterial infiltration of the resected root end which makes laser a promising tool for endodontic surgery [105]

In early nineteenths, it have been suggested that Er:YAG laser has a potential application in root end surgical procedures as it resulted in smooth and clean resected root surfaces, without charring (in presence of water spray). Erbium lasers results in less thermal damage and carbonization in treating hard and soft tissues than other lasers [106].

A combination of several types of laser had been suggested in root end surgery by Gouw-Soares et al. as Er:YAG laser used for root end resection, followed by the Nd:YAG laser to eliminate bacteria and to seal the DTs while Ga-Al-As laser used to optimize the healing. The outcome of this technique indicates that lasers is suitable and useful to perform this surgery [107]. Another study that confirmed the effectiveness of Er:YAG laser is conducted by Takeda et al. who found that apicoectomy by Er:YAG laser is both safe and practical [108]. Furthermore, it was found that decrease in infiltration indices can be obtained with Nd:YAG laser irradiation after Er:YAG RER [109]. Later, Duarte et al. implicated a comparison between Er:YAG laser (350 mJ, 6 Hz) with water spray and multipurpose burs (#699 bur for cutting plus Shofu point for finishing) and found that multipurpose burs produced better regular and smooth surface than Er:YAG laser [110].

Pozza et al. found that Er:YAG laser (400 mJ and 10 Hz) removed the smear layer and open the DTs, smear layer removal may be responsible for the leakage in resected end surface [100].

Sullivan et al. studied the root end resections in both the Er,Cr: YSGG laser (4.5w, 30 Hz, 20% water and 50% air) and Lindeman bur; they found that root end resections with bur followed by retrograde filling with MTA resulted in better canal sealing than with bur or laser without a retrograde filling [111].

The three methods of RER had been evaluated by Ayranci et al. Who compare between Er:YAG laser of (100 mJ, 20 Hz), tungsten carbide bur (Ela,Germany) at low speed 40,000 rpm and diamond‑coated SG6D ultrasonic tip. It was found that TC bur and Er:YAG 2940 nm laser produce better root end surfaces than the SG6D tip while Er:YAG laser resulted in least number of cracks among the other methods [112]. One year later, two comprehensive studies carried out by Babar et al. to compare between Er,Cr:YSGG 2780 nm laser and TC bur in RER and the results revealed that using Er,Cr:YSGG laser (5 W, 20 Hz, 50% air, 100% water) with 600 µm sapphire tip resulted in less gap between Gutta Percha and root canal wall, less Gutta Percha disruption (less smearing and overlapping on dentin), less cemental damage, smoother resected surface , less surface cracks and microcracks, less debris, opened DTs and better smear layer removal than TC bur. It was observed bubbling effect over Gutta Percha cut end with laser. Micrographs showed exposure of collagen of both intertubular and peritubular dentin. Scaly appearance of the surface is observed with protruding peritubular dentin because the collagen of intertubular dentin was more ablated [113, 114].

2. Retrograde cavity preparation or root end cavity preparation (REP)

The main objective of REP and placement of retrograde filling after RER is to provide an effective barrier which prevents the microorganisms and their by-products from passing the root canal into the periradicular tissues [115].

Wallace J.A. studied the effect of Waterlase laser in REP at setting of 4W, 55% water and 65% air and found that there was no significant rate of cracks [116].

Reyhanian et al. used Er:YAG 2940 nm laser in all phases of root end surgery: flap incision, bone and granulation tissue removal , RER, REP. The laser optimized the patient comfort and resulted in better bactericidal and decontamination effects [117].

Batista de Faria-Junior N. compare between ultrasonic and Er,Cr:YSGG (Waterlase) at parameters of 300 mJ, 20 Hz, 150 µs, 3.5 W ,55% water and 65% air and found that laser took longer time to prepare the cavity than ultrasonic but none of them creates cracks on the root end surface; however, there were microfractures found on the margins of the retrograde cavities prepared with ultrasonic tips [118]. There is also another study which compared between those two methods of REP and found that chipping occurred in 23% of cavities prepared using the ultrasonic tip but no chipping was found in the laser prepared cavities [119]. On the other hand, Camargo Villela Berbert et al. claimed that ultrasonic tips provide more conservative REP and that no relation was found between the prevalence of crack along the apical surface and the thinner remaining adjacent walls. Laser tips should be used carefully in order to avoid excessive unnecessary preparation as it removed more dentin than the ultrasonic tips [120].

Clinically it was proven that erbium lasers can results in clinical success improvement of all the phases of endodontic surgery (mucosal incision, osteotomy, RER and REP) [121]. An in vitro study carried out by Aydemir et al. found that Er:YAG laser REPs using parameters of 160 mJ and 30 Hz didnt differ from ultrasonic tips regarding the total number of cracks (complete, incomplete and intradentinal cracks) [115].

Different studies tried to find the most suitable parameters used to prepare retrograde cavity with Er,Cr:YSGG laser; Arslan et al found that Er,Cr:YSGG laser at 4 W and 20 Hz is the safest laser setting which gave better results than bur and ultrasonic tips while the latter was the most aggressive technique [122].

Karlović et al. compared between steel bur and Er:YAG laser at 380 mJ, 100 μs and 20 Hz and found that both techniques were not different regarding REP while retrograde filling showed greater leakage in cavity prepared using laser than that prepared using bur and this could be related to the irregular shape of the cavity resulted from laser preparation [123].

Roghanizad et al. suggested that the use of Er,Cr:YSGG laser at 3 W, 150 mJ/pulse, 20 Hz, 140 µs, 55% water, 65% air might increase the success rate of endodontic surgery but with longer time for preparation than ultrasonic retrotips. It was found that Er,Cr:YSGG laser ablation create irregular intertubular dentin surface that will result in micro-retentive surface which might increase the mechanical bond between retrograde filling material and the cavity walls [124].

Chaudhry et al. evaluated of REP using the three available techniques which are Er,Cr:YSGG laser (280 mJ/pulse, 10 Hz , 4 W, 55% water, 65% air and pulse duration of 100 µs), ultrasonic retrotips (32 KHz) and conventional bur (slow speed handpiece with water cooling). it was found that Er,Cr:YSGG laser create the least number of cracks and marginal chippings; therefore, this improve the apical seal and consequently increase the success rate of periapical surgery [125].

1.11 Aim of study

●To compare between carbide cross cut bur and Er;Cr:YSGG 2780 nm laser resected root-end under scanning electron microscope in terms of the characteristic and microscopical changes including dentinal cracks, cemental damage, roughness of dentin and gap between the filling material and the wall of the root canal as well as temperature changes and the duration of procedure.

● To compare between carbide fissure bur and Er;Cr:YSGG 2780 nm laser root-end cavity preparation under scanning electron microscope in terms of the characteristic and microscopical changes including dentinal cracks, roughness of dentin surface, smear layer and opened dentinal tubule as well as temperature changes and the duration of procedure.

Chapter two

Materials and methods

Chapter two: Materials and methods

This chapter includes description of the materials and equipments used in the present study, with the methods that used to perform root end surgery and to prepare samples and examining them and also the methods of their evaluations.

2.1 Materials and equipment

The following list include all the materials and equipments that had been used in this study.

2.1.1 Access cavity tools and materials

1. Carbide round bur .

2. Phosphoric acid etching

3. Universal bond .

4. Brushes.

5. Tetric-N ceram A2 shade (Ivoclar Vivadent, Liechtenstein).

2.1.2 Chemical materials and irrigants

1.Thymole 0.1 % concentration.

2. EDTA 17% (PD , Switzerland) **(figure 2-1 b)**.

3. Sodium hypochlorite 5.25% (Spi, Iraq).

4. Normal saline sodium chloride BP (0.9% w/v).

5. Distilled water.

2.1.3 Root canal preparation tools and materials

1. Endodontic K-files (Dentsply Maillefer, Switzerland)
2. ProTaper universal files (Dentsply ,Maillefer,Swtzerland) **(figure 2-1 a)**.

3.ProTaper Gutta Percha (Dia –ProT^{plus}™) # 40/.06 **(figure 2-1 d)**

4.AH plus sealer (Dentsply ,Maillefer,USA) **(figure 2-1 c)**.

5. Stainless steel finger spreader #15 and #20.

6. ProTaper paper point # 40/.06.

7. plugger.

8. Disposable irrigation syringe 5 ml.

9. Needle with end closed and double sided vent gauge 30.

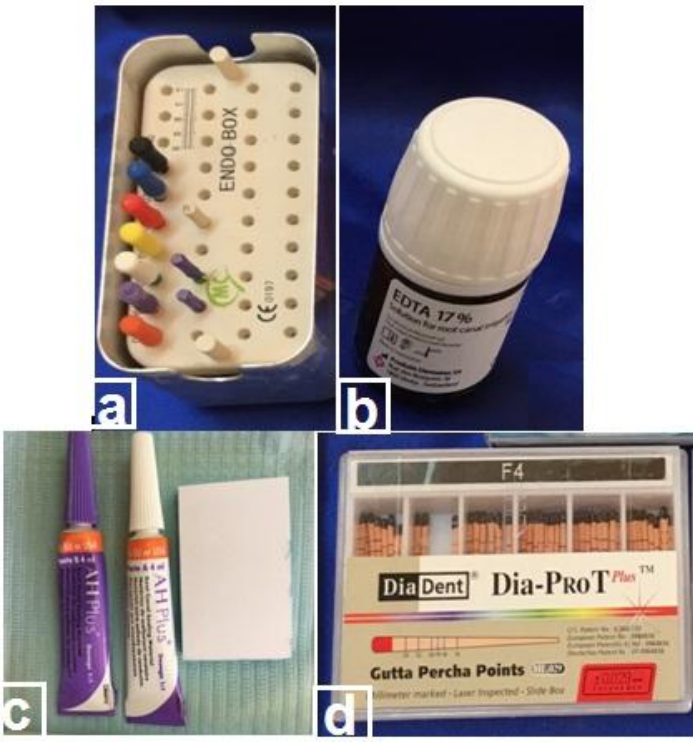


Figure (2-1): Some of materials and instruments used in the research (a)ProTaper hand-operated files (b)EDTA 17% (c)AH Plus sealer (d) Gutta Percha F4.

2.1.4 Diagnostic and measurements tools and devices

1.Vernier caliper (TOPEX sp.z.o.o. S.K.,Warsow, Poland), the resolution is 0.01 mm and measurement accuracy: ± 0.02 mm.

2. Weight balance (Storious ,Goettingen, Germany).

3. X-ray film

4. X-ray machine (Xgenus, Olgiate Olona (VA)- Italy).

5. Thermometer (AMPROBE TMD® -56, Everett, WA, USA) with K type thermocouple and universal serial bus interface for data logging. The accuracy is ± (0.05% rdg +0.3 Celsius) **(figure 2-3 c)**.

6. Mobile stop watch.

7.Stereomicroscope (Hamilton,Altay Scientific,Rome,Italy) **(figure 2-3 d)**.

8.Scanning electron microscope (Inspect S50,Czech Republic).

9.Sputter coater.

10. Image J software program.

2.1.5 Rotary tools and devices

1. Carbide cross cut tapered bur 52 mm (HP C 33016, LOT 546011 ELA , Germany) **(figure 2-2 a)**.

2. Carbide fissure bur (LOT 24331496, MEDIN, a.s. Czech Republic) **(figure 2-2 b)**.

3. Straight surgical handpiece of Max Speed: 40,000 rpm (NSK style dental low speed surgical straight handpiece fit E-type motor,China) **(figure 2-2 a)**.

4. Angled slow speed handpiece of max speed 20.000 rpm (W&H, Australia) **(figure 2-2 b)**.

5. Wafering blade (Smart Cut™ ,Ted Pella,USA).

2.1.6 Laser tools and device

1. MGG6 tips of 600 µm diameter, 6 mm length, calibration factor =1 (Biolase, San Clemente, CA ,USA) **(figure 2-2 c)**.

2. MZ6 tips 660 µm diameter, 6 mm length, calibration factor =1 (Biolase, San Clemente, CA ,USA) **(figure 2-2 d)**.

3. Protective eyewear

4. Waterlase™ iPlus (Biolase ,USA) Er:Cr:YSGG solid state laser, 2780 nm wavelength **(figure 2-3 b)** with the following specifications (according to the manual brochure):

a. Aiming beam 635 nm(red) laser ,1 mW max (safety classification 1).

b. Er:Cr:YSGG laser emitting radiation at wavelength of 2780 nm in the infrared region of the electromagnetic spectrum, and classified as a class IV laser:

• average power 0.1-10.0 W

• Pulse energy of the therapeutic Er:Cr:YSGG laser is from 0-600 mJ.

• Adjustable in two modes: S mode with pulse width 700 µs and H mode with pulse width 60 µs.

• P.R.R. is also adjustable from 5-100 Hz.

• The gold handpiece with tip diameter 200-1200 µm.

• Power accuracy is ± 20%.

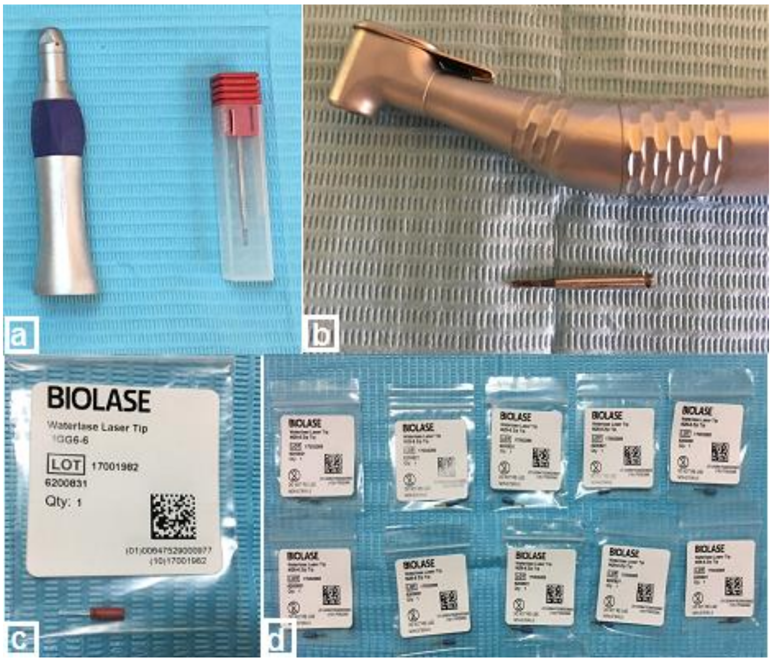
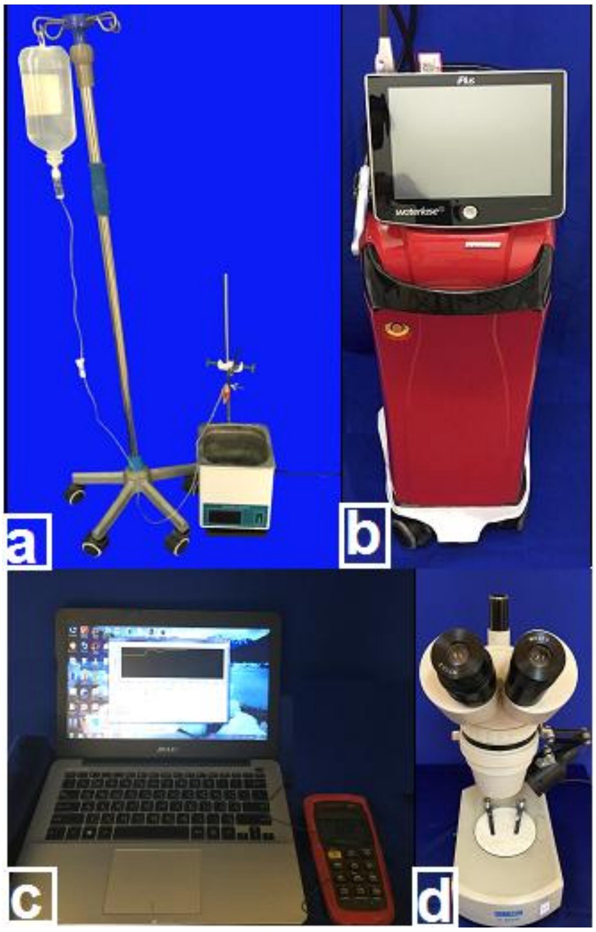


Figure (2-2): Instruments used in RER and REP(a) straight surgical handpiece with cross cut tapered carbide bur (b) angled handpiece with carbide fissure bur (c) MGG6 tip (d)MZ6 tip .



Figure(2-3): Some of equipments used in the research (a)water bath with IV administration set up (b)IPlus waterlase (c)Thermometer connected to software program (d) Stereomicroscope.

2.1.7 Other instruments and tools

1. Dental hand scaler.

2. Burnisher

3.Clear test tubes (AFCO,Amman,Jordan)

4. 25mm*30-Holes rectangle test tube rack holder

5. Artery forceps

6. Bench vice

8. Digital water bath model WH-1(China) **(figure 2-3 a)**.

9. Intravenous administration set up **(figure 2-3 a)**.

10. Artery forceps.

11. Masks.

2.2 Methods

Various methods was used to prepare teeth before, during and after the root end surgery (in vitro) procedure in order to evaluate them under SEM.

2.2.1 Samples collection and selection

Forty extracted human single rooted teeth of single canal and mature apices were used in this study **(figure 2-4 a)** after approval of the university of Baghdad on research proposal (number 17 in 12 July 2017). They were examined under stereomicroscope at x40 **(figure 2-4 b)** to ensure that they were free of root caries, resorption, developmental anomalies or crack lines. The canals were free of calcification. They were collected from different dental centers. The age of patients was between

(18-40 years). The samples were washed with normal saline then the soft tissue remnants and any hard deposits were removed using hand scaler to avoid cementum removal, then they were kept hydrated in isolated tubes filled with 0.1% thymol at 4˚C until the time they have been used in this study (as 0.1 % thymol doesn't affect the structure of dentin [126]).

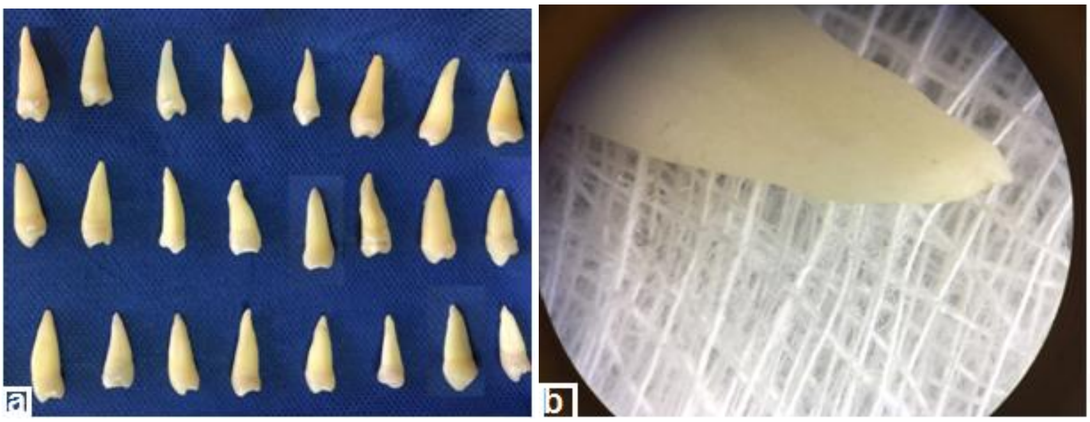


Figure (2-4): Teeth collection and examination (a) some of the teeth used in the study (b)examination of root under stereomicoscope at x40.

2.2.2 Root canal preparation and obturation

The teeth were rapped with wet gauze to prevent the dehydration during canals preparation and obturation. Standard access cavities were prepared with carbide round bur under copious amount of water flow. Barbed broach used to remove the pulpal tissue. K-files #10 moved down into the canal until the file was just visible at the apical foramen and the working length was determined by substracting 0.5 mm from this length.

Root canal were prepared using the conventional technique with hand-operated ProTaper files. The instrumentation sequences began with SX file for coronal flaring, followed by S1,S2,F1,F2 ,F3 respectively and reach a final size of F4. Irrigation of root canal using disposable syringe with a 30-gauge end closed and double sided vent needle moving it from canal coronally till 1-2 mm shorter from the apical foramen.

The irrigation protocol as follow: one ml of 5.25% NaOCl before instrumentation and 2 ml of it between instrument changes, root canals received final irrigation with 1 ml of 17% Ethylendiaminetetraacetic acid (EDTA) for one minute, followed by 3 ml of 5.25% NaOCl [127, 128] then washed with 5 ml of normal saline, this irrigation protocol was used to ensure complete smear layer removal and antibacterial effect obtained along the full length of canal with emphasis that the irrigants reach the apical third of the canal. Dryness of root canal with ProTaper paper point F4, followed by obturation with cold lateral condensation technique using Gutta Percha F4 and AH Plus sealer along with accessory Gutta Percha. Periapical radiograph was taken to ensure complete obturation of root canal (**figure 2-5)**. Finally the access cavity was prepared to be filled with Tetric-N ceram A2. Teeth were stored in normal saline sodium chloride BP(0.9% w/v) at 37^0C in a water bath .

Figure (2-5): Periapical radiograph of obturated canal.

2.2.3 Samples grouping

Forty samples were randomly divided into four groups of 10 samples for each group, depending on the type and method of root end procedure **(figure 2-6)**.

Group 1 (G1): Root end resection using cross cut tapered carbide bur under 14 ml/min water flow.

Group 2 (G2): Root end resection using Er:Cr:YSGG laser with MGG6 tip of 600 µm diameter (laser parameters according to the manufacturer instructions: average power is 5 watt, frequency is 25 Hz, fluence is 25.47 J/Cm^2, water level is 50% while air level is 80%).

Group 3 (G3): Root end cavity preparation using carbide fissure bur under 11 ml/min water flow .

Group 4 (G4): Root end cavity preparation using Er:Cr:YSGG laser with MZ6 tip of 660 µm diameter (laser parameters according to the manufacturer instructions: average power is 3.75 watt, frequency is 15 Hz, fluence is 31.84 J/cm^2, water level is 30% while air level is 60%).

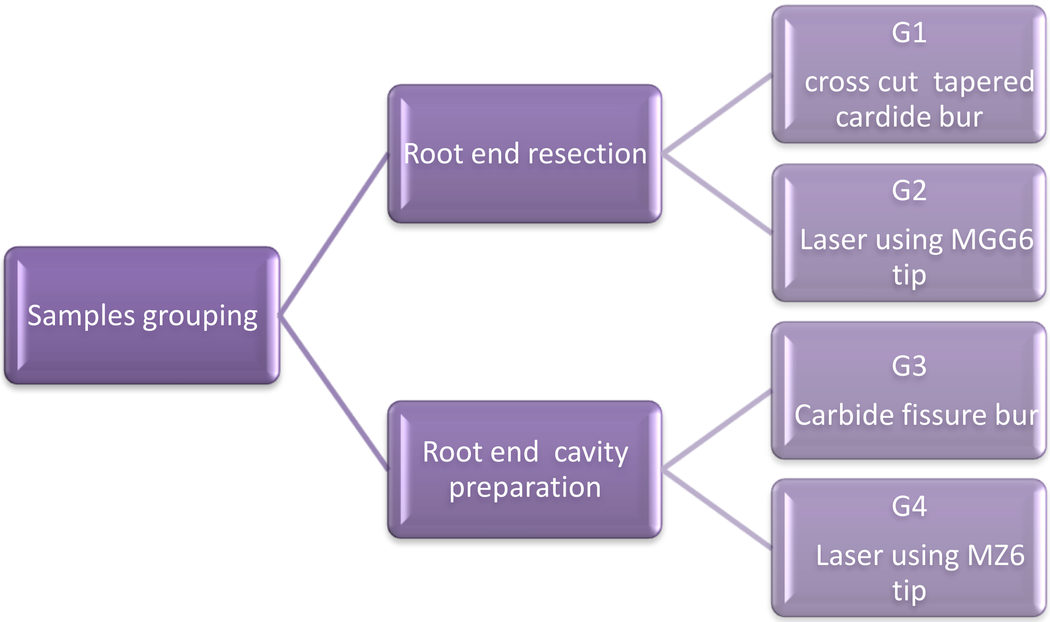


Figure (2-6): Sample grouping

2.2.4 Samples preparation

All the teeth were stabilized in the water bath with their crowns immersed in water and the temperature on the external apical root surface was stabilized at 37 °C at the starting point of the resection or cavity preparation process.

The same rate of water flow (ml/min) was set to be standardized between G1 and G2 with the aid of Beker and clock watch and the same was applied to G3 and G4 **(figure 2-7)**. The samples were fixed via bench vice and artery forceps inside the water bath with their crown immersed in the the water and the root exposed to the air. The rate of water flow during resection with bur was set via intravenous administration set up. The temperature was recorded every second during resection or cavity preparation with the aid of the thermocouple probe which was hold to the external tooth surface at 5mm from apical end. The probe connected to computer software program (AMPROBE TMD®-56, Everett, WA, USA).

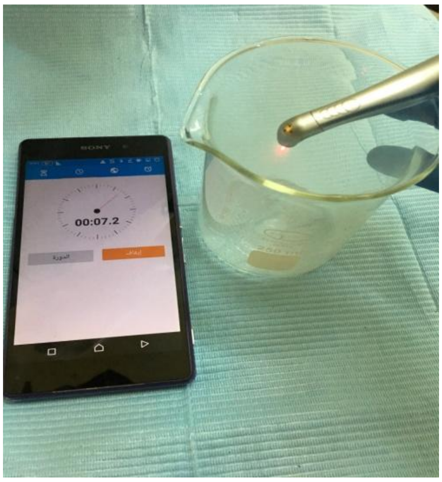


Figure (2-7): Water rate adjustment .

2.2.5 Design of the study

This include samples grouping along with various parameters which were evaluated **(figure 2-8)**.

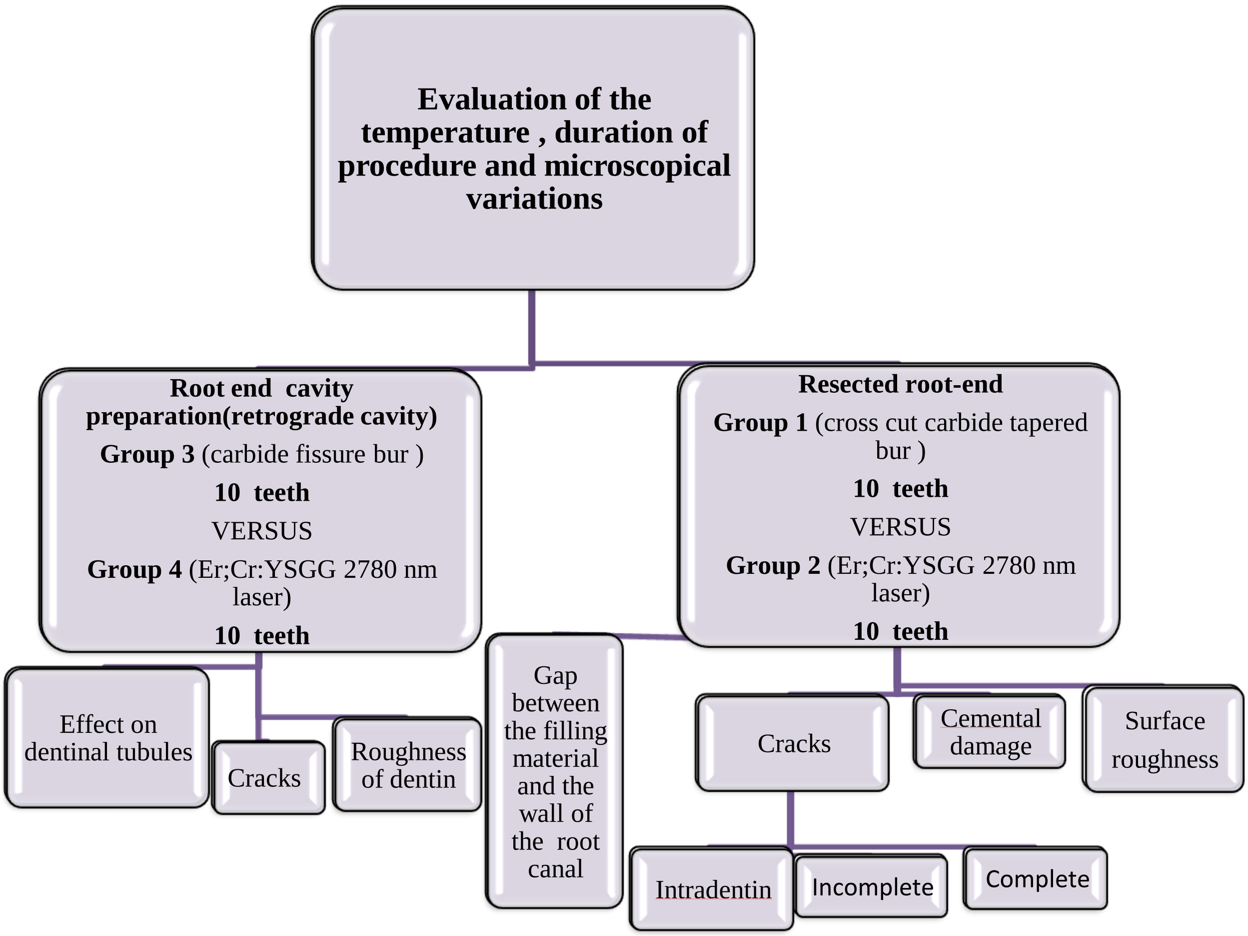


Figure (2-8): Design of the study

2.2.6 Root end surgery

It involve both root end resection procedure and root end preparation (retrograde cavity preparation).

I .Root end resection

The resection was performed from buccal to palatal aspect of root at 0° to the long axis of the tooth. Each single carbide bur and MGG6 tip was used for 10 teeth .

Root end resection (RER) in G1 was performed using slow speed surgical handpiece 40,000 rpm (NSK,China) along with carbide cross cut tapered bur 52 mm (ELA ,Germany). The direction of cutting was with the direction of the rotation of bur (starting from the apical end and cutting coronally, 3 mm of the root end is shaved away), **(figure 2-9 a)** while the root end resection in the G2 was carried out using MGG6 sapphire tip of 6 mm length and 600 µm in diameter which is of calibration factor 1.00 **(figure 2-9 b)**.The tip–hard tissue distance is 1.5 mm so as to obtain 1mm diameter spot size. The root amputation set up used in this study was according to the manufacturer instruction (P_{ave}=5 watt, PRR=25 Hz, water level is 50%, air spray is 80%) and the fluence was 25.47 J/cm^2 **(figure 2-9 c)**, RER in laser group was performed with single cut at 3 mm from apical end. Following root end resection the Gutta Percha was cold burnished in both groups **(figure 2-9 d)**. During the resection process, the duration of resection process and the temperature on the external root surface was recorded for each sample.

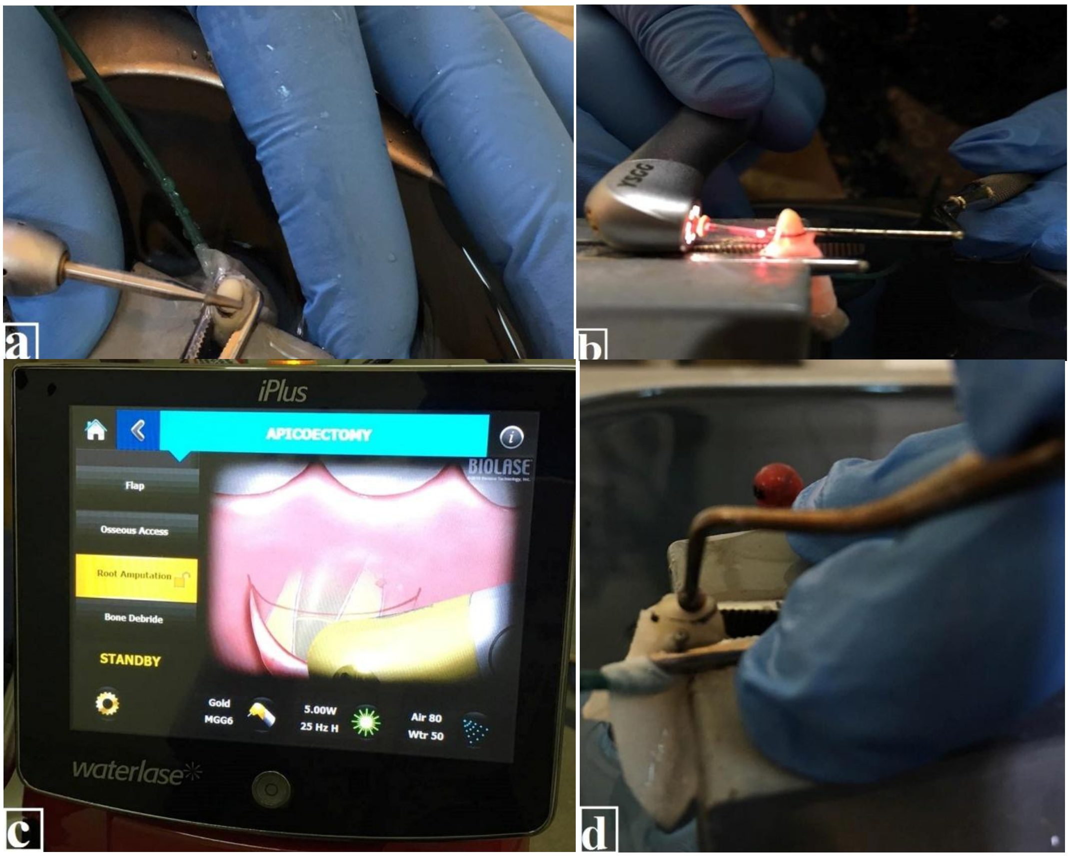


Figure (2-9): Root end resection process (a) RER with cross cut carbide bur (b) RER with Er,Cr:YSGG laser using MGG6 tip (c) root amputation parameters as set by manufacturer (d) cold burnishing of the apical surface of the root canal filling.

II .Retrograde cavity preparation

The root end resection in both G3 and G4 was performed using slow speed surgical handpiece NSK 40,000 rpm and carbide cross cut tapered bur 52 mm (ELA ,Germany). The retrograde cavity was prepared in G3 using slow speed handpiece (20.000 rpm) along with carbide fissure bur (MEDIN ,a.,s.,Czech Republic), each single bur was used for 5 samples preparation **(figure 2-10 a)**. The water flow was set to be 11ml/min supplied through IV administration set up, while retrograde cavity in G4 was prepared using Er,Cr:YSGG pulsed laser (Biolase, waterlase, Iplus, CA, USA) delivered through MZ6 glass tip of 660 µm diameter and 6 mm length while the calibration factor is 1.00 **(figure 2-10 b)**, the parameters used according to manufacturer instruction of class I comfort preparation (average power 3.75 W, frequency 15 Hz, water level 30% and air level 60%) the fluence was 31.84 J/cm^2 **(figure 2-10 c)**. The MZ6 tip placed about 1.5 mm away from the hard tissue to obtain spot size of 1mm diameter and the cavity irrigated with normal saline every 1 mm cavity preparation depth using irrigation needle of double sided vent 30-gauge to prevent the charring inside the retrograde cavity **(figure 2-11)**. The duration of motion during Er:Cr.YSGG laser irradiation to create retrograde cavity of 1 mm diameter was about 20 seconds with circular motion of the tip in the same fixed area then downward spiral motion till reach 3 mm depth of preparation. For the purpose of standardization, the diameter of the cavity was 1 mm and 3 mm depth in all samples and this was confirmed with diameter of periodontal probe **(figure 2-10 d)**. At the end of the preparation in both groups, the retrograde cavity was irrigated with normal saline to remove the debris and remnants from the cavity. Each single laser tip was used for REP of single tooth and then discarded. During cavity preparation, the average duration of cavity preparation and the temperature on the external root surface was recorded for each sample.

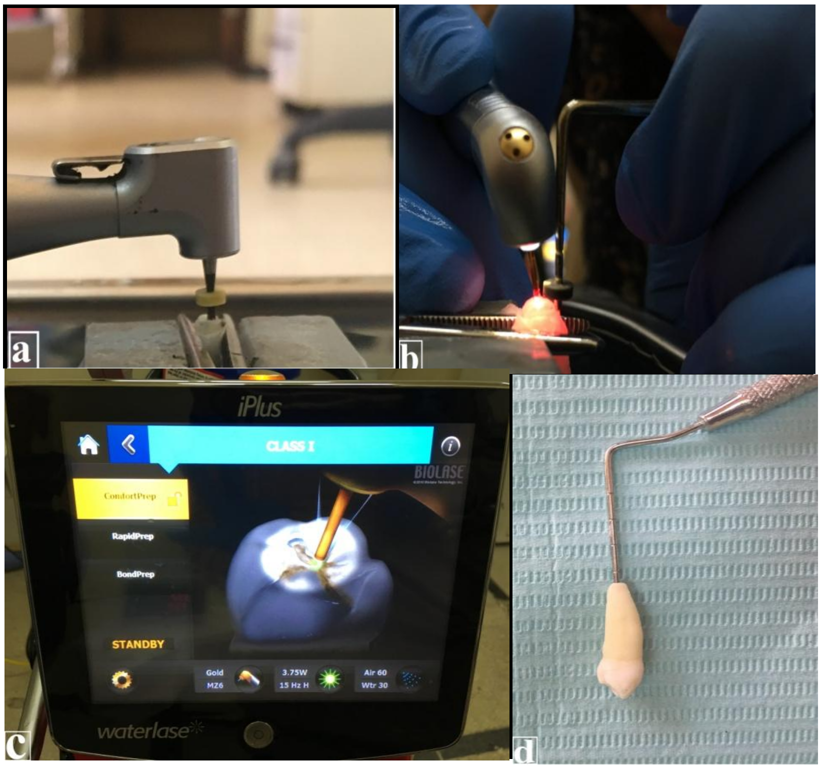


Figure (2-10) Root end cavity preparation (a) cavity preparation using carbide fissure bur (b) cavity preparation using Er,Cr:YSGG laser delivered through MZ6 tip (c) class 1 parameters as set by manufacturer (d) measuring diameter of the prepared cavity.

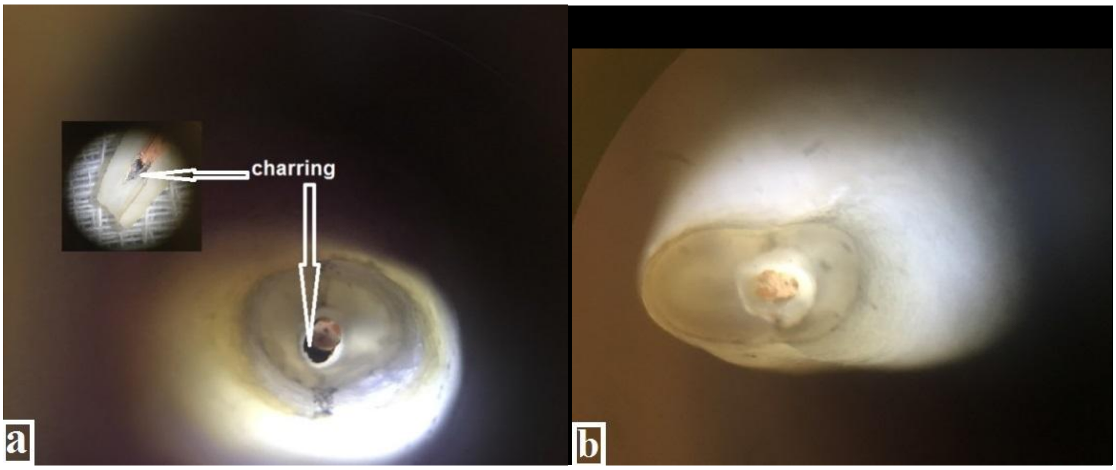


Figure (2-11) Two methods of root end cavity preparation (a) cavity with charring as the preparation was continuous till reach 3 mm depth (b) cavity without charring as the preparation was interrupted with intracavity irrigation every 1 mm depth preparation.

2.2.7 Preparation for SEM

This involve evaluation of the prepared teeth followed by several steps for their preparation to be examined under scanning electron microscope.

I. Sample preparation for SEM

All the samples were examined under x20 stereomicroscope. The teeth of two canals or accessory root canals, fractures in apical third and those of retrograde cavity which is not on the path of canals were excluded from SEM evaluation.

The selected teeth for SEM evaluation is sectioned with diamond wafering blade (Smart Cut™ ,Ted Pella,USA) under copious amount of normal saline flow. In both G1 and G2, a line was drawn at 4 mm coronal to the resected surface then a horizontal sectioning was performed. In both G3 and G4, a longitudinal line drawn that divided the root into two equal halves buccal (labial) and palatal (or lingual). The line drawn under stereomicroscope at x20 **(figure 2-12 a)**.

The sectioning of samples in both G3 and G4 was accomplished with two cut, one of them was at the cementoenamel junction to separate the crown from the root while the other was longitudinal that separate the root into two equal halves buccal (labial) and palatal(lingual) **(figure 2-12 b)**.

Figure (2-12): Sectioning of tooth to prepare it for SEM evaluation (a) demarcation of lines that divided the root into two equal halves (b) tooth sectioning with diamond warfaring blade.

II. The preparation protocol for SEM evaluation

According to the protocol used by Marchesan et al. [129], the fixation and dehydration of sample was accomplished through the following steps:

Each sample was immersed in 3 ml of 2.5% buffered glutarldehyde (EOBA CHEMIE PVT, India) with 0.1 M sodium cocodylate (BDH chemical Ldt, England) of PH =7.4 at 4°C for 12 h , then the sample were washed with distilled water for 3 minutes then immersed in 3 ml of distilled water for one hour as the water was changed every 20 minutes. Samples were dehydrated in ethyl alcohol ascending series, beginning from 25% for 20 min, 50% for 20 min,75 % for 20 min, 95% for 30 min and finally 100% for 60 min respectively. The specimens were left to dry in open air for 24 hrs. They were metalized with a layer of gold using a vacuum evaporation then were fixed on aluminum stubs **(figure 2-13)**. Finally, the specimen were examined under different magnifications at 10 kV under SEM (Inspect S50,Czech Republic).

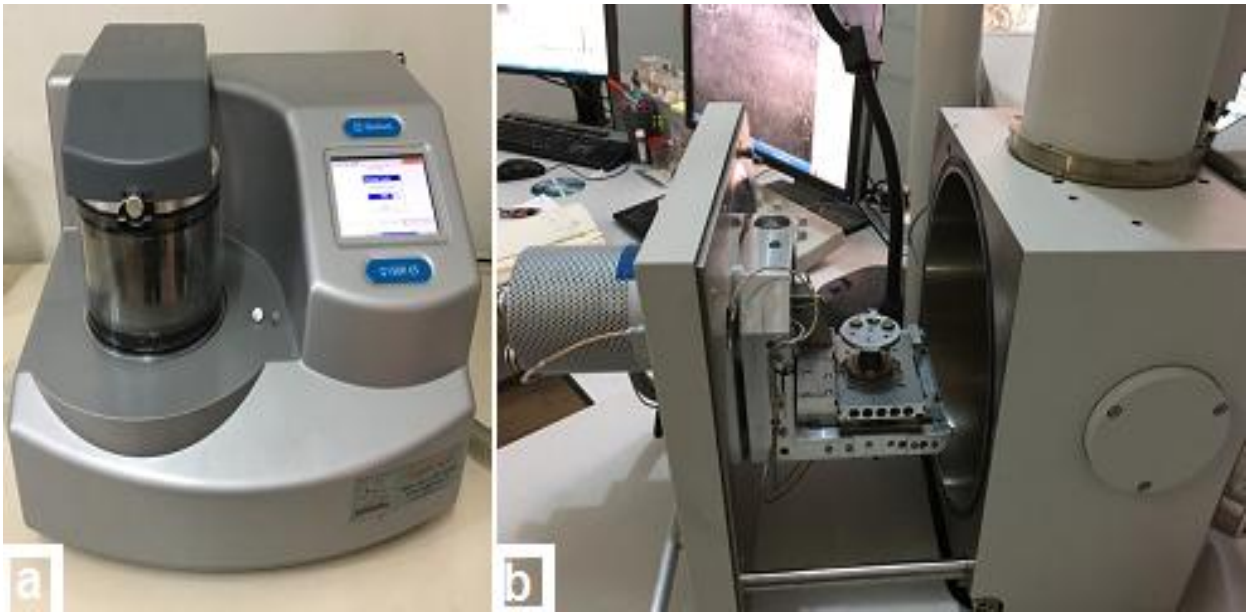


Figure (2-13): Scanning electron microscope (a) samples sputter coated (b) sample fixed on aluminum stubs inside SEM.

2.2.8 SEM evaluation

It involve microscopical evaluations of root end resection and root end preparation groups.

2.2.8.1 Root end resection groups (RER)

It involves evaluation of different parameters in both G1 and G2 under SEM.

I. Dentinal cracks

All specimens in both G1 and G2 were examined at x50 under SEM and evaluated by single observer to evaluate the cracks on the resected root end surface which were classified into intradentinal, incomplete and complete cracks according to Beiling et al. [130] **(table 2-1)**.

Table (2-1): Dentinal crack scoring system

Type of crack	Definition
Intradentinal crack	When crack is confined within the dentine.
Incomplete crack	When crack originating from the root canal and radiating into the dentine or originating from the root surface radiating into the dentine.
Complete crack	When crack extend from the root canal to the outer root surface.

II. Cemental damage

All specimens of both G1 and G2 were examined at x50 by single observer to detect presence or absence of cemental damage .

III. Filling material–root canal wall interface (gap measurement)

Under SEM and at x150 magnification, the area of gap between the filling material and the canal walls was measured in μm^2 with the aid of Image J software program **(figure 2-14)**.

Figure (2-14): Measurement of the gap at x150 with the aid of Image J software program.

IV. Surface roughness

On the buccal side of the resected surface and at 0.5 mm from the border of root canal, The area was observed at x400 under SEM to evaluate surface roughness in both G1 and G2. Two calibrated observers in a double-blinded fashion used scoring system described by Duarte et al. [110] **(table 2-2)**.

Table (2-2): Surface roughness scoring system.

Score	Definition
0	Smooth surface
1	Surface with slight roughness
2	Surface with moderate roughness
3	Surface with severe roughness

2.2.8.2. Retrograde cavity preparation groups (REP)

I. Dentinal cracks

All specimens of both G3 and G4 were examined at x50 magnification under SEM and evaluated by single observer to detect the presence or absence of dentinal cracks.

II. Surface roughness

On the middle and at about 1 mm from the incisal edge of the retrograde cavity wall, the area was observed at x400 under SEM in both G3 and G4 to evaluate surface roughness by two calibrated observers in a double-blinded fashion using scoring system described by Duarte et al. [110] ,**(table 2-2)**.

III. Effect on dentinal tubules

The evaluation of the effect of the preparation method on the dentinal tubules was carried out using two methods.

1. Smear layer and open dentinal tubules

On the middle and at about 1 mm from the incisal edge of the retrograde cavity wall, the area was observed at x2000 under SEM in both G3 and G4 to evaluate the smear layer and opened dentinal tubules by three calibrated blind observers using scoring system described by Hulsmann et al. [131] **(table 2-3)**.

Table (2-3): Smear layer and opened dentinal tubules scoring system.

Score	Definition
1	Dentinal tubules completely open.
2	More than 50% of dentinal tubules open.
3	Less than 50% of dentinal tubules open.
4	Almost all dentinal tubules covered with smear layer.

2. Quantitative assessment of opened dentine tubules

On the middle and at about 1 mm from the incisal edge of the retrograde cavity wall, the area was observed at x2000 under SEM in both G3 and G4 to count the number of opened dentinal tubules (both partial and completely opened dentinal tubules had been considered), this was accomplished with the aid of Image J software program **(figure 2-15)**. The quatitative assessment was used to confirm the results obtained with the gold standard method which was established by Hulsmann et al.

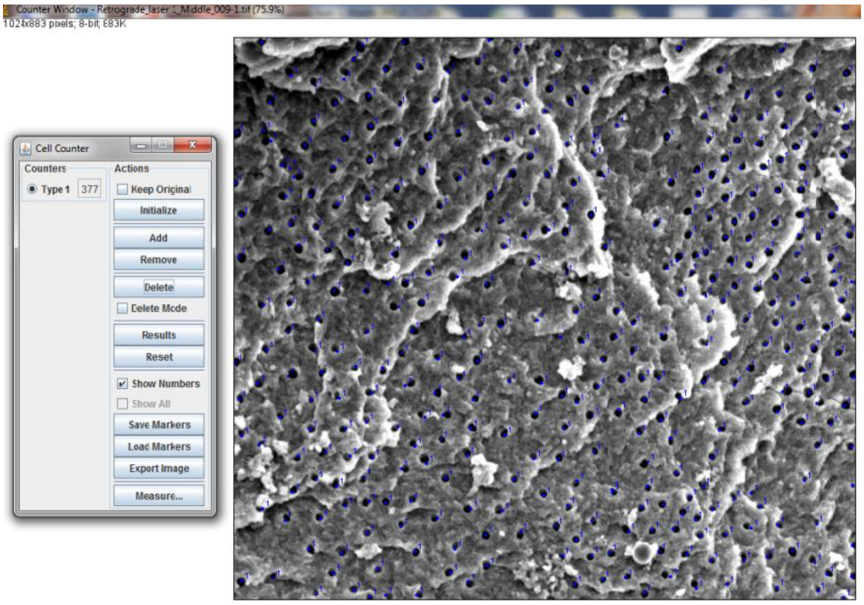


Figure (2-15): Counting opened dentinal tubule at x2000 with the aid of Image J software program (manual method) in retrograde cavity prepared using laser.

IV. Energy dispersive X-ray spectroscopy (EDS , EDX)

The Energy dispersive X-ray spectroscopy (EDS or EDX) at 25 kV accelerating voltage was taken for each sample of laser retrograde cavity group (G4) to measure the weight percentage of Ca and P in order to investigate the relation between incidence or number of dentinal cracks and them through relating the data obtained from EDS with the number of cracks in the same sample and finally comparing it with another sample with about the same or higher Ca and P weight percentage. This test was performed at the end of the SEM analysis.

2.2.9 Pilot study

A pilot study had been made before the research at hand to evaluate the following:

● The motion of the tip during RER and REP, as in RER the best motion was sweeping from one side of tooth to the end of other side in a single motion because repeating the irradiation to the same area resulted in carbonization **(figure 2-16 a)** and melting (**figure 2-16 b)** while the resected surface was irregular. It is necessary to avoid the entrapment of the MGG6 tip in a narrow space between the separated apical portion and the apical end of root during the cutting process as this resulted in debris flew back to the tip precluding the hard tissue removal by laser and damaging the tip .

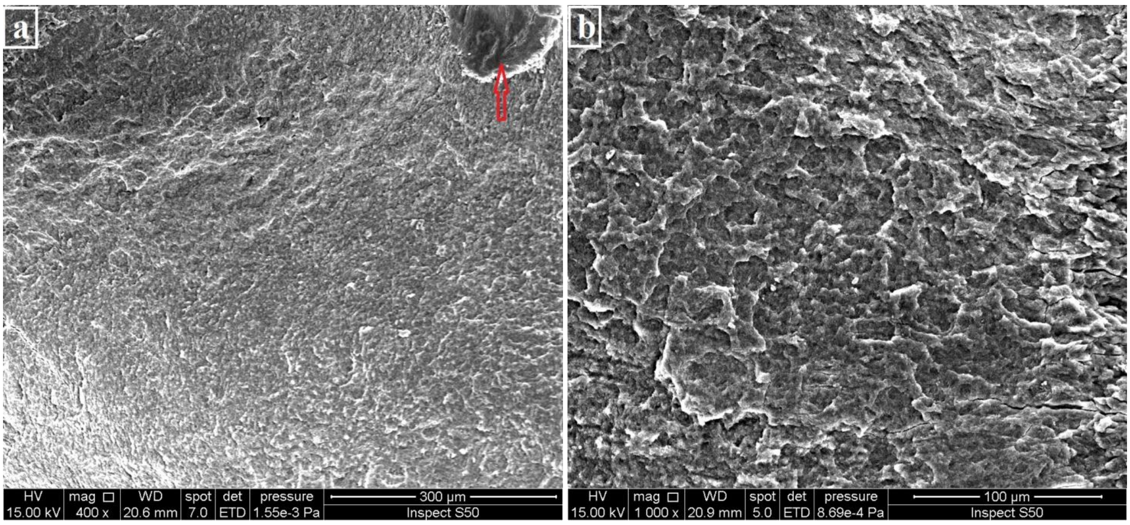


Figure (2-16): Sample treated with multiple radiation to the area during resection process (a) the sample examined at x400 with evidence of carbonization (red arrow).(b) the sample examined at x1000 with evidence of melting.

In REP ; the continuous motion of the laser tip from a point of 1.5 mm away from hard tissue downward till reach a depth of 3mm in retrograde cavity resulted in debris accumulation within the cavity and excessive charring therefore the new method of motion was established by irrigation of cavity after each 1 mm depth preparation; this was sufficient to solved this problem and resulted in preparing cavities which were clean and devoid of charring **(figure 2-17)**.

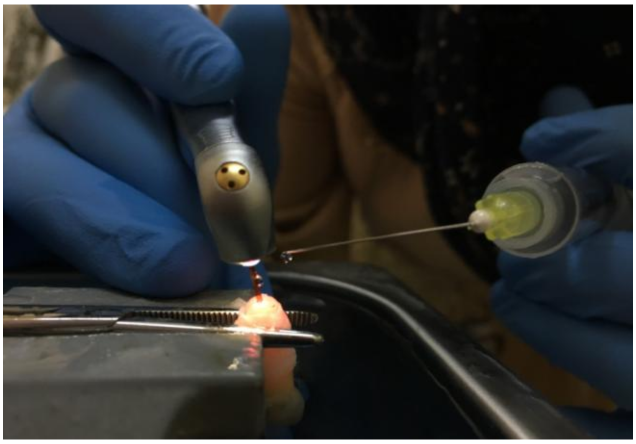
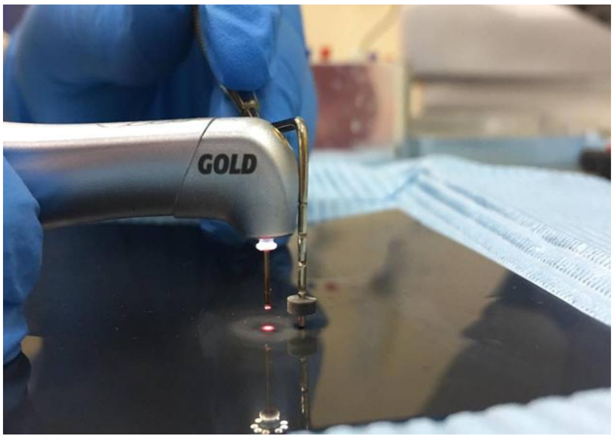


Figure (2-17): A photograph shows a method to avoid the charring inside retrograde prepared cavities.

●The distance between the end of the laser tip and the hard tissue to be cut which will give the 1 mm spot size diameter on the cutting surface was established with the aid of digital caliber and a floppy disk film **(figure 2-18)**.



Figure(2-18): A photograph shows the establishment of 1mm spot size diameter.

●The duration of motion during Er:Cr.YSGG laser irradiation to create retrograde cavity of 1 mm diameter was established at about 20 seconds with circular motion of the tip in the same fixed area then downward spiral motion.

● The magnitude of volts that to be used in the SEM which is most appropriate for specimen evaluation and can give adequate image resolution **(figure 2-19)**.

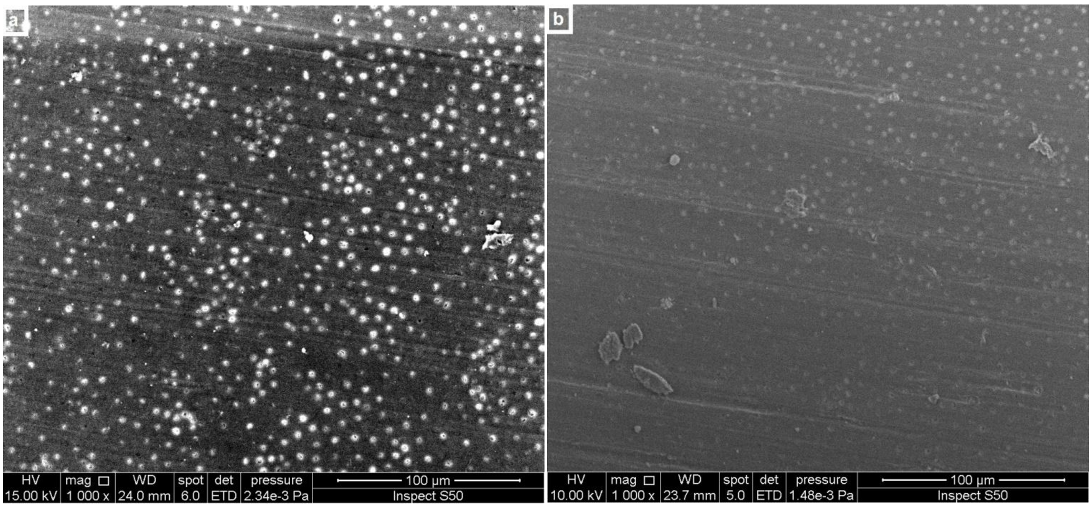


Figure (2-19): SEM images at different parameter (a) at 15 kV (b) at 10 kV.

●The effect of diamond wafering blade on the tooth surface to ensure that it doesn't produce cracks **(figure 2-20)**.

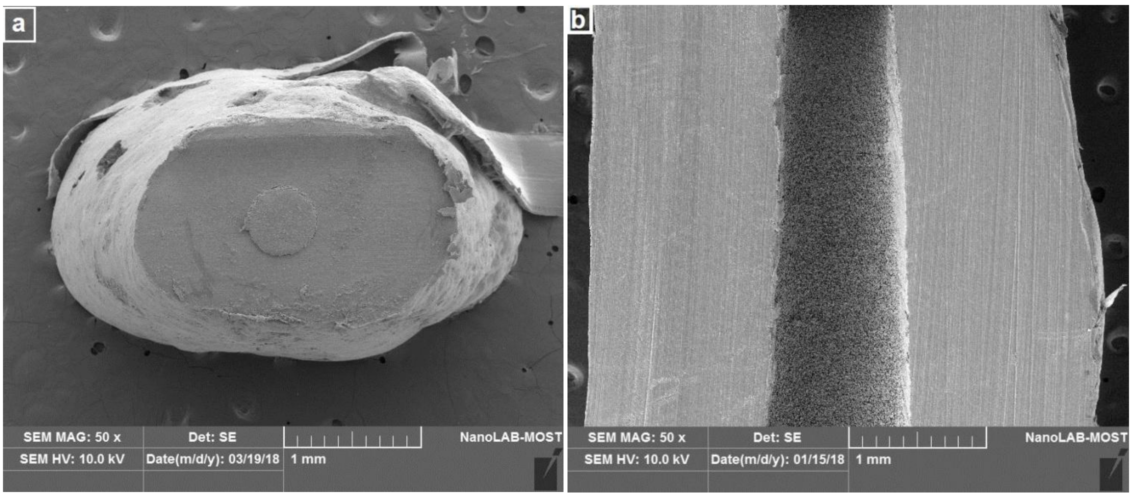


Figure (2-20) SEM of root sectioned by diamond wafering blade at 50X. (a) horizontal resection as RER (b) longitudinal resection along the root.

2.2.10 Statistical analysis

All the data were statistically analyzed using SPSS V.20 for windows 7, and Excel 2010 for tables.

The statistical analysis consists of the following:

1.Descriptive statistics which include mean, median ,minimum values, maximum values and standard deviation (SD).

2. Inferential statistics:

• Chi-square test ($\chi 2$) test/Fisher's exact test to determine if there was a significant difference between G1 and G2 or between G3 and G4, where the level of significance (P value) was referred to this difference.

Chi-square test ($\chi 2$) test /Fisher's exact test used in the statistical analysis of data obtained from evaluation of the following parameters: dentinal cracks, cemental damage, gap measurement, number of opened dentinal tubules, smear layer and open dentinal tubules, duration of the process and temperature.

• Kruskal–Wallis and Dunn tests were used to analyze the difference between the groups for evaluation of surface roughness, smear layer and opened dentinal tubules parameters. Kruskal–Wallis test was used to analyze the interexaminer agreements for the scores of the surface roughness and the intraexaminer evaluation of cut quality within the same group.

The level of significant was set into the following :

$P \geq 0.05$ Not Significant (NS)

$P < 0.05$ Significant (S)

$P \leq 0.01$ Highly Significant (HS)

$P \leq 0.001$ Very Highly Significant (VHS).

Chapter three

Results, Discussion and Conclusion

Chapter three: Results, Discussion and Conclusion

This chapter include the results of the study, discussion, conclusion and finally the suggestions for the future work.

3.1 Results

Include the data and its statistical analysis of the four groups for both RER groups and REP groups.

3.1.1 Root end resection groups

This include the results of both G1 and G2 with the statistical analysis of the collected data to compare between them.

I. Dentinal cracks

As it was mentioned in the previous chapter, the dentinal crack was classified into intradentin, incomplete and complete cracks as shown in (**figure 3-1)**. The number of samples with each category in each group was calculated and described by percentage.

X^2 test/Fisher's exact test used to compare between G1 and G2 revealed statistically significant difference in the term of intradentin crack as P value is 0.04 but the difference was not significant in the terms of incomplete and complete cracks (**table 3-1).**

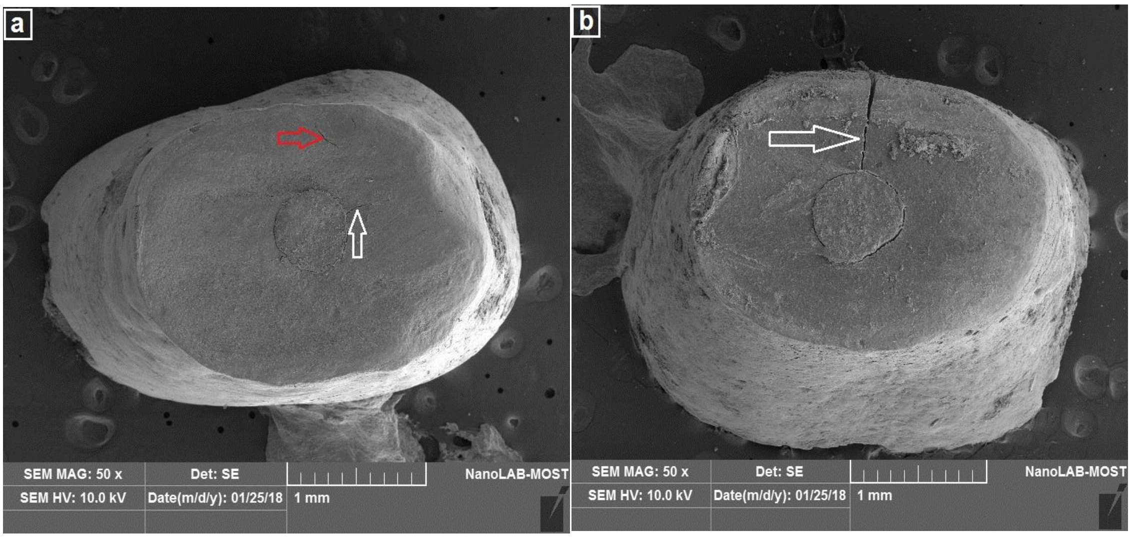


Figure (3-1) SEM of resected samples at x50 shows types of dentinal cracks(a) incomplete crack (white arrow), intradentinal crack (red arrow) (b) complete crack (white arrow).

Table (3-1): X^2 test/ fisher exact test for dentinal cracks

Groups	Complete cracks	Incomplete cracks	Intradentin cracks
	With (%)	**With (%)**	**With (%)**
Bur Samples (10)	1 (10%)	6 (60%)	3 (30%)
Laser Samples (10)	3 (30%)	8 (80%)	7 (70%)
***P*- Value (x^2 test/Fisher's exact test)**	0.07(NS)	0.07(NS)	0.04

II. Cemental damage

The evaluation of the cemental damage was for presence or absence of cemental damage (**figure 3-2)**. Bur resulted in cemental damge in 7(70%) of samples while laser revealed absence of cemental damage. X^2

test/Fisher's exact test revealed highly statistically significant difference between G1 and G2 as P value is 0.01 (**table 3-2).**

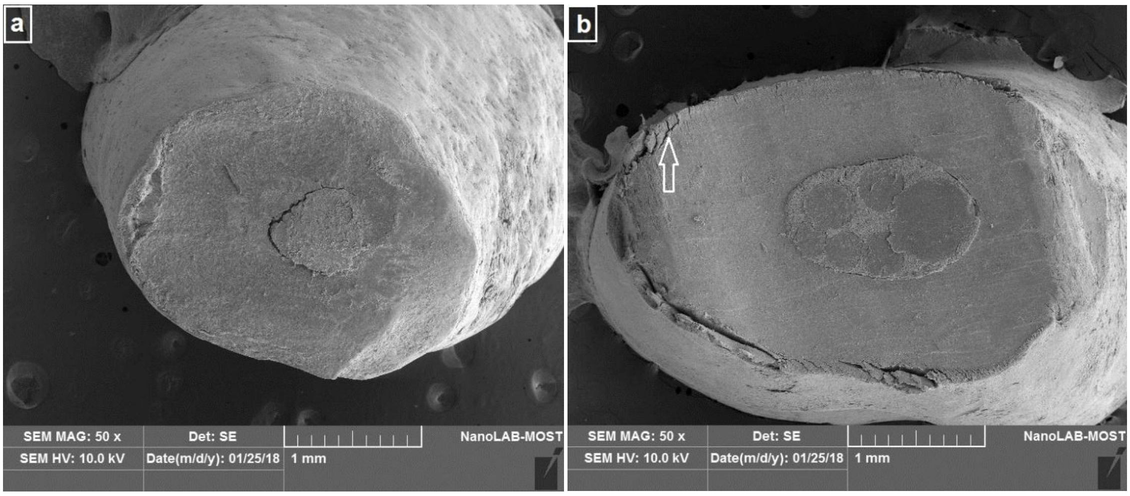


Figure (3-2): SEM of resected samples at x50 (a) resected by laser without cemental damage (b) resected by bur with cemental damage(white arrow).

Table (3-2): X^2 test/Fisher's exact test for cemental damage.

Techniques	**Cemental damage**
	With (%)
Bur Samples (10)	7 (70%)
Laser Samples (10)	0 (0%)
***P*- Value (x^2 test/Fisher's exact test)**	0.01

III. Filling material–root canal wall interface (gap measurement)

The gap between filling material and the dentinal wall was measured with the aid of Image J software program. The area measurement was set in μm^2 and the statistical analysis was performed using x^2

test/Fisher's exact test. Resection with laser resulted in larger gap between filling material and the dentinal wall. The difference between G1 and G2 was statistically significant as P value is 0.05 (**table 3-3)**.

Table (3-3): Descriptive and x^2 test/Fisher's exact test for filling material-root canal wall interface (gap measurements).

Techniques	**Gap measurement (μm^2)** **Mean±SD**
Bur Samples (10)	7042.7 ± 2310
Laser Samples (10)	7164.3 ± 3412
***P*- Value** **(x^2 test/Fisher's exact test)**	0.05

IV. Roughness

The surface roughness evaluated by two observers in double-blinded fashion as they gave a descriptive score for each sample as shown in (**figure 3-3)** and (**table 3-4)**. The analysis of the interexaminer agreement of the scores obtained for the surface roughness by the Kruskal–Wallis test determined significant differences between both groups ($P \leq 0.05$). Burs group produced significantly smoother surface than the laser groups ($P < 0.05$). The analysis of scores obtained for the cut quality by the Kruskal–Wallis test revealed no significant differences inside the groups in both observer 1 and observer 2 as $P > 0.05$. The comparison between the groups for the surface roughness were performed using the descriptive analysis and the Kruskal–Wallis and Dunn tests. The significant level was established at 5%. Statistical significant differences ($p < 0.05$) occurred in the comparisons between the bur and laser groups (**table 3-5)**.

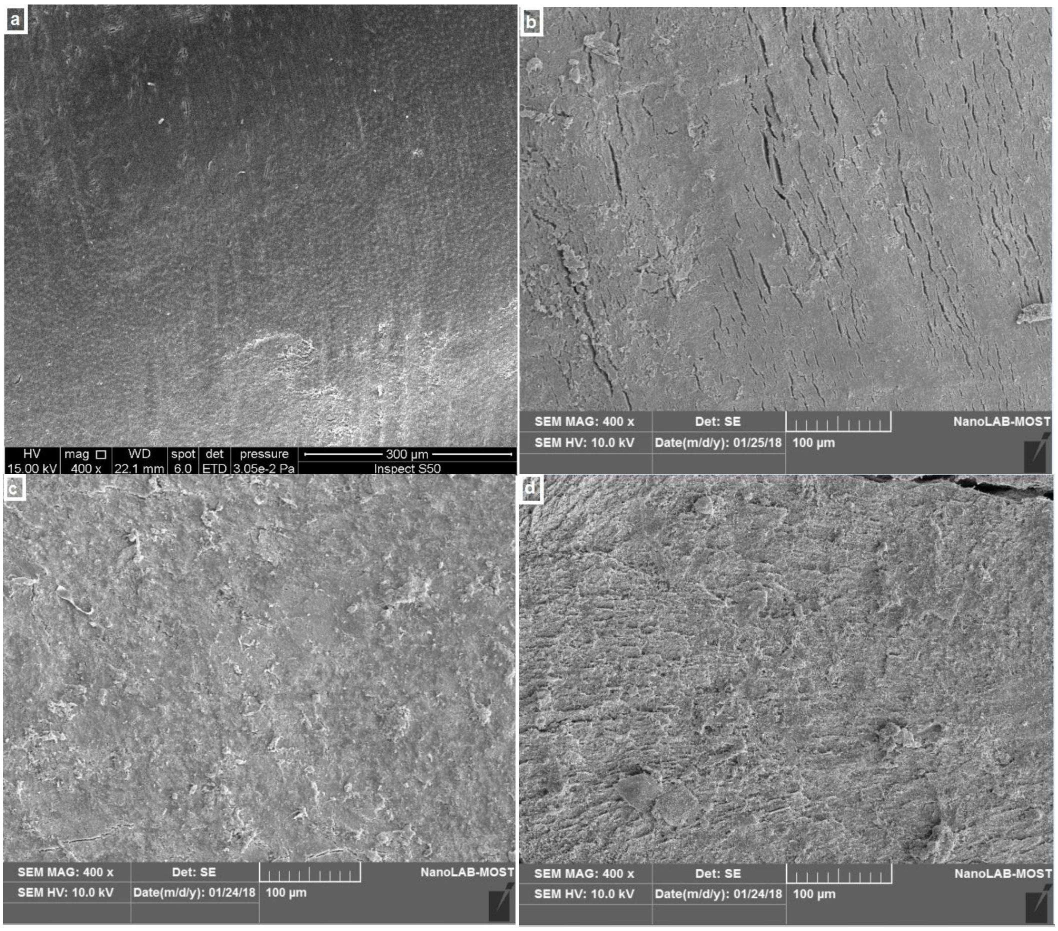


Figure (3-3): SEM of root end resected sample at x400 shows surface roughness (a) root-end resected by cross cut carbide tapered bur score 0 (b) root-end resected by cross cut carbide tapered score 1(c) root-end resected by MGG6 laser tip score 2 (d) root-end resected by MGG6 laser tip score 3.

Table(3-4):Roughness scores by two observers.

Specimen	BUR (resection group)		LASER (resection group)	
	Observer 1	Observer 2	Observer 1	Observer 2
1	2	2	2	2
2	2	2	1	2
3	2	2	1	2
4	1	1	2	2
5	1	1	2	1
6	2	1	3	2
7	1	1	2	2
8	0	0	2	2
9	0	0	2	2
10	0	1	3	2

Table (3-5): Descriptive, Kruskal–Wallis and Dunn tests for surface roughness

Groups	Median	Minimum	Maximum
Bur	1^{a}	0	2
Laser	2^{b}	1	3
Kruskal–Wallis and Dunn tests	Different letters show significant statistical differences (p<0.05)		

V. Temperature

There wasn't elevation in temperature above 37°C (the starting point temperature on the root surface) in both groups. The recorded temperature was lower than 37 °C during root end resection in both bur and laser groups (by 13.3± 1.5 and 12.5± 0.7 °C respectively). The minimum temperature reached during the resection at the external root surface was considered for each sample in both groups. There was no statistical significant difference between the G1 and G2 (**table 3-6)**.

Table (3-6): Descriptive and x^2 test/Fisher's exact test for temperature measurements of resection groups

Group	Temperature (°C) Mean±SD
Bur Samples (10)	23.7 ± 1.5
Laser Samples (10)	24.5 ± 0.7
***P*- Value** **(x^2 test/Fisher's exact test)**	0.1(NS)

VI. Duration of resection process

The time consumed in root end resection in both groups was recorded. Laser took longer time to perform root-end resection than bur (by 1.79 ± 0.6). The difference was statistically significant at which p value is 0.03 (**table 3-7**).

Table (3-7): Descriptive and x^2 test/Fisher's exact test for duration of RER process.

Techniques	Duration of cutting (min) Mean±SD
Bur Samples (10)	1.61 ± 0.3*
Laser Samples (10)	3.4 ± 0.9
***P*- Value** **(x^2 test/Fisher's exact test)**	0.03

3.1.2 Retrograde cavity preparation groups

This include the results of both G3 and G4 with the statistical analysis of the collected data to compare between them.

I. Dentinal cracks

The evaluation of dentinal crack within the retrograde cavity was performed by single observer to determine presence or absence of the crack **(figure 3-4)**. Laser showed greater percentage of samples with cracks. The statistical analysis was performed using x^2 test/Fisher's exact test. The difference between G3 and G4 was statistically significant at which P value is 0.04 **(table 3-8)**.

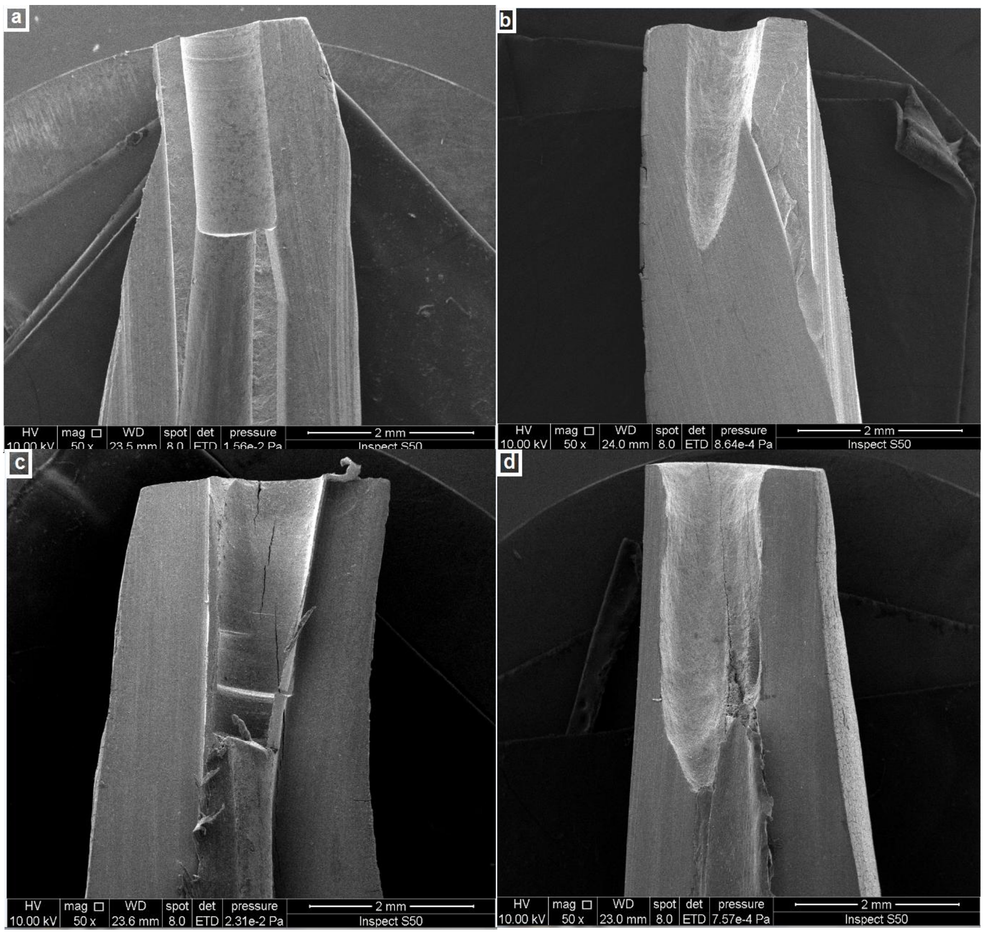


Figure (3-4): SEM of retrograde cavity at x50 (a) prepared by carbide fissure bur without crack (b)prepared by MZ6 laser tip without crack (c) prepared with carbide fissure bur with cracks (d) prepared by MZ6 laser tip with cracks.

Table (3-8): X^2 test/Fisher's exact test for dentinal cracks in retrograde cavity.

Groups	**Dentinal cracks**
	With cracks (%)
Bur Samples (10)	3(30%)
Laser Samples (10)	7(70%)
***P*- Value (x^2 test/Fisher's exact test)**	0.04

II. Roughness

The samples examined under SEM at x400 for analysis of surface roughness by two observers in a double-blind fashion **(figure 3-5)** and **(table 3-9)**. The analysis of the interexaminer agreement of the scores obtained for the surface roughness by the Kruskal–Wallis test determined significant differences between the groups ($P \leq 0.05$). Bur group produced significantly smoother surface than the laser groups ($P \leq 0.05$).

The analysis of scores obtained for the cut quality by the Kruskal–Wallis test revealed no significant differences inside the groups as evaluated by observer 1 and observer 2 ($P > 0.05$). The comparison between the groups for the surface roughness was performed using descriptive, the Kruskal–Wallis and Dunn tests. The significant level was established at 5%. Significant statistical differences ($p \leq 0.05$) occurred in the comparison between the bur and laser groups as cavities prepared using bur showed smoother surface than that prepared by laser **(table 3-10)**.

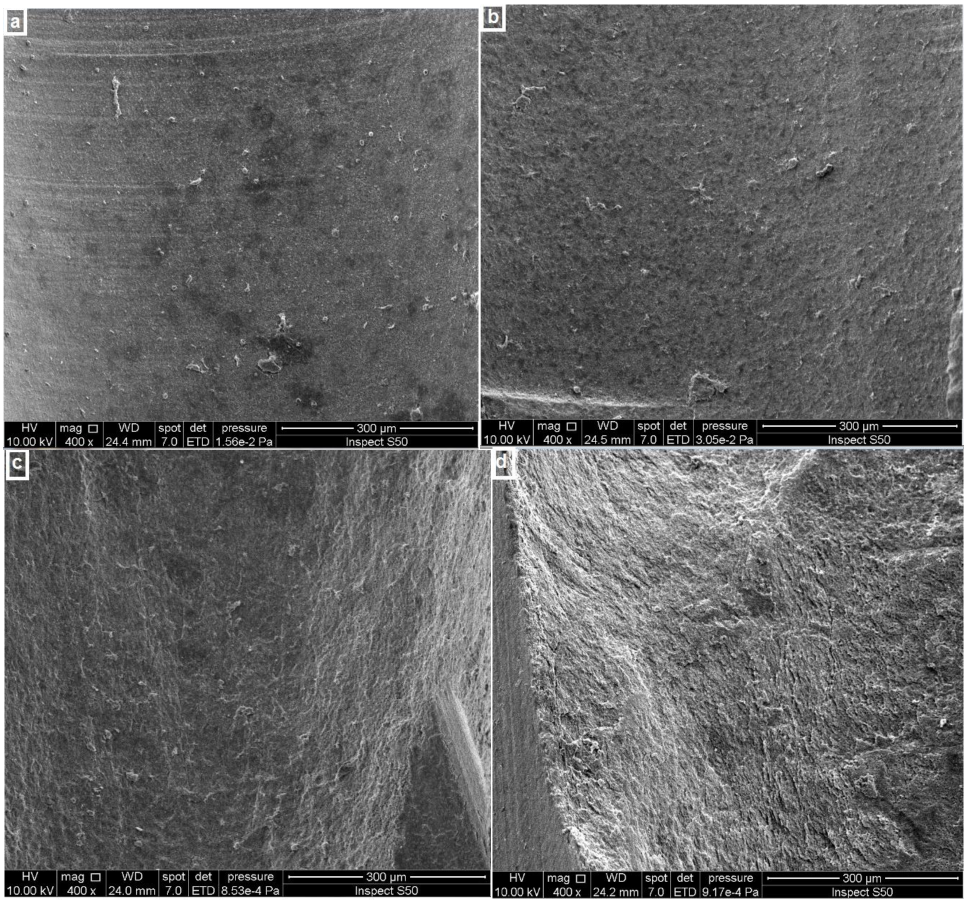


Figure (3-5): SEM of retrograde cavities at x400 shows surface roughness (a) cavity prepared by carbide fissure bur score 0 (b) cavity prepared by carbide fissure bur score 1(c) cavity prepared by MZ6 laser tip score 2(d) cavity prepared by MZ6 laser tip score 3.

Table (3-9): Scores of surface roughness by two observers.

Samples	Bur retrograde cavity group (Group 3)		Laser retrograde cavity group (Group 4)	
	Observer 1	Observer 2	Observer 1	Observer 2
1	0	2	2	2
2	1	1	3	2
3	1	1	3	2
4	1	1	2	2
5	2	1	2	1
6	1	1	2	2
7	0	1	3	2
8	0	1	2	2
9	1	2	2	2
10	0	0	3	2

Table (3-10): Descriptive, Kruskal–Wallis and Dunn tests for surface roughness.

Groups	Median	Minimum	Maximum
Bur	1[a]	0	2
Laser	2[b]	1	3
Kruskal–Wallis and Dunn tests	Different letters show significant statistical differences ($p \leq 0.05$)		

III. Effect on dentinal tubules

The effect of the instruments used during preparation on DTs had been assessed using two methods of evaluation.

1. Smear layer and open dentinal tubules

The samples examined under SEM at x2000 for analysis of opened dentinal tubule by three well calibrated observers **(figure 3-6)**. Both mean and standard deviation was calculated for the scores of each sample obtained from the three observations then statistical analysis was performed using x^2 test/Fisher's exact test. Firstly, the comparison was performed on the level of individual samples between G3 and G4, each one with three observations so the mean and standard deviation were calculated and then a comparison was performed using the x^2 test/Fisher's exact showed fluctuations in the term of statistical differences from no significant, significant to highly significant differences. On the other hand, the total comparison between G3 and G4 using x^2 test/Fisher's exact showed the difference was statistically significant at which P is 0.05 **(tables 3-11)** .To confirm the results obtained by x^2 test/Fisher's exact test another test was carried out which is the Kruskal–Wallis test which also revealed statistically significant difference between G3 and G4 as P value ≤ 0.05 **(table 3-12)**.

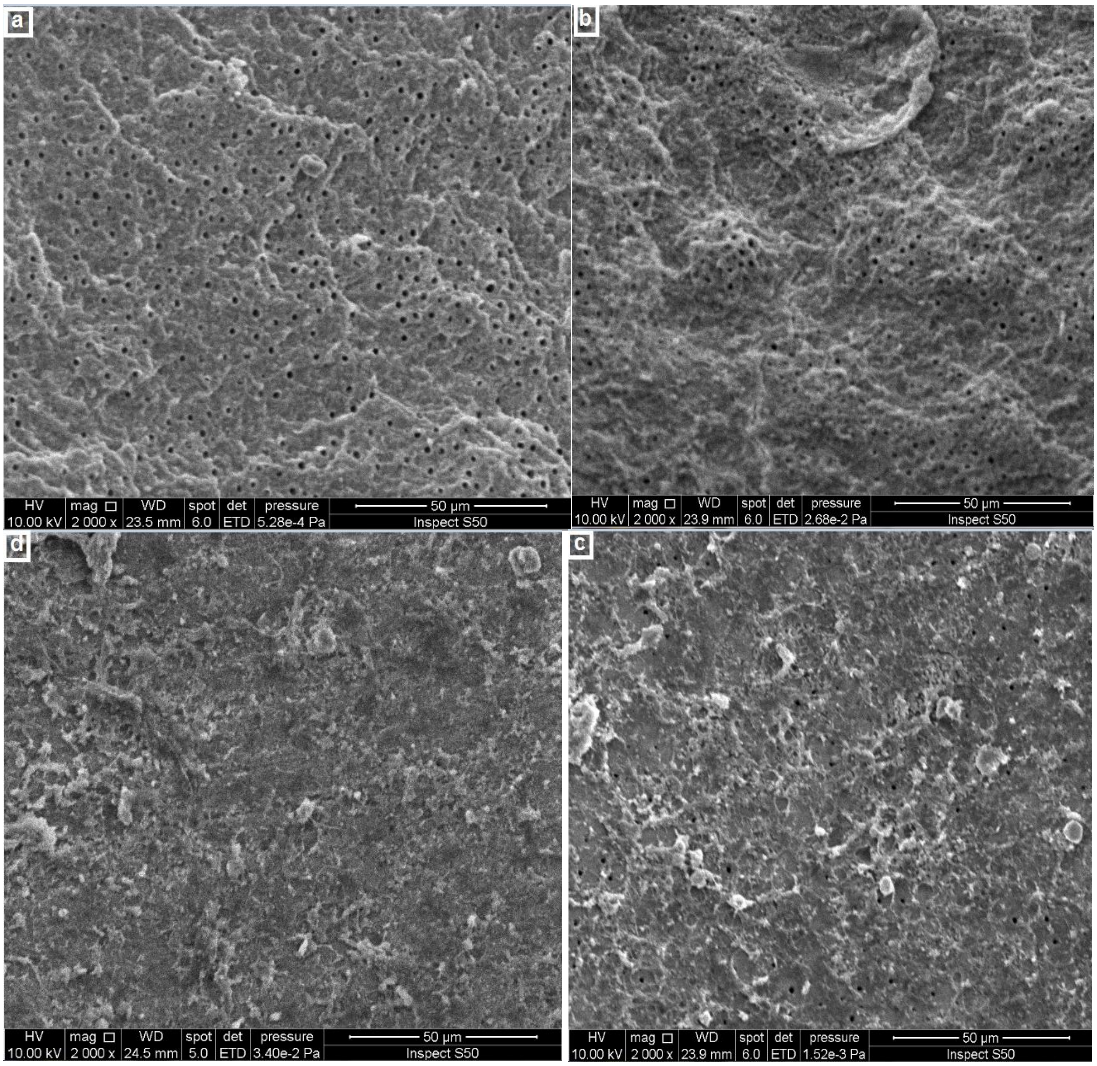


Figure (3-6): SEM of retrograde cavities at x2000 shows smear layer and opened DTs (a) cavity prepared by MZ6 laser tip score 1(b) cavity prepared by MZ6 laser tip score 2(c) cavity prepared by carbide fissure bur score 3.(d) cavity prepared by carbide fissure bur score 4.

Table (3-11): Descriptive and x^2 test/Fisher's exact test for smear layer and opened dentinal tubules scores.

Samples	Bur retrograde cavity group (Group 3) Mean±SD	Laser retrograde cavity group (Group 4) Mean±SD	*P*- Value (x^2 test/Fisher's exact test)
1	4±0	1.67±0.58	0.01
2	3.33±0.6	2.33±0.58	0.05
3	4±0	4±0	NS
4	4±0	3.33±0.57	NS
5	4±0	4±0	NS
6	4±0	4±0	NS
7	3±0	2.66±1.3	NS
8	4±0	2±0	0.01
9	4±0	1.33±0.57	0.01
10	2.66±0.5	1±0	NS
Total	3.7±0.11	2.6±0.45	0.05

Table (3-12): Descriptive, Kruskal–Wallis and Dunn tests for smear layer and opened dentinal tubules scores.

Groups	Median	Minimum	Maximum
Bur	4^b	2	4
Laser	2.5^a	1	4
Kruskal–Wallis and Dunn tests	Different letters show significant statistical differences ($p \leq 0.05$)		

2. Quantitative assessment of opened dentine tubules

The mean and standard deviation of the number of opened dentinal tubules was calculated for both groups then x^2 test/Fisher's exact test was used to assess them statistically. The difference between G3 and G4 was very highly significant at which P value is 0.001 as laser resulted in greater number of opened dentinal tubules than bur **(Table 3-13)**.

Table (3-13): Descriptive and x^2 test/Fisher's exact test for number of opened DTs in retrograde cavity groups.

Groups	Number of opened dentinal tubules Mean±SD
Bur Samples (10)	57.41 ± 23.5
Laser Samples (10)	225.3 ± 65.9*
***P*- Value** **(x^2 test/Fisher's exact test)**	0.001

IV. Energy dispersive X-ray spectroscopy (EDS , EDX)

SEM-EDS measurements were taken for each sample in G4 at 25 kV accelerating voltage. Ca (weight%) and P (weight %) in each sample of laser retrograde cavity group were correlated with the incidence or the number of cracks within that sample. The data obtained revealed no relation between the incidence or the number of dentinal cracks and the Ca (weight%) and P (weight %) within the sample **(table 3-14)** and **(figure 3-7)**.

Table (3-14): Ca and P weight percentages of samples and the number of crack in each of them.

Sample	Number of cracks	Ca (weight%)	P (weight %)
(a)	0	29.31%	14.01%
(b)	5	31.79%	20.07%
(c)	0	28.38 %	18.06%
(d)	3	31.20%	19.29%

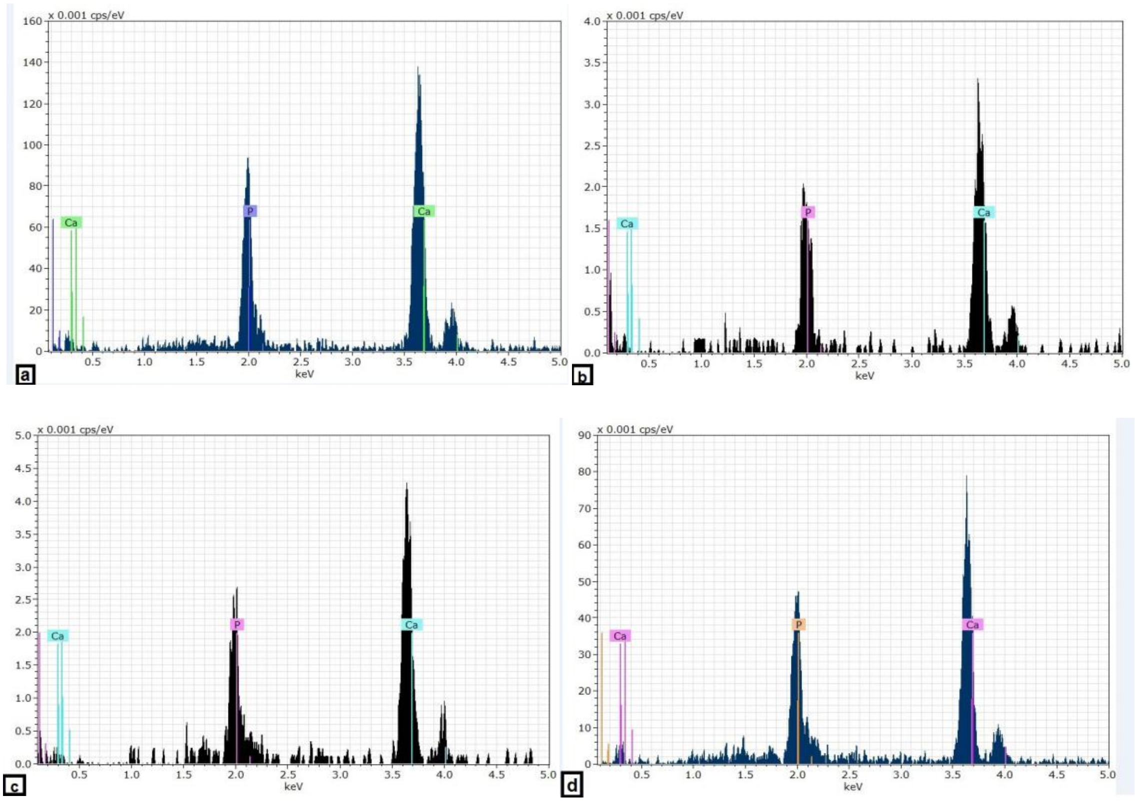


Figure (3-7): Different samples with different Ca and P weight percentages.

V. Temperature

There wasn’t elevation in temperature above 37°C in G3 and G4. The recorded temperature was below 37 °C (below the starting point temperature) during REP in both of them. The minimum temperature reached during REP at the external root surface was considered for each sample in both groups and involved in the statistical analysis. The statistical analysis was performed using x^2 test/Fisher's exact test. G3 reach lower temperature at the external root surface than G4, the difference between them was statistically significant **(table 3-15)**.

Table (3-15): Descriptive and x^2 test/Fisher's exact test for temperature measurements of retrograde cavity groups .

Groups	Temperature (°C)
Bur Samples (10)	22.9 ± 2.9*
Laser Samples (10)	26.1 ± 1.6
***P*- Value** **(x^2 test/Fisher's exact test)**	0.05

VI. Duration of preparation procedure

Time consumed in REP in both groups was calculated. The difference was statistically significant. Laser took longer time to prepare the retrograde cavity than bur, longer by 1.29± 0.6 min **(table 3-16)**.

Table (3-16) : Descriptive and x^2 test/Fisher's exact test for duration of REP.

Groups	Duration of preparation (min) Mean±SD
Bur Samples (10)	1.21 ± 0.2*
Laser Samples (10)	2.5 ± 0.8
***P*- Value** **(x^2 test/Fisher's exact test)**	0.05

3.2 Discussion

Erbium lasers (Er:YAG 2940 nm and Er,Cr:YSGG 2780 nm lasers) are highly absorbed by water-rich tissues [115]. The hydroxyl group of the (carbonated) hydroxyapatite mineral of the tissues shows a small absorption at around 2800 nm [92]. For the removal of dental hard tissue, erbium lasers wavelengths correlate closely with the maximum absorption of hydroxyapatite in which water contained evaporates and ablation occur with only minimal thermal side effects [93]. Therefore, the aim of study was to compare between Er,Cr:YSGG 2780 nm laser and carbide bur in root end surgery considering the microscopical changes, temperature and duration of procedure. This study was divided into two parts, according to the two process involved in root end surgery, one of them is root end resection and the other was root end cavity preparation (retrograde cavity preparation). The teeth of young age group was chosen for this study because of higher water content than that of older age group [132].

3.2.1 Root end resection

The Er,Cr:YSGG 2780 nm laser offer many advantages when used for root-end resection, the resection can be performed without carbonization or thermal damage if optimum parameters were used, Er,Cr:YSGG laser has antibacterial effect so that it can be used for sterilization of root apex and the surrounding tissue [121]. The cross cut fissure burs commonly recommended for use in apical root resection because of their rapid cutting characteristic. Shredding and pulling of the gutta-percha occur when high-speed handpiece used in resection process [96]; furthermore, this occur when direction of cutting is in reverse direction in relation to the direction of rotation of the bur [97]. Therefore the choice was to use cross cut tapered bur with slow speed handpiece and the direction of resection from buccal to palatal side which mean it was with the direction of rotation of bur.

I. Dentinal cracks

According to our study, higher percentage of samples at which root-end resected using Er,Cr:YSGG laser were associated with intradentinal cracks than those resected using carbide bur. This is coincide with a study conducted by Ayranci et al.[112], while both groups showed no statistical difference in term of complete and incomplete cracks. In general, this contradict with Babar et al. [113] Those cracks may provide sanctuaries that favor bacterial growth and result in accumulation of their irritant and toxic metabolites[133]. Therefore, an attempt to decrease those cracks might be necessary through alteration of the laser parameters.

II. Cemental damage

The dentine of the root is covered with thin layer of mesenchymal tissue “cementum” that support the tooth along with alveolar bone and the periodontal ligament. The cementum is affected by environmental stimuli [134]. Therefore, its preservation is essential for successful outcome. According to our study, Er,Cr:YSGG laser didn’t cause damage in the cementum, this might be related to the higher water content in cementum than in dentin [92] which results in less thermal damage applied on cementum as Er,Cr:YSGG 2780 nm laser is highly absorbed by water [135]. This might explain why there were cracks in dentin while there was no crack or damage in cementum.

III. Surface roughness

The Kruskal–Wallis test was used to evaluate the cut quality which showed no significant differences inside both groups which indicated that the resection process was standardized for all samples. The laser group resulted in rougher surface than bur group. This is coincide with Sullivan et al. study who suggested that this might increase the root-end surface area after resection and theoretically this will expose more DTs than a smooth flat resected surface which make it more difficult to burnish the retrograde filling material smoothly against the margins [111]. Surface´s irregularities and roughness may serve as irritant and lead to accumulation of debris and stimulation of the resorption during the reparation [36] but this is not parallel with a study conducted by Hakki et al. who considered that rough surface endorsed cell attachment as short pulse setting of Er,Cr:YSGG laser is suitable for cell attachment and migration, and also there was increase in the number of cells which may differentiate into cells which is important for periodontal regeneration [136]. The pulsed cutting mode of the laser prevent the uniform cutting of dentin which results in rough surface [110].

IV. Filling material–root canal wall interface

Root-end resection may created gaps at the Gutta Percha-tooth interface which may jeopardized previously sealed canals by obturation and exposed them to bacteria as well as support their growth [97]. There are many controversies about the effect of laser radiation on interface between Gutta Percha and the wall of dentin. In the present study, the mean area of gap between filling material and dentin walls in G2 was larger than that of G1 and the difference was statistically significant. This contradict with a study conducted by Babar et al.[113] which might be due to the minor differences in parameters which were used in those studies. Mahdee et al. suggested that rapid increase in the temperature generated by laser applied to the Gutta Percha and root canal sealer cause shrinkage and thermal damage of the Gutta Percha which will jeopardize the apical seal area [137]. Those results may indicate the necessity of using retrograde filling to seal the canal after resection with laser at those specific laser parameters.

V. Duration of resection process

RER using laser was slower than that performed using bur and this coincide with a study conducted by Berbert et al.[120] The correlation between the speed of cutting and the incidence of crack is controversial[138]. However; in our study there was variation of time spent in cutting among the samples within the same group and this could be related to the variation of the cross section area of the apical third and also could be related to the variation to the thickness of dentin, this is coincide with Paghdiwala et al.[106] The time required for the RER could be reduced by increasing in the power setting of the laser which results in greater amounts of ablated dentin taking in consideration maintaining the integrity of dental structures[120].

3.2.2 Root end cavity preparation (retrograde cavity preparation)

Various techniques and devices have been advocated for REP. Traditionally, preparation using burs with high-speed handpieces shows lack of parallelism, inaccessible root tip and perforation of the root lingually [115]. The success rate is approximately 60% while using ultrasonic retro-tips for REP results in dentin cracks and smear layers which can threaten the apical seal [124].

I. Dentinal cracks

The finding of this study revealed that preparation of retrograde cavity using Er,Cr:YSGG laser associated with more cracks than using carbide fissure bur. This is contradict with the previous studies as laser revealed absence of vibration or pressure exerted during cavity preparation which predispose cracks[116]. The incidence of cracks in this study might be related to the the small diameter of retrograde cavity thus insufficient water spray from the handpiece reaching the full depth inside the cavity during the preparation. On the other hand; increasing the diameter to 1.5 mm resulted in fracture at the apical end of the cavity in both methods of preparation (bur and laser) due to the thin remained dentin in apical cross section therefore REP of 1 mm diameter was the choice for this study. Those dentinal cracks may also predisposed due to high energy used in this study (250 mJ/pulse) as a result of the parameters set by manufacture as erbium laser with high energy value can cause dentinal cracks [139] and /or short pulse duration of Er:Cr:YSGG laser used in this study (60 μs) short laser pulses create strong elastic waves within the hard tissue undergo ablation which is because of the transient thermal shocks resulted from laser heating, thermal expansion, and the recoil of the ablation products. As a result of those stress waves which propagate through dentin, cracks and fractures occur which are often observed during laser irradiation of dental hard tissues[140].

II. Dentinal tubule and smear layer removal

The proper interaction between retrograde filling material and the retrograde cavity surface depends on both the materials characteristics and the surface conditions of the cavity. Smear layer removal is necessary to provide a proper interface which lead to a better adaptation of the material, as long as Er;Cr:YSGG laser is highly absorbed by water, causing microexplosions of the water content of dentin, this will results in debris and smear layer removal which will increase the number of opened DTs and the root dentin permeability [141].

Two method for evaluation of opened dentinal tubules were used in this study to overcome the subjectivity of the evaluation. Both evaluation methods revealed that Er,Cr:YSGG laser treated cavity showed larger number of opened dentinal tubules than bur which coincides with studies conducted by Ishizaki et al.[142] and Yamazaki et al.[143]

III. Surface roughness

Similar to the RER process which was performed in this study, the cut quality analysis by the Kruskal–Wallis test revealed no significant differences inside both groups which indicate that standardization of cutting was achieved for all samples. On the other hand, laser preparation resulted in rougher surface than bur, this is coincide with a study conveyed by Winik et al. who suggested that this roughness can affect the interface between the filling material and retrograde cavity walls according to the viscosity of the filling material which results in increase or decrease the seal between them [141]. From another point of view, Er:Cr:YSGG laser ablation results in a micro-retentive surface because of irregular intertubular dentin surface that will lead to increase mechanical bond between retrograde filling material and dentinal walls [124].

IV. Charring

Er,Cr:YSGG results in charring more than Er:YAG laser under the same conditions, this is because Er:Cr:YSGG laser has higher heat deposition within the tooth [86]. Tissue charring occur when the tissue dehydrated and then burned, the carbon which is the end products of this process is a high absorber of all wavelengths, thus can become a “heat sink” as the lasing continues and the heat conduction will then result in broad collateral thermal trauma [70]. Continuous drilling of 3 mm depth and 1 mm diameter retrograde cavity resulted in charring which may be due to the tip entrapment inside the 1 mm diameter cavity and the water spray didn't reach the cavity during lasing process, to overcome this problem every 1 mm of REP followed by normal saline irrigation using needle gauge 30, this procedure continued till reach 3 mm depth and this resulted in absence of charring with this new method .

V. Energy dispersive X-ray spectroscopy (EDS, EDX)

As it was observed a high fluctuation in the number of cracks between the samples of laser retrograde cavity group, this test was performed in an attempt to understand the cause of those variations among the samples that subjected to the same treatment conditions. SEM-EDS can provide quantitative analysis of the material elemental compositions therefore Ca and P weight % in the hydroxyapatite crystals which constitute the inorganic structure of the dental hard tissues can be determined [144]. It was found that there wasn't correlation between the incidence or the number of cracks and the weight percentage of both P and Ca in the teeth. This results agree with Parker et al. who assumed that many publications about the effect of laser on hard tissues have perpetuated the misguided statements that dental mineral strongly absorbs those wavelengths which misdirects the use of those laser wavelengths because there is a small absorption at around 2800 nm by the hydroxyl group of the (carbonated) hydroxyapatite mineral of the tissues, but this is far dominated by the water effects [92].

VI. Duration of preparation procedure

The time consumed in retrograde cavity preparation using laser was longer than bur and this is coincide with Batista de Faria-Junior et al.[118]

3.2.3 Temperature

Thermal energy released as a result of using laser in endodontic treatment depends on the laser type, pulse energy, pulse repetition rate and pulse duration. Increase in temperature leads to denaturation of enzymes, particularly alkaline phosphatase. Absorption of laser energy results in instant water evaporation which lead to increase in volume and results in the cracking of the dentine structure. External root resorption is also one of its consequences. Because of the reduced vascularization of the surrounding bone, this make it more sensitive to thermal stress than periodontium [145]. Elevation of temperature of more than 10°C on the external surface of root for 1 minute results in external root resorption and necrosis of periodontal ligament [72]. Er:Cr:YSGG laser preparation cut the dentin in a way that the temperature of root surface during cavity preparation remains low due to the energized water molecules, which is critical for the surrounding bone [125]. The recorded temperature in this study was below 37°C for all samples in RER and REP groups, the extreme reduction in temperature in all sample could be related to the limitation of in vitro study as a result of absence of blood circulation role in maintaining the steady temperature inside operation site.

3.2.4 Technique of sample preparation for SEM evaluation

There are two method for sample´s preparation for SEM analysis either by dehydration and drying of samples (direct method) which may create artifacts in hard tissues or creation of replica to the hard tissue (indirect method) but this technique lack the detailed information of the tooth structure [115]. A preliminary study was performed to evaluate the effect of direct method on the hard tissue and results showed that using the direct method with dehydration protocol described by Marchesan et al.[129] didn’t affect teeth adversely as there was no crack detected in 10 random samples prepared using direct method and at 10 kV of SEM analysis, therefore it was suggested that direct method was suitable and doesn’t produce artifact using this protocol of dehydration and SEM setting.

3.3 Conclusion

Under the limitation of this in vitro study and the conditions of the current research. Based on the results obtained, the following conclusion could be obtained:

• Root end surgery using Er,Cr:YSGG 2780 nm laser according to the manufacturer instruction parameters resulted in greater number of crack than the conventional method in both RER and REP.

• Laser can cut the cementum without any damage; on contrary the bur resulted in cracks and damage to the cementum due to the vibration of bur during cutting.

• Larger gap between the filling material and the dentinal wall in laser resected root end (laser resulted in shrinkage of the filling material) than that resected using cross cut carbide bur.

• Both RER and REP using Er,Cr:YSGG 2780 nm laser resulted in rough surface.

• Best method of retrograde cavity preparation is by interrupting the preparation with irrigation in between each 1 mm prepared depth.

• Both process of root end surgery using Er,Cr:YSGG laser took longer time than carbide bur.

• Root end surgery using laser and bur showed reduction in temperature on external root surface below 37°C (the starting point temperature on external root surface).

• REP with Er,Cr:YSGG laser resulted in more smear layer removal and greater number of opened dentinal tubules (DTs) than bur.

• Finally, there is no correlation between the incidence or the number of cracks in laser group and the mineral contents of dentin.

3.4 Suggestion for future works

The future works can be related to anyone of the parameters previously mentioned in this study, which may include :

1-Further different studies on different power and frequency or water/air level that may give better results in the term of endodontic surgery.

2-Further studies about the effect of Er,Cr:YSGG laser on different types of Gutta Percha in the RER process.

3- Further studies about the effect of using Er,Cr:YSGG laser in the REP on different types of retrograde filling material sealing ability.

4- More evaluation of using combination of different tools such as bur, ultrasonic tips and laser radiation in endodontic surgery.

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Appendices

Appendix 1: Filling material-root canal wall interface area measurements (μm^2) for root end resection group, G1: bur root end resection group, G2:laser root end resection.

No.	G1	G2
1	3718	3592
2	1441	12014
3	6075	12242
4	2479	6691
5	1310	2795
6	4507	7276
7	6677	13762
8	5419	5057
9	22809	3822
10	15992	4390

Appendix 2: Roughness score by two observers for root end resection and root end cavity preparation processes, G1: bur root end resection group, G2:laser root end resection group , G3: bur root end cavity preparation group, G4: laser root end cavity preparation group.

No.	**G1 (1st observer)**	**G2 (1st observer)**	**G3 (1st observer)**	**G4 (1st observer)**	**G1 (2nd observer)**	**G2 (2nd observer)**	**G3 (2nd observer)**	**G4 (2nd observer)**
1	2	2	0	2	2	2	2	2
2	2	1	1	3	2	2	1	3
3	2	1	1	3	2	2	1	3
4	1	2	1	2	1	2	1	2
5	1	2	2	2	1	1	1	3
6	2	3	1	2	1	2	1	2
7	1	2	0	3	1	2	1	2
8	0	2	0	2	0	2	1	2
9	0	2	1	2	0	2	2	1
10	0	3	0	3	1	2	0	2

Appendix 3: Smear layer and dentinal tubules score by three observers for root end cavity preparation groups , G3: bur root end cavity preparation group ,G4: laser root end cavity preparation group.

NO.	G3 (1st observer)	G4 (1st observer)	G3 (2nd observer)	G4 (2nd observer)	G3 (3rd observer)	G4 (3rd observer)
1	4	2	4	1	4	2
2	3	2	4	2	3	3
3	4	4	4	4	4	4
4	4	3	4	3	4	4
5	4	4	4	4	4	4
6	4	4	4	4	4	4
7	3	1	3	3	3	4
8	4	1	4	2	4	3
9	4	1	4	1	4	2
10	3	1	2	1	3	1

Appendix 4: number of opened dentinal tubules in root end cavity preparation groups , G3: bur root end cavity preparation group ,G4: laser root end cavity preparation group.

No.	G3	G4
1	0	550
2	65	255
3	3	7
4	13	196
5	13	4
6	7	39
7	61	277
8	3	378
9	21	192
10	143	353

Appendix 5: Temperature measurements of root end resection and root end cavity preparation groups (°C), , G1: bur root end resection group, G2:laser root end resection group , G3: bur root end cavity preparation group, G4: laser root end cavity preparation group.

No.	G1	G2	G3	G4
1	26.6	24.9	18.7	25.9
2	23	23.2	21.6	25.6
3	22.4	24.6	20	25.2
4	22.8	26	26.9	26.8
5	22.5	24.7	25.1	27
6	25.3	25	27.4	25.5
7	22.8	24	24.7	26
8	23.1	24.2	21.9	27.1
9	22.8	23.9	19.6	27.9
10	25.9	24.6	22.6	21.6

Appendix 6: Duration of root end resection and root end cavity preparation processes (minutes) , G1: bur root end resection group, G2:laser root end resection group , G3: bur root end cavity preparation group, G4: laser root end cavity preparation group.

NO.	G1	G2	G3	G4
1	1.37	6.12	1.26	1.14
2	1.45	3.47	1.06	1.44
3	2.06	3	1.17	1.17
4	1.47	4.22	1	4.08
5	1.23	1.29	1.18	1.56
6	2.07	2.08	1.34	3.31
7	2.19	2.17	1.17	4.37
8	1.2	3.17	0.5	4.14
9	1.52	5.07	1.23	2.37
10	1.49	3.34	1.33	1.4

وزارة التعليم العالي والبحث العلمي

جامعة بغداد

معهد الليزر للدراسات العليا

مقارنة بين ليزر Er,Cr:YSGG (٢٧٨٠ نانومتر) والمثقب في عملية تحضير نهاية الجذر:-دراسة مختبرية

رسالة مقدمة إلى
معهد الليزر للدراسات العليا/جامعة بغداد/ لأستكمال متطلبات
نيل شهادة ماجستير علوم الليزر/ طب الاسنان

من قبل

دعاء أياد الميران

بكلوريوس طب وجراحة الفم والأسنان -٢٠١٠

بأشراف

استشاري جراحة الوجه والفكين الدكتور صلاح عبد المهدي

١٤٤٠هـ **٢٠١٨ م**

الخلاصة

المقدمة: جراحة نهاية الجذر هي الخيار المفضل عند فشل المعالجة اللبية غير الجراحية بشكل مستمر أو عندما لا يمكن تحقيقها. تقنيات مختلفة مع أدوات مختلفة تستخدم لتنفيذ هذه العملية مما يؤدي إلى تغييرات مجهريه مختلفة في بنية الجذر والأنسجة الداعمة المحيطة التي تؤثر على نجاح العلاج ونتائجه ؛ لذلك أجريت العديد من الدراسات للمقارنة بينها لتحديد التقنية والأدوات المفضلة.

الهدف: الهدف من هذه الدراسة هو المقارنة بين ليزر الاربيوم كروميوم٢٧٨٠ نانومتر و مثقب كربيد في جراحة نهاية الجذر (استئصال نهاية الجذر وإعداد تجويف نهاية الجذر) فيما يتعلق باختلاف الخصائص والإختلافات المجهريه ، تغيرات درجة الحرارة ومدة اجراء القطع او التحضير.

المواد والطريقة: أربعون سنا مقلوع ذا جذر واحد تم معالجته لبياً ، ثم تم تقسيمها إلى أربع مجموعات وفقًا لنوع العملية. تم استئصال طرف الجذر في المجموعة الأولى باستخدام مثقب كربيد المقطع المحزز بينما تم استئصال طرف الجذر في المجموعة الثانية باستخدام الليزر من خلال طرف الياقوت MGG6 والذي يبلغ قطره ٦٠٠ ميكرومتر (٥ واط ، ٢٥ هرتز ، ٥٠٪ ماء ، ٨٠٪ هواء، ٢٥٫٤٧ جول/سم٢) ،أما تجويف نهاية الجذر في المجموعة الثالثة فقد تم تحضيره باستخدام مثقب كربيد ذا الشقوق وتم تحضير المجموعة الرابعة باستخدام الليزر من خلال طرف زجاج MZ6 بقطر ٦٠٠ ميكرومتر (٣٫٧٥ واط ، ١٥ هرتز ، ٣٠٪ ماء ، ٦٠٪ هواء، ٣١٫٨٤جول / سم٢). تم تسجيل درجة الحرارة على سطح الجذر الخارجي ومدة إجراء القطع أو التحضير.حضرت العينات ليتم فحصها بواسطة المجهر الماسح الالكتروني وذلك لغرض تقييم تغير الخصائص والتغيرات المجهريه. أستخدم جهاز الأشعة السينية الطيفي المشتت للطاقة لغرض قياس نسبة المعادن في العاج للأسنان في المجموعة الرابعة. تم استخدام اختبارات X^2 test/Fisher's exact و Kruskal – Wallis للتحليل الإحصائي ، تم تعيين الفرق المعنوي عندما يكون الفرق الاحصائي $\leq$ ٠٫٠٥ .

النتائج: هناك فرق معنوي بين المجموعة الأولى والثانية فيما يتعلق بعدد الشقوق المتداخلة في العاج حيث نتج عن استخدام الليزر أعلى نسبة من العينات ذات الشقوق المتداخلة في العاج بينما لم يكن هناك اختلاف كبير بينهما من حيث الشقوق الكاملة وغير الكاملة. لم يسبب الليزر تلفًا في طبقة الملاط داخل العينة المعالجة وكان الفرق بين المجموعتين معنويا بدرجة كبيرة. تقييم خشونة

السطح ومدة الاستئصال كشف فرق معنوي إحصائي حيث أنتج الليزر سطح أكثر خشونة وأستغرق وقت أطول لعملية القطع في حين لم يكن الفرق معنويا من حيث قياسات درجة الحرارة. أظهر الليزر أعلى قيمه إحصائية من مثقب الكربيد عند تحضير تجويف نهاية الجذر فيما يخص التشقق العاجي ، خشونة السطح، وإزالة طبقة اللطاخة وفتح الأنابيب العاجية، قياس درجة الحرارة على سطح الجذر الخارجي ومدة تحضير التجويف. في حين أن الفرق الاحصائي بين المجموعتين فيما يخص التقييم الكمي للأنابيب العاجية المفتوحة كان كبيرا جدا.

الاستنتاج: أظهر استخدام الليزر الإربيوم كروميوم في عملية استئصال نهاية الجذر أعلى نسبة من الشقوق في داخل العاج ، بينما لا يوجد ضرر في طبقة الملاط، ووجود فجوة ذات مساحة أكبر بين مادة الحشوة وسطح العاج ، سطح أكثر خشونة وأطول وقت للقطع من المثقب. أظهر استخدام ليزر الاربيوم كروميوم في عملية تحضير جوف نهاية الجذر نسبة أعلى من الشقوق العاجية ، سطح عاج أكثر خشونة ، إزالة أفضل لطبقة اللطاخة ، أكثر عدد من القنوات العاجية المفتوحة ووقت أطول للتحضير من المثقب. لا يوجد ارتفاع في درجة الحرارة على سطح الجذر الخارجي لجميع المجموعات. ولم يظهر جهاز الأشعة السينية الطيفي المشتت للطاقة أي علاقة بين النسبة المئوية لوزن الكالسيوم والفسفور في العاج وبين إمكانية حدوث التشققات.