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

Evaluation of Shear Bond Strength and mechanism of hypersensitivity after laser treatment

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

Done by:
Rusal Mohammed Mubaraq
(B. D. S)

Supervised by
Asst.Prof. Dr.Basima Mohammed Ali Hussien
(B.D.S, M.Sc, Ph.d)

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بسم الله الرحمن الرحيم

﴿ قَالُوا سُبْحَانَكَ لا عِلْمَ لَنَا إِلَّا مَا عَلَّمْتَنَا إِنَّكَ أَنْتَ الْعَلِيمُ الْحَكِيمُ ﴾

صدق الله العظيم

﴿سورة البقرة: 32﴾

Dedication

To my precious mother and father for their endless support, care and love.

To my dears, best ever sister and brothers

To my loving, supporting husband

To my angles Yazan and Hassan

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Abstract

Background: Dentinal hypersensitivity described as severe, and sharp pain evoked by thermal, tactile, osmotic, and chemical stimuli. It is one of the most popular complication, that fallows crown preparation. Crown preparation requires the removal of tooth structure to provide space for the prosthesis. Usually ends with exposed, opened dentinal tubules, which may cause dentinal hypersensitivity. Laser could be considered as an approach for treatment of dentinal hypersensitivity.

This study focused on: testing the effect of Er:Cr:YSGG 2780nm and Fractional CO_2 10600nm lasers on tooth-Zirconia Shear Bond Strength, considering opened dentinal tubule or hypersensitivity, results from crown preparation.

Material and methods: One hundred and fifteen extracted sound maxillary premolars were used. Preserved in a 1% thymole solution. Grouped into five groups, control G(A) received no laser treatment. G(B) Fractional CO_2 10600nm, with (1W, 2.5 ms, 2.5 mJ). G(C) Fractional CO_2 10600nm with (1W, 3ms, 3mJ). G(D) Er:Cr:YSGG 2780nm laser irradiated with (0.25W, 20 Hz, 10% water and 10% air) and, G (E) Er:Cr:YSGG 2780nm laser with (0.5 W, 20 Hz, 10% water and 10% air). The entire samples were prepared by cutting the occlusal part of the crown. SEM examination was done on all groups, temperature change for laser treated groups during lasing was recorded, Change in surface roughness after laser irradiation was recorded, Shear bond strength (SBS) was measured by Universal testing machine. SBS examined samples were examined by stereo-microscope to determine the mode of failure.

The results: SEM examination showed that the control group G(A) with open dentinal tubules, G(B) showed partial occluding of dentinal tubules, while G(C) showed complete occluding of dentinal tubules. Both groups (D and E) also showed complete occlusion of dentinal tubules. All groups showed no cracks or carbonization. Maximum temperature rise was with G(C) with (1.7 °C), while the minimum temperature rise was with G(D) with (0.9 °C). Statistical analysis of roughness measurement results showed significant increase in surface roughness in all laser treated Groups (D, B, and E). except with G(C) showed no significant increase in surface roughness. Statistical analysis for the SBS showed a significant increase in SBS in Group (D and, B). With no significant increase in SBS in GC and GE.

Conclusion: All laser parameters showed effective treatment of opened dentinal tubules, by partial and complete closure. Also they improve bonding strength of resin cement to dentin by increase SBS.The best treatment was with Er:Cr:YSGG with a power 0.25W, pulse repetition rate 20Hz,10 % water and 10% air.

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Lists of Abbreviations

Symbol	**Term**
Er:Cr:YSGG	Erbium, Chromium:Yttrium, Scanium, Scandium,Gallium,Garnet
CO_2	Carbone Dioxide
W	Watt
Ms	Millisecond
mJ	MilliJoule
Hz	Hertz
SEM	Scanning Electronic Microscope
SBS	Shear Bond Strength
°C	Celsius
µm	Micrometer
Nm	Nanometer
Odp	Odontoblast process
KNO3	Potassium nitrate
(Ca(OH)2	Calcium hydroxide
(NaF)	Sodium Fluoride
NaF_2	Stannous Fluoride
FDA	Food and drug administration
He-Ne	Helium Neon
Er:YAG	Erbium-doped Yttrium Aluminum Garnet
Nd:YAG	Neodymium –doped Yttrium Aluminum Garnet
CW	Continuous mode
UV	Ultra-violet
CNC	Computer numerical control
CAD\CAM	Computer aided design and Manufacturing
ANSI	American National Standard Institute

MTZs	Microscopic treatment zone
SD	Standard deviation
SE	Standard error
df	Degree of freedom

Chapter one

Introduction and basic concepts

Chapter one

Introduction and basic concepts

1.1. Definition of Dentinal Hypersensitivity

Dentinal hypersensitivity is defined as short, sharp, painful clinical condition caused by thermal, tactile, chemical, osmotic stimuli on an open dentinal tubule. Dentinal hypersensitivity is a pathological condition not classified under any other condition, such as cracked teeth, fractured restorations, or pulpitis (Arua et al., 2021). It was found that an increase in the number and diameter of open dentinal tubules in teeth with hypersensitivity (Schmidlin and Sahrmann, 2013).

The distribution and appearance of dentinal hypersensitivity has been reported in different studies. A recent review showed that an increase in the prevalence of dentinal hypersensitivity in patients with periodontal diseases (ranging from 2% up to 98%) (Bresciani et al., 2020), and a higher prevalence in maxillary premolars than in other teeth such as canines and molars (Que et al., 2013). Dentinal hypersensitivity shows a Peak under 40 years of age and decreases with increasing age due to tertiary dentin formation (Splieth and Tachou, 2013).

Dentinal hypersensitivity is a multi-factorial clinical condition that occurs when dentin became reveal to oral cavity due to loss of enamel or cementum. Loss of attachment is the most common cause of dentinal hypersensitivity, especially in patients with gingival rescission, as in figure (1-1) (Seong et al., 2018). In teeth with recession the exposed cementum erodes easier than enamel due to their lower inorganic mineral content compared to enamel, so cementum erodes by 35 times faster than enamel, leaving behind exposed dentin that is susceptible to hypersensitivity (Kim and Karastathis, 2010).

Figure (1-1) Gingival rescission (Kasaj, 2018)

Dentinal hypersensitivity may be considering as a post periodontal treatment complications such as scaling and root planning which results in exposed of dentin due to traumatic cementum removal (Draenert et al., 2013).

The main reason for loss of enamel is tooth wear, an irreversible morphological change of the dental hard tissue (Warreth et al., 2020), classified clinically into:

1) Erosion: which defined as a nonbacterial destruction of the enamel due to physical and chemical factors, this includes sever acidic or sour food intake (Carvalho et al., 2015).

2) Abrasion: an abnormal tooth loss due to severe friction between the tooth surface and other objects. For example improper tooth brushing results in a V-shaped notch in the gingival portion of the tooth (Zanatta et al., 2020).

3) Attrition: is a result of bruxism, a parafunctional habit that causes mechanical wear of the occlusal side of the teeth which causes occlusal hypersensitivity (Trushkowsky and Oquendo, 2011).

Clinician reported that most of their patients complain from hypersensitivity after vital tooth preparation for fixed prosthesis, which may occur due to formation of an open passage between the oral environment and pulp tissue via dentinal tubules, dentinal fluid movement inside the dentinal tubules, or both, this causes pulp tissue stimulation (Abdollahi and Jalalian, 2019). During preparation removal of enamel and part of the dentin result in an increase in dentinal tubules' diameter and yet, an increase in their permeability and inducing pulp irritation (Ayer, 2018).

1.2. Anatomy of the tooth

To understand the mechanism, treatment modalities of dentinal hypersensitivity, proper understanding of the anatomy of the tooth is required. The tooth consists of four parts Enamel, Dentin, and Cementum (hard tissues) and Pulp which is a soft tissue.

1.2.1 Enamel

Enamel considers the hardest biological tissue of the body, so its main function is to protect the clinical tooth structure from the force of mastication and other external factors. It also gives the shape and contour of the tooth. Its consists of 96% of inorganic minerals in the form of hydroxyapatite and 4% water and organic components (Berkovitz et al., 2017).

1.2.2 Dentin

Dentin is a mineralized connective tissue that make up the largest part of the tooth structure, making the hard part of dentin-pulp complex, have many functions. It's main function is to provide support to enamel during occlusal load, and prevent enamel fracture (Orstavik, 2020).

1.2.3. Chemical composition

In general, dentin is composed of 70% by weight (55% by volume) of minerals hydroxyapatite and impurities such as sodium, magnesium, potassium, carbonate, and fluoride, and 20% by weight (30% by volume) of organic components that mainly consist of collagen type I which makes 90% of it, and the rest being noncollagenous proteins such as proteoglycans, growth factors, enzymes, and lipids in small amounts. Water makes 10% of the weight of the dentin and 15% of its volume (Tjäderhane and Paju, 2019).

1.2.3.1. Histology of dentin

Microscopic examination of dentin shows many structural features could be recognized. So, the dentin consists of intertubular dentin, peritubular dentin, and dentinal tubules. (figure 1-2)

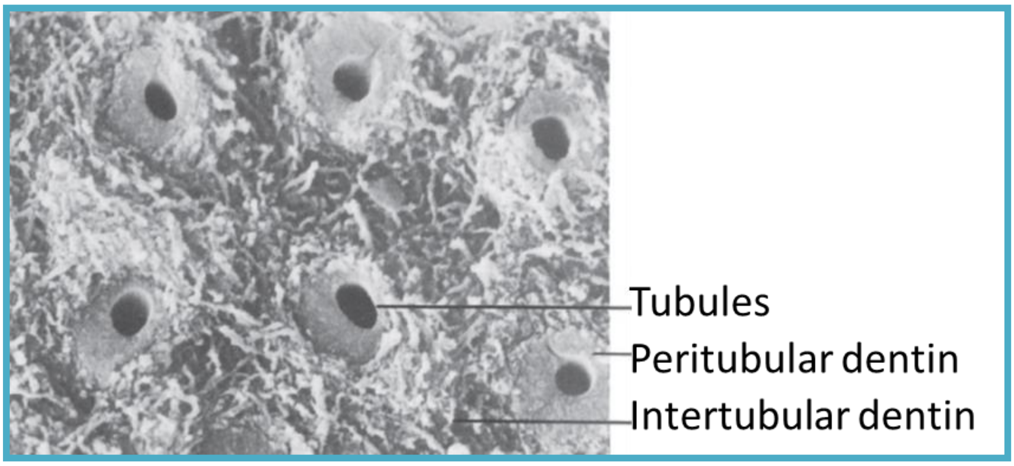

Figure (1-2) Scanning electronic microscope view of the dentin (Nanci, 2012)

1.2.3.2. Peritubular dentin

Peritubular dentin is a collar of highly calcified matrix that border the dentinal tubules. It contains few collagens fibers but a high concentration of noncollagenous proteins. Mechanism of Peritubular dentin formation still obscure (Sui et al., 2018).

1.2.3.3. Intertubular dentin

It is the part of the dentin that spreads between the dentinal tubules. Formed by dentin forming odontoblast and it consists of apatite crystals that participated in a collagen matrix. Also contain noncollagenous proteins that involve in tissues calcification also contain some plasma proteins (Sui et al., 2018).

1.2.3.4. dentinal tubules

The major part of the dentin formed by odontoblast on the dentin-pulp complex border is called dentinal tubules, that cross throughout the whole dentinal thickness, extended from the pulp to the dentin-enamel junction, figure (1-3) (Orstavik, 2020). The odontoblast processes lined up in a direction transvers to the dentin and forming the dentinal tubules, this processes contain afferent nerve endings (Berkovitz et al., 2017). Dentinal tubules are tapered in nature with a diameter of about 2 μm at dentin-pulp complex end and about 0.5 μm or less at dentin-enamel junction (Orstavik, 2020). Dentinal tubules contain the processes of the odontoblasts, in which these processes may have nerve endings. These tubules are filled with extracellular dentinal fluids rich in sodium and potassium ions (Galler et al., 2021).

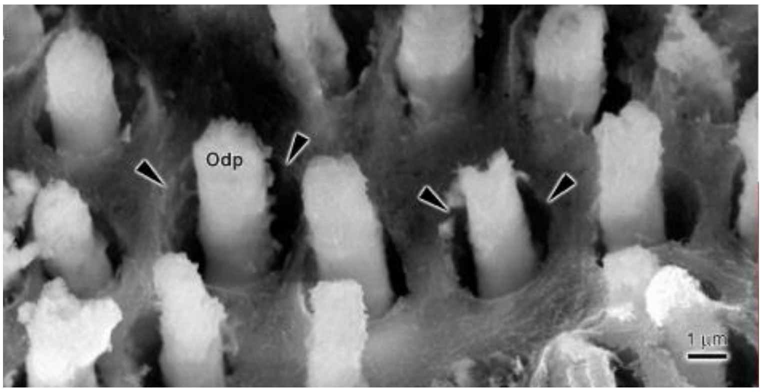

Figure (1-3) Extension of odontoblast processes (Odp) through the dentinal tubules, dentinal tubules comprise the processes of the odontoblasts (arrowheads) (Nanci, 2012).

1.2.2 pulp

The pulp is a loose connective tissue, made of cells embedded in a gelatinous matrix contains chondroitin sulfate, proteoglycan, and interstitial fluid, which consider as transporters of nutrients and oxygen. The pulp consists of 75% of its weight in water and 25% of organic materials. Histologically, from the outer to inner direction, dental pulp has four zones: (1) Cellular zone which run along the pulp border contains odontoblast cells that's why called odontoblast zone. (2) Area devoid from cells (no cells); (3) next to the 2^{nd} area, the cells count increased and concentrate in this zone; and (4) the central part contains nerves and all the blood vessels; it is the pulp core (Nelson, 2014). The apical foramen is the site where the branches of trigeminal nerve emerge in to innervate the pulp and give sensory innervation, then run together with blood vessels. Sensory nerve fibers of the pulp A (δ delat and beta β), (myelinated) which makes about 25% of the pulpal nerves and C (unmyelinated)(Pawar and Singh, 2021).

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1.2.3 Cementum

The outer covering of the teeth's roots is made up of a surface layer of calcified mesenchymal tissues. From the cement-enamel junction to the apex of the tooth, cementum plugs the open dentinal tubules of root dentin and serves as an attachment point for the periodontal ligament, which keeps the tooth in its socket (Berkovitz et al., 2017). At diverse aspects of the roots, the thickness of the cementum varies. It is thickest at the apex of the root and in the inter-radicular portions of multi-rooted teeth, and thinnest at the cervical level. The thickness is 16-60mm in the cervical region and 150-200mm in the apical region (Walmsley et al., 2007).

1.3 Mechanism of dentinal hypersensitivity

Pulp tissue of a vital tooth is highly innervated, and the nerve terminals are secluded from any trigger or excitation because it is surrounded with hard tooth layers (enamel and dentine) (Lee et al., 2019). Thermal and mechanical stimuli such as noxious changes in temperature, brushing, or enamel wear, also in some instances an increasing of the opening of dentinal tubule such as carious tooth, erosive tooth, or even after crown preparation, the dentin will become sensitive (Won and Oh, 2019). Three main theories aimed to explain the mechanism of dentinal hypersensitivity, and they are the Neural Theory, Odontoblast transducer theory, and Hydrodynamic theory, as shown in figure (1-4). (Chung et al., 2013).

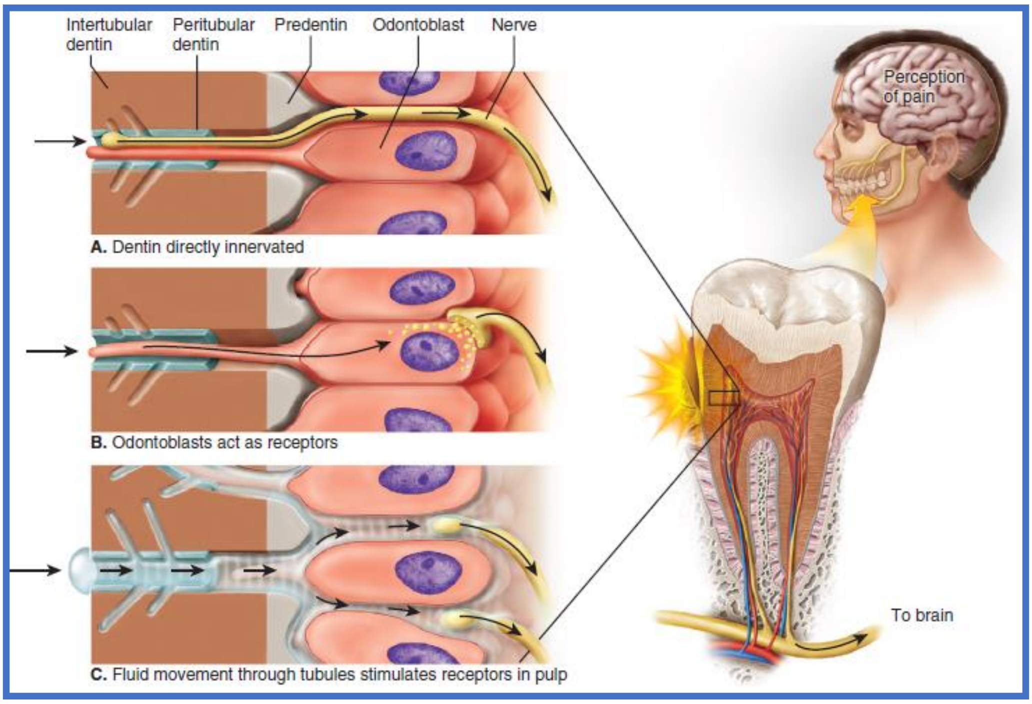

Figure (1-4) Mechanisms of dentinal hypersensitivity: a)Neural (dentine direct innervation) Theory; b) Odontoblast transducer theory; and c) Hydrodynamic theory (Nanci, 2012).

1.3.1 The Neural Theory

The first theory that was believed to explain dentinal hypersensitivity, stated that, the dentin was innervated and direct stimuli to the dentin evoked pain due to stimulation of the dentin (West et al., 2013). This hypothesis was questionable because histopathological studies proved that it was not specific nerve fibers (Rapp et al., 1957). Later, the use of an electronic microscope supported the theory in which it proved that the presence of unmyelinated nerve fibers extended for a short distance in the inner dentin (Frank and Steuer, 1988).

1.3.2. The Odontoblast transducer theory

It was suggested by Rapp et al., returned to the embryology of the odontoblast, which originated from ectomesenchyme cells of the neural crest, and it is responsible for dentin formation (Rapp et al., 1968). They form the outermost layer of the dentin-pulp complex, and the odentoblast processes emerged inside the dentinal tubules (El Karim et al., 2011). This theory suggested that the odontoblasts function as a receptor cells that mediate dental pain sensations, via synaptic junctions with nerve endings that located or defused on the border of the dentin- pulp complex (Shibukawa et al., 2015).

1.3.3. The Hydrodynamic theory

The one that mostly authorized is the hydrodynamic theory. This theory was submitted by Brannstrom and Astrom, by experiment they found drying the tooth using an air puff or using an absorbent paper will induce hypersensitivity (Brännström and Åström, 1964). Basically this theory concentrated on activation of sensory elements on the dentin-pulp area. The external stimuli initiate fluid movement in the dentinal tubules of uncovered dentine (Pashley et al., 1996). According to the type of the stimuli the direction of fluid movement changes this affects the response to sensitivity for example, cooling, drying, hypertonic chemical, and evaporating stimuli lead to movement of fluids away from dentin-pulp complex this induce increase in sensitivity, while heat stimuli causes movement of fluids toward the pulp (Roberson et al., 2006). The most stimuli that trigger pain is cold stimuli 75% of patient feeling pain due to cold stimuli (Miglani et al., 2010).

1.4 Effect of crown preparation on dentinal hypersensitivity

Crown preparation is one of the most effective treatment approaches to conserve a distractive, badly carious, or endodontically treated tooth. But in some instances may need preparation of a vital sound teeth for example, preparation of abutment teeth for fixed bridge (Bader and Shugars, 2009). Dentinal hypersensitivity or pulp tissue reaction is a big concern in crown preparation due to the removal of enamel and friction of the dentin, which leads to an increase in opened dentinal tubules and yet more dentinal sensitivity and pulp damage (Davis et al., 2012). Prepared teeth are mostly liable to have hypersensitivity due to increased number of opened dentinal tubules. After crown preparation, about 1-2 million of dentinal tubules become liable and lack of protection. This lead to subsequent dentinal hypersensitivity(Ayer, 2018). During teeth preparation for crown restoration, part of the tooth structure should be removed up to 1.5 mm, in more conservative preparation the thickness limited to 1.2 mm only, to ensure proper adaptation and retention of the prosthesis (Pilo et al., 2018). Heat generation during preparation and bacterial byproduct formation induce pulpal irritation. Micro leakage of the provisional restoration into the dentinal tubules may induce hypersensitivity (Ra'fat, 2019). Cementation may induce dentinal hypersensitivity to the prepared tooth due to impingement of cement into the opened tubules this will cause changes in dentinal fluid movement and in hydrostatic pressure (Rosenstiel and Rashid, 2003).

1.5 Treatment options for post preparation hypersensitivity

Treatment of dentinal hypersensitivity govern by the occlusion of dentinal tubules, or dentin permeability, and restricting or reducing fluid movement inside the tubules and blocking pulpal nerves (Kingsley et al., 2014), and since this study focused on desensitization of prepared teeth, treatment should not interfere with crown retention (Kumar et al., 2015). Many methods, protocols, and materials are used for achieving not only treatment but also prevention of dentinal hypersensitivity.

1.5.1 Desensitization agents

Many agents used to treat dentinal sensitivity differ in their role of administration and mechanism, but all must meet certain criteria: they must be effective, biocompatible, not an irritant to the pulp, easy to apply, should not cause tooth discoloration, and should not interfere with crown retention when applied to a prepared tooth prior to cementation.

1.5.1.1 Classification of Desensitization agents

- According to their role of administration desensitizing agents can be classified to:
  - At home desensitization.
  - In office desensitization.

- According to action or mechanism classified to: (de Oliveira da Rosa et al., 2013) (Markowitz, 2013) (Romano et al., 2011) (Bartold, 2006)

- Nerve blocking:
- ❖ Potassium nitrate

- Occluding dentinal tubule:
- ❖ A) Scleroting dentinal tubules
- ❖ Fluoride as Sodium or Stannous fluoride or even combinations.
- ❖ Chlorides of Strontium
- ❖ Ions/ salts
- ❖ Potassium oxalate
- ❖ Sodium monofluorophosphate

- ❖ B) Protein precipitants
- ❖ Formaldehyde and Glutaraldehyde
- ❖ Silver nitrate
- ❖ Strontium chloride hexahydrate
- ❖ Casein phosphopeptides

- ❖ C) Dentine sealers
- ❖ Some restorative materials that includes Glass ionomer, and composite
- ❖ Resins
- ❖ Varnishes
- ❖ Sealants

I. Nerve blocking

Potassium nitrate (KNO3)

The role of potassium nitrate on treatment of dentinal hypersensitivity have been demonstrated previously in studies. Its effect in blocking of dentinal tubules by crystallization was maintained (Markowitz, 2013). Also it was investigated clinically and found that when compared to a control paste, 5% of potassium nitrate helps to block dentine sensitivity for few weeks when it introduced with toothpaste contains low abrasive criteria. Potassium nitrate in bio-adhesive gel has also been proven to be beneficial in reducing dentinal hypersensitivity without any changes to pulp (Mishra et al., 2021).

II. Occluding dentinal tubules.

a. Scleroting dentinal tubules

1.Calcium hydroxide (Ca(OH)$_2$

Have been used for treatment of dentinal hypersensitivity it is mode of action based on the dentinal tubules obliteration by linking the calcium ions to the protein radicals, also it acts by increasing surface dentin mineralization (Romano et al., 2011).

2.Flouride

Many studies improve the success of fluoride in the treatment of dentinal hypersensitivity. Fluoride increase enamel and dentin mineralization, decrease permeability of the dentin by precipitation of calcium fluoride crystals inside the dentinal tubules (Orchardson and Gillam, 2006). Various fluoride compounds are used for treatment of dentinal hypersensitivity. These include sodium and stannous fluoride (Hu et al., 2018) .

Sodium Fluoride (NaF)

Sodium fluoride is very effective in management of dentinal hypersensitivity. Some studies indicated an effective management of root dentine using toothpaste with sodium fluoride through enhancing dentin resistance to acid decalcification, also it inducing mechanical occluding of exposed dentinal tubules by precipitate fluoride into the dentinal tubules (Xia et al., 2020). Studies that used NaF containing tooth paste or mouth washes showed effective reduction of dentinal hypersensitivity (Anderson et al., 2020) .

Stannous Fluoride (SnF_2)

Clinical study shows effective coating and occluding of dentinal tubules of toothpaste contain stannous fluoride, its effect is by generating a calcified segments on the dentine surface, obstructing the tubules (Hines et al., 2019). On the other hand it may accumulated on the dentine surface, occluding the exposed dentinal tubules (Takamizawa et al., 2019).

B. Protein precipitants

Formaldehyde or glutaraldehyde

The capacity of formaldehyde and glutaraldehyde to accumulate some proteins of saliva in dentinal tubules has led to claims that they can be used to treat dentinal hypersensitivity. This impact, however, is not permanent and this is due to many formulas that have no effect on treatment of dentinal hypersensitivity (Bartold, 2006).

1.5.1.2 Treatment of Dentinal hypersensitivity by laser

The first use of lasers to treat dentin hypersensitivity was in 1980. Lasers are superior to other therapies because they are simple to use, safe, and reliable, and they have a quick analgesic impact. The ability to control tissue reactions and alleviate pain (Moeintaghavi et al., 2021). Lasers are effective not only in terms of treatment of dentinal hypersensitivity, but also in the prevention of this intensive tooth pain(Rezazadeh et al., 2019). High-intensity lasers, such as Nd:YAG , CO_2 ,and Er:YAG lasers, raise the temperature of the dentin, causing fusion and the obliteration of dentinal tubules (Mendes et al., 2021). Low-intensity lasers, on the other hand, do not emit heat and have a short wavelength that stimulates the normal functioning of cellular functions, acting in biostimulation due to increased mitochondrial ATP production, resulting in an increase in the excitability threshold of free nerve endings, resulting in analgesic actions (Carroll et al., 2014).

1.6 Laser light

1.6.1. Fundamentals of the laser

Laser light is a form of electromagnetic spectrum, exist as a particle, moves as waves in one speed. Photon is the basic unit of that spectrum. Waves of the photons define by their basics properties: **Amplitude** which is the vertical height of the wave from zero to the peak of the wave, potential work respond in a direct manner to it when amplitude increased. For a wave emitting light, amplitude correlates with **brightness** and **Wavelength** which is the horizontal distance between two point in the wave that are adjacent to each other. In dental practice wavelength important which determine how laser deliver to the operation site and how to interact with the tissue (figure 1-5) (Renk, 2012).

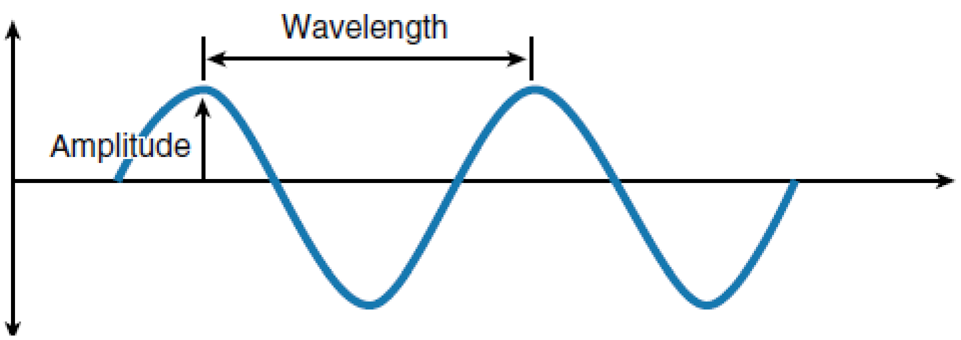

Figure 1-5 properties electromagnetic waves (Convissar, 2015).

As the waves travels cross the zero axes up and down in certain times per one second known as oscillation. And the number of oscillations per time is called **Frequency**. Also it refers to the number of pulses per unit time, which inversely proportions to the wavelength (Renk, 2012).

1.6.1.1. Component of the laser cavity

Laser cavity consist of three parts as fallowing:

A. active medium: The main part of the laser cavity made of compound or a molecule that the laser named according to. Types of active medium as fallowing:

- **Gas Laser:** which is a Container of gas or mixture of gases such Helium and Neon in He-Ne laser that emitted in the visible range with (632.8 nm) (Webb, 2010).
- **Solid state lasers:** A crystal of solid matrix, such as Nd:YAG . the crystal Yttrium Aluminium Garnet which function as the host for the Neodymium ions. With wavelength of (1064 nm) (Fan et al., 2020).
- **Semiconductor lasers:** (or diode lasers). Which consist of two layers of semiconductor material sandwiched together. Diode laser with multiple wavelengths 810, 840, 940, 980,1064 nm (Ning et al., 2021).
- **Dye Lasers:** A suspension filled with organic dye. They characterized by their "tunability." That different wavelengths can be obtained from the same laser. For example Rhodamine 6G with tunability in two wavelengths 200 nm and 620 nm (García-Villarreal et al., 2021).

B. Pumping source: Also called Exiting source. That delivers energy to the active medium which give raise to an excited state. This could be an Optical pumping system that use flash lamp of Xenon gas or may use other laser such us Diode laser (Wang and Groves, 1992).

Other example (Chemical pumping system) that use chemical reaction to exited the active medium. Another pumping mechanism by electrical source (Parker, 2007).

C. **Optical resonator**: represent by pair of mirrors located at each side of optical cavity and aligned parallel to each other, but in semiconductor Diode laser two highly finished surfaces instead of the mirror at both ends. These mirrors or polished surfaces reflects the waves back and forth. These multiple reflections enable collimating and amplification of the laser beam..(Convissar, 2015). (figure 1-6)

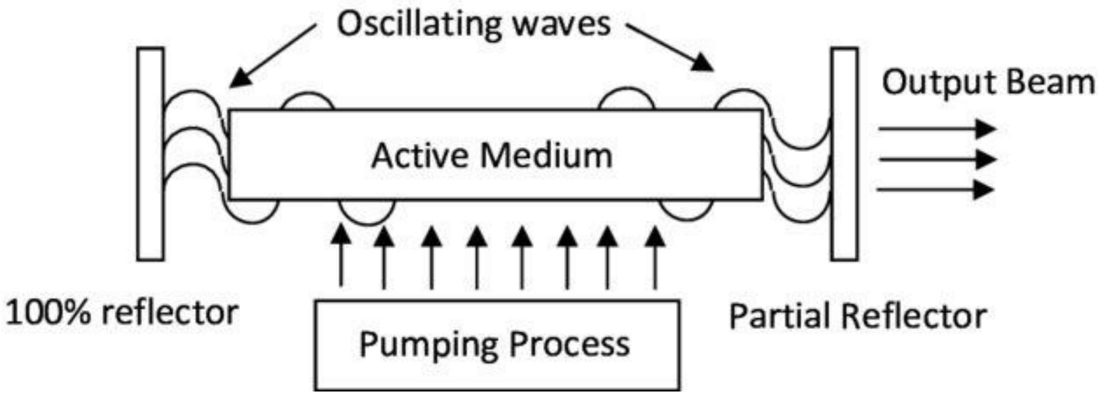

Figure (1-6) Schematic image of main components of laser system (Renk, 2012).

D. **Cooling system:** Heat generation is one of side effect of lasing process and consider as a loses inside the laser cavity, increases with increased power. Co-axial cooling systems represented by air or water (Jianyu et al., 2021).

E. **Delivery system:** is the part of the laser device that deliver the laser radiation from the laser cavity to the tissue. Many delivery systems are available and the selection of the type to be used depend on the wavelength. These are quartz fibrotic, a flexible hollow waveguide, an articulated arm (incorporating mirrors), or a hand-piece containing the laser unit (Khalkhal et al., 2019).

1.6.2. Production of laser light

After identifying the components of the laser cavity and their types, maintaining the process of laser light production will be obvious. Pumping or exiting source surrounded the active medium, pumps energy to the active medium, and the electrons of the outer shell of the active medium absorbed pumped energy and exited to the next shell far from the nucleus with higher energy level. When number of exited electrons in higher energy level is more than that found in the ground state, this situation called **population inversion.** Exited electrons gives away their energy in the form of photon and return to the ground state this called **spontaneous emission,** figure (1-7). Optical resonator reflects the waves to increase excitation of the active medium. Further amount of energy absorbed by atoms that already energized resulting in release of two identical photons move in coherent waves. These photons also exited other atoms result in amplification of radiation inside laser cavity and finally production of laser beam (Freitas and Simões, 2015) (Convissar, 2015).

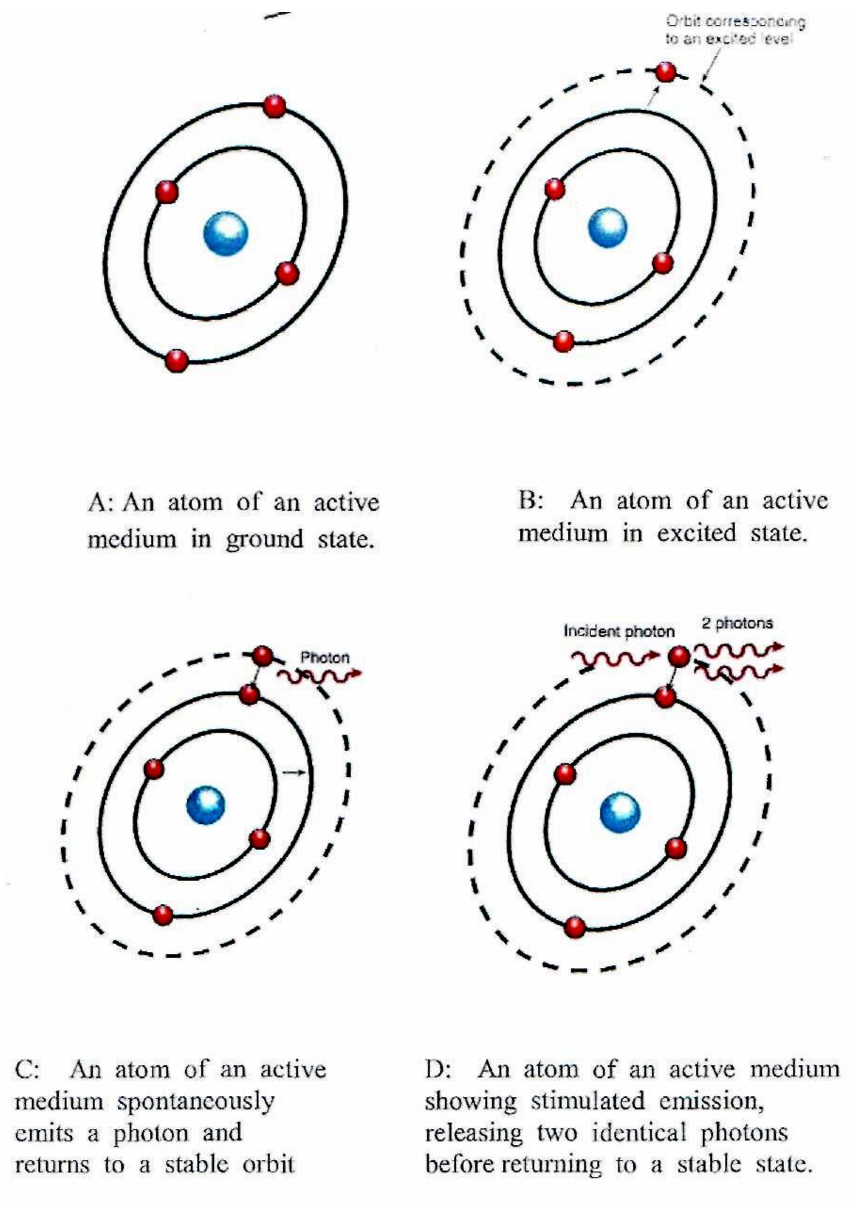

Figure (1-7) Spontaneous and Stimulated emission (Convissar, 2015)

1.6.3. properties of the laser light

1. **Coherence**: This mean that all the waves identical in frequencies and amplitudes.This property makes the laser light a very focused electro-magnetic radiation (Convissar, 2015). In the coherent light waves , their oscillation overlapped in space, and time (spatial, and temporal coherence) (Donges and Noll, 2014).

2. **Collimation:** Collimated light have all their waves travels in the same direction (unidirectional) and parallel to each other. Laser light consider the most collimated light waves ever, it can travel for a long distance with very little divergence (Silfvast, 2008). As in figure (1-8).

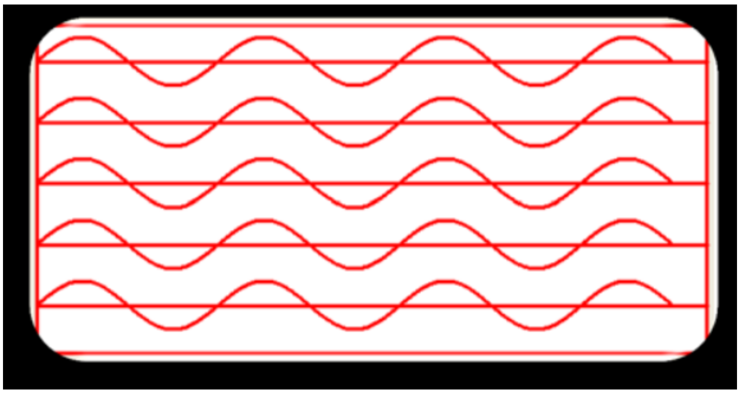

Figure (1-8) Distribution of light waves within a highly collimated laser beam (Dawood, 2014).

3. **Monochromatic:** Mean have one color in which laser light emitted waves with single wavelength. In contrast to ordinary light which emitted in multi wavelength as in (figure 1-9) (Silfvast, 2008).

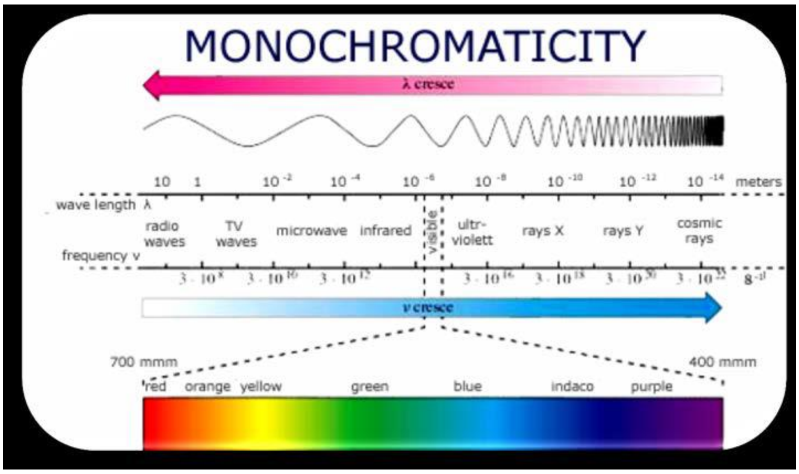

Figure (1-9) Monochromaticity of laser light with emission at precise wavelength (Dawood, 2014).

4. **Focusability:** focusing of the laser beam within a minute spot size in some applications is required. The smallest diameter obtained

from a laser beam in the single transverse electromagnetic mode (TEM00), which is approximately the dimension of the wavelength of the laser (Donges and Noll, 2014).

1.6.4. Laser emission modes

1. **Continuous mode**: meaning emitting radiation with one power as long as the device is operating for example He-Ne laser (Convissar, 2015).
2. **Gate-pulse laser:** represent alteration of the laser energy by mechanical shutter in front of continuous emission. Previously these shutter were mechanically open and close now a day new computer-controlled shutters developed that gives a very short pulses. These short pulse durations, includes super pulse and ultra-speed. All surgical laser with continuous emission mode have Gate-pulse feature (Convissar, 2015).
3. **3.Free-running pulse mode:** This is a true pulse in which laser emission with peak power usually within a microsecond fallowed by long period of laser turn of. Free-running pulsed lasers have a rapid strobe flash lamp that pumps the active medium. These pulses are characterized very high peak powers may rise up to hundreds or even thousands of watts. Free-running pulsed lasers cannot have a continuous-wave or gated-pulse emission mode (Silfvast, 2008).

1.6.5. Laser tissue interaction

Laser tissue interaction depend on tissue optical properties represent by coefficients of reflection, scattering and absorption. Laser tissue interaction represent with four types of interactions, described as following (figure 1-11).

- **Reflection:** Is the redirection of laser beam by reflecting surface where it incident on. Reflecting surface is a physical boundary between mediums with two different indices of refraction for example air and tissue. Reflected radiation have no effect on the tissue but may be dangerous because the radiation may have redirected and cause eye or skin damage (van Gemert and Niemz, 2013)
- **Transmission:** Is the passing of laser radiation throughout the tissue directly, without any interaction with that target tissue. This effect depended on the type of tissue and wavelength of laser light, for example; Erbium and CO_2 lasers absorbed by water while Diode and Nd:YAG transmitted by the water. (van Gemert and Niemz, 2013).
- **Scattering:** Is the changing in photons directions, promotes absorption, this because the enhanced opportunity of interaction between the laser and the chromospheres. It is commonly cause heating of the adjacent tissues or structures (van Gemert and Niemz, 2013).
- **Absorption:** is the most preferred effect on the tissue in which the target of laser treatment is the absorption of the laser radiation by the tissue.

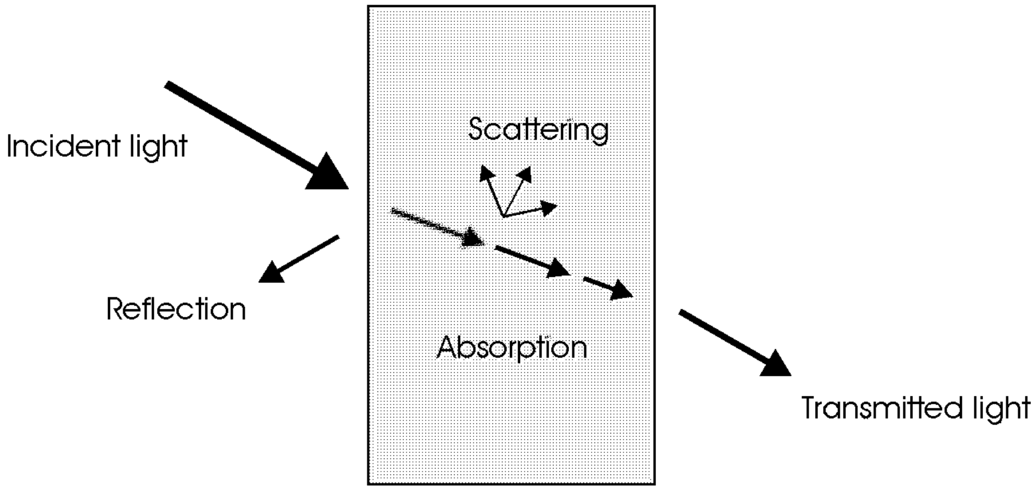

Figure (1-11) Laser tissue interaction (van Gemert and Niemz, 2013).

1.6.6. Laser Tissue Interaction Mechanisms

Many different interaction mechanisms occur between laser radiation and the irradiated biological tissue depends on tissue characteristics (tissue optical properties and thermal tissue properties) together with laser parameters that includes: wavelength, exposure time, energy, power, energy and power densities, special consideration for the exposure time which is an important parameter for selecting interaction type. These interactions are photochemical interactions, photothermal , photochemical, photoablation, plasma-induced ablation, and photodisruption, figure (1-12) (Renk, 2012).

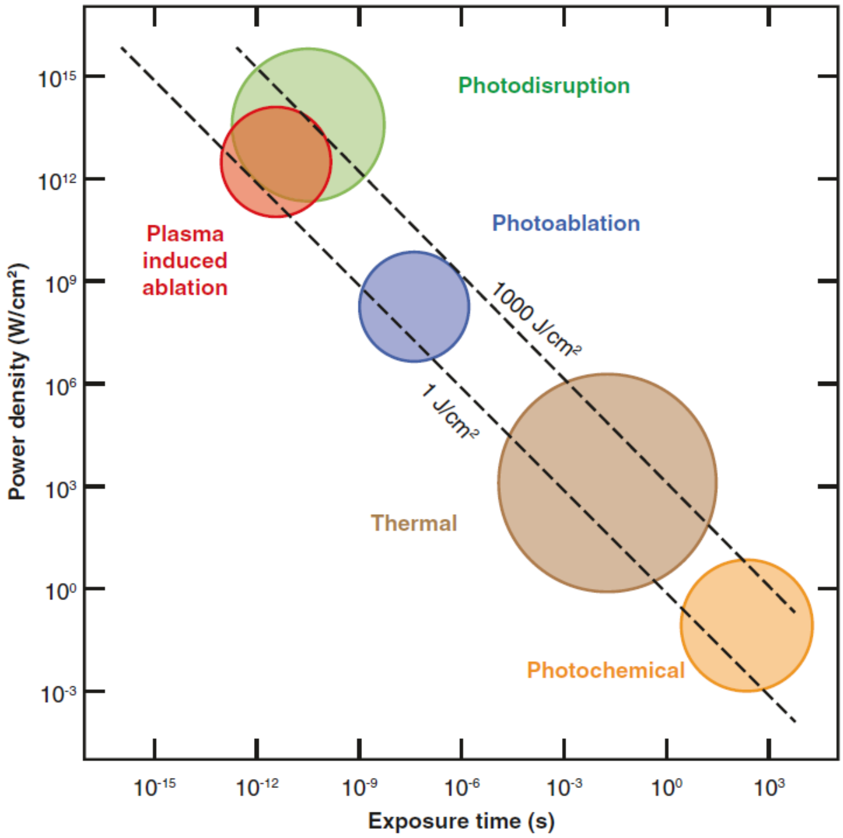

Figure (1-12) Laser-Tissue interaction map (Renk, 2012)

1.6.6.1. Photochemical Interaction

Photochemical interaction occurs at power density that is very low, mainly ($1W/cm^2$) with a long exposure time. In which light waves can induce chemical effect on biological tissue. Distribution of these waves inside the tissue represent by scattering. The most lasers used in photochemical interaction are in the visible range because of their high optical penetration depth and their efficiency. Photochemical interaction represents by photodynamic therapy and bio-stimulation (Romanos, 2021).

1.Photo-Dynamic therapy

Is one of the most popular treatment approach of cancer. Chromophores (Photosensitizer) have the ability to induce light interactions are injected into the body. Laser induces selective photochemical reaction; releasing highly cytotoxic reactants producing an irreversible oxidation of major tissue cells components. Photosensitizer when excited with their stored energy moved from resonant absorption, when deactivated it leads to toxic interaction while the photosensitizer are left as in its normal position, it is also called photosensitized oxidation figure (1-13) (Abdel-Kader, 2014).

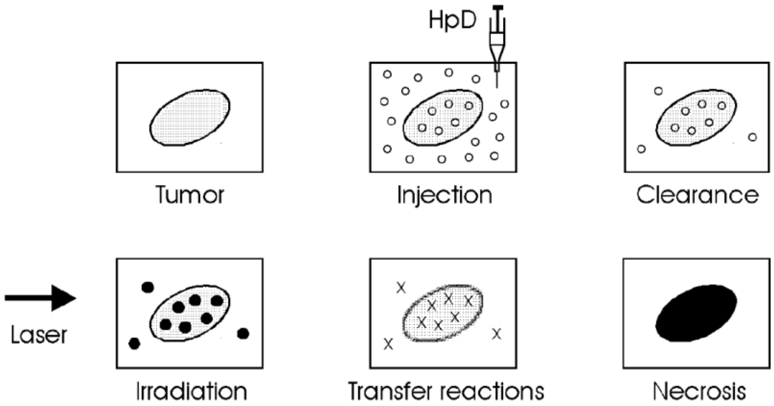

Figure (1-13) Scheme represent steps of Photodynamic therapy (van Gemert and Niemz, 2013).

2.Biostimulation

This therapeutic effect occurs within visible or near infrared range of the spectrum from 630 to 980nm, with a very low output power range from 50- 500mW, with pulse or continuous emission mode. In this range the main absorption occurs at muscles while skin, bone, and mucosa are transparent. The advantage of this therapy is when laser initiates ordinary biologic processes affecting cells by lowering oxidation–reduction interaction. Cells within the low redox are acidic, but when laser irradiation is finished the cells functionally are performing as in normal way almost in ideal way, here the cells now are alkaline. The main effect is the increase of ATP (fuel of the cells) and synthesis of Mitochondria (Mester, 2013).

1.6.6.2. Photothermal Interaction

Photothermal interaction stand for a numerous types of interactions depend on duration and peak power. It's generally tend to be nonspecific interaction, increase in tissue local temperature is the main effect. Photothermal effect can be induce with both CW or Pulsed lasers. These interactions are: Coagulation, Vaporization, Carbonization and melting. Table (1-1), along with figure(1-14),will summarize all thermal interactions(van Gemert and Niemz, 2013)

- **Coagulation** occurs when tissue temperature is between 60 °C and 100 °C. In this range of temperature rise denaturation of collagen and protein occurs, leading to cell death, and subsequently, tissue necrosis (Franzen, 2011).

- **Vaporization** happens when tissue temperature reaches 100 °C. In this phase water of the molecules vaporized lead to steam of gasses or bubbles formation which significantly enlarge the volume making progress increase in pressure affecting the tissues by rupture or decomposition, leaving hollow of ablation in addition to further damage to the adjacent tissues (Franzen, 2011).

- **Carbonization** if the temperatures exceed 150 °C. Carbonization of the tissue can be observing by smoke liberation and darkness of the sites. Charring of all tissue organic component because of its conversion to carbon. Carbonization simply is avoided through profound cooling using air or water (Franzen, 2011).

- **Melting** results in when temperature exceeds 300 °C, considering the melting point of the irradiated structure. With sufficiently high power density of pulse laser, the temperature may rise even above melting point (Franzen, 2011).

Table (1-1) summary of Photothermal Interaction (Stübinger et al., 2020)

Temperature (°C)	Biological effect
37	Normal
45	Hyperthermia
50	Cell immobility
60	*Coagulation*
100	*Vaporization*
>150	*Carbonization*
>300	*Melting*

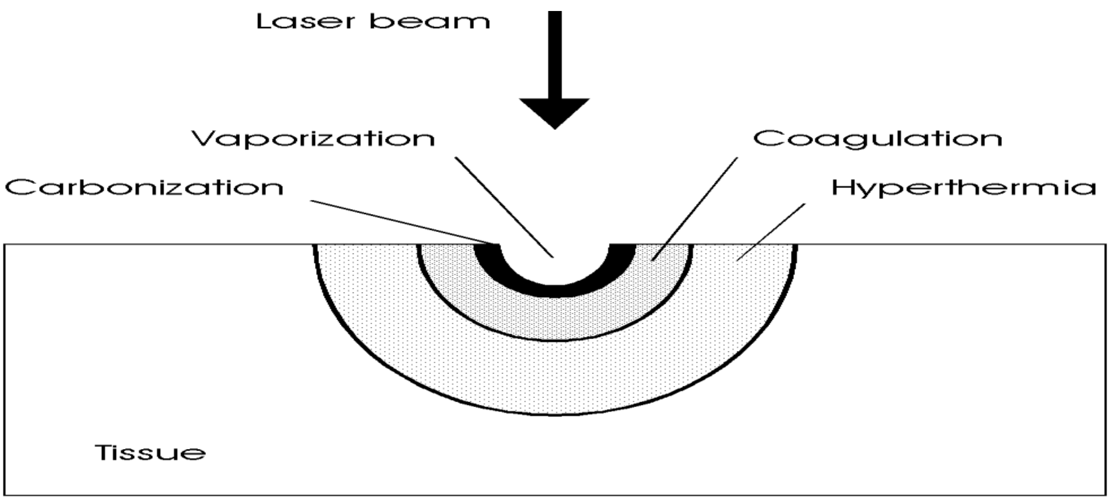

Figure (1-14) Scheme of Photothermal interactions (Stübinger et al., 2020)

1.6.6.3. Photoablation

This interaction take place with very high power density, typically 10^7 -10^8 W\cm^2 this power generates by UV Lasers. This lasing process should be performing in very short time (nanoseconds) to avoid surrounding tissue thermal damage. Photoablation is a mechanical process induce tissue thermoelastic expansion due to laser high energy densities. Figure (1-15) will summarize the ablation process (Stübinger et al., 2020).

Figure (1-15) Summary of Photoablation process (Stübinger et al., 2020)

1.6.6.4. Plasma Induce Ablation

Occur at a concentrated energy in time and space. With power density 10^{11} W/ cm^2. And a very high electric field of about 10^7 V/cm experienced by the tissue led to optical break down, producing large number of free ions and plasma over very short time within femtosecond or picoseconds. A clear well defined removal of tissue can be performed by this interaction without thermal or mechanical damage. (Romanos, 2021).

1.6.6.5. Photodisruption

Mechanical effect of extremely high intensity laser that produce plasma due to optical damage to the tissue. A shock waves are created with the high-energy plasma. Furthermore, the other mechanical consequences of optical breakdown can destroy the tissue by (photomechanical effect). If soft tissues are irradiated with laser or even if fluid irradiated, then jet formation or cavitation that composed of CO_2 gas and gaseous vapor usually result. Photodisruption effect can be spread to adjacent tissues (Freitas and Simões, 2015).

1.7. Interaction of Laser with Dental Hard Tissue

In dental practice, lasers are the tool of choice in many situations as anti-inflammatory effects, hard or soft tissue surgery, caries prevention, caries removal, decontamination, cavity preparation, treatment of dentinal hypersensitivity and caries decontamination (De Moor and Delmé, 2009), (Rechmann et al., 2011). Heat is generated in all irradiation when high powers lasers are used (Ana et al., 2007). Choosing the appropriate laser wavelength to assume the wanted interaction is very important. All laser radiation must be absorbed by the tissue to ensure a localized thermal effect without causing damage to the surrounding tissues (van Gemert and Niemz, 2013). The following table (1-2) will maintain mostly used laser in dental practice and their main applications.

Table (1-2) High Power Lasers used in dental practice (Freitas and Simões, 2015)

Laser	Wavelength	Emission mode	Typical pulse width	Main interactions	Main clinical applications
CO_2	10600nm	-CW, and -Gate pulsed	Continuous, 50 ms	WaterH_2O, hydroxyapatite (PO_{-4} radicals)	Coagulation, Soft tissue surgery, and caries prevention
Er:YAG	2940nm	Free running pulse	100-150 µs	WaterH_2O	Cavity preparation, caries removal, bone, hard and soft tissue surgery. Caries prevention, decontamination, endodontics.
Er:Cr;YSGG	2780nm	Free running pulse	140 µs	WaterH_2O, hydroxyapatite (OH- radical)	Cavity preparation, Bone, Hard and Soft Tissue surgery. Caries prevention, endodontics. hypersensitivity,

					and decontamination,.
Nd:YAG	1064nm	Continuous, Free running pulse	Continuous or 100 µs	Melanin, hemoglobin	Soft tissue surgery Caries prevention, , hypersensitivity, decontamination, endodontics.
Diode	810-980nm	CW, Gated pulsed	Continuous or 50 ms	Melanin, hemoglobin	Endodontics, Soft tissue surgery, and decontamination,

CW: continuous mode

Hydroxyapatite is the main constitutes of hard dental tissues as cementum, enamel and dentine. Dentin characterized by low thermal conductivity, this could indicate a significant rise in local temperature (Srimaneepong et al., 2002). photothermal and photomechanical effects are mainly results in laser application in hard tissues. Due to composition of dentin which, consist mainly from hydroxyapatite and, water. Lasers that emitted in the infrared region is the most effective on dentin as shown in the figure (1-16) (Franzen, 2011).

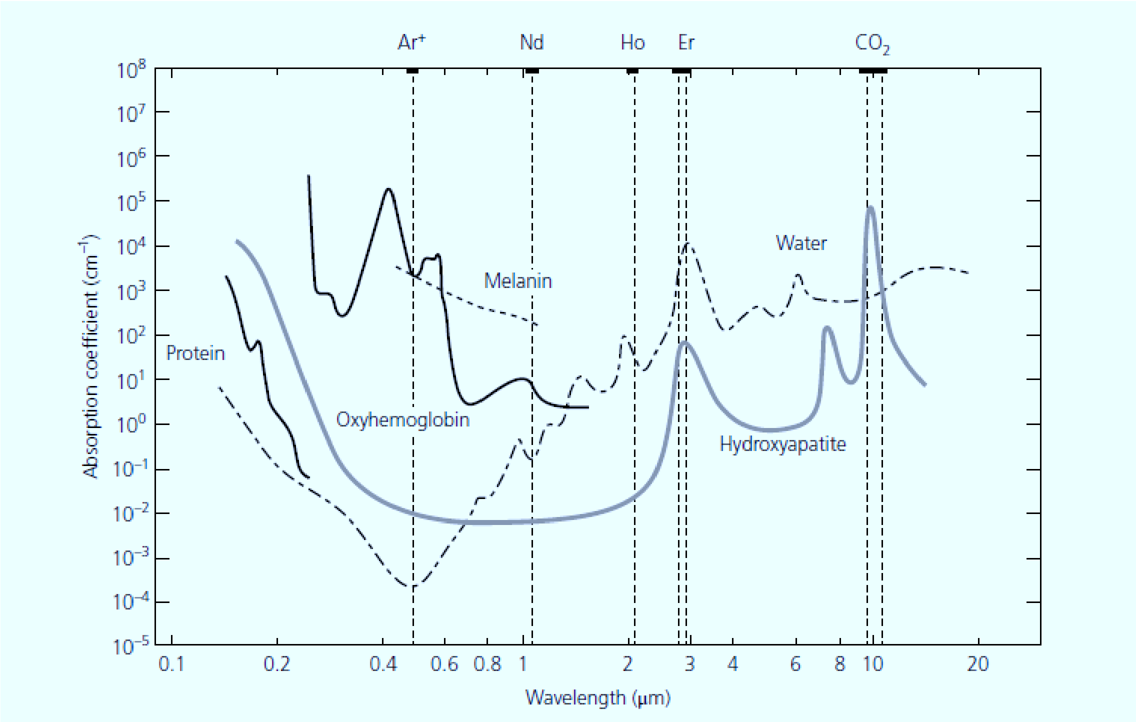

Figure (1-16) Chromophores with their absorption coefficient with the main dental lasers (Freitas and Simões, 2015).

Erbium lasers perform thermal ablation to the dental hard tissues, this process is explosive in nature mediated by water. This application cause heating of the water in the sub-surface layers, the temperature may exceed 100 °C considering the surrounded hard tissue to these heated sites creates pressure overcome tissue strength causing an “explosion” with removal of hard tissues. To allow for this phenomenon it is important not to exceeds melting point of enamel or dentine which may around (1200 °C), depending on laser type (e.g. ablation threshold of Er:YAG lasers is at 300 °C while Er,Cr:YSGG lasers reaches up to 800 °C, and CO_2 lasers 1000 °C) (Jelínková, 2013)

Tissues with large water content can absorbed radiation from CO_2 laser easily, with superficial penetration. Also dental hard tissue has great interaction with CO2 laser because 10600nm wavelength has great absorption of hydroxyapatite. CO_2 laser has a small penetration depth with low risk to create deep thermal damage, considering proper selection of the parameters(Freitas and Simões, 2015). Interaction of CO_2 laser with water are similar to interaction of Erbium lasers, while with hydroxyapatite it induce melting and recrystallization (Endo and Walter, 2018)

1.8. Literature review of treatment of post preparation hypersensitivity

Laser is one of the most popular choices for treatment of dentinal hypersensitivity, and its effects differ depends on the laser type to be used, irradiation parameters, and applications techniques (Al-khafaji et al., 2018). There are two options for treatment of dentinal hypersensitivity by laser the first is low level laser therapy (low power lasers like He-Ne and Diode lasers). The other option is middle output lasers power (Nd:YAG, Er:YAG, ErCr:YSGG, and CO_2 lasers) (Rezazadeh et al., 2019). The mechanism of treatment of dentinal hypersensitivity by law power and high power lasers can be explained in the figure (1-17) (Freitas and Simões, 2015).

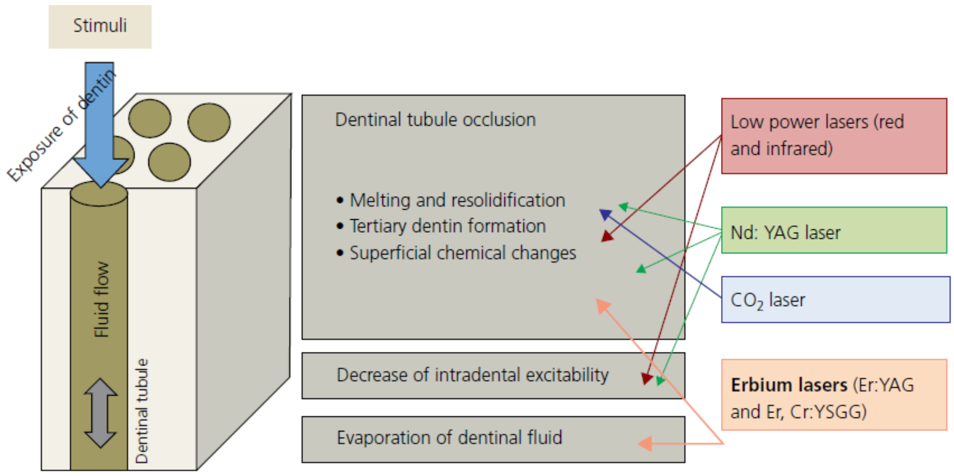

Figure (1-17) scheme represent treatment mechanism of dentinal hypersensitivity by lasers (Freitas and Simões, 2015).

The start point of using He-Ne laser in the treatment of dentinal hypersensitivity, was with an output power of 6mW with two types of irradiation modes: the first one pulsed at 5Hz and the other was a continuous mode (Senda, 1985). He-Ne laser irradiation to teeth does not cause any morphological changes to the dentin surface, but part of the radiation reaches the pulp throughout the dentin. He-Ne effected the electric activity (action potential), which were had an effect lasting for a long period, by increasing the values of nerve action potential up to eight months fallowing the radiation. The effectiveness of desensitization with He-Ne was ranged between (5.2%- 17.5%) (Rochkind et al., 1986).

Many studies used Diode lasers for treating dentinal hypersensitivity. Diode lasers are used in high and low powers. Using a Diode 660 nm at 30 mW and, 810 nm at 100 mW (low power) for 2 minutes, showed effective reduction in dentinal hypersensitivity (Naghsh et al., 2020). Diode laser 980 nm with 1 W, continuous non-contact mode shows effectiveness reduction of dentinal hypersensitivity (El Mobadder et al., 2019).Diode laser 980 nm with 3 w, for 1 min, in continuous, non-contact mode for dentin desensitization result in decreasing shear bond strength between resin composite and dentin (Gupta et al., 2017).

Nd:YAG used for treating dentinal hypersensitivity, Nd:YAG 1064 nm used at power of 1 W , 100mJ/pulse, 10 Hz ,non-contact mode with 2mm distance between the laser tip and the dentin surface. And the other parameter cooling with water with a power of 4 W, energy density 80 mJ/pulse, PRR 50 Hz, water and air, in contact mode (gently moving in a zigzag pattern)). SEM images showed that both parameters used had effective occlusion and reduction in diameter of the dentinal tubules by melting the superficial layer of the dentin , but when used without water it shows micro cracks in the samples (Xiao et al., 2017) . Beside their occlusion effect of latent dentinal tubules Nd:YAG laser can also improve shear bond strength of resin to desensitized dentin, the parameters used (power 1W. energy 40 mJ, 25Hz, with an irradiation time of 60s) (Fatih et al., 2019).

Er:YAG laser is an useful tool for treatment of dentinal hypersensitivity. Many parameters was investigated (0.5 W, 50mJ, 167J/cm^2 ,and 10Hz) ,(1W, 50mJ, 334 J/cm2 ,and 20 Hz) ,(2 W, 100mJ, 668 J/cm^2 ,and 20Hz) and ,(4W, 200mJ, 1336 J/cm^2,and 20 Hz), the suitable occluding dentinal tubules without any damage to the pulp tissue, were with the use of a power with 0.5 W, energy density 167 J/cm^2 (Zhuang et al., 2021). A comparative study that used CO_2 and Er:YAG and evaluate their effect on occluding of dentinal tubules the parameters used for CO_2 was 2W , and energy density 2.7 J/cm^2 in a repetitive pulse mode , and setting Er:YAG in 40 mJ/ pulse , 10Hz and in contact mode with continuous irrigation by water. Both shows effective occluding of dentinal tubules, but Er:YAG had more significant effect (Belal and Yassin, 2014). Dentin surface desensitization with Er:YAG with two powers (2.1W , 30 Hz, 70 mJ) and (4.8 W, 30 Hz,160 mJ) also improve bonding of resin to dentin, after cementation with self-adhesive resin cement. The result of shear bond strength showed that in 160mJ have higher bonding strength than the other parameter obtained (Capa et al., 2010). CO_2 laser is one of the lasers used in dental practice and many clinical trials found that it can be used safely on dental hard tissue without necrosis or pulp damage and had pleasing result especially with dentin desensitizing (Praveen et al., 2018). CO2 with 50 W, 2.5mj, ultra-pulse mode that resulted with successful melting of dentinal tubules leading to partial occlusion of the tubules, with no carbonization or cracks(Gholami et al., 2011)

A study used Er:Cr:SSGG 2780nm at a power of 0.25 W and a PRR of 30 Hz ,with Mz5 laser tip applied perpendicularly, traveling slowly for 30 s and 5 mm distance between the tip and tooth surface. SEM evaluation shows optimum closure of almost all the dentinal tubules, the rest tubules showed narrowing in the size of the orifice (Habdan et al., 2017).

Er:Cr:YSGG also used for the treatment of post preparation sensitivity with 0.5 W potency for 15 s . laser irradiation causes morphological changes to surface of dentin, the results of scanning electron microscopy (SEM) examination showed using of the Er,Cr:YSGG laser with for 15s and a power of 0.5 W, to treat opened dentinal tubules gave good closure of them, it shows debris accumulation at the orifice of the tubules , describing lasers desensitization. However significantly deterioration of the tensile bond strength values with glass ionomer cement was resulted following laser desensitizing treatment in comparison to the control. This picture is differ when Self-adhesive resin was used with marginal improvement following laser application (Kumar et al., 2015).

Desensitizing agents are used in dental practice, but consequences of their desensitization on the retention of crown restoration have been questionable. A combination of Gluma with GIC resulted in a decrease in crown retention values but with no significance. While application of Ultraseal desensitizing agent to GIC resulted in a decrease in crown retention and was statistically significant (Mapkar et al., 2018). Raphael et al in 2016 found that an 8.0% arginine and calcium carbonate safely treated sensitivity resulted from cementation with no hazards on the retention of zirconia restoration (Pilo et al., 2016). Same findings were shown when this method applied in chromium-cobalt cementation zinc phosphate or with glass ionomer cement (Pilo et al., 2018).

1.9. The Aim of this study

1. select the most suitable laser parameter of Er:Cr;YSGG 2780nm Laser and Fractional CO_2 10600 nm laser of treating dentinal hypersensitivity, by evaluating the effect of each laser on the opened dentinal tubule.
2. Also to make comparison between two different lasers with different parameters for the same laser.
3. Measurement of the temperature increase at the selected parameters.
4. To study the effect of the two lasers with their two different parameters on the surface roughness to the irradiated dentin surface.
5. To evaluate Shear Bond Strength of zirconia cemented with self-adhesive resin cement to prepared dentin surface.

Chapter two

Materials and Methods

Chapter two

Materials and Methods

This chapter includes all the materials, tools, and equipment used in this research, also includes all the steps, and preparation that were performed in this study.

2.1 Materials, tools, and equipments.

a. Materials:

1. One hundred and fifteen sound maxillary premolars.

2.Thymol (AVONCHM SK116PJ- UK) figure(2-1a).

3. Cold cure acrylic resin (Duracel Plus, SpofaDental a.s., Markova 238, Czech Republic) figure (2-1 b).

4.Pumice (i-dental, UAB) figure(2-1c).

5.Thermal Paste (HUTIXI HI-GY260, China) figure(2-1d).

6.Dual-cure resin cement (Breeze, Pentron Clinical, CA92867, USA) (2-1e).

Figure (2-1) a) Thymol solution, b) Cold cure acrylic, c) Pumice, d) Thermal paste, e) self- adhesive resin cement

b. Tools and Equipment:

1.Er:Cr:YSGG Dental Laser (WaterLase iPlus .USA), figure (2-2a),the specifications are:

a. Active medium: Erbium, Chromium: Yttrium, Scandium, Gallium, Garnet

b. Wavelength: 2780nm

c. Frequency: 5-100Hz

d. Average power: 0.1-10.0 W

e. Power accuracy: ±20%

f. Pulse energy: 0-600mJ

g. Pulse duration for hard tissue (H mode): 60 µs

h. Pulse duration for soft tissue (S mode): 600µs

i. Mode: multimode

j. Nominal Ocular Hazard Distance(NOHD): 5cm

2. Fractional CO_2 Laser (CO_2 Fractional Laser Brochure, JHC1180, China), figure(2-2b), and device specifications are:

a. Laser wavelength: 10600 nm
b. Output power: ≤30 W
c. Pulse Duration: 0.1-10 ms (adjustable)
d. Spots distance: 0.1 – 2.6 mm (adjustable)
e. Interval time (time between pulses): 0.1 ms-500 ms (adjustable)
f. Mode of scan: order, disorder, parallel (switching)
g. Pulse energy: maximum 300 mJ
h. Area of Focal Spot: 0.05 mm^2
i. Output graphic: square, rectangle, triangle, circle, oval, hexagon, linear (scalable)
j. Graphic area: ≤ 20 mm × 20 mm
k. Optical system: 7 articulated arms.

3.Thermometer (AMPROBE TMD®-56, Everett, WA, USA) figure(2-2C), the specifications are:
a. Dual input T1, T2
b. Thermocouple K-type (-200°C to 1372°C), with a head diameter of 0.8 mm.

c. Measures temperature every one second.

d. All the collected data are arranged and processed with system software.

4.Scanning Electronic Microscope SEM (INSPECT F50, USA).

5. Instron Universal testing machine (LARYEE, WDW-50,50 KN, China).

6. Digital Ultra-sonic cleaner (TreeDental, USA).

7. Water- Bath (Numerical show constant temperature water-bathing boiler HH2, XMTE-205, China),

8. Curing light, LED.C (Guilin Woodpecker Medical Co.,China).

9. Stereo Microscope (ME, 2665, Euromex, Holand).

10. Optical Microscope (Olympus, Korea)

11.Dental surveyor (Dentaurum paratherm, German), figure (2-2c)

12. laboratory dental engine (Marathon, Dentsupply, Korea), figure(2-2d).

13. Diamond disc (C01\220, Stardent, China), figure (2-2e).

14.MZ6 tip (WaterLase iPlus. USA).

15. Protective googles (WaterLase iPlus. USA).

Figure (2-2) A) Er:Cr:YSGG laser, B)CO_2 laser, C)Dental syrvuer, D) Labrotary engine, E) diamond disc

2.2. Methods

2.2.1. Samples collection and samples preparation

One hundred and fifteen sound premolars teeth were collected for orthodontic and periodontics reasons. Carious, cracked, and filled teeth were excluded. All teeth were scaled with ultra-sonic scaler for removal of debris, then washed under running water. All teeth were preserved with a 1% thymol solution, the solution was replaced weekly(Aydın et al., 2015). Cold-cure acrylic was used to fabricate a cylindrical mold (15 mm in height, 12mm in diameter), the root embedded in the mold up to the cementum-enamel junction as in figure (2-3).

Figure (2-3) Tooth root embedded in acrylic mold

After tooth molding, cutting of the teeth was achieved with the help of a dental surveyor, a hand piece, and a diamond disc. Each tooth was fixed on the surveyor with the use of fabricated holder in the zero-plane, while the hand piece with the disc could be moved in a horizontal line as shown in Figure (2-4). The cutting was done perpendicular to the long axes of the tooth (Nahas et al., 2020). The disc passes through the tooth occlusally. Finally, the cutting was within the level of central groove, producing a clear dentin surface surrounded by a rime of enamel. Cooling was performed with water along the cutting procedure. For standardization, the disc was used for two teeth only and replaced with a new one. The occlusal surface after cutting was inspected carefully, to check if there was any caries, cracks, or enamel remnants.

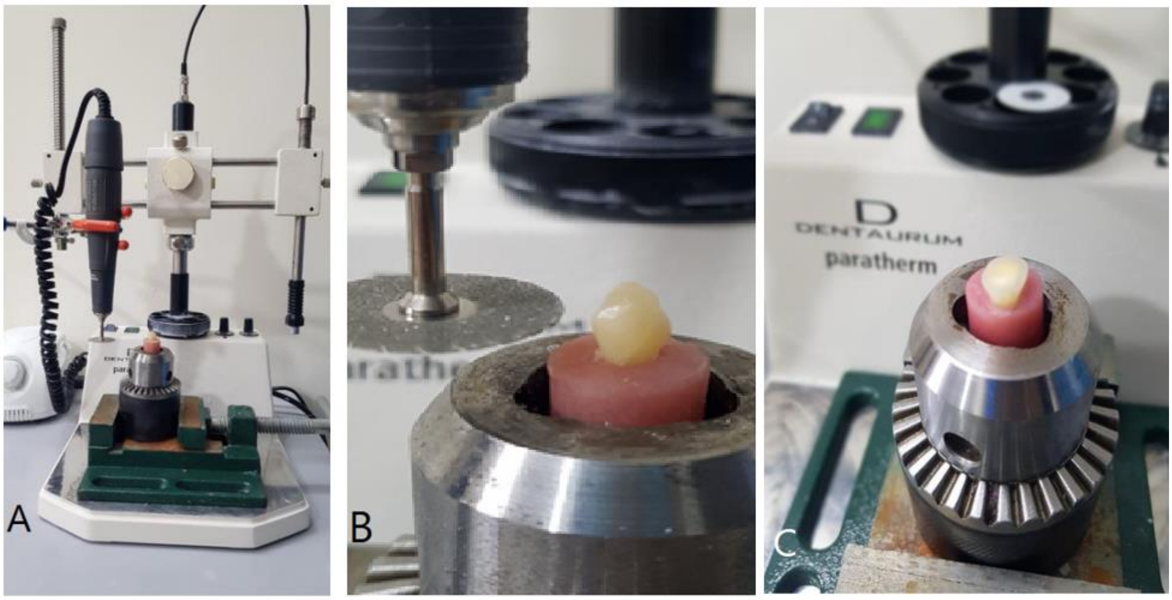

Figure (2-4) A) The setup of dental Surveyor and tooth during cutting procedures, B) Straight hand piece and diamond disc, C) The final shape of the prepared tooth.

Than a non- fluoride polishing paste was used for polishing dentin surface, and a rubber cup for 15 sec. The teeth were washed in ultra-sonic cleaner with distal water for 15 min for proper debris removal, as if figure (2-5).

Figure (2-5) Ultrasonic cleaner.

2.2.2 Sample Grouping

All the samples grouped into five groups according to treatment protocol, for scanning electronic microscope SEM evaluation, measure temperature rise, measuring roughness and shear bond strength (SBS), and finally failure mode examination.

Group A: Control group

Group B: Fractional CO_2 Laser 10600nm, 2.5 mJ, 1 W,2.5 ms)

Group C: Fractional CO_2 Laser (10600nm, 3mJ, 1W, 3 ms)

Group D: Er:Cr;YSGG (2780 nm, 0.25 W, 20 Hz , 10% water and air)

Group E: Er:Cr;YSGG (2780nm, 0.5 w, 20 Hz, 10% water and air).

2.3. Lasers application

2.3.1. Er:Cr;YSGG applications

Two groups were treated with Erbium laser group D and E. Standardized laser applications were done with the help of specially fabricated CNC machine. The CNC machine has two arms, that move around the X, and Y axes, with a holder that hold the tooth in a vertical direction that can be moved around the two axes (X, Y). The hand-piece of the laser is fixed perpendicularly over the prepared occlusal surface of tooth at a 2mm distance between the tooth surface and the fiber tip(Almojaly et al., 2019). The set-up shown in the figure (2-6).

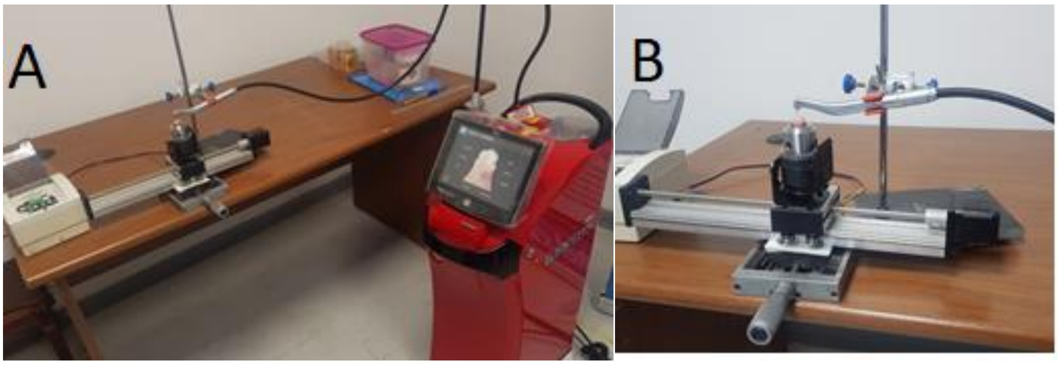

Figure (2-6) A) The set-up of the application of Er:Cr;YSGG laser with the CNC machine, B) The CNC Machine.

Pilot studies were done to select the best laser parameters. Many trial have done to get most effective treatment with minimum adverse effect on the pulp. In which the Frequency was fixed, while the power, water and, air ratio was changed, all samples examined under Light microscope and as in figure (2-7):

-The First trial was with (1 W, 50 mJ, 1% air and water ratio) get a clear clinical carbonization so these parameters were excluded.

-The Second trial (0.75 W, 37.5 mJ, 1% air and water ratio) Also we get clear clinical carbonization so these parameters were excluded too.

-The Third trial (0.5 W, 25 mJ, 1% air and water) get a clear clinical effect So increasing the cooling to reduce thermal damage to the tooth structure by increasing water and air ratio up to 10 % and determine the effect under light microscope.

Figure (2-7) Light Microscope.

-The Fourth trial the power reduced to see its effect with a power 0.25W and frequency 20Hz, 10% water and 10% air.

2.3.2. Fractional CO_2 Laser application

Two groups selected for treatment with this laser, Fractionated lasers deliver energy in a vertical columns range in a parallel manor of multiple thermal spots. This called the microscopic treatment zones (MTZs), with unaffected area between the spots (Hantash et al., 2007). According to searches from indexed literatures, evidence related to Fractional CO_2 laser used as a dentine desensitizing is scarce. Figure (2-10) shows the laser with its arm during laser application.

Figure (2-10) a) Fractional CO_2 laser, b) position of sample during lasing.

Many trial used to get the proper effect of CO_2 laser:

-The first trial the parameters used (1W ,2mJ, 2ms) minimum or no effect observe under light microscopic evaluation, so these parameters excluded.

-The second trial the parameters used (1W,2.5 mJ, 2.5 ms) with uniform effect without any adverse effect as carbonization or cracks.

-The third trial the parameters used (1W, 3mJ, 3ms).

2.4. Scanning Electronic Microscope Examination

One sample from each group examined under SEM, all the samples was treated and prepared as recommended for SEM testing device, before examine the samples, figure (2-8) shows the device used in this examination.

Figure (2-8) SEM (INSPECT F50).

2.5. Temperature Measurement

Five samples for each laser treated groups (group B, C, D, E) were prepared. All the samples were cut from the apex with a diamond disc, and the root canals were cleaned from the apex of the tooth with pro-taper S_x file to provide adequate space for the K-type thermocouple until reaching the pulp chamber, which was already greased with thermal paste. A Thermometer used to measure the rise in temperature. The tooth temperature was fixed at 37 C^0 with the use of water-bath to simulate human body temperature, only the root of the tooth embedded in the water-bath while the crown was out of water (Hassab et al., 2021). The thermometer was connected to a computer to record the readings. Figure (2-9), (2-10), and (2-11) will show the set-ups.

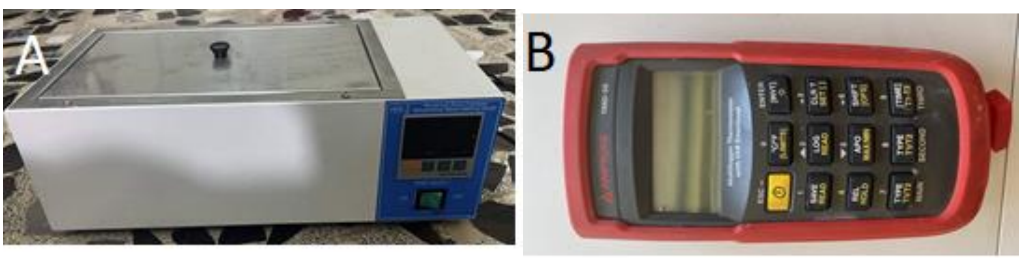

Figure (2-9) A) Water-Bath, B) Thermometer

Figure (2-10) show the set-up for measuring temperature rise by Er:Cr;YSGG Laser (consist of water-path and thermometer connected to a computer).

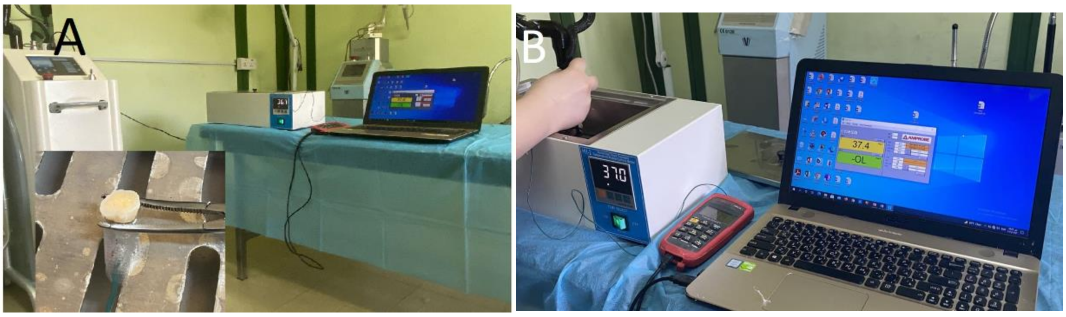

Figure (2-11) Set-up for measuring temperature with Fractional CO_2 Laser.

2.6. Roughness measurement

40 samples were used to measure roughness for laser treated groups (groups B, C, D, and E). Ten samples for each group, were measured before and after laser treatment to determine changes in surface roughness. The measurement was done with profile- meter as in figure (2-12). For each sample, three measurements from different points of the dentin surface were taken. For every measurement, the pin of the device was cut off at 0.25mm distance. Finally, the mean of the three readings was calculated.

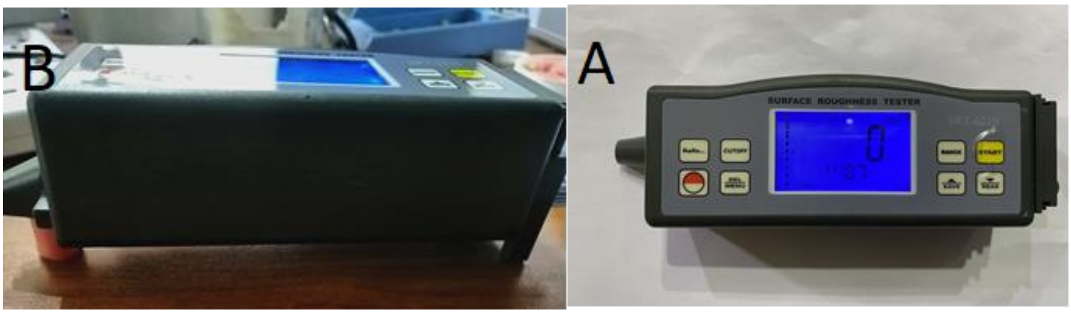

Figure (2-12) A) Profile- meter, B) Position of the samples during measuring roughness.

2.7. Fabrication of Zirconia discs

With a 3D builder, 50 zirconia cylindrical discs were fabricated, with a 5 mm in height, 3mm in diameter. Fabricated with CAD\CAM, these discs used for proper cementation also for simulation of the crown restoration when measuring shear bond strength as shown in the figure (2-13).

Figure (2-13) Zirconia Discs

2.8. Cementation of zirconia discs to tooth surface

For cementation, Dual-cure adhesive resin cement was used. The cement is self-mixed applicate by a disposable mixing tips, with direct application to the tooth surface. Silicon mold was fabricated with a central hole of 3mm in diameter, and 3mm in height divided from the internal surface into 1mm for cement and 2 mm for the disc to insure proper curing, and to have enough cement-dentin interface (3mm diameter, 1 mm height of the cement bonded to the prepared tooth surface) to measure shear bond strength between dentin and resin cement. To avoid any air-bubbles and proper cementation, a load of 2 Kg was used with the use of dental surveyor (Beuer et al., 2008) (figure 2-14). After 4 minutes, the load was removed and curing was done according to the manufacturer for Breeze resin cement, which is a dual-cure needing 40 second curing. After curing, the samples were left on the table for one hour to ensure complete curing. After that, the cemented samples are embedded in the water-bath at 37 °C for 24 hours before measuring shear bond strength (Gorler and Ozdemir, 2016).

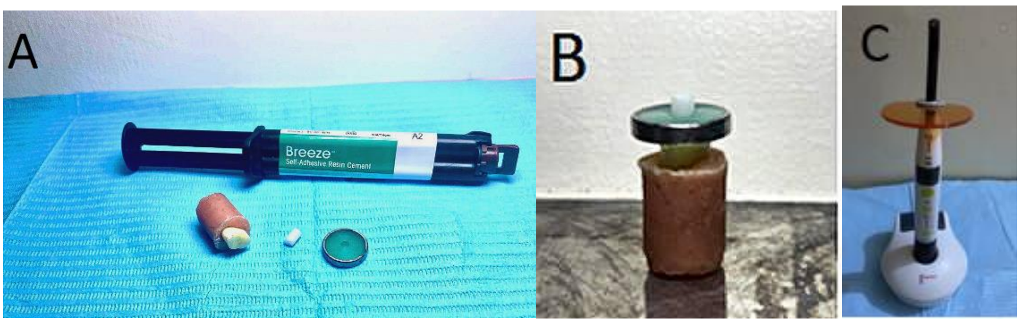

Figure (2-14) represent the set-up of cementation A) Resin cement, tooth, zirconia disc and the silicone mold, B) The mold that fixed to the tooth surface, c) Light cure used for curing.

2.9. Measurement of Shear Bond Strength (SBS).

After 24 hours of cementation, SBS was measured with Universal Testing Machine. 50 samples were cemented and tested for SBS. 10 samples were for each group (A, B, C, D, and E). The teeth were placed and fixed horizontally in which the samples were secured tightly to ensure that the occlusal surface of the tooth was always at 90 degrees to the vertical plane. A stainless steel, chiselled-shaped blade with a cross head at speed of an 0.5 mm/min was applied perpendicular to the dentin-cement interface, until failure occurred (figure 2-15) (Alavi et al., 2017). The force (in Newton) required to separate the samples was recorded on the computer. The Shear bond test values were calculated from the results taken and expressed in the formula:

Shear strength = maximum force [N] / bonding area [mm^2] (Piwowarczyk et al., 2005)

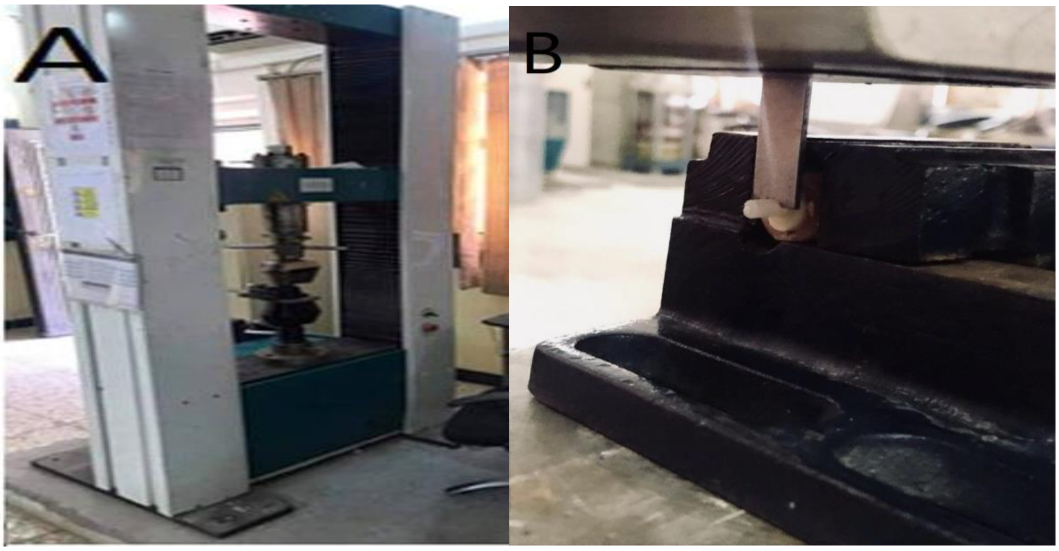

Figure (2-15) A) Set-up for measuring SBS by universal testing machine, B) position of the blade.

2.10. Failure mode testing

Tested samples for SBS were examined after de-bonding to determine the failure mode. Dentine surface examined under stereo- microscope. Figure (2-16) with 40X magnification. The classification of the mode of failure as the fallowing (Tsuo et al., 2006):

Figure (2-16) Stereo- microscope

1. Adhesive failure: If more than 75% of the dentin surface free from resin cement.

2. Cohesive failure: If more than 75% of the dentin surface was covered with resin cement.

3. Mixed failure: if 40-50% of the dentin surface was covered by the resin cement.

2.11. Statistical analysis

In this study statistical analysis done to compute Temperature, Roughness, Shear Bond Strength and Failure mode which includes:

A. Descriptive statistic:

a- Mean of values

b- Stander deviation

c- Stander Error

d-Minimum mean value

e- Maximum mean value

B. Inferential Statistics: that includes:

1. Shapiro-Wilk test: describe data distribution:

- Not significant that mean the data is normally distributed.

-Significant mean the data is not normally distributed.

2. ANOVA Test: which used to make comparison between groups.

3.Tukey HSD: fallowing ANOVA test to make comparison between two groups.

4. Paired T Test: to compare changes between two readings of tested sample.

Statistical significance was recorded according to probability value (P) to be as:

1- Non-significant at $P > 0.05$.

2- Significant at $P \leq 0.05$.

3- Highly significant at $P \leq 0.01$.

4- Very high significant $p \leq 0.001$.

Chapter Three

Results, Discussion, and future work

Chapter Three

Results, Discussion, and future work

In this chapter, the obtained results will be maintained and discussed. This includes evaluation of the laser effect on the opened dentinal tubules, measurement of temperature and roughness, and examination of shear bond strength, along with failure mode. Statistical analysis using descriptive statistics, Shapiro-Wilk test, Paired T test, Tukey HSD, and one-Way ANOVA analysis using SPSS 24 will be maintained and discussed.

3.1. Results

3.1.1 Light Microscope examination

Light microscopic examination for each selected parameters was as fallowing, for Er:Cr:YSGG laser figure (3-1) showed the effect of group E with obvious effect on dentin surface. And figure (3-2) showed the effect of group D also with clear effect. With no carbonization for both groups.

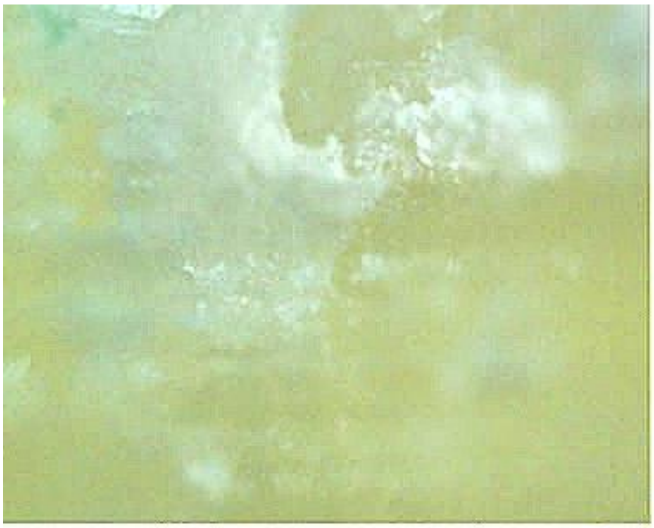

Figure (3-1) Microscope image of (0.5W, 20Hz, 10% water and air), 10X magnification clear effect with no carbonization or cracks.

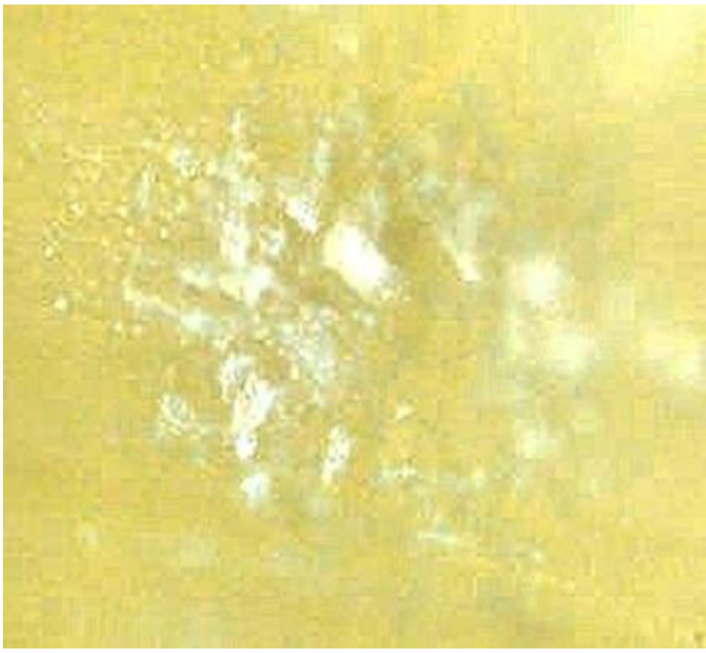

Figure (3-2) Microscopic examination with 10 x magnification 0f 0.25 W

For Fractional CO_2 laser the effect also was obvious with no carbonization or cracks and as seen in figure (3-3) and figure (3-4). Which represent group B and group C respectively.

Figure (3-3) 4x magnification of 2.5 mJ fractional CO_2 laser.

Figure (3-4) 4X magnification of 3 mJ effect of Fractional CO_2 laser.

3.1.3. Temperature Measurement

Table (3-1) will shows the maximum temperature rise during laser application together with the Mean and Standard Deviation (SD). The maximum temperature rise of all experimental groups was recorded with group C (Fractional CO_2 laser irradiation with power 1W, energy 3 mJ , was 1.7 ℃, and the mean was 1.58 ℃. Fallowed by 1.4 ℃, and the mean was 1.24 ℃ with group E (Er:Cr;YSGG Laser irradiation with a power 0.5 W. The minimum temperature rise recorded among all groups was with group D with 0.7 ℃, and the mean was 0.9℃ Er:Cr;YSGG Laser irradiation with a power 0.25 W.

Table (3-1) Maximum temperature rise, the Mean, and the Standard Deviation.

Groups	Max. temperature rise	Min. temperature rise	Mean	Standard Deviation (SD)
Group B	1.3 °C	1.1°C	1.04°C	0.194
Group C	1.7°C	1.5°C	1.58°C	0.083
Group D	1.1°C	0.7°C	0.9°C	0.158
Group E	1.4°C	1.1°C	1.24°C	0.114

3.1.2. SEM Evaluation

Scanning Electronic Microscope examination shows the effect of lasers irradiation on the dentin surface of the prepared samples and the morphological changes induces with different groups. Figure (3-5) shows the control group (Group A) with opened dentinal tubules. Group B showed partial occluding of dentinal tubules. Group C showed effective occlusion of dentinal tubules. Group D showed approximately complete occluding of dentinal tubules. with complete occluding of dentinal tubules in group E. All groups showed no cracks or carbonization.

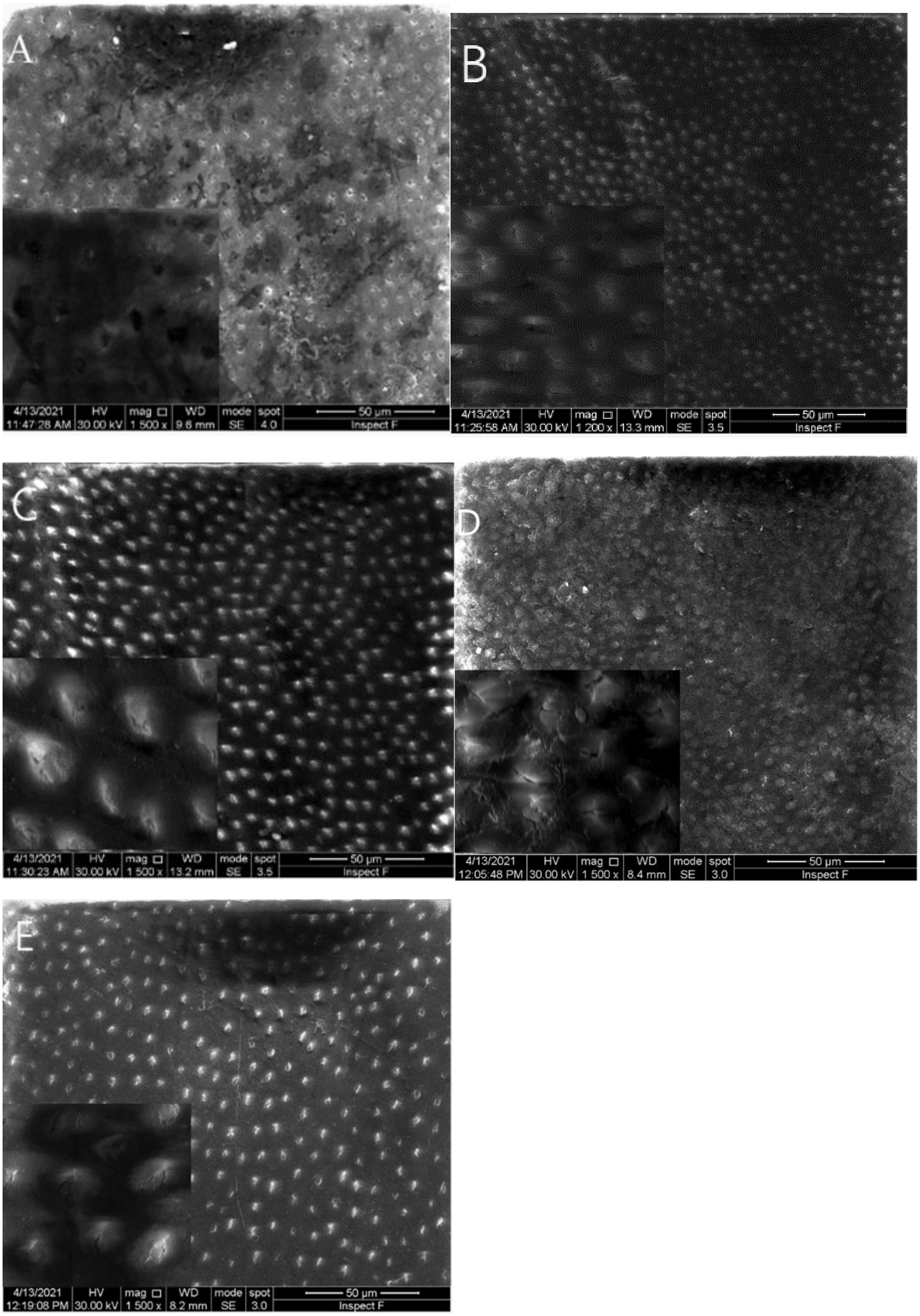

Figure (3-5) SEM images of all groups A) Group A, B) Group B, C) Group C, D) Group D, E) Group E.

3.1.4. Roughness Assessment

The Mean of the surface roughness changes in all experimental groups before and after laser application were summarized in figure (3-6).

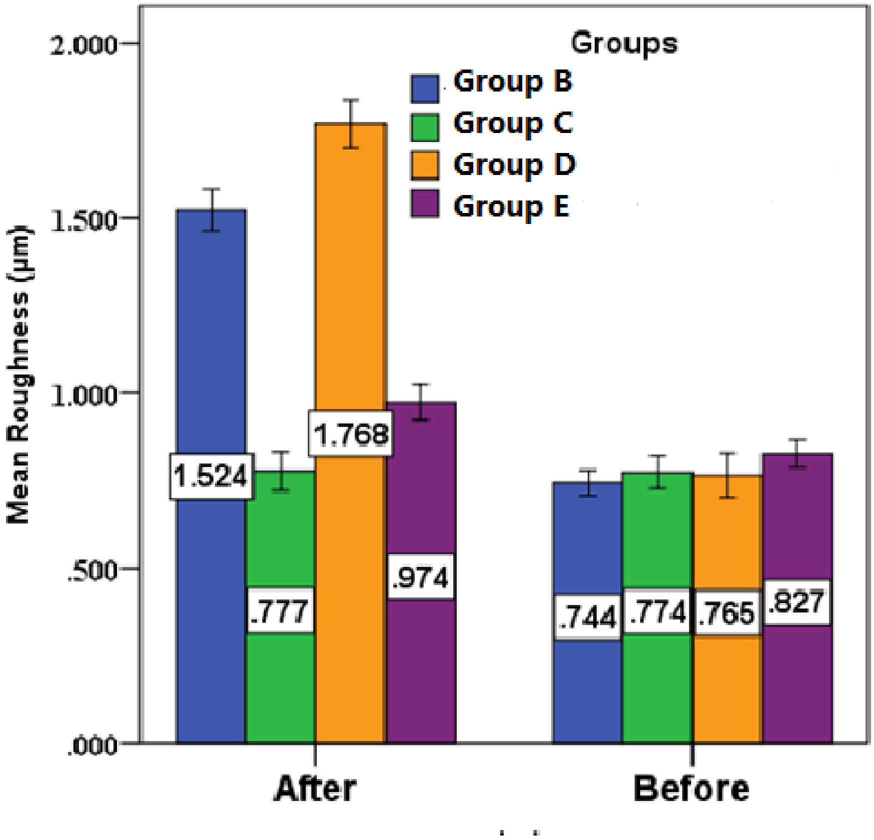

Figure (3-6) Histogram of Roughness mean in experimental groups.

Descriptive statistic of all the groups shows the highest mean of roughness change in group D (0.25W Er:Cr:YSGG laser irradiation), followed by mean of roughness change in group B (2.5 mJ Fractional CO_2 laser irradiation). The lowest mean of roughness change seen in group C (3mJ Fractional CO_2 laser irradiation) as seen in table (3-2).

Table (3-2) Descriptive Statistic, maintaining the Mean, Standard Deviation (SD), Standard Error (SE), of surface roughness with the minimum and maximum values of samples before and after laser irradiation

Groups		Mean	±SD	±SE	Minimum	Maximum
Before	Group B	0.744	0.050	0.016	0.662	0.830
	Group C	0.774	0.066	0.021	0.684	0.913
	Group D	0.765	0.088	0.028	0.632	0.905
	Group E	0.827	0.055	0.017	0.769	0.932
After	Group B	1.524	0.082	0.026	1.393	1.656
	Group C	0.777	0.078	0.025	0.651	0.917
	Group D	1.768	0.095	0.030	1.608	1.930
	Group E	0.974	0.071	0.023	0.879	1.127

In testing for normality with Shapiro-Wilk test, the results show that all samples were normally distributed in which non-significant difference between the groups, as shown in table (3-3).

Table (3-3) Shapiro-Wilk test shows normal distribution for all experimental groups

Tests of Normality					
Periods	Groups	Shapiro-Wilk			
		Statistic	df	P value	
Before	Group B (2.5mJ CO_2 Laser)	0.967	10	0.857	NS
	Group C (3 mJ CO_2 laser)	0.939	10	0.544	
	Group D (0.25W Er:CrYSGG laser)	0.950	10	0.670	
	Group E (0.5W Er:Cr;YSGG laser)	0.875	10	0.115	

After	Group B (2.5mJ CO_2 Laser)	0.983	10	0.979	
	Group C (3 mJ CO_2 laser)	0.977	10	0.945	
	Group D (0.25W Er:CrYSGG laser)	0.960	10	0.789	
	Group E (0.5W Er:Cr;YSGG laser)	0.928	10	0.427	

In comparison between groups, ANOVA test was performed, and the results showed a significant difference in means of roughness in groups after laser irradiation, with no significant difference before laser irradiation, as shown in table (3-4).

Table (3-4) Statistical comparison between groups using (one-way ANOVA), shows significant difference between groups after laser irradiation

ANOVA						
		Sum of Squares	df	Mean Square	F	P value
Before	Between Groups	.037	3	.012	2.811	0.053 NS
	Within Groups	.158	36	.004		
	Total	.195	39			
After	Between Groups	6.431	3	2.144	318.017	0.000 Sig.
	Within Groups	.243	36	.007		
	Total	6.674	39			

To test the difference between each two groups regarding surface roughness, Tukey HSD test was performed. Results showed high significant differences between all groups. as showed in Table (3-5).

Table (3-5) Tukey HSD test between each two groups.

Multiple Comparisons			
Tukey HSD		Mean difference	P value *
Group B	Group C	0.747300	0.00000
	Group D	-0.243500	0.00000

	Group E	0.550800	0.00000
Group C	Group D	-0.990800	0.00000
	Group E	-0.196500	0.00003
Group D	Group E	0.794300	0.00000

Further analysis using Paired T test to measure the significant in difference between samples before laser irradiation and after laser irradiation in the same group. The results showed highly significant difference in groups (B, D, and E) while in group C there was no significant difference in roughness after laser irradiation. As seen in table (3-6).

Table (3-6) Paired T test to shows the differences between the same group

Groups		Before	After
Group B 2.5 mj CO_2 Laser	Minimum	.662	1.393
	Maximum	.830	1.656
	Mean	.744	1.524
	SD	.050	.082
	SE	.016	.026
	% of change	104.838	
	Paired T test	34.519	
	P value	0.00000 Sig.	
	Effect size	10.916 large	
Group C 3 mj CO_2 Laser	Minimum	0.684	0.651
	Maximum	0.913	0.917
	Mean	0.774	0.777
	SD	0.066	0.078
	SE	0.021	0.025
	% of change	0.3876	
	Paired T test	0.484	
	P value	0.63971 NS	
	Effect size	0.153 weak	
Group D 0.25 W-ER:CR:YSGG Laser	Minimum	0.632	1.608
	Maximum	0.905	1.930
	Mean	0.765	1.768
	SD	0.088	0.095
	SE	0.028	0.030

	% of change	131.111	
	Paired T test	38.972	
	P value	0.00000 Sig.	
	Effect size	12.324 large	
Group E 0.5 W-ER:CR:YSGG Laser	Minimum	0.769	0.879
	Maximum	0.932	1.127
	Mean	0.827	0.974
	SD	0.055	0.071
	SE	0.017	0.023
	% of change	17.7751	
	Paired T test	6.233	
	P value	0.00015 Sig.	
	Effect size	1.971 large	

3.1.5. Shear Bond Strength (SBS)

Figure (3-7) showed the means of SBS of all groups experimental and control. Statistical analysis, and comparison between different parameters of the same laser treatment, also a comparison between all experimental groups will be discus.

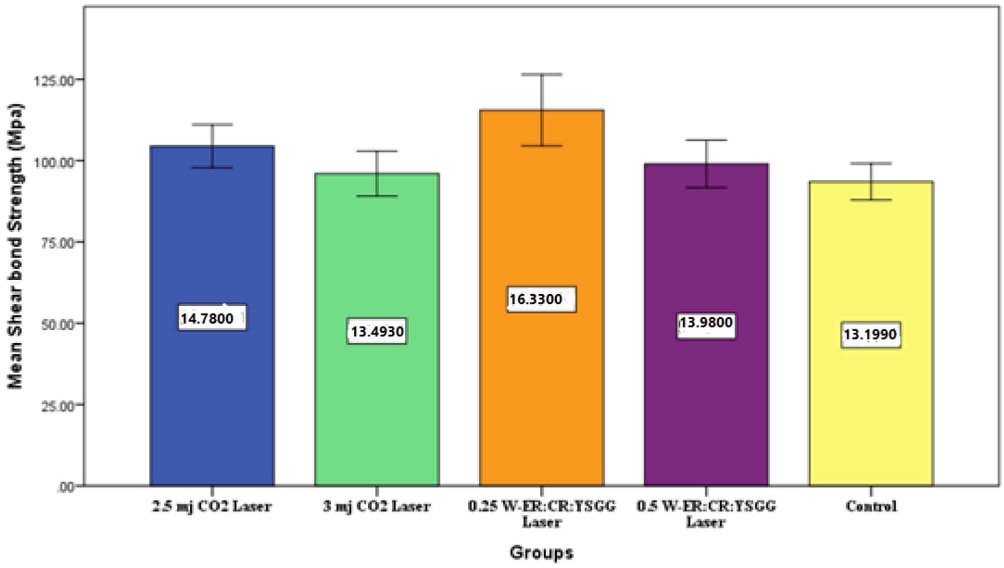

Figure (3-7) Histogram of means of SBS of all groups

- **Er:Cr;YSGG with the control group.**

Descriptive statistical analysis, showed highest bond strength mean was in group D with 16.3300 (Mpa) the lowest bond strength mean was in group A which is the control group 13.1990 (Mpa). As showed within table (3-7).

Table (3-7) Descriptive statistical analysis of SBS of Er:Cr:YSGG laser treated groups and control group.

Groups	Mean	±SD	±SE	Minimum	Maximum
Group A (Control Group)	13.1990	1.08611	.34346	12.03	14.80
Group D 0.25 W-ER:CR:YSGG Laser	16.3300	2.18177	.68994	12.70	19.80
Group E 0.5 W-ER:CR:YSGG Laser	13.9800	1.46652	.46375	11.30	16.40

Samples of Er:Cr:YSGG laser treated groups (groups D, and E), with the control group (group A), were normally distributed according to Shapiro-Wilk test, as seen in table (3-8).

Table (3-8) Shapiro-Wilk test of SBS

Tests of Normality of SBS (Mpa)				
Groups	Shapiro-Wilk			
	Statistic	df	P value	
Group A Control group	0.881	10	0.134	NS
Group D (0.25 W-ER:CR:YSGG Laser)	0.983	10	0.980	
Group E (0.5 W-ER:CR:YSGG Laser)	0.976	10	0.942	

In order to test the difference in significance between groups, for all groups regarding SBS, ANOVA test was performed. Table (3-9) shows high significant difference among all the groups.

Table (3-9) One-way ANOVA test to see differences in SBS

ANOVA					
	Sum of Squares	Df	Mean Square	F	P value
Between Groups	53.119	2	26.559	9.848	0.001 Sig.
Within Groups	72.814	27	2.697		
Total	125.932	29			

In order to testing the difference between each groups, Tukey HSD test was performed. Table (3-10) Showed that high significant increase in SBS in group D (with 0.25 W), from the control group. The increasing in SBS of Group E (with 0.5 W) was not significant than the control group. In comparison between both groups (laser treated groups) showed significant increase in SBS of group D than group E.

Table (3-10) Tukey HSD Test

Dependent Variable: SBS				
Tukey HSD				
(I) Groups	(J) Groups	Mean Difference (I-J)	p value	
Group A (Control group)	Group D	-3.13100-*	.001	Sig.
	Group E	-.78100-	.544	NS.
Group D	Group A	3.13100*	.001	Sig.
	Group E	2.35000*	0.009	Sig.
Group E	Group A	.78100	0.544	NS
	Group D	-2.35000-*	.009	Sig

- **Fractional CO_2 laser with the control group.**

Table (3-11) showed descriptive statistical analysis of SBS of Fractional CO_2 laser treated groups (groups B, and C), and group A (Control). Group B showed the highest mean for SBS with14.7800 (Mpa), followed by group C with 13.4900 (Mpa). The lowest mean showed in the control group with 13.1990 (Mpa).

Table (3-11) Descriptive statistical analysis of SBS of Fractional CO_2 laser treated groups and the Control group.

Groups	Mean	±SD	±SE	Minimum	Maximum
Group A (Control Group)	13.1990	1.08611	.34346	12.03	14.80
Group B	14.7800	1.37421	.43456	12.70	16.40
Group C	13.4930	1.49445	.47259	11.30	16.40

Shapiro-Wilk Test showed normal distribution of all samples of Fractional CO_2 laser treated groups (groups B, and C), and the Control group (group A), as seen in table (3-12).

Table (3-12) Shapiro-Wilk Test

Tests of Normality of SBS (Mpa)				
Groups	Shapiro-Wilk			
	Statistic	df	P value	
Group A Control group	.884	10	.144	NS
Group B	.908	10	.268	
Group E	.948	10	.645	

For testing the difference in significance between all groups regarding SBS, ANOVA test was used. Table (3-13) shows significant difference between the groups.

Table (3-13) One-way ANOVA test

ANOVA					
	Sum of Squares	df	Mean Square	F	P value
Between Groups	14.141	2	7.071	4.001	0.030 Sig.
Within Groups	47.713	27	1.767		
Total	61.854	29			

Tukey HSD test as showed in table (3-14) was done to test the statistical difference between ever two groups. There is a significant difference between group B and group A, in which SBS was significantly higher in group B than the control group. No significant difference between group C and group A. Also no significant difference between group B and group C.

Table (3-14) Tukey HSD Test

Dependent Variable: SBS				
Tukey HSD				
(I) Groups	(J) Groups	Mean Difference (I-J)	p value	
Group A (control group)	Group B	-1.58100-	.034	Sig
	Group C	-.29400-	.875	NS
Group B	Group A	1.58100	.034	Sig.
	Group C	1.28700	.096	NS
Group C	Group A	.29400	.875	NS
	Group B	-1.28700-	0.96	NS

- **Comparison between all laser groups**

In order to determine the effect of each laser on shear bond strength a comparison between the four experimental groups were done. Descriptive statistical analysis of all experimental groups showed that the highest mean of shear bond strength was in group D with 16.3300 (Mpa). followed by group B with 14.7800 (Mpa). Group C and group E was 13.4930 (Mpa), and 13.9800 (Mpa) consequently, as showed by table (3-15).

Table (3-15) Descriptive statistical analysis of SBS of all experimental groups

Groups	Mean	±SD	±SE	Minimum	Maximum
Group B	14.7800	1.37421	.43456	12.70	16.40
Group C	13.4930	1.49445	.47259	11.30	16.40
Group D	16.3300	2.18177	.68994	12.70	19.80
Group E	13.9800	1.46652	.46375	11.30	16.40

All samples were normally distributed as shown by Shapiro-Wilk test in table (3-16).

Table (3-16) Shapiro-Wilk test

Tests of Normality of SBS (Mpa) among groups.				
Groups	Shapiro-Wilk			
	Statistic	df	P value	
Group B	.908	10	.268	NS
Group C	.948	10	.245	
Group D	.983	10	.980	
Group E	.976	10	.942	

ANOVA test showed a significant difference between all experimental groups as showed in table (3-17).

Table (3-17) One-way ANOVA test of SBS of all experimental groups

ANOVA					
	Sum of Squares	df	Mean Square	F	P value
Between Groups	46.268	3	15.423	5.592	0.003 Sig.
Within Groups	99.293	36	2.758		

Total	145.561	39			

To make a comparison between every two groups Tukey test was done as showed in table (3-18). The results showed only a high significant difference between group C and group D. And a significant difference between group D and group E.

Table (3-18) Tukey test, comparison between both lasers groups SBS

Dependent Variable: SBS				
Tukey HSD				
(I) Groups	(J) Groups	Mean Difference (I-J)	p value	
Group B	Group C	1.28700	.322	NS
	Group D	-1.55000	.177	
	Group E	.80000	.705	
Group C	Group B	-1.28700-	.322	NS
	Group D	-2.83700	.003	Sig.
	Group E	-.48700	.913	NS
Group D	Group B	1.55000	.177	NS
	Group C	2.83700	.003	Sig.
	Group E	2.35000	.016	Sig.
Group E	Group B	-.80000	.705	NS
	Group C	.48700	.913	NS
	Group D	-2.35000	.016	Sig.

3.1.5. Assessment of Failure Mode.

Failure mode are shown in table (3-19), in the control group the mixed mode is the most dominant. While for group B, and group D the most dominant mode is cohesive. The dominant mode is adhesive in groups C and E.

Table (3-19) Failure mode of all groups.

Groups	Cohesive	Adhesive	Mixed
Group A	20%	40%	40%

Group B	50%	30%	20%
Group C	20%	50%	30%
Group D	60%	10%	30%
Group E	30%	40%	30%

3.2. Discussion

Before the preface of implant to dental practice, the only treatment or the restoration of edentulous area was fixed partial denture, which still very popular and effective treatment approach till present time (Yadav et al., 2014). Crown preparation is an invasive treatment approach required removal of tooth structure, in some instants, vital or even sound tooth, to be used as an abutment for fixation of the bridge. The removal of tooth structure generates open dentinal tubules that susceptible to sensitivity (Mapkar et al., 2018). Crown preparation involves the removal of enamel and cementum coverage, consequently leaving the tooth with exposed latent dentinal tubules (Awang et al., 2007). The number of exposed tubules is correlated to severity of dentin hypersensitivity. Pain is related to fluid flow inside the exposed dentinal tubules as a result of various stimuli. The diameter reduction and obstruction of dentinal tubules caused by hypersensitivity treatment will result in the relief of this discomfort, and this is the major goal of a successful hypersensitivity treatment (Tunar et al., 2014). The best treatment of this post-operative complication is the occluding of dentinal tubules without adverse effects on the retention of the prosthesis. Adhesion to laser irradiated dentin is controversial in results, in which many studies obtained different results from adhesion of various types of adhesive materials to laser irradiated dentin (Cardoso et al., 2008).

In this study, prevention of post preparation hypersensitivity, with the consequence of laser treatment on shear bond strength (SBS) of resin cement to prepared dentin was evaluated. Two lasers were used Er:Cr;YSGG 2780nm, and Fractional CO_2 10600 nm with different parameters for every laser treated groups. The mechanism of high power lasers in treatment of dentinal hypersensitivity by block the entrances to the dentinal tubules through thermal and mechanical action (Freitas and Simões, 2015).

CO_2 laser is one of the lasers used in dental practice and many clinical trials found that it can be used safely on dental hard tissue without necrosis or pulp damage and had pleasing result especially with dentin conditioning and desensitizing (Praveen et al., 2018).

3.2.1. Temperature Measurement

Since the interaction of both Er:Cr;YSGG 2780nm, and Fractional CO_2 10600 nm lasers with dentin is photothermal, it is important to ensure that temperature rise inside the pulp chamber will not induce tissue necrosis. Temperature rise inside the pulp chamber should not exceed 5.5℃, since the maximum temperature rise that will not affect the vitality of the dental pulp is 5.5 ℃ (van Gemert and Niemz, 2013).

The maximum temperature rise during laser irradiation inside the pulp chamber, was with group C with 1.7 ℃. Which were still within the accepted range of temperature rise. This indicated the safety of all experimental laser groups' parameters on the vitality of the pulp. For CO_2 lasers the use of very low energy (2.5 mJ for group B, and 3 mJ for group C) associated with limited temperature rise. With Er:Cr:YSGG laser groups the use of lower powers (0.25 W for group D, and 0.5 W for group E), along with 10% water and air, that increase tissue cooling during laser application. Percentage of air and water have great effect in dentin ablation with minimal thermal damage (Shinkai et al., 2019). This agree with a study that was done to evaluate temperature changes during dentin irradiation with CO_2 laser, and Er:Cr:YSGG laser, for treatment of dentinal hypersensitivity, in both lasers no significant temperature changes was noted, but the means of temperature rise for both lasers were higher than temperature changes in this study due to use of higher energy with CO_2 laser (5mJ), and in despite of the use of same energy with Er:Cr:YSGG laser, but no water cooling was used (Asnaashari et al., 2010). The amount of energy delivered, as well as the exposure time, is directly proportional to the temperature increase in the pulp chamber (Romano et al., 2011).

3.2.2. SEM Evaluation

Scanning electronic microscope evaluation was done to evaluate the effect of different lasers types and parameters, on the dentin surface, which induced morphological changes to the dentin surface. For Er:Cr:YSGG laser in both groups group D, and group E showed complete occluding of open dentinal tubules, with no carbonization or crack. This agree with another trial used Er:Cr:YSGG for treatment of dentinal hypersensitivity and get complete occluding of dentinal tubules use (0,25 W, 30 Hz, 5mm distance from the dentin surface), which support the results obtained from this study (Habdan et al., 2017). This agree with Yilmaz who used Er:Cr:YSGG with two parameters (0.25 W, and 0.5 W) both parameters showed significant reduction of tubules diameter than control group (Yilmaz and Bayindir, 2014). This can be explained by the interaction of Er:Cr:YSGG laser with dentin. When Er:Cr:YSGG lasers interacts with dentin, absorbed by water of the dentin, converting water to steam by heating, then the steam expand and since this reaction is explosive in nature (microexplosion), this microexplosion causing dentin debris to occluded or tightening the dentinal tubules (Stübinger et al., 2020). This will prevent emerging of cement to the dentinal tubules and prevent post cementation hypersensitivity(Abdollahi and Jalalian, 2019).

For CO_2 laser treated groups SEM showed partial occluding of dentinal tubules in group B, and complete occluding in group C. Many studies approve the role of CO_2 laser on the obliteration of opened dentinal tubules,

CO_2 laser has low penetration depth, maximum hydroxyapatite absorption, and high water absorption, all these factors result in its ability to modify dentin structure safely (Freitas and Simões, 2015) (Coluzzi and Parker, 2017). Results obtained from this study agree with those of Golami et al., who used CO_2 with 50 W, 50µs, 2.5mj, ultra-pulse mode that resulted with successful melting of dentinal tubules leading to partial occlusion of the tubules, with no carbonization or cracks (Gholami et al., 2011). This study agree with the application of CO_2 laser in continuous mode, with 1 W, 50 Hz, 20 mJ and also got complete obliteration of dentinal tubules without hazard effect on dental pulp (Saluja et al., 2016). All these results support results obtained in this study, in which partial occluding of dentinal tubules with low energy. While increase laser energy delivered to the tissue resulted in complete occluding of dentinal tubules.

3.2.3. Roughness assessment

Other morphological changes to the dentin surface that induce by laser is changing in surface roughness. For Ee:Cr:YSGG laser treated groups, both showed significant increase in surface roughness after laser irradiation. But in group D the increase in roughness was higher than the increase in roughness in group E. This can attributed to higher energy delivered to the dentin surface induce melting of the peritubular dentin (Gholami et al., 2011). Laser irradiation induce surface roughness due to debris deposition that produced from their microexplosive nature of interaction with the dentin surface. In this study CNC machine was used for complete scanning of the dentin surface by laser radiation, which might increase spatial overlap between pulses which increase surface roughness caused by the laser radiation (Gardner et al., 2005).

Furthermore in this study using of CO_2 laser application, roughness of tooth surface shows a significant increase in group B and marginal increase in group C, and this could be referred to the laser interaction with the water and hydroxyapatite that result in melting and recrystallization of dentin and producing fungi-form projection on the dentin surface (Endo and Walter, 2018).

Saberi et al., used Er:YAG and CO_2 lasers for treatment of dentinal hypersensitivity, found increase in surface roughness of dentin after laser irradiation (Saberi et al., 2018). This support the results obtained from this study.

3.2.4. SBS Evaluation

Increase in surface roughness is a favourite morphological change for adhesion to laser treated tooth surface, by increasing shear bond strength (Hossain et al., 2001). For Er:Cr:YSGG laser significant increase in SBS in group D was found, with slight increase in SBS in group E (which was not significant than the control). Garbui et al., s upported the results of this study, by founding that increase in SBS after laser irradiation of dentin surface with Er:Cr:YSGG, was significant with lower powers, SBS was reduced as the power used were increased (Garbui et al., 2013). Kumar et al., also get marginal increase(not significant than the control) in bond strength between resin cement and desensitized dentin with 0.5 W Er:Cr:YSGG laser (Kumar et al., 2015)

According to authors' knowledge no previous study that discusses the effect of desensitization of dentin by Fractional CO_2 on shear bond strength to cement, but uses of Fractional CO_2 for dentin surface treatment or conditioning found that 0.8 W, 10 Hz, 80 mJ will reduce shear bond strength of resin cement to dentin, this supports our results in which increase energy irradiation to dentin surface, reduce shear bond strength (Al-Jeaidi, 2020). In this study, group A with 2.5 mJ had significantly higher shear bond strength than group B (3mJ) and group C (control). This could be attributed to the significant increase in surface roughness in group A, and no significant increase in roughness in group B. Roughness increase the surface area which directly proportional to SBS, also it might create a favorable mechanical interlock that enhance SBS.

3.2.5. Failure Mode Evaluation

Evaluation of the failure modes can provide great image about the quality of the bond strength between tooth surface and the cement. Mixed and cohesive failure modes are more beneficial clinically than adhesive mode. This related to higher bond strength with cohesive and mixed modes. (Toledano et al., 2007). In group B and D, the highest SBS were obtained and the most dominant failure mode for both groups were cohesive. Adhesive failure mode was dominant in groups with lower SBS.

3.3. conclusion

From the obtained results of this study, the fallowing con be concluded:

1. Both Er:Cr:YSGG laser and Fractional CO_2 laser con be use safely, for treatment of dentinal hypersensitivity, by partial, and even complete occluding of dentinal tubules without and adverse effect on pulp vitality.
2. The most suitable laser parameter was with group D (Er:Cr:YSGG 2780 nm , 0.25 W, 12.5 mJ , 20 Hz, 10% water and air) , to induce the highest roughness. Finally improve bonding strength of resin cement to prepared, desensitized dentin, by increasing Shear bond strength of resin cement to dentin.

So laser desensitization, by Er:Cr:YSGG 2780 nm , 0.25 W, 12.5 mJ , 20 Hz, 10% water and air. Con be considering as post preparation protocol, for preventing developing of dentinal hypersensitivity after crown preparation.

3.4. Suggestion and future work

1. Further studies needed to determine the effect of different lasers with another parameter on the bonding strength of desensitized tooth.
2. Since the parameters used were within the accepted level of temperature rise than, performing these parameters clinically most be suggested for treatment of dentinal hypersensitivity.
3. Performing different tests, for example performing Atomic Force Microscopy (AFM) to gives the form of roughness obtained after laser irradiation.
4. performing Histopathological examination for the dentin surface after laser irradiation to identify the factors that induce occluding of the tubules.
5. Combination of Lasers with different kind of desensitizing agents to study the consequences of desensitization of prepared tooth on bonding strength of restoration or crown.

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الخلاصة

خلفيه :ان فرط حساسية الاسنان والتي توصف بانها الم شديد وحاد تثيره المحفزات الحراريه واللمسية والتناضحية والكيميائية. إنها واحدة من المضاعفات الأكثر شعبية، التي تصاحب تحضير الاسنان لتغليفها بالتاج. يتطلب إعداد التاج إزالة بنية الأسنان لتوفير مساحة للتعويض الاصطناعي. عادة ما ينتهي بأنابيب الأسنان المكشوفة والمفتوحة، والتي قد تسبب فرط حساسية الأسنان. يمكن اعتبار الليزرنوع من انواع العلاجات لفرط حساسية الأسنان. .

الهدف من هذه الدراسه: هو اختبار تاثير ليزر الاربيوم كروميوم وليزر ثنائي اوكسيد الكاربون على قوه رابطة القص بين الزاركونيا والاسنان، مع الاخذ بالاعتبار للانابيب العاجيه المفتوحة او فرط حساسيه الاسنان الناتج عن اعداد التاج.

المواد والطرق: تم استخدام مئه وخمسه عشر ضرس من ضواحك الفك العلوية. محفوظه في محلول الثايمول بتركيز 1% . تم تقسيم العينات في خمسه مجاميع ، لم تلق المجموعه(أ) اي علاج لحساسيه الاسنان. المجموعه (ب) تم تشعيعها بليزر ثنائي اوكسيد الكاربون الجزئي مع (1 واط ، 2.5 مللي ثانيه ،2.5 ملي جول) ، المجموعه (ج) ايضا تشععت بليزر ثنائي اوكسيد الكاربون الجزئي (1 واط، 3 مللي ثانيه، 3 ملي جول). المجموعه (د) تلقت اشعاع بليزر الاربيوم كروميوم (0.25 واط ، 20 هرتز و10% ماء و 10% هواء) و والمجموعه (ه) (0.5 واط و 20 هرتز ،10% ماء و10% هواء) وتم قطع الجزء الاطباقي من تاج السن. ثم تم اجراء فحص بالمجهر الماسح الالكتروني لجميع العينات لتقييم تاثير الليزرات على الانابيب السنية، وتم تسجيل التغيير في درجه الحرارة للمجموعات المعالجه بالليزر اثناء التشعع بالليزر،وتم فحص تغيير الخشونة عن طريق قياس خشونة السطح قبل وبعد التشعيع بالليزر، وتم قياس قوة رابطة القص لتقييم تاثيرازاله تحسس الاسنان على قوة الترابط بين الاسمنت الراتنجي وعاج السن .

النتائج: أظهر فحص المايكروسكوب الماسح الالكتروني ان المجموعة الضابطه (مجموعه أ) ذات انابيب عاجيه مفتوحه، بينما في المجموعة المعالجة بليزر ثنائي اوكسيد الكاربون الجزئي (مجموعه ب) غلق جزئي في الانابيب العاجيه ، واظهرت كل من المجموعات العلاجية (ج ، د ، ه) اغلاق تام للقنوات العاجيه المفتوحه ،بدون اي تشققات او تفحم في السن . كان ارتفاع درجة الحرارة الاقصى في المجموعة (ج) 1.7 سليزي وكان الحد الادنى لارتفاع درجه الحرارة في المجموعه (د) 0.9 سليزيه . اظهر التحليل الإحصائي لنتائج قياس الخشونة زيادة معنوية في الخشونة في المجموعة د والمجموعة ب والمجموعة ه. في حين لم تظهر المجموعة ج أي زيادة معنوية في الخشونة. واظهر زياده كبيره في قوة رابطه القص في المجموعه (د) تليها المجموعه ب ولم تظهر زياده في المجموعتين (ج و ه) .

الخلاصة: أظهرت جميع معاملات الليزر معالجة فعالة لأنابيب الأسنان المفتوحة، عن طريق الإغلاق الجزئي والكامل. كما أنها تحسن قوة الترابط بين الأسمنت الراتنجي إلى العاج عن طريق زيادة قوة ربط القص. وكانت افضل النتائج من جميع المعايير في المجموعه (د) حيث تم استخدام جهاز ليزر الاربيوم كروميوم بقوة 1 واط وتردد 20 هرتز وبنسب ماء وهواء 10% لكليهما.

وزارة التعليم العالي والبحث العلمي

جامعه بغداد

معهد الليزر للدراسات العليا

تقييم لقوة القص الرابطة وتقنيه الحساسية المفرطة بعد المعالجة بالليزر

رساله مقدمه الى

جامعه بغداد\ معهد الليزر للدراسات العليا\ لاستكمال متطلبات نيل شهادة ماجستير علوم في الليزر\طب الاسنان

مقدمه من قبل

رسل محمد مبارك

بكلوريوس طب وجراحه الفم والاسنان/٢٠١٤

باشراف

أ. م. د. باسمة محمد علي حسين

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