International Journal of Pharmacology

ISSN 1811-7775

science alert

ansinet
Asian Network for Scientific Information

International Journal of Pharmacology 7 (2): 149-160, 2011
ISSN 1811-7775 / DOI: 10.3923/ijp.2011.149.160

An Overview of Laser Principle, Laser-Tissue Interaction Mechanisms and Laser Safety Precautions for Medical Laser Users

[1,3]Mohammed M. Jawad, [2,3]Sarah T. Abdul Qader, [4,5]A.A. Zaidan, [4,5]B.B. Zaidan,
[6]A.W. Naji and [1]Ibraheem T. Abdul Qader
[1]Department of Medical Engineering, College of Engineering, Al-Nahrain University, Baghdad, Iraq
[2]Department of Paediatric and Preventive Dentistry, College of Dentistry,
University of Baghdad, Baghdad, Iraq
[3]School of Dental Sciences, University Sains Malaysia, 16150, Kelantan, Malaysia
[4]Faculty of Engineering, Multimedia University, 63100, Selangor Darul Ehsan Cyberjaya, Malaysia
[5]Predictive Intelligence Research Cluster, Office of Research and Higher Degrees,
Sunway University, No. 5, Jalam Universiti, Bandar Sunway, 46150 Petaling Jaya, Selangor, Malaysia
[6]Faculty of Engineering, International Islamic University Malaysia (IIUM),
53100 Gombak, Kuala Lumpur, Malaysia

Abstract: Laser can now be regarded as practical and economical tool with unique properties that has been utilized effectively in several applications. Medical, dental, biological and various chemical and physical investigations use lasers due to their advantages. The medical laser systems offer the physician and the dentist not only a window, but also a door into this high technology which facilitate a lot of clinical and therapeutic applications. The user of the medical laser should understand the fact that there is no certain laser can be used for all tasks, therefore, it is important for the medical laser users to have a fundamental understanding of qualitative laser technology and essential operation of those lasers with biological tissues. In spite of their advantages, lasers have definite hazard by causing serious damage on the tissue of both patient and laser operation personnel. Due to this fact, laser users should study the laser hazards and safety precautions.

Key words: Laser modes, laser operation, biostimulation, photodynamic therapy, laser hazard, laser precaution

INTRODUCTION

Light is the electromagnetic spectrum which covers an extremely broad range, from radio waves with wavelengths of a meter or more, down to X-rays with wavelengths of less than a billionth of a meter. Optical radiation lies between radio waves and X-rays on the spectrum, exhibiting a unique mix of ray, wave and quantum properties (Abdul Qader, 2006).

It is possible to say that a light signal may have dual behavior. At X-ray and shorter wavelengths, electromagnetic radiation tends to be quite particle like in its behavior, whereas toward the long wavelength end of the spectrum the behavior is mostly wavelike. The visible light portion of electromagnetic spectrum occupies an intermediate position, exhibiting both wave and particle properties in varying degrees. Short wavelength UV light exhibits more quantum properties than its visible and infrared counterparts (Ryer, 1998).

The name LASER is an acronym for Light Amplification by Stimulated Emission of Radiation. Thus, the term reflects the crucial role of the process of stimulated emission for the quantum generators and amplifiers of coherent light (Tarasov, 1986). Therefore, the history of laser development should be traced as far back as 1917 when Albert Einstein showed that the process of stimulated emission must exist (Elliott, 1995). This was the first step towards the laser. In 1953, a group at Columbia University headed by Charles H.Townes operated a microwave device that amplifier radiation by stimulated emission process, it was termed MASER, an acronym for Microwave Amplification by Stimulated Emission of Radiation (Elliott, 1995; Oshea *et al.*, 1978). Over next year's Schawlow and Townes made important contributions that help to extend these ideas from the microwaves to the optical wavelength region. These efforts culminated in July 1960 when T.H. Mainian announced the generation of a pulse coherent red light by

---

Corresponding Author: Mohammed M. Jawad, Department of Medical Engineering, College of Engineering, Al-Nahrain University, Baghdad, Iraq means of a ruby crystal-the first laser (Mosaad, 1997). After that laser started to be used by engineering sciences and industry. An example of its use in computer science such as information security, thus making it possible to secure transmission of information from the patient to data stored in the hospital (Alanazi *et al.*, 2010a, b) or from a hospital to another (Nabi *et al.*, 2010). Also in the field of electronic engineering and medical engineering which made it possible to develop laser devices to be used in medicine and medical applications (Jawad, 2008). There is no universal laser device or set of laser light Parameters for effective treatment of all medical diseases just as there is no universal drug for all human disorders (Sisecioglu *et al.*, 2011; Khosravi *et al.*, 2008). Therefore, greater acceptance of lasers for medical treatment will come with better understanding of the proper choice of laser light energy value needed to perform a specific treatment, when this knowledge is identified from careful scientific studies in the research laboratory a safety packaged laser device and delivery system operated within appropriate range of conditions will greatly increase the acceptance of laser for clinical applications (Keye, 1990).

LASER LIGHT PROPERTIES

Coherence: Coherence means that the electromagnetic waves of light rays are in phase with each other in both space and time. The coherent nature of laser radiation is derived from its generation by stimulated emission that means the emitted photon is exactly in phase with the stimulating photon (Moseley, 1988). There are two types of coherence spatial and temporal (Powell, 1992). Spatial coherence means that the crests and troughs of all the waves coincide along lines perpendicular to the rays. Temporal coherence means that the frequency, wavelength and speed of travel are all constant (Wright and Fisherm, 1993). Coherence is the most fundamental property of laser and distinguishes it from the light from other sources. Thus, a laser may be defined as a source of coherent light.

Brightness or intensity: This property arises from the parallelism or collimation of the laser light as it moves through space maintaining its concentration and thus, the characteristic brightness. The brightness translates to high concentrations of energy when the laser is focused on a small spot (Powell, 1992).

Monochromaticity: Monochrome means that all the photons have the same wavelength. The light produced by a Particular laser will be of a characteristic wavelength or wavelengths (Niemz, 1996). This contrasts greatly with a typical incandescent light bulb which emits wavelengths of the entire spectrum, usually wavelengths from ultraviolet through the entire visible and then into the infrared range or more (Powell, 1992).

Directionality: There is little divergence of the laser beam as it exits the laser device and the beam can travel a considerable distance with very little movement away from parallelism. By not diverging over distance, laser light maintains brightness (Powell, 1992; Niemz, 1996).

LASER PRINCIPLES

To describe how a laser works, some basic aspects of light/matter interaction will be reviewed. The electrons in an atom or molecule exist in very specific energy level called (states). Each atom possesses electrons that are characteristic to the Specific element or combination of elements (molecules) (Elliott, 1995). The transition of an atom or molecule from one state to another occurs and is called the quantum transition. Quantum transitions may be induced by various causes; in particular they can occur when atoms interact with optical radiation (Tarasov, 1986). If the atom is in the upper state and makes a transition to the lower state then energy as a photon of electromagnetic radiation can be emitted with a frequency given by:

$$V = E_2\text{-}E_1/h,\ E_2\text{-}E_1 = hV,\ E = hc/\lambda$$

where, E_2-E_1 is the energy difference between the two levels E_2 and E_1 which is E, h is plank's constant (6.625×10^{-34} J sec^{-1}), c is the speed of light (3×10^{8} m sec^{-1}), v is the frequency and λ is the wavelength in (m).

On the other hand, if the atom is initially in the lower energy state (E_1) and makes a transition to the higher state (E_2), then energy and hence radiation of frequency given by the above equation must be absorbed (Beesly, 1978). By absorbing a photon that has energy equal to the difference between the lower state and a higher one. Electron can move to more energetic state (called an excited state). This excited state is less stable than the lower or ground state, thus electrons tend to give up energy by radiating a photon of an energy equal to the energy difference between the two states and returning to some lower state. This emission occurs after a period of time called (life time of spontaneous emission) (Elliott, 1995; Mosaad, 1997). The emission of the photon can occur by two ways (Tarasov, 1986; Mosaad, 1997):

Spontaneous emission: where the atoms at level E_2 tend to decay to level E_1 spontaneously without any stimulus. The decay of different atoms occurs at random, the instant of the transition, direction of the emitted photon and its polarization all are random quantities

Stimulated emission: where the atom lies in the upper energy level then the same incident photon may play the role of a trigger and induce the transition from E_2 to E_1, the transition causes an emission of a photon. Both the inducing and the induced photons have the energy equal E_2-E_1, same direction and polarization

Therefore, if a large number of matching-energy photons come past an excited state, there is a high probability that this process occurs, so that its lifetime for stimulated emission can be much less than its spontaneous lifetime. This process is called amplification; it is the critical process that makes a laser possible (Elliott, 1995) as shown in Fig. 1.

In order to obtain a laser action, it must be ensured that more atoms in the lasing medium are in an excited state than in the lower-energy state. When this condition is met, it is said that a population inversion takes place in the medium. Pumping energy into the lasing medium can create this condition (Tarasov, 1986; Mosaad, 1997; Oshea *et al.*, 1978). Now a stray photon of the correct wavelength, produced by spontaneous emission, is enough to set off a chain of stimulated emissions. The lasing medium lies between two mirrors, one of them is totally reflecting and the other is partially reflecting. Photons can bounce back and forth, stimulating more and more atoms to emit photons, thus rapidly increasing the intensity, as they leave through the partially reflecting mirror (Oshea *et al.*, 1978). If the pumping energy is applied continuously, population inversion is maintained and new excited atoms will recoup the exhaustive atoms and give rise to a continuous wave laser (Ashour, 2006). While if the pumping energy is applied intermittently, as in pulsed laser, the stimulated emission die down as the atoms that are in an excited state are developed and lose its excessive energy, destroying the population inversion (Mosaad, 1997).

ELEMENTS OF LASER DEVICES

In order to operate most laser devices, three basic conditions must be satisfied:

Active medium: This is a collection of atoms, molecules, or ions that can be solid, liquid, gas, or plasma states. The composition of the lasing medium determines the wavelength output and name of a particular laser (Keye, 1990).

Pumping source: The source of energy to pump the laser medium. When the laser medium in the optical cavity is pumped, a laser beam is generated that leaves the cavity through the partially transmitive mirror by which the population inversion is created inside the active medium (Cember, 1987).

Optical resonator: This consists of two mirrors. The laser medium is placed in the optical cavity and its axis is made to coincide with the common axis of the mirrors. One mirror is generally fully reflective for the wavelength of operation of the laser and the other is partially transmitive, by which the selection of some photon states and the suppression of other states can be realized (Oshea *et al.*, 1978) as shown in Fig. 2.

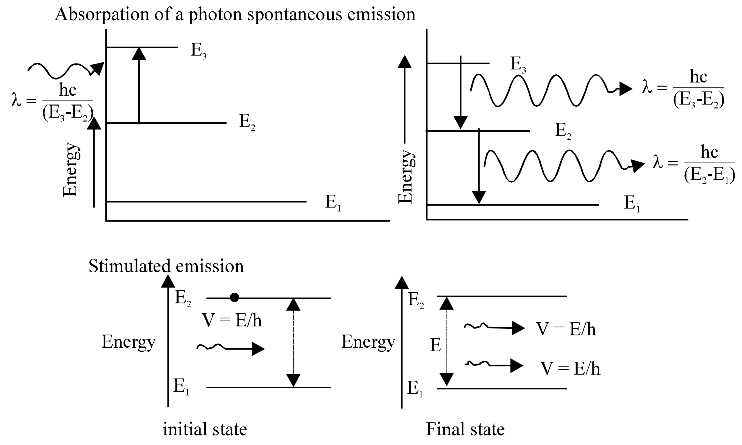

Fig. 1: Type of emission when a photon is absorbed (Al-Feraon, 2000)

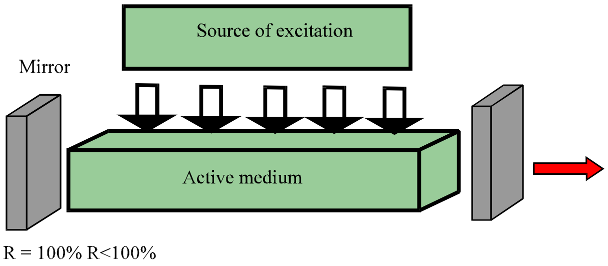

Fig. 2: Basic components of laser system (Chopra and Chawla, 1992)

LASER MODES

The longitudinal (or axial) mode of a laser is a function of the distance between the resonating mirrors and determines photon wavelength. The optical cavity is structured to optimize the amplification of only one frequency in order to maintain monochromatizing output (Cember, 1987). The Transverse Electromagnetic Mode (TEM) defines the special energy distribution pattern across the face of the beam. The smallest effective beam diameter and hence the highest power intensity occurs with a TEM_{00} beam when we have a Gaussian or normal distribution of energy across the beam (Keye, 1990).

Types of laser operation: Lasers can operate in the following modes:

CW or continuous mode: If the partially transmitting end of the optical cavity allows a fraction of the light energy that strikes it to escape and if energy can be pumped in to the lasing medium at such a rate that the laser output can be maintained uninterruptedly, then we get a continuous laser beam. Most CW lasers employ gas as the lasing medium (Seckel, 1996).

Chopped mode: A shutter may interrupt The output of a CW laser that chops the beam into trains of short pulses. The maximum power level of each pulse is the same as that obtained in the CW mode. The duration of the pulse when the shutter is open is limited by the speed of the shutter and is typically 100 to 500 m sec. The useful proportion of the laser beam during which the light is transmitted by the chopped laser is called Duly Cycle (DC):

$$DC = \frac{P_{average}}{P_{max}}$$

The duty cycle is obtained by multiplying the pulse width by the frequency (in hertz) (Al-Qalamjy, 2001).

Pulsed: Gas lasers such as the CO_2 laser can be gated or pulsed electronically. The gating permits the duration of the pulses to be compressed; producing a corresponding increase in peak power that is much higher than it is commonly available in the CV mode (Dederich, 1993).

Q-Switched: Short and more intense pulse can be obtained with the technique of Q-switching. By introducing a shutter into the resonant cavity of the laser, the energy in the active medium is raised to a level far above that is obtainable without the shutter or obstruction in the system. If the shutter is then rapidly opened or the obstruction is removed to permit light to traverse the resonant cavity, all of the stored energy is discharged in an extremely short period. The result is a short duration pulse (1 μ sec to 1 n sec) whose peak intensity reaches to 10^7 W or more. This extremely high-powered flash is also referred to as a giant pulse (Miserendino and Pick, 1995; Powell, 1992).

LASER PARAMETERS

Wavelength: Wavelength is the most important determinant in how light affects tissue. It is the distance between two successive crests of the wave. Each type of laser has a certain wavelength (or wavelengths) according to the nature of the active medium. Laser wavelengths are commonly measured in units of length: nanometers (nm) or micrometers (μm), depending on whether they are in UV, visible or IR range of the electromagnetic spectrum. Simply stated, the wavelength determines the quality or type of interaction between the laser and the tissue (Dederich, 1993).

Energy and energy density: Radiant energy is the total amount of energy radiated by optical source (Hadley *et al*., 2000). CW lasers generate laser outputs in certain ranges of energy according to its application. Therefore, the output energy could be manipulated within the range of the system. Pulse energy is the energy contained in a single pulse. This term is used in pulsed laser. The operator cannot change pulse energy. The units of the energy are Joules (J). In pulsed laser, the energy density term is used to determine the energy deposition in a certain area of the target. In a single pulse the energy density equals the energy of a single pulse divided by the irradiated area:

$$\text{Energy density} = \frac{\text{Pulse energy}}{\text{Area}}$$

In the multipulsed irradiation the number of the pulses multiplies the last term:

$$\text{Energy density} = \frac{\text{Pulse energy}}{\text{Area}} \times \text{No. of Pulses}$$

$$\text{Energy density} = \frac{\text{Pulse energy}}{\text{Area}} \times \text{Repetition rate} \times \text{Exposure time}$$

$$\text{Energy density} = \frac{(\text{Average (or mean) power} \times \text{Exposure time})}{\text{Area}}$$

The energy density is measured in Joules per square centimeter (J cm^{-2} or J cm^{-1}).

Pulse duration: This term is used in pulsed lasers. It refers to the full width at half maximum of the peak of the pulse. Pulse duration is measured in units of time (milliseconds, microseconds, nanoseconds, picoseconds or femtoseconds). The operator cannot control the pulse duration.

Repetition rate: It is the number of pulses per one second. The operator controls it through the manipulation in the control panel of the laser unit in a certain range. It is measured in Hertz (Hz) or (S^{-1}).

Duty cycle: It is the useful proportion of the laser beam during which the light is transmitted by the chopped laser. It is a unit less quantity. The range of the duty cycle enables the operator to reduce the unwanted thermal effect of the CW laser beam. Duty cycle can be calculated from:

$$\text{Duty cycle} = \frac{\text{Mean power}}{\text{Maximum power}}$$

Power and power density: Radiant power is the amount of radiant energy. The average power of the laser is equal to the output energy over the exposure time.

$$\text{Average power} = \frac{\text{Energy}}{\text{Time}}$$

In pulsed laser the peak power is expressed as the following:

$$\text{Peak power} = \frac{\text{Energy of the pulse}}{\text{Pulse duration}}$$

Average power of the pulsed laser or mean power of the chopped laser is equal to the energy of the pulse multiplied by the repetition rate.

$$\text{Average power (mean or power)} = \text{Pulse energy} \times \text{Repetition rate}$$

The units of the power are Watts (W).

For a CW laser the power density is the average output power in watts divided by the irradiated area in square centimeters:

$$\text{Power density} = \frac{\text{Average power}}{\text{Area}}$$

The units of the power density are (W cm^{-2})

Peak power of the pulsed laser divided by the irradiated area gives the power density of the pulsed laser:

$$\text{Power density} = \frac{\text{Peak power}}{\text{Area}}$$

The units of the power density are (W cm^{-2}).

Spot diameter: It is the diameter of the irradiated area on the target. Using focusing lenses could change this area. The spot diameter ($2W_2$) is directly proportional to the focal length of the lens (F) and the laser wavelength (λ) and is inversely proportional to the beam diameter ($2W_1$):

$$2W_2 = (4F\lambda)/W_1$$

The spot diameter is considered to be equal to the beam diameter when the lenses are not be used. The units of the spot diameter are usually centimeters.

LASER-TISSUE INTERACTION

When laser light strikes a tissue surface, it can be reflected and refracted, scattered, absorbed or transmitted (Das, 1991). The fractional intensity that goes into these different processes depends on the optical properties of the tissue like it's reflectivity, scattering and absorption coefficients, particle size (Chopra and Chawla, 1992), as well as the laser parameters like wavelength, energy, pulse duration, operation mode and output spectral profile (Bedrym, 1997; Ashour, 2006). In medical laser applications, refraction plays a significant role when irradiating transparent media like corneal tissue. In opaque media, usually, the effect of refraction is difficult to measure due to the absorption and scattering (Niemz, 1996). Laser light passing through the tissue undergoes multiple scattering processes and is transformed from a narrow collimated beam into a broad diffuse beam (Mosaad, 1997). Scattering coefficient increases with the increase of the wavelength, thus, UV light is scattered more than IR light (Niemz, 1996). All the effects of light begin with the absorption of electromagnetic radiation (Elliott, 1995). During absorption, the intensity of an incident light is attenuated by passing through a medium due to a partial conversion of light energy into heat motion or certain vibrations of molecules of the absorbing material. The ability of a medium to absorb electromagnetic radiation depends on a number of factors, mainly the electronic constitution of its atoms and molecules, the wavelength of radiation, the thickness of the absorbing layer and internal parameters such as temperature or concentration; Fig. 3 shows these processes.

Two laws are frequently applied; they describe the effect of either the thickness or concentration on absorption, respectively. They are commonly called Lambert's law and Beer's law (Beer-Lambert's law) and are expressed by:

$$I_{(z)} = I_0 \exp^{(-\alpha z)}$$

$$I_{(z)} = I_0 \exp^{(-k c z)}$$

where, z is the optical axis, $I_{(z)}$ is the intensity at a distance z, I_0 is the incident intensity, α is the absorption coefficient of the medium, c is the concentration of the absorbing agent and k depends on the internal parameter other than concentration (extinction coefficient) (Niemz, 1996).

The most important optical property that decides the suitability of a laser for a surgical procedure is the penetration depth of its radiation in the tissue. It is equal to the inverse of the absorption coefficient (α) of the laser radiation in the tissue and is defined as the depth at which the intensity of the laser radiation reduces to 37% (drops to l/e) of its maximum value at the surface of the tissue. The penetration depth changes significantly with the wavelength of the laser radiation (Julia *et al*., 1998). In the red portion of the spectrum and in near infrared region, the penetration depth can be considerably greater. In spectral regions where the absorption coefficient is relatively high, such as at 10.6 nm, the radiation is absorbed in a thin layer near the surface (Mosaad, 1997; Julia *et al*., 1998). In biological tissue, either water molecules or macromolecules such as proteins and pigments mainly cause absorption. The absorption of infrared light can be attributed to water molecules, whereas UV and visible light absorbs by proteins and pigments (Julia *et al*., 1998).The absorbed portion of the laser radiation can produce photochemical and/or Photothermal effects depending on the wavelength of the laser radiation and nature of the tissue. It can produce fluorescence and this is used in dentistry in diagnosis of initial dental carries that based on spot emission fluorescence (Julia *et al*., 1998).

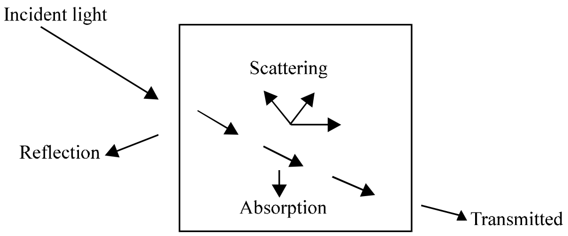

Fig. 3: Reflected, refracted, scattered, absorbed or transmitted when laser light strikes a tissue surface (Chopra and Chawla, 1992)

LASER INTERACTION MECHANISMS

The variety of interaction mechanisms may occur when applying laser light to biological tissue due to specific tissue characteristics as well as laser parameters (Julia *et al*., 1998; Khosravi *et al*., 2008).

Wavelength dependent mechanisms

Photothermal interaction mechanisms: The most frequently used mechanism of photon energy conversion in laser medicine is heating. Heating of irradiated sample occurs with all methods of tissue destruction (coagulation, vaporization, cutting, etc.) (Karu, 1999). Photons absorbed by the tissue are thought to cause biological effect via nonspecific Photothermal effects caused by kinetic mechanism, the external energy from the laser photons is deposited into the target materials via transitional, rotational and vibrational modes of movements of the target molecules. The rotational and vibrational modes of movement which are in fact criteria of the temperature or Kinetic Energy (KE) of the target molecules. The extracted energy from the incident light most efficient when the frequency of the incident photons is close to the characteristic frequencies of these modes (resonance absorption) (Bedrym, 1997; Fitzpatrick and Goldman, 2000). When laser energy is converted into heat in the tissue, thermal diffusion begins. Diffusion of heat through the tissue depends on the thermal properties of the irradiated material. The thermal relaxation (cooling) phenomenon is influenced by the thermal coefficient of the tissue, the properties of the surrounding tissue or fluids and the temperature differential between the irradiated and non irradiated tissue (Litvack *et al*., 1988). However, depending on the duration and peak value of the tissue temperature achieved, different effects like coagulation, carbonization, vaporization and melting may be distinguished. For thermal decomposition of tissues, it is important to adjust the duration of the laser pulse in order to minimize thermal damage to adjacent structures. For laser pulse durations $\tau<\tau_{\text{thermal relaxation time}}$, heat does not even diffuse to the distance given by the optical penetration depth L. for $\tau>\tau_{\text{thermal relaxation time}}$ heat can diffuse to a multiple of the optical penetration depth, i.e., thermal damage of tissue adjacent to the decomposed volume is possible (Niemz, 1996). The microscopical and biochemical analysis showed that as the temperature is raised, the large, specially configured molecules necessary for life are shaken open. Most proteins, DNA, RNA, membranes and their integral structures start to unwind or melt at temperatures ranging from 40-100°C, the result is denaturation or loss of function (Niemz, 1996; Fitzpatrick and Goldman, 2000).

The most important and significant tissue alterations are dependent on the temperature of the tissue after absorption of the laser radiation, as follows:

- At 37°C; no measurable effects are observed for the next 5°C above this
- The first mechanism by which tissue is thermally affected can be attributed to conformational changes of molecules. These effects, accompanied by bond destruction and membrane alterations are summarized in the single term hyperthermia ranging from approximately 42-50°C. If such a hyperthermia lasts for several minutes, a significant percentage of the tissue will already undergo necrosis
- At 60°C, denaturation of proteins and collagen occurs which leads to coagulation of tissue and necrosis of cells. The corresponding macroscopic response is the visible paling of the tissue. Several treatment techniques such as LITT aim at temperatures just above 60°C
- At higher temperatures (>80°C), the cell membrane permeability is drastically increased, thereby destroying the otherwise maintained equilibrium of chemical concentrations
- At 100°C, water molecules contained in most tissues start to vaporize. Due to the large increase in volume during this phase transition, gas bubbles are formed inducing mechanical ruptures and thermal decomposition of tissue fragments
- At temperatures exceeding 150°C, carbonization takes place which is observable by the blackening of an adjacent tissue and the escape of smoke
- Finally, melting may occur. The temperature must have reached a few hundred degrees Celsius to melt the tooth substance which mainly consists of hydroxyapatite crystals (a chemical compound of calcium and phosphate) (Niemz, 2004)

Thermal effects of laser radiation are listed in Table 1.

The group of photochemical interaction mechanisms stems from empirical observations that light can induce chemical effects and reactions within macromolecules or tissues. Photochemical effects occur as a result of direct excitation of electronic bonds by the laser energy (Litvack *et al*., 1988). In general most of the molecules of the tissue have their bonding in the ultraviolet frequency region (Bedrym, 1997). At shorter wavelengths, tissue components become electronically excited, thus, this (photo excitation) leads to rupture of molecular bonds and formation of molecular fragments (Litvack *et al*., 1988). Photochemical reactions generally do not result in a significant rise in temperature. Photochemical effects involved either a change in the course of biochemical reaction due to the presence of an electromagnetic field or photodecomposition due to high energy photons that rupture molecular bonds (Das, 1991; Monajembashi *et al*., 1986). Photochemical interaction mechanisms take place at very low power densities (typically 1 W cm^{-2}) and long exposure times ranging from seconds to CW lasers . In most cases, wavelengths in the visible range are used because of their high optical penetration depths. Several applications of the photochemical interaction mechanisms have been used as in the following sections (Niemz, 2004).

Photodynamic Therapy: The photodynamic therapy reaction is mediated by exogenous chromospheres. At low light intensities, laser energy is absorbed by exogenous chromospheres molecules called photosensitizes (photo acceptors). In this case, the light is used for activation of molecules or drugs by a specific wavelength of the laser light. The absorbing molecule can

Table 1: Thermal effect of laser radiation (Miserendino *et al*., 1995)

Temperature (°C)	Biological effect
37	Normal
<43	Biostimulation
43-45	Hyperthermia
50	Reduction in enzyme activity
60	Protein denaturation (coagulation)
70-80	Welding
80	Permeabilization of cell membranes
100°	Vaporization
>150	Carbonization
>300	Rapid cutting and ablation

transfer the energy to another molecule and this activated molecule can then cause chemical reactions in the surrounding tissue. The molecule may be transformed into toxic compound, often involving oxygen-free radical that can cause cellular death through destruction of the DNA molecule (Niemz, 2004; Khosravi *et al*., 2008). This type of reaction is successfully used in the Photodynamic Therapy (PDT) of tumor; where the photoabsorbing molecules are artificially introduced into a tissue before irradiation. Irradiation of cells at certain wavelength can also activate some of the native components (Sisecioglu *et al*., 2011). In this way specific biochemical reactions as well as whole cellular metabolism can be altered. This type of reaction is believed to form the basis for low power laser effect.

Biostimulation: This process is also known as low energy, low light, soft, cold laser and low intensity, low power therapy is the application of monochromatic red light energy close to infrared wavelengths to stimulate growth factor cells and improve wound/soft tissue healing. Low Laser Level Therapy (LLLT) was pioneered in Europe and Russia in the early 1960's (Monajembashi *et al*., 1986). Biostimulation using light energy which is usually considered a photochemical effect, is a procedure that has attracted interest in both the clinical and research arenas in both human medicine and veterinary. To many scientists and clinicians, the idea is that low intensity light energy can promote and upgrade metabolic processes that result in tissue repair and pain relief which is unbelievable. Also in the area of injuries, conditions are usually created preventing proliferation such as low oxygen concentration or pH. The exposure to red or near infrared light might thus serve as a stimulus to increase cell proliferation (Niemz, 2004). Reports from almost every region of the world indicate that low intensity lasers promote the repair process of skin, tendons, ligaments, bone and cartilage in experimental animals as well as wounds from various etiologies in humans (Weesner, 1995).

Photoablation therapy: Photoablation was first discovered by Srinivasan and Mayne-Banton in the year 1982. They identified it as ablative photodecomposition, meaning that material is decomposed when exposed to high intense laser irradiation. It occurs when the energetic photons of the laser light decomposes the molecules by breaking the chemical bonds. In this interaction, photoablation is due to the "volume stress" as a result of bond breaking. The removal of tissue is performed in a very clean and exact fashion without any appearance of thermal damage such as coagulation or vaporization. Photoablation takes place in the intensity range of 10^4-10^{10} W cm^{-2} and interaction time in the range of 10^{-3}-10^{-10} sec. But the typical threshold values of this type of interaction are 10^7-10^8 W cm^{-2} at laser pulse durations in the nanosecond range. The main advantages of this ablation technique lie in the precision of the dental enamel etching process and the lack of thermal damage to adjacent tissues (Niemz, 2004). Currently, most of the ablation work is done with UV excimer laser (Beesly, 1978; Karu, 1999). When the energetic photons of the laser light decompose the molecules by breaking the bonds at the impart excess energy for ejection (Weesner, 1998; Hemachandran and Arumugam, 1983). Interaction of light with biological tissue is seen in Fig. 4.

Wavelength independent mechanisms: When using power densities exceeding 10^{11} W cm^{-2} in solids and fluids or 10^{14} W cm^{-2} in air, where the pulse duration is in picosecond or femtosecond range, multiphoton ionization of atoms and molecules may occur a phenomenon called optical breakdown occurs. The physical effects associated with optical breakdown are plasma formation and shock wave generation .If breakdown occurs inside soft tissues or fluids, cavitations and jet formation may additionally take place. By means of plasma-induced ablation, very clean and well defined removal of tissue without evidence of thermal or mechanical damage can be achieved when choosing appropriate laser parameters (Gordon, 1966) as shown in Fig. 5. Uncontrolled, the effect of the plasma on the tissue surface can cause tissue

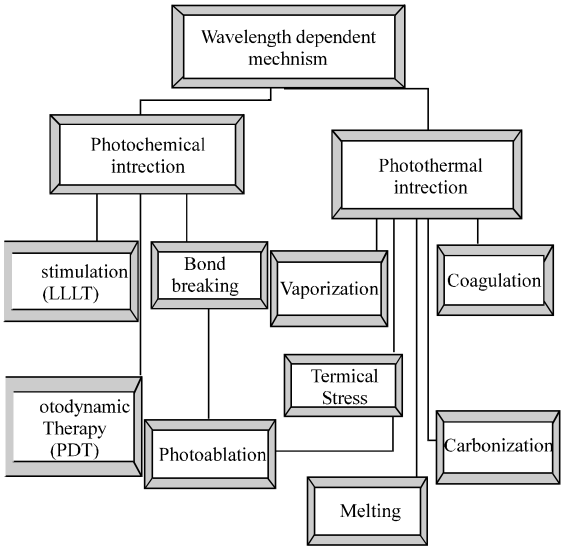

Fig. 4: Interaction of light with biological tissue (Wavelength dependent mechanism) (Aboud, 2005)

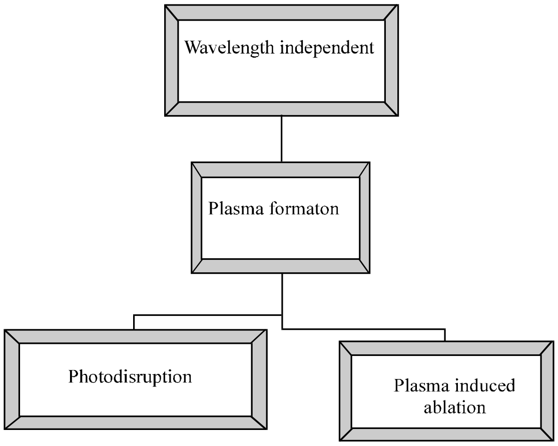

Fig. 5: Interaction of light with biological tissue (Wavelenght independent mechanism) (Aboud, 2005)

damage (Featherstone and Neslon, 1987). The ultra short laser pulses with pulse durations shorter than 100 ps-each of them having no thermal effect-may add up to a measurable increase in temperature if it applied at repetition rates higher than about 10-20 Hz, depending on the laser. The most important parameter of plasma-induced ablation is the local electric field E which determines when optical breakdown is achieved. If E exceeds a certain threshold value as in mode locked lasers, where the pulse duration is in picosecond or femtosecond range, multiphoton ionization of atoms and molecules may occur, optical breakdown is achieved (Wintner, 2001; Stern, 1969). The important feature of optical breakdown is that it renders possible an energy deposition not only in pigmented tissue but also in nominally weakly absorbing media. This means that the interaction does not depend on the wavelength (Wintner, 2001). During photo disruption, the tissue is split by mechanical forces. Whereas plasma-induced ablation is spatially confined to the breakdown region. For nanosecond pulses optical breakdown is always associated with shock wave formation even at the very high threshold. Since adjacent tissue can be damaged by disruptive forces, the presence of these effects is often an undesired but associated symptom (Wintner, 2001). Picosecond or femtosecond pulses permit the generation of high peak intensities with considerably lower pulse energies. With these extremely short pulse durations, optical breakdown may still be achieved while significantly reducing plasma energy and, thus, disruptive effects (Wintner, 2001). The important feature of optical breakdown is that it renders possible an energy deposition not only in pigmented tissue but also in nominally weakly absorbing media, This means that the interaction does not depend on the wavelength (Stern, 1969). During photo disruption, the tissue is split by mechanical forces. Whereas plasma-induced ablation is spatially confined to the breakdown region. For nanosecond pulses optical breakdown is always associated with shock wave formation even at the very high threshold. Since adjacent tissue can be damaged by disruptive forces, the presence of these effects is often an undesired but associated symptom (Stern, 1969). Picosecond or femtosecond pulses permit the generation of high peak intensities with considerably lower pulse energies. With these extremely short pulse durations, optical breakdown may still be achieved while significantly reducing plasma energy and, thus, disruptive effects (Wintner, 2001).

LASER HAZARDS AND SAFETY

Laser hazards effects: Laser radiation hazards must be identified and evaluated. Types of laser hazards:

- Eye: Acute exposure of the eye to lasers of certain wavelength and power can cause corneal and retinal burns (or both). Chronic exposure to excessive levels may cause corneal or lenticular opacities (cataracts) or retinal injury
- Skin: Acute exposure to high levels of optical radiation may cause skin burn; while carcinogenesis may occur for ultraviolet and near ultraviolet wavelengths
- Chemical: Some lasers require hazardous or toxic substance operates (i.e., chemical dye)
- Electric shock: most lasers produce high voltage that can be lethal
- Fire hazards: The solvents used in dye lasers are flammable. High voltage pulse or flash lamps may cause ignition. Direct beams may ignite flammable materials or a specular reflection from high power Continues Wave (CW) infrared lasers.
- Another hazard involves the potential inhalation of airborne biohazardous materials that may be released as a result of the surgical application of laser

Inhaled airborne contaminants can be emitted in the form of smoke or plume that generated through thermal interaction of surgical lasers with tissue (Miserendino and Pick, 1995; Sisecioglu *et al*., 2011). Laser plume evacuated device is used, to eliminate laser plume or smoke which is irritant to the pulmonary tree because it is carrying particles of tissue and microorganism. In addition, masks are necessary to use by the medical staff. They act as filters to protect the pulmonary system from the possibilities of an infection by microorganism. (Muncheryan, 1975; Al-Alawi, 2005). Laser and laser systems are grouped according to their capacity to produce injury and specific controls are then described for each group. Lasers manufactured after august 1976, are classified and labeled by the manufacturer. Information on the label must include class, the maximum output power, the pulsed duration (if pulsed) and laser medium or emitted wavelength (Ashour, 2006). Maximum Permissible Exposure (MPE): the level of laser radiation to which person may be exposed without hazardous effect. or adverse biological changes in the eye or skin.

Laser safety standards and hazard classification: This standard was developed by the American National Standard Institute (ANSI) in year 1993. The classification is based upon the beam output power or energy from the laser. Basically, the classification is used to describe the capability of the laser to produce injury to personnel. The higher the classification number, the greater is the potential hazard (Niemz, 2004):

- **Class 1:** Low-power lasers and laser systems that cannot emit laser radiation levels greater than Maximum Permissible Exposure (MPE). Class I CW lasers emitting at 400-550 nm and should have output power no larger than 0.39 mW. Class one laser and laser system are incapable of causing eye damage and therefore except from any control measures and considered safe. No requirement for special safety measures
- **Class 2:** Visible low power lasers or laser systems and may be continuous or pulsed that are incapable of causing eye damage unless they are viewed directly for an extended period (greater than 1000 sec). the power output is 1 mW or less. Eye protection is only special safety measures
- **Class 3:** Medium power lasers and laser systems capable of causing eye damage with short-duration (<0.25 sec) exposures to the direct or secularly reflected beam. Includes class 3a and 3b Lasers
- **Class 3a:** Lasers or laser systems that are normally would not produce a hazard if viewed for only momentary period with unaided eye. They may present hazard if viewed using collecting optics. It have power output limited to 1-5 mW at wavelengths of 400-700 nm. Adequate eye protection must be done
- **Class 3b:** Lasers have out power limits 5-500 mW at CW modes and have energy density less than 10 J cm^{-2} at visible or invisible laser light direct beam impact to the eye is always hazardous. This includes intra beam viewing or specular reflections
- **Class 4:** Lasers have high out power and exceed of 500 mW at CW mode and more than 10 J cm^{-2} for pulsed mode, this laser systems capable of causing severe eye damage with short-duration (<0.25 sec). Class 4 laser and laser systems are also capable of causing severe skin damage and igniting flammable and combustible materials, as seen in Table 2.

Laser safety recommendations and requirements

Precautions against electrical shock: Almost all laser systems operate at voltages of dangerous levels (in Kilovolts). The following should be observed before anyone attempts to work on the circuit:

- The main switch should be turned off before any one handles the circuit connections
- A jumper with an insulated handle should be used to discharge the capacitors before any work is done on the circuits
- Any one should not work on the system unless he is familiar with the circuitry and the proper safety precautions
- For maximum safety, all laser systems should have grounded outlets
- The circuitry should be covered up when no one is dealing with it (Muncheryan, 1975)

Precautions against laser radiations

Eye protection: The human eye is the most vulnerable tissue to all types of laser radiation .The tissue in the retina (the screen at the back of the eyeball that receives the light or image) is susceptible to damage because the lens concentrates and focuses the laser beam on the retina. The retina is surrounded by a thin, dark-brown membrane containing arteries , veins and pigment cells, it would easily absorb radiation .The retina is sensitive to all color wavelength , from the 380 to 900 nanometer spectral range and to some degree to infrared wavelengths beyond 900 nanometer (Muncheryan, 1975). Within the retinal

Table 2: Principle laser radiation hazards according to the laser class (Estephan, 2007)

Class 1	Safe, due to very low radiant emission.
Class 2	(Covers visible emission only) Possible eye hazard other than for accidental momentary viewing.
Class 3a	Eye hazard if magnifying viewing instruments are used to view or intercept the beam.
Class 3b	Hazard to the unaided eye. The viewing of diffuse reflections is normally safe. It can also exceed the skin safety threshold, but would not be expected to cause serious harm to the skin.
Class 4	Eye and skin hazard. Diffuse reflections may also be hazardous. Possible fire and fume hazard by interaction with target material.

area, the most critical area for vision is the fovea. This area is about 1 mm in diameter and contains the highest density of cone cells, resulting in the highest image resolution of the eye. Minimal damage in the peripheral field of the retina may go undetected since the brain compensates, up to a certain point, for small-area vision losses. The fovea is much more susceptible to damage than the para-macular region of the retina. It is necessary for the therapist to use a protective eye filter because of the back-scatter qualities of the beam. Therefore, the eyes of everyone in the operating room must be protected by safety goggles which should be procured for the specific energy and wavelength of the beam under consideration (Catone and Alling, 1997). For beam control and to minimize direct eye exposure observe these precaution:

- Do not intentionally look directly into the laser beam or at a specular reflection, regardless of its power
- Terminate the beam path at the end of its useful path
- Locate the beam path at a point other than eye level when standing or when sitting at a desk
- Orient the laser so that the beam is not directed toward entry doors or aisles
- Minimize specular reflections
- Securely mount the laser system on a stable flat room to maintain the beam in a fixed position during operation and limit beam traverse during adjustment.
- Confined primary beams and dangerous reflections to the optical table
- Clearly identify beam paths and ensure that they don't cross populated area of traffic path
- When the beam path is not totally enclosed, locate the laser system so that the beam will be outside the normal eye-level range which is 1.2 to 2 m from the floor. A beam path that exits from controlled area must be enclosed where the beam irradiants exceeds the MPE
- Warning signs should be placed on the doors at the entrance to the operating room

Skin protection: High power laser can inflect skin burns and the effect of laser radiation of the skin depends on both the wavelength and the pigmentation of the skin. In visible spectrum range, the skin can reflect much of then while in the infrared region the skin become highly absorbing. The laser injury to the skin may be much less serious than to the eye (Moseley, 1988). Skin of the face is also considered in this precaution by placing a towel over the patient face. The working in the oral cavity, the lips and nose also be protected teeth are covered with saline-soaked sponges to avoid enamel teeth burns (Nicholas *et al*., 1995).

CONCLUSION

From this study, it is concluded that laser is an useful tool in many medical applications if used properly, with taking in consideration the good understanding of laser principle and interaction between different laser parameters with biological tissues. This will enhance better operators performances with different laser treatments. It is suggested that more researches on laser applications in medical fields are needed because laser is still a promising tool.

REFERENCES

Abdul Qader, S.T., 2006. Evaluation of calcium and hydroxyl ions release from non-stting calicium hydroxide paste and mineral trioxide aggregate through three different apical aperture sizes during apexification procedure. M.Sc. Thesis, University of Baghdad.

Aboud, G.T., 2005. Treatment of oral ulcerations. M.Sc. Thesis, University of Baghdad.

Al-Alawi, A.S., 2005. Evaluation of low level diode laser in skin wound healing (experimental study clinical observation). M.Sc. Thesis, University of Baghdad.

Al-Feraon, M.A.S., 2000. Comparative study between CO_2 laser and conventional surgical techniques applied to remove chemically induced ulcer in rabbits lip. M.Sc. Thesis, University of Baghdad

Al-Qalamjy, B.M.M., 2001. Caries like lesion initiation in sound enamel following CW CO_2 laser irradiation. M.Sc. Thesis, University of Baghdad

Alanazi, H.O., H.A. Jalab, G.M. Alam, B.B. Zaidan and A.A. Zaidan, 2010a. Securing electronic medical records transmissions over unsecured communications: An overview for better medical governance. J. Med. Plants Res., 4: 2059-2074.

Alanazi, H.O., M.L.M. Kiah, A.A. Zaidan, B.B. Zaidan and G.M. Alam, 2010b. Secure topology for electronic medical record transmissions. Int. J. Pharmacol., 6: 954-958.

Ashour, H.S., 2006. Tuning semiconductor laser diode lasing frequency and narrowing the laser linewidth using external oscillating driving field. J. Applied Sci., 6: 2209-2216.

Bedrym, M., 1997. A study of interaction of XeCl excimer laser with human tissue. Ph.D. Thesis, Baghdad University

Beesly, M.J., 1978. Laser and their Applications. Taylor and Francis Ltd., London.

Catone, G.A. and C.C. Alling, 1997. Laser Applications in Oral and Maxillofacial Surgery. W.B. Saunders Company, Philadelphia.

Cember, H., 1987. Introduction to Health Physics. Pergamon Press, Germany.

Chopra, S. and H.M. Chawla, 1992. Laser in Chemical and Biological Sciences. Wiley Eastern Ltd., New Delhi.

Das, P., 1991. Laser and Optical Engineering USA. Springer-Verlag, New York, pp: 41-42.

Dederich, D.N., 1993. Laser/tissue interaction: What happens to laser light when it strikes tissue. J. Am. Dent. Assoc., 124: 57-61.

Elliott, D.J., 1995. Ultraviolet Laser Technology and Applications. Academic Press, USA.

Estephan, R.K., 2007. Efficacy of different Er:YAG laser parameters and conventional bur cavity preparation on the microleakage of class V cavities restored with composite restoration: An *in vitro* study. M.Sc. Thesis, University of Baghdad.

Featherstone, J.D. and D.G. Neslon, 1987. Laser effects on dental hard tissues. Adv. Dent. Res., 1: 21-26.

Fitzpatrick, R.E. and M.P. Goldman, 2000. Cosmetic Laser Surgery. John Wiley New York.

Gordon, T.E Jr., 1966. Laser interaction with extracted human teeth. A preliminary report. Dent. Dig., 72: 154-158.

Hadley, J., D.A. Young, L.R. Eversole and J.A. Gornbein, 2000. Laser powered hydrokinetic system. J. Am. Dent. Assoc., 131: 777-785.

Hemachandran, N. and N.V. Arumugam, 1983. Laser and its applications in dentistry. J. Indian Dent. Assoc., 55: 459-461.

Jawad, M.M., 2008. Healing response of soft tissue incisions made by diode laser versus metallic scalpel on rabbits skin. M.Sc. Thesis, University of Baghdad.

Julia, J.E., V. Aboites., M.A. Casillas, 1998. CO_2 laser interaction with biological tissue. Instrum. Dev., 3: 53-59.

Karu, T., 1999. Primary and secondary mechanisms of action of visible to near-IR radiations on cells. J. Photochem. Photobiol. B, 49: 1-17.

Keye, W.R., 1990. Laser surgery in gynecology and obstetrics. 2nd Edn., G.K. Hall and Co., Mosby, Montana.

Khosravi, A.D., J. Rostamian and P. Moradinegad, 2008. Investigation of bactericidal effect of low level laser of galium-aluminium-arsenide on *Cariogenic* species of *Streptococci* and *Lactobacillus*. J. Med. Sci., 8: 579-582.

Litvack, F., W.S. Grundfest, T. Papaioannou, F.W. Mohr, A.T. Jakubowski and J.S. Forrester, 1988. Role of laser and thermal ablation devices in the treatment of vascular diseases. Am. J. Cardiol., 61: 81-86.

Miserendino, L.J. and R.M. Pick, 1995. Laser in Dentistry. Quintessence Publishing Co., Chicago.

Miserendino, L.J., G.C. Levy and I.M. Rizoiu, 1995. Effects of Nd:YAG laser on the permeability of root canal wall dentin. J. Endodontics, 21: 83-87.

Monajembashi, S., C. Cremer, T. Cremer, J. Wolfrum and K.O. Greulich, 1986. Microdissection of human chromosomes by laser microbeam. Exp. Cell. Res., 167: 262-265.

Mosaad, N.R.M., 1997. Laser Technology and Laser Applications in Medicine and Surgery. IESCO, Rabat.

Moseley, H., 1988. Non-Ionizing Radiation, Microwaves, Ultraviolet and Laser Radiation. Taylor and Francis, London, pp: 228-236.

Muncheryan, H.M., 1975. Laser Technology. Howard W. Sams Co. Inc., United States.

Nabi, M.S.A., M.L.M. Kiah, B.B. Zaidan, A.A. Zaidan and G.M. Alam, 2010. Suitability of SOAP protocol in securing transmissions of EMR database. Int. J. Pharmacol., 6: 959-964.

Nicholas, J., G. Lask and A. Maxwell, 1995. Skin Resurfacing with the Ultra Pulse CO_2 laser. Esevier Science Inc., New York.

Niemz, M.H., 1996. Laser Tissue Interaction. Springer, Heidelberg, Germany.

Niemz, M.H., 2004. Laser-Tissue Interactions: Fundamentals and Applications. 3rd Edn., Springer, Germany.

Oshea, D.C., W.R. Callen and W.T. Rhodes, 1978. Introduction to Lasers and their Applications. 2nd Edn., Addison-Wesley Publicating Company, USA.

Powell, G.L., 1992. Laser in the limelight: What will the future bring. J. Am. Dent. Assoc., 123: 71-74.

Ryer, A., 1998. Light Measurement Handbook. International Light Inc., USA.

Seckel, B.R., 1996. Aesthetic Laser Surgery. Little and Brown Company, Boston.

Sisecioglu, M., M.T. Uguz, M. Cankaya, H. Ozdemir and I. Gulcin, 2011. Effect of ceftazidime pentahydrate, prednisolone, amikacin sulfate, ceftriaxone sodium and teicoplanin on bovine milk lactoperoxidase activity. Int. J. Pharmacol., 7: 79-83.

Stern, R.H., 1969. The potential of various lasers in caries prevention. Ann. N.Y. Acad. Sci., 168: 642-648.

Tarasov, L., 1986. Laser Physics and Applications. Mir Publishers, Moscow.

Weesner, B.W. Jr., 1995. Laser in medicine and dentistry. J. Tennessee Dental Assoc., 78: 1-1.

Weesner, B.W. Jr., 1998. Laser in Dentistry. AADR, Alexandria.

Wintner, E., 2001. Ultra-Short-Pulse Laser. Technology and Applications. Photonics Institute, Vienna University of Technology, Vienna, Austria.

Wright, V.C. and J.C. Fisherm, 1993. Laser Surgery in gynecology: A Clinical Guide. W.B. Saunders Company, Philadelphia.