Atlas of Current Oral Laser Surgery

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S. Namour

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INTRODUCTION

"Imagination is more important than knowledge."
–Albert Einstein

When Einstein, at the beginning of the 19th century, envisioned the possibility of producing a spontaneous emission of excited atoms, he could not have imagined that electromagnetic wave amplification (MASER) (Townes et al., 1950) immediately followed by Light Amplification by Stimulated Emission of Radiation (LASER) (Maiman et al., 1960) would one day be utilized in such diverse ways.

Today, increasingly versatile and sophisticated lasers are available. These lasers vary in application based on the choice of different technologies, materials (gas, solids, semi-conductors, colorants, etc.), and a diversity of wavelengths. These various wavelengths have made it possible for laser technology to become a safe, simplified, and effective component in current oral surgery.

In the face of these technologies, the problem that might arise for the dental practitioner is choosing the appropriate adapted wavelength for his professional exercise. One of the aims of the present book is to assist practitioners by presenting knowledge regarding wavelengths, technique, and precautions when performing oral laser surgery.

The CO_2 laser beam's efficiency in oral surgery is due to its high absorption level in water. Subsequently, the laser beam provides a bloodless operative field and clear incisions and, if used in the correct mode, is absolutely safe. Due to technical progress in the field, indications are continually enlarging: some of the latest progressions are the super-pulsed and ultra-pulsed modes that represent a new technical approach in oral surgery, with very little carbonization residue.

The present book will examine and discuss some procedures common in different fields of current oral surgery. First, we present an introduction to laser physics, as well as guidelines for proper clinical protocol. Then, we examine how the laser beam can be useful to practitioners in different specialties, such as periodontics, endodontics, orthodontics, implantology, pre-prosthetic surgery, and oral soft tissues diseases treatments. Finally, we engage in a round table discussion with some of the best international experts in the field of oral surgery.

2

LASER PHYSICS

A Short Introduction to the Laser

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Abstract

This chapter aims to describe the fundamental principles of the production of laser radiation. The focus is to convey a general understanding of the underlying physical phenomena without entering into a detailed mathematical formulation. Some practical aspects especially devoted to the use of lasers in the dentistry environment are also covered.

1 LASER Principle

1.1 The Energy of Electrons, Atoms and Molecules is Quantized

Classical Newtonian mechanics applied to a satellite orbiting around the earth does not yield any constraint on the energy of the satellite. Any value of the energy is feasible, but will result in a different orbit. This is no longer true in the nanoworld of electrons, atoms, and molecules where not all energy values (i.e., not all electronic orbitals) are allowed, but instead only *a very few*. The energy of the electrons is "quantized" according to four "quantum numbers" which can have only integer values. This is the reason why a new type of physics called Quantum Mechanics had to be developed in order to explain the energetic behavior of nanoparticles.

In the following chapter, we shall thus represent the discrete energy levels of an atom by drawing a series of horizontal bars, the lowest one being the "ground state" energy level corresponding to the lowest values of all quantum numbers (Figure 1).

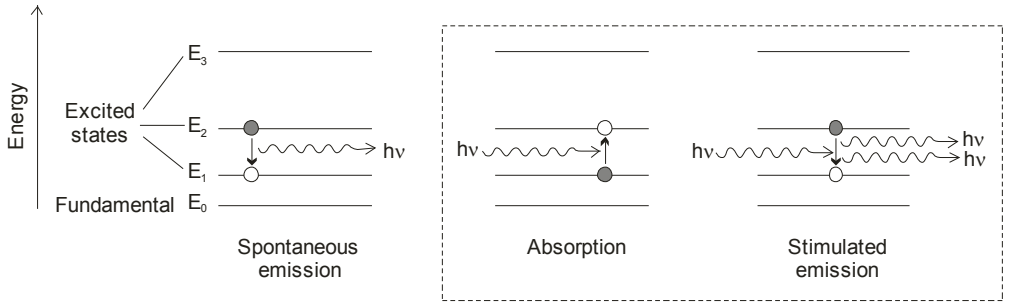

Figure 1. Schematic representation of the energy levels of an atom, with the three processes involved in the interaction with an electromagnetic wave of frequency $\nu = (E_2 - E_1)/h$

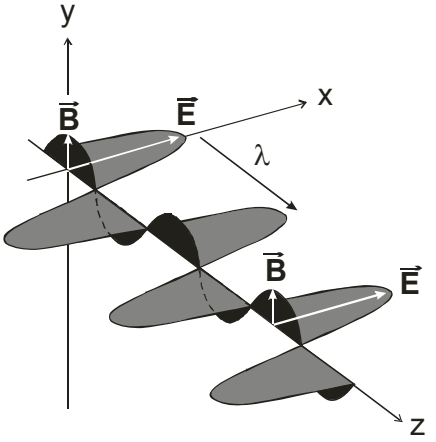

Figure 2. Schematic representation of an electromagnetic wave propagating in the direction of the z-axis. The oscillating vectors $\vec{E}$ and $\vec{B}$ represent the electric and magnetic fields respectively. They are always perpendicular to one another. Most of the effects of the electromagnetic wave are caused by the electric vector $\vec{E}$.

1.2 Electromagnetic Radiation

In order to jump from one orbital to another one, an electron will have to gain or lose energy. Because the electron is a charged particle, it can interact with an electromagnetic radiation and thus can gain or lose energy by absorbing or emitting an electromagnetic wave. Such an electromagnetic wave is represented in Figure 2. It is characterized by a wavelength λ and a frequency ν (Hertz), which is the number of cycles performed during one second. In a vacuum, an electromagnetic wave is travelling at the speed of light c = 299,792,458 m/s. The following formula holds for any electromagnetic wave:

$$\lambda \nu = c\,, \tag{1}$$

Note that the frequency is an invariant of the electromagnetic wave. It determines the "color" of the wave. If the wave passes from the vacuum in another medium, like air, water, or solid, its speed will decrease and only its wavelength will be affected: its direction will be modified (refraction phenomenon), but its color (frequency) will not change. Depending on their wavelengths, electromagnetic radiations are classified into several ranges (Table 1), the most important one for our purpose being the "visible light" range between the infrared and the ultraviolet ranges.

	Wavelength range
γ-ray	< 0.03 nm
X-ray	0.03 nm → 3 nm
Ultraviolet light	3 nm → 0.4 μm
Visible light	0.4 μm → 0.8 μm
Infrared light	1 μm → 3 mm
Microwaves	3 mm → 30 cm
Radio	> 30 cm

Table 1. Wavelength ranges of the electromagnetic spectrum.

As for electrons, atoms, and molecules, the energy of an electromagnetic wave is also quantized. As a consequence, an electromagnetic wave can only exchange energy with a molecule, as an integer number of an indivisible amount "hν" that depends on its frequency and on the Planck constant $h = 6.62 \times 10^{-34}$ *Js*. The energy quantum of the electromagnetic wave is called a "photon." An electromagnetic wave can thus be represented as a flow of massless particles or "photons," each of which carries the same quantum of energy.

1.3 Interaction of Electromagnetic Radiation with an Atom

Let us assume that the atom or the molecule is in an excited state. This means that some electrons can jump from their orbital into another one of lower energy closer to the nucleus. Consider an electron in an orbital of energy E_2 (Figure 1) jumping into the energy level E_1. The amount of energy lost $E_2 - E_1$ will be radiated as one "energy quantum" of an electromagnetic wave according to the Bohr formula:

$$E_2 - E_1 = h\nu \,, \tag{2}$$

ν being the frequency of the *emitted* wave. Such a process will always happen after a certain period of time, because there is a general law of physics stating that a system always tends to its lowest possible energy level (ground state). The de-excitation

phenomenon is at the origin of any light that can be seen, and it is called *spontaneous emission* (see Figure 1). The reverse process, i.e., a transition from E_1 to E_2, is possible if and only if the atom of energy E_1 is in contact with an electromagnetic wave of the suitable frequency $\nu = (E_2 - E_1)/h$ and shall result in an energy quantum hν being *absorbed* by the atom: this process is called *absorption* (see Figure 1).

From theoretical considerations, Einstein deduced the existence of a third process called "*stimulated emission*" when a photon of energy $h\nu = E_2 - E_1$ strikes an excited atom of energy E_2. In that case, the excited atom shall immediately jump from E_2 to E_1 and emit a second photon of energy hν *that has exactly the same characteristics* as the initial impinging photon. The two photons will perfectly match and travel in the same direction without any de-phasing, giving rise to a beam of "coherent" light. This process results in amplification of light, i.e., amplification of the electromagnetic wave upon interaction with the molecule.

This process of *stimulated emission* is very efficient because Einstein could predict that it will happen with exactly the same probability as the *absorption* process. However, in order to obtain real efficiency, one has to take account of the number of participating atoms. It is well known that at thermodynamic equilibrium, the number of excited atoms drops very rapidly with the increasing energy i.e., the number of E_1 atoms shall always be much higher than the number of E_2 atoms. Therefore, for more than thirty years, the "stimulated emission" process was considered a scientific curiosity without any practical applications.

1.4 The Inversion of Population

It took until 1951 for Townes to realize that one could get light amplification if the system could be artificially maintained in a state of thermodynamic non-equilibrium where the population of the higher energy level E_2 is always higher than the population of the lower level E_1. Such a configuration is called "inversion of population."

Another prerequisite is that the "lifetime" of the higher level, where all the atoms are accumulated, has to be as long as possible. This is a means to avoid, as much as possible, the process of spontaneous emission (i.e., emission that is not triggered by an incoming photon) that happens in any direction and without coherence with the impinging beam of photons. The lifetime of an energy level can be easily determined by spectroscopy. In a usual spectroscopy experiment, an atomic energy level is measured as a "peak" having a certain energy width. This width is inversely proportional to the (spontaneous) lifetime of the level, i.e., the long-lived levels, which will resist spontaneous emission and wait for de-excitation via stimulated emission, appearing as very narrow peaks. These properties provide a clue for selecting suitable materials for possible laser application.

1.5 The First LASER

The LASER acronym stands for Light Amplification by Stimulated Emission of Radiation. It was coined in 1957 by G. Gould, a Ph.D. student of Columbia University. At the same university, Townes had already succeeded in getting amplification in the microwave range (maser), but not in the visible energy range. Theodore Maiman made the first laser operate on 16 May 1960 at the Hughes Research Laboratory in California 1. The laser setup is depicted in Figure 3. A coiled flash lamp was used to excite a ruby rod and provide the population inversion. The electronic levels of ruby are schematized in Figure 4.

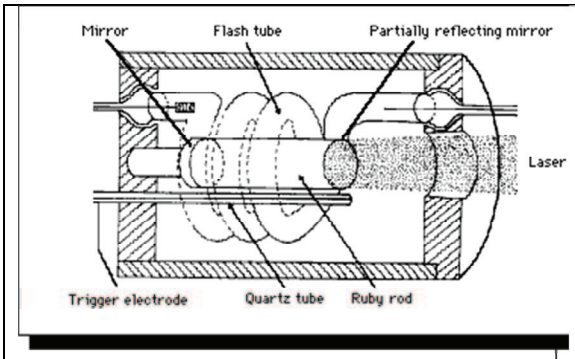

Figure 3

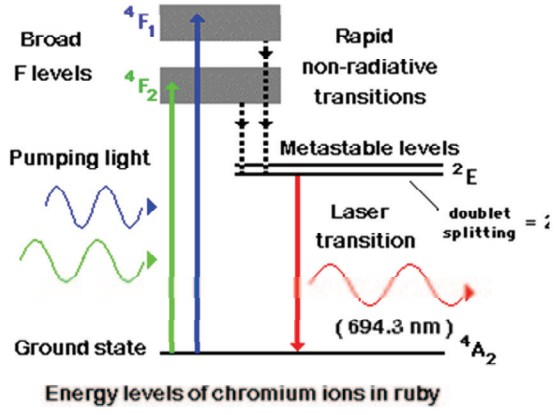

Figure 4

Nature, August 6, 1960, Vol. 187, No. 4736, pp. 493-494.

2 Laser Beam Characteristics

The main difference between lasers and incoherent light sources is the laser's ability to concentrate all the optical power into a low diverging monochromatic beam and short optical pulses with high peak power. This is achieved by placing the optically active medium into a laser cavity constituted by two autocollimated mirrors, such that only the beam that propagates along the cavity axis can be amplified by multi-passes through the active medium. Several techniques are available to constrain the

release of the optical energy stored in the "population inversion of the gain medium" into a laser beam with the appropriated spatial, spectral, and temporal characteristics .[2]

The use of long cavities with intra-cavity diagrams, small diameter gain medium, and cavity mirrors with a higher reflection coefficient in the centre favor the generation of the "TEM 00 beam" or "Gaussian beam," whose diameter and divergence reach the minimum values limited by the diffraction of light. As represented in Figure 5, the radial distribution of this ideal beam profile follows a Gaussian shape, the diameter of which increases with the propagation distance according the divergence angle, θ_d

$$\omega_0 = 2\lambda/\pi\ \theta_d \tag{3}$$

where, ω_0, is the diameter of the beam at its waist.

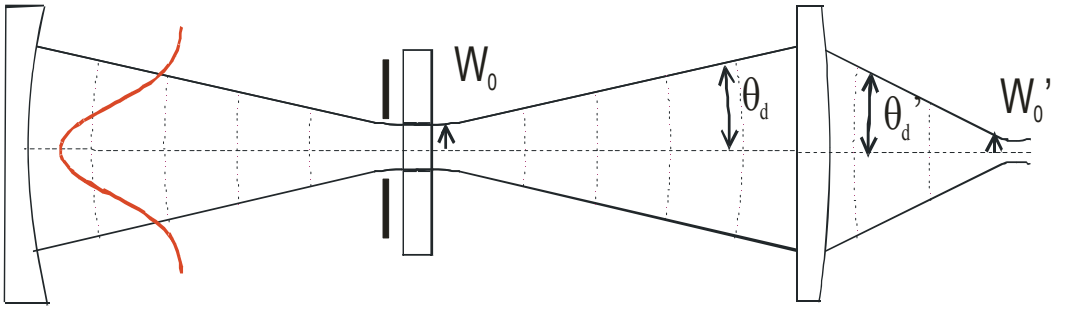

Fig. 5 The left part shows a laser cavity with an intra-cavity diaphragm for the generation of a Gaussian beam. The right part shows the propagation of the Gaussian beam through the optics. The Gaussian represents the beam intensity distribution. The dotted line represents the slightly curved wave front, e.g., the region where the electric field represented in Fig. 2 reaches its maximum. The continuous lines give the limits containing 86% of the beam power.

Equation (3) also sets the limit of the minimum achievable laser spot diameter. For example, a beam diameter of 1 cm focused by a lens with 100 mm focal length leads to a minimum spot diameter of 10 μm at the wavelength of 1 μm. If aberration is negligible, the quantity $\frac{\pi\omega_0}{2\lambda}\theta_d = M^2$ is conserved as the beam propagates through different optics. Therefore, M^2 is the measure of the beam spatial profile quality and approaches the minimum value of 1 for the highest beam quality near the theoretical diffraction limit.

The energy distribution of the states E_1 and E_2, defining the laser transition, will set the spectral bandwidth of the laser, $\Delta\nu$. Although this is a key parameter for spectroscopic applications of lasers, laser bandwidths are usually negligible in front of the broad absorption bands of biological molecules, and the laser beam can be considered as monochromatic in medical applications. Finally, the concentration of optical ener-

gy in short laser pulses has important implications for the effect of the laser beam on biological tissues. Pulse durations of the order of a few seconds or a few μs are obtained by modulation of the continuous operation of the laser using mechanical shoppers or modulation of the electric power. Pulses with duration of a few nanoseconds are achieved by using the Q-switching method. This technique implies using an intracavity fast shutter, usually made by combining a polarizer with a Pockels cell, which prevents laser oscillation before high optical energy is stored in the population inversion. When the shutter opens, its optical energy is released in a short pulse, the duration of which corresponds to a few round-trips of the light in the cavity. Even shorter pulses with duration down to the picoseconds and femtoseconds range can be generated by mode-locking the laser, e.g., concentrating the optical energy into a few millimeters- or micrometers-long pulse that will oscillate in the cavity. This is achieved by inserting in the cavity either a high-frequency shutter based on acoustic waves, or any non-linear optical device, such as a non-linear absorbing dye or a non-linear mirror that favors the oscillation of a short pulse with high peak power. Pulse duration as short as a few femtoseconds is achieved with Ti: a sapphire laser. As we will discuss hereafter, the majority of medical applications require a deposition of energy density ranging from 1 to 10^3 Joule of optical energy per cm^2 of irradiated tissue. Depending on the pulse duration, τ, which can vary from several seconds for a continuous laser to a few hundred femtoseconds for a mode-locked laser, the peak intensity can vary by 12 orders of magnitude from $\sim 10^{12}$ to ~1 Watt per cm^2. This later parameter, along with the laser frequency, governs the nature of the tissue-laser interaction.

3 Laser Technologies

One important class of medical lasers[3] uses an electric discharge in gas as the active medium. Such discharge results from a cold plasma where electrons are accelerated by the electric field and further ionize adjacent molecules. During the relaxation from their highly excited state to their fundamental state, the molecules will be trapped in meta-stable excited states, E_2, evoking population inversion with the lower empty level E_1. In the very common CO_2 laser, the laser transition takes place between vibrationally excited states, hence the particularly long emission wavelength of 10 μm. In other gas lasers, the emission occurs between electronic excited states of atoms or ions with emission wavelengths lying in the visible light and near UV range (He-Ne laser ~633 nm, argon ion laser ~ 488 or 514 nm, krypton ~ 647, 568.2, 520.8 or 476.2 nm , Cadmium: 425 or 325 nm). These lasers provide a continuous beam, or can be pulsed down to microsecond pulse durations by modulation of the discharge high voltage, but cannot reach high peak power because of the limited size. Excimer lasers form a particular class of gas laser where the level, E_2, is the molecular complex of electronically excited atoms formed in powerful transient gas discharge, while the lowest level, E_1, is the dissociated form of this complex. Such lasers present the ad-

vantage of emitting nanosecond long pulses in the UV (Ar-F: 193 nm, Kr-F: 248 nm, Xe-F: 351 nm). The "Solid-state"[2] qualification refers to lasers where the active medium is made of ions trapped in transparent glasses. The ions are excited by flash lamp irradiation. This technology enables the implementation of the Q-switching and mode locking techniques for the emission of short and energetic nanosecond and picoseconds pulses (Nd-YAG:1 μm, ~20 ps, ~100 ps, ~10 ns, ~100 μs, Nd-YLF: 1 μm, ~20 ps, ~100 ps, ~10 ns, 100 μs, Ti: sapphire: 700- 900 nm, ~100 fs). Among these lasers, the Ho:YAG and, particularly, Er:YAG present emission lines down to the infrared spectral ranges (Ho:YAG: 2.1 μm, 10 ns, ~100 μs, Er:YAG: 2,78 μm, 10 ns, ~100 μs). Semiconductor lasers, based on diode junctions, present the advantage of cost effectiveness, and high-energy conversion yield from electric to optical power. Their emission wavelength can be adjusted by the semiconductor constitution from the blue (InGaN: 416 nm) down to the infrared (AlGaAs/GaAs: 1200-1600 nm, lead salts diode: down to 30 μm). They usually generate continuous beams, but they can be pulsed down to nanosecond duration with limited energy because of the limited volume of the active medium.[4] Dye lasers[5] have been developed to allow the user to adjust the beam output frequency anywhere within the visible spectral range from 450 to 900 nm within minutes by changing the appropriate dye solution. The particular dye is dissolved in a liquid solvent and is pumped by another visible laser. Depending on the pulse duration of the pump laser, they can generate picoseconds, nanoseconds pulses, or continuous waves. Their main disadvantage is their complicated maintenance, since the dye solution must be periodically adapted. Continuous tunability of the laser frequency can now be obtained using non-linear optical devices such as optical parametric oscillators (OPOs) or generators.[6] These devices are built around non-linear crystals that will act as frequency converters when irradiated at high intensity of the order of 10^8 to 10^{10} W/cm^2 according to the sum frequency formula of the second order non-linear optical process: $\nu_0 = \nu_1 + \nu_2$. The KTP laser (532 nm) is an example of such a device, where the frequency of the Nd: YAG laser (1.064 μm) beam is doubled ($\nu_0 = 2\ \nu_1$) in a crystal of KT_iOPO_4. The available non-linear crystals enable us to cover the complete spectral range from ~250 nm to 20 μm. OPOs will generate pulses with duration reflecting that of the pump laser, e.g., typically in the nanoseconds, picoseconds, and femtoseconds ranges.

4 Laser-tissue Interaction

The medical applications of lasers rely on the possibility to induce local necrosis, local etching, or fragmentation of tissues [7]. The particular effect depends on the laser beam and tissue characteristics and can be evaluated using the following models of the processes of laser beam absorption and propagation in the tissue, diffusion of heat, and the initiation of local plasmas.

4.1 Laser Light Absorption

Light absorption follows a simple scaling law: the rate of energy absorption per molecule is equal to the local beam intensity I multiplied by a cross-section, s. If N is the molecular concentration, the absorbed intensity per unit volume and time, S, reads

$$S = \alpha I, \tag{4}$$

where $\alpha = s\,N$ is the absorption coefficient of the tissue. α becomes significant only when the frequency of the laser beam, ν, matches that of a molecular transition according to equation (2). If ν lies in the infrared spectral range, the laser beam couples predominantly with molecular vibrations. Since the ubiquitous H_2O molecules show an OH vibration at 2.7 μm, α in soft tissues reaches the highest value $> 10^4$ cm^{-1} near the particular wavelength of the Er:YAG laser (2,94 μm) but can be as low as $\sim 1\ 10^0$ cm^{-1} at the wavelength of the Nd:YAG laser (1.06 μm). Because of the small photon energy $h\nu$ in the infrared, such an excitation cannot evoke any change in the molecular conformation nor break chemical bounds, but is rapidly statistically distributed among the other vibrations and rotations of adjacent molecules, i.e., it decays into heat. For ν in the visible, the absorption occurs by excitation of the molecular electronic system. Although such a process may lead to photochemical effects, e.g., changes of the chemical properties of the excited molecules, as exploited in photodynamic therapy or observed naturally in some important biological reactions such as photosynthesis, this excitation often decays into heat. Finally, the higher frequency UV light is classified as ionizing radiation because it induces more severe electronic excitations, which can lead to ionization and chemical bond breaking.

The linear absorption law (equation(4)) and its resonant character holds as long as the electric field associated with the laser beam remains smaller than the one maintaining the electrons in their molecular orbitals. Indeed, above the so-called "optical break-down" threshold that occurs at beam intensities in the order of 10^{10} W/cm^2, molecules are ionized and dissociate independently of the laser beam frequency.

4.2 Light Propagation

The integration of equation (4) leads to the expression describing the laser intensity attenuation as it penetrates into a tissue:

$$I(z) = I(0)\, e^{-\alpha z}, \tag{5}$$

where $I(z)$ is the beam intensity at the depth z. From equation (5), we deduce the penetration depth of the light into the tissue:

$$L = 1 / \alpha \tag{6}$$

Equations (5) and (6) are not valid if strong scattering of the light occurs onto the inhomogeneities of the tissue. Such scattering is parameterized by the scattering coefficient (α_s) and scattering anisotropy (g). α_s adds up to α to give the total attenuation coefficient of the coherent beam in the tissue, while the geometrical factor g varies from -1 to 1 if the scattering is predominantly backward, isotropic and forward, respectively. The light propagation in such a turbid medium cannot be described by a simple analytical solution. Fortunately, different calculation methods[7] enable us to predict that the diffuse light local intensity can be evaluated using equations (5) and (6) with an effective diffusion length, L_{eff}, and diffusion coefficient α_{eff} evaluated to

$$L_{eff} = 1/\alpha_{eff} = 1/\sqrt{3\,\alpha\,(\alpha+\alpha_s(1-g))} \tag{7}$$

when $\alpha_s >> \alpha$ [8]. Data from ref. 7 and 8 show that beam attenuation is usually dominated by scattering with L_{eff} of soft tissues lying between 10 and 500 μm in the visible spectral range.

4.3 Heat Diffusion

When the absorbed optical energy decays into heat, the local temperature evolution of the tissue can be predicted by solving the heat diffusion equation:

$$\frac{\partial T(\vec{r})}{\partial t} = k\left(\frac{\partial^2}{\partial x^2}+\frac{\partial^2}{\partial y^2}+\frac{\partial^2}{\partial z^2}\right)T(\vec{r})+\frac{1}{C}S(\vec{r}), \tag{8}$$

where T and S, defined by equation (4), are the local temperature increase and heat source, respectively. C is the heat capacity per unit of volume that takes typical values between 1.5 and 4.5 J / K cm^3. k is the temperature conductivity, which is close to 1.4 10^{-3} cm^2/s for most tissues [9]. This value indicates that the temperature increase will "diffuse" on distances of the order of 1 μm and 100 μm after a time delay of 1 μs and 10 ms, respectively ($1\ \mu m \sim \sqrt{1\,\mu s\ k}$, $100\ \mu m \sim \sqrt{1\,ms\ k}$). If we compare this temperature penetration depth to the shortest light penetration depth in tissue as observed for Er:YAG laser ($L \sim 1/10^4$ cm$^{-1} \sim$ 1μm), we conclude that the heat will not escape the irradiate area if the laser pulse duration is smaller than 1 μs. The most important thermal effects are local necrosis of the tissue by coagulation that occurs between 60°C and 70°C and local etching by vaporization at 100°C. Continuous wave or pulsed CO_2 lasers are often selected for this operation because of the strong absorption of these moist tissues at 10 μm.[7]

4.4 Plasma Formation

Achieving optical breakdown in a collection of atoms and molecules will result in the formation of a plasma of free electrons, ions, and excited molecules. The local sublimation and decomposition of the tissue in the plasma evoke a transient pressure increase in the neighboring tissue. This takes the form of chock waves, which, in the case of soft tissues, can be accompanied by cavitation, e.g., the formation of gas bubbles with diameters that oscillate to accommodate the mechanical energy, and by jet formation, e.g., ejection of tissue due to the collapse of the cavitation bubbles near the surface. The damage due to these mechanical side effects is referred to as photodisruption. The local plasma-induced ablation can be favoured over the non-local photodisruption effects by minimizing the energy injected in plasma. A phenomenological modeling of the plasma formation[10-13] leads to the following evaluation of fluency threshold (F_{th}) required to initiate the plasma:

$$\eta F_{th} = \frac{s}{2} + \sqrt{\left(\frac{s}{2}\right)^2 + \frac{\tau}{2\tau_c}} + \frac{\tau}{\tau_d}, \tag{9}$$

with the phenomenological parameters τ_c, and τ_d being the mean collision and mean diffusion time of electrons. s, reflects, on a logarithmic scale, the necessary increase of electron density from the initial breakdown to sustained plasma. Adjusting τ_c, τ_d and s to 1 fs, 500 ps, and 18 respectively, enables us to mimic the experimental observations that, for all tissues, F_{th} evolved as $\sim \sqrt{\tau}$ for pulse duration ranging from a few ps to few μs, as $\sim \tau$, for longer pulse durations, and is independent of τ, for subpicoseconds pulses. Using picoseconds or femtoseconds pulses enables us to keep F_{th} as small as possible and to suppress the disruptive effect that appears omnipresent using nanosecond or longer pulses. η is the ionization probability and appears higher for teeth and corneas ($\sim$13 [J/cm^2]$^{-1}$) than for soft tissue ($\sim$5 [J/cm^2]$^{-1}$). These numbers indicate that plasma induced ablation on teeth is already initiated at fluencies of 10 J/cm^2 for 10 ps long pulses. Although lithotripsy of urinary calculi is an example where photo-disruptive effects can be exploited in a particular therapy, early trials using ruby and CO_2 lasers to replace the mechanical drills with laser etching in caries therapy have long been discouraged. However, suppression of the thermal and photodisruptive effects has been demonstrated more recently using 30 ps laser pulses generated by a Nd:YLF laser [14].

4.5 Photoablaton by UV Beam

Ablation of polymer and biological tissue without thermal damage can be achieved at lower fluency by using the nanosecond pulses of an Excimer laser,[15-16] in particular ,the ArF laser emitting at shortest wavelength of 193 nm. The efficiency of the

process relies on the fact that the absorption of a single UV photon can ionize or bring the molecule into a pre-dissociated state even at low fluency where the light absorption still obeys equation (4). Indeed, the photon energy at 193 nm (6,4 eV) is higher than the dissociation energy of most chemical bonds (O-H: 4.8 eV, C-C: 6.4 eV). The ablation depth z_{abl} as a function of fluency can be derived from equations (4) and (5), assuming that the tissue will decompose and be ejected if the concentration of pre-dissociated molecules, e.g., the local intensity (I_{th}) or fluency (F_{th}), reaches a particular threshold value:

$$\alpha I(z_{abl}) = \alpha I_{th} \quad or \quad z_{abl} = \frac{1}{\alpha} ln\left(\frac{F}{F_{th}}\right) \tag{10}$$

Typical ablation rate is 0.5 μm/pulse for fluency of a few 0,1 J/cm^2 for a cornea irradiated by ArF Excimer laser pulses.[15] Higher fluencies initiate plasma that absorbs the incident UV beam, limiting the ablation rate to about 1 μm/pulse. Such a low ablation rate has discouraged the use of this process in dentistry.[7]

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3

CLINICAL PROTOCOL

3.1 Anamnesis and Precautions Prior to Surgery

Precautions and protocols followed for conventional surgeries should be respected for oral laser surgeries:

1. Consultations and assessments: The practitioner should take into consideration the personal history and complaints of the patient. Clinical examination and complementary examinations (RX, MRI, bleeding level, etc.) should be completed prior to surgery. It is mandatory that a biopsy be carried out before any ablation of oral diseases, tumors, hyperkeratosis, lesions, or unusual mucosa. Anamnesis of the patient and different examinations can reveal if the patient has any risk factors. Make a diagnosis before any surgery.
2. The patient should be informed about the surgery procedure, the eventual risks of the surgery, and the undesirable effects and side effects, if any.

3.2 Precautions during Surgery

Observe similar precautions to those respected for conventional surgeries. It is necessary to protect the eyes of the practitioners, nurses, assistants, and patient with adapted protective glasses. For patients considered risky cases (hemophilic, diabetic, transplanted [organ grafted], immune-deficient, healing deficient, or with heart diseases [endocarditic, shunt, etc.], a weakened immune system, or if the patient is in chemotherapy, etc.), it is highly recommended that the wound be sutured at the end of the laser surgery.

3.3 Precautions in Post-Operative Period

A similar procedure to that used in conventional surgeries is respected for oral laser surgeries. Prescribe an oral disinfecting solution for a maximum of 10 days to avoid the risk of secondary infection of the wound in the post-op period. For patients considered high-risk, it is highly recommended that the wound be sutured at the end of the laser surgery. Prescribe the adapted antibiotics and precautions for the post-op period.

On the other hand, for patients considered healthy, the decision about which antibiotics and analgesics to prescribe depends on the kind and nature of the disease, topography, and the size of the ablated tissues. This decision is left to the practitioner's discretion.