In: International Journal of Clinical Dentistry
Volume 4, Number 2
ISSN: 1939-5833

LASERS GENERAL PRINCIPLES - A REVIEW

N. Vasudev Ballal [1*], Kundabal, M.[2] and K. S. Bhat[1]
[1]Manipal College of Dental Sciences, Manipal, Karnataka – India
[2]Manipal College of Dental Sciences, Mangalore, Karnataka – India

Abstract

The scientific literature regarding dental application for laser is increasing. The past decade has seen a veritable explosion of research into the clinical applications of lasers in dental practice. Once regarded as a complex technology with limited uses in clinical dentistry, has grown with its awareness and usefulness in the armamentarium of the modern dental practice. They have been used as an adjunct or alternative to the traditional approaches.

Since the development of the ruby laser by Maimam in 1960, a variety of papers on potential application of lasers in dentistry have been published. Various, and at times conflicting, claims by manufacturers, scientists and clinicians fill dental meetings and journals.

The purpose of this paper is to review the general principles of lasers including their properties, components, tissue interaction, hazards and laser safety. With the potential availability of many new laser wave lengths and modes, much interest is developing in this promising field.

Keywords: Biostimulation; hydroxyapatite; laser light; pulp necrosis.

Introduction

The dental profession has become extremely enthusiastic about the potential for lasers in the practice of dentistry. Over the past several years, we have seen the strong emergence of lasers in the field of dentistry. In just one generation, lasers have moved out of the realm of fantasy and into everyday life. Lasers are not however, new to the field of dentistry. Some of the first reports on in vitro studies, date back to the late 1960s. It was not until the early 1980s however that lasers truly saw their first use in clinical practice.

Ranking among the most significant laser applications are those in medicine and dentistry. Recent advances in laser technology and research into its potential have set the stage for a revolution in dental practice. When used efficaciously and ethically, lasers are an exceptional modality of treatment for many clinical conditions that dentists or dental specialists treat on daily basis. Only a few years after the discovery of the first ruby

* Corresponding author: Telephone: 91- 0820-2922172 Fax: 0091-820-2570061 Email: drballal@yahoo.com or vasudev.ballal@gmail.com

lasers, investigations were undertaken to introduce laser technology in dentistry for "optical drilling" of teeth & replacement of conventional treatment methods. Since then laser technology has steadily progressed until today, where more than 600 laser medias are known which can emit laser radiation of different wave length.

One of the greatest advantages of laser use in dentistry is a high rate to patient acceptance. Patients today are aware of lasers and their advantages. Some clinicians are wary of entering this exciting field because of the equipments size and cost. The original lasers were not only large but had high price tags. However dental lasers today are small, light weight, highly portable and increasingly affordable.

Discussion

History and Development of Lasers

Laser is an acronym for "**L**ight **a**mplification by **s**timulated **e**mission of **r**adiation". The dental lasers of today have benefited from decades of laser research and have their basis in certain theories from the field of quantum mechanics, initially formulated during early 1900's by Danish physicist Nails Bohr. Einstein's atomic theories on controlled radiation can be credited as the foundation for laser technology. Einstein's article [1] on the stimulated emission of radiant energy, published in 1917, is acknowledged as the conceptual basis for amplified light. Nearly 40 years later, American physicist Townes fires amplified microwave frequencies by the stimulated emission process and the acronym MASER (microwave amplification by stimulated emission of radiation) came into use [2]. In 1958, Schawlow & Townes discussed extending the maser principle to the optical portion of the electromagnetic field, hence LASER came into the field [3]. In 1960, the first working laser a pulsed ruby instrument was built by Maiman of Hughas Research laboratories [4]. It emitted light of 0.694 μm wave length.

Many of these initial investigators used the ruby laser to explore tissue interaction with enamel and dentin because synthetic ruby was the only material to be used routinely as the active medium in lasers during those early years. In 1961, the second laser called neodymium in glass was developed by Snitzer [5]. Later Johnson & Nassan developed the first solid state Neodymium laser which used Neodymium ion in calcium tungstate [6].

In 1961, Javan *et al* introduced Helium & Neon Laser. In 1964, Carbon dioxide laser was introduced by Patel [7]. In 1964, Argon laser was developed by Bridges of the Hughes Research Lab [8]. In 1982, Excimer Lasers; in 1991, Erbium: YAG Laser; in 1992, Holmium: YAG laser was introduced.

Historically the first laser to be marketed for intra oral use generally was carbon dioxide (CO_2) laser. Early pioneering teams such as Fisher & Frame in the United Kingdom, Pecaro and Pick in the United States and Melcer in France started using CO_2 lasers for tissue surgery [9].

In 1990's FDA cleared for intraoral use of Nd: YAG laser developed by Myers & Myers and was recognized as the first laser designed specifically for general dentistry

[10]. Currently numerous lasers of different wavelengths are being used clinically in dental practices. The specific parameters of how they are used depend on their individual tissue absorption characteristics.

DIFERENT TYPES OF LASERS USED IN DENTISTRY: [DCNA 2000]

Laser Type	Wavelength
ArF Excimer	193nm
KrF Excimer	248 nm
Xecl Excimer	308 n
Frequency-Doubled Alexandrite	377 nm
Krypton ion	407 nm
Argon ion	488,514.5 nm
Dye	507-510 nm
Frequency-Doubled Nd: YAG (KTP)	532 nm
Diode (Low Level)	600-908 nm
Gold Vapor	628 nm
Argon-Pumped Dye	630 nm
Copper Vapor Pumped Dye	630 nm
Helium-Neon	632 nm
Ruby	694.3 nm
Diode (GaAlAs, GaAs)	800-830,904-950 nm
Nd: YLF	1.053μm
Nd: YAG	1.064 μm
Nd: YAP	1.34 μm
Ho: YAG	2.12 μm
Er: YSGG	2.79 μm
Er: YAG	2.94 μm
Free Electron	3.0, 6.1, 6.45 μm
Carbon Dioxide (CO2)	9.3, 9.6, 10.6 μm

Arf = Argon Fluoride; Er:YAG =Erbium: Yttrium Aluminum Garnet; Er: YSGG = Erbium: Yttrium Scandium Gallium Garnet; GaAlAs = Gallium Aluminum Arsenide; GaAs = Gallium Arsenide; Ho: YAG = Holmium: Yttrium Aluminum Garnet; KrF = Krypton Fluoride; KTP = Potassium Titanyl phosphate; Nd:YAG = Neodymium: Yttrium Aluminum Garnet; Nd:YAP = Neodymium: Yttrium Aluminum perovskite; Nd:YLF = Neodymium: Yttrium Lanthanum Fluoride; Xecl = Xenon Chloride.

Laser Physics

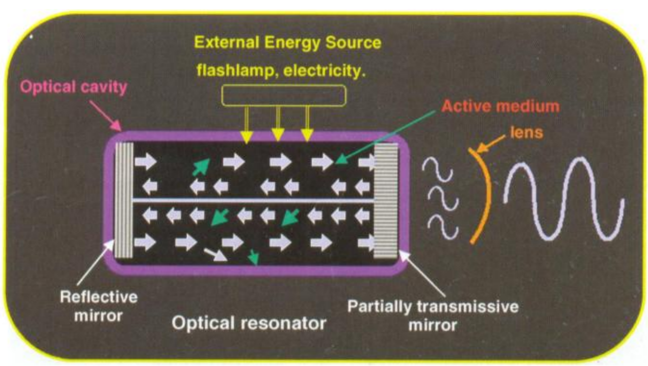
For most clinicians, laser fundamentals are not intuitively obvious. Laser is a form of electromagnetic energy that travels in waves, at a constant velocity. The basic unit of this radiant energy is called a photon, or a particle of light. A wave of photons can be defined by two basic properties. The first is the amplitude and second is the wave length. Amplitude gives the measurement of the amount of energy in the wave. Larger the amplitude, greater is the amount of energy that can do the useful work. Wave length is the distance between any two corresponding points on the wave. This is a measurement of physical size, which is important with respect to how the laser light is delivered to the surgical site and how it reacts with the tissue.

All available dental laser devices have emission wave lengths of approximately 0.5μ or 500 nm to 10.6μ or 10,600 nm. These wave lengths are in the visible or the non ionizing invisible portion of electromagnetic spectrum. All dental lasers emit either a visible light beam or an invisible infrared light beam in the portion of the nonionizing spectrum called thermal radiation.

Components of Laser System

The basic component of a laser is quite simple. It includes a lasing medium placed within an optical cavity, a pump energy source and a cooling system. To contain and amplify the photon chain reaction, it is necessary to place this reaction within an optical cavity.

An optical cavity consists of two parallel mirrors placed on either side of the laser medium or lasant. The mirrors are separated by a fixed distance (d), forming a Fabry-Perot interferometer. Lasing medium can be a container of gas (CO_2, argon), liquid or solid crystal rod (garnet crystal generally made from Yttrium & aluminum to which are added the elements chromium, neodymium, holmium or erbium). It can also be solid-state semiconductors made with metals such as gallium, aluminum and arsenide. In this configuration, photons bounce off the mirrors and re-enter the medium to stimulate the release of more photons. The mirrors collimate the light; i.e photons exactly perpendicular to the mirrors re-enter the active medium, while those off the axis leave the lasing process. Since the process is not 100% efficient and some energy is converted into heat, a cooling system is provided. If one mirror is totally reflective (M_2), the other mirror (M_1) is partially transmissive. The light that escapes through M_1 becomes the laser beam. The laser is named after the contents of the active medium and their state of suspension.



Optical Feedback in Laser Chamber

One could conceive the mirror system within the laser cavity as a completely silvered mirror opposed by a parallel partly silvered mirror that allows some light to leave the resonant cavity and to be emitted as a collimated beam of laser energy. The laser cavity is designed so that enough light reflects back into the laser cavity to continue the laser action within the laser medium. Indeed, it is very difficult to maintain parallelism if one designs a laser based on parallel flat plane or so called planer mirrors. These mirrors are the dielectric mirrors which rely on a constructive interference phenomenon to produce significant reflectivity. Within the dielectric system, there are alternative layers of high refractive index materials, such as titanium oxide, and low refractive index materials such as silicon oxide. These materials are deposited on a glass substrate.

The optical cavity itself can be of many different shapes and materials. The simplest design is set up with one of the mirror (M_1) having a reflectivity of 100%, and the other (M_2) having a reflectivity of less than 1-10% which are called the total reflector and the output coupler respectively. Optical cavity may be of cylindrical or rectangular shape. Circular chambers also are made with the lamp and rod parallel to one another. Optical cavity sometimes is constructed of a reflecting or scattering material like ceramic or a polished metal.

Properties of Laser Light

There are several important properties of laser light that distinguish it from the normal light.

Monochromatism: Lasers emit light that is monochromatic or specifically have a single wave length from UV to infra red. i.e. lasers express one color. Lasers of varying types emit an individual wave length or specified wavelengths and indeed, same can be tuned to different wave lengths based on the desires of the operator. This property is important for the high spectra power density of the laser beam.

Collimation or (Directionality)**:** The laser beam, as it exists from the laser device, has very little divergence. They do not diverge and travel parallel to each other. The beam which is emitted has constant size and shape. Most of the gas or solid-state laser emit laser beam with a divergence angle of approximately a mill radian. This explains why laser light is extraordinarily hazardous. By not diverging over distance, laser light maintains brightness, so that it is still concentrated enough to be dangerous. But this property is important for good transmission through delivery system.

Coherency: The laser light waves produced are physically identical. i.e. they have identical amplitude and frequency. There are two types of coherence of laser light, longitudinal and transverse. The longitudinal type of coherence represents time coherence along the longitudinal beam, whereas transverse coherence or spectral coherence refers to coherence across the beam. Coherence causes the collimation of a laser beam over extremely large distances and allows the beam to accept extremely fine focusing. Any given laser beam can be focused only to a diameter equal to the wavelength of the specific laser.

Brightness: Another property of laser light that distinguishes it from other conventional light sources is that of brightness. This property arises from the parallelism or collimation of the laser light as it moves through space maintaining its concentration. The high brightness factor translates to high concentrations of energy when the laser is focused on a small spot. The focusing of the brightness of the laser beam is what the clinicians depends on to elevate the temperature of tissues or to cut or to vaporize the tissues.

Excellent concentration of energy: Lasers have excellent concentration of energy and hence it has got tissue targeting effect.

Classification of Lasers

1) *BASED ON ACTIVE MEDIUM*
   Solid state, Liquid state and Gas

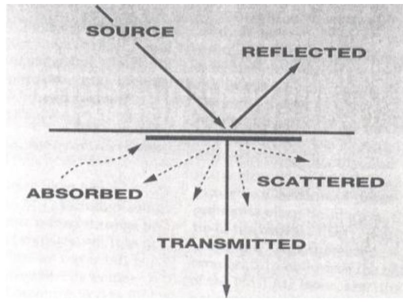
2) *DEPENDING ON WAVE LENGTH*
   Hard lasers- comes in infrared Spectrum (> 700 nm)
   Eg: CO_2; Nd: YAG; Argon laser

   Soft Lasers – Comes in UV (140-400nm) & visible light (400-700) spectrum
   Eg: HeNe, diode laser

3) *BASED ON SAFETY PROCEDURE*
   - Class 1: safe under all conditions (fully enclosed system) – Eg: Nd: YAG laser. Laser used in dental laboratory.
   - Class 2: Output is 1 mm- visible low power laser- Visible red aiming beam of a surgical laser.
   - Class 3A: Visible laser above 1 milli watt- No dental examples.
   - Class 3B: Upper continuous power output limit is 0.5 w- Low power diode laser used for biostimulation. Direct viewing is hazardous to the eye.
   - Class 4: Output excess of class 3B & are used for cutting & drilling- All lasers used for oral surgery, whitening and cavity preparation. Direct or indirect viewing is hazardous to the eyes.

Laser Interaction with Biologic Tissues

The optical properties of tissue elements determine the nature and extent of the tissue response through the process of absorption, transmission, reflection and scattering of the laser beam [11].



The extent of the interaction of laser light as a form of radiant energy with tissue will generally be determined by two dependent variables, i.e. specific wave length of the laser beam and optical characteristics of the target tissue [11].

Optical Properties of Tissues

Laser energy will interact with tissue in four ways:

First, a portion of the incident beam may be reflected off the surface without penetration or interaction of the light energy with the tissue. Second, a portion of the light may be transmitted through the tissue untenanted. Third, some of the light may be absorbed into a component of the tissue. Fourth, the remaining light may penetrate the tissue and be scattered without producing a noticeable effect on the tissue.

In most of the cases, the extent of the interaction will be proportional to the level of absorption of the particular wavelength by tissue. Spectrographic analysis of oral hard tissues like enamel, dentin, bone and synthetic hydroxyapatite reveals that absorption, transmission and scattering spectrographs for these four materials are different.

Tissue Effects of Laser Irradiaton

When radiant energy is absorbed by tissue, four basic types of interactions takes place:

A) Photo chemical interactions
B) Photo mechanical interactions
C) Photo thermal interactions
D) Photo electrical interactions

Photo chemical interactions include biostimulation which describes the stimulatory effects of laser light on biochemical and molecular processes that normally occur in tissues.

Photo mechanical interactions include photo disruption or photo disassociation which is the breaking apart of structures by laser light and photo acoustic interactions which involve the removal of tissue with shock wave generation.

Photo thermal interactions manifest clinically as photo ablation or removal of tissue by vaporization and super heating of tissue fluids, coagulation and homeostasis and photo pyrolysis or the burning away of the tissue.

Photo electrical interactions include photo plasmolysis in which tissues are removed through the formation of electrically charged ions. Generally, laser light of relatively low intensity and long duration are less destructive and include their effects at the cellular or molecular level, producing photo chemical effects.

Laser Delivery Systems

The beam of laser light must be able to be delivered to the target tissue in a manner that is ergonomic & precise.

Two delivery systems are used in dental lasers:-

One is flexible hollow tube that has interior mirror finish:

The laser energy is reflected along this tube & exists through a hand piece at the surgical end with the beam striking the tissue in a non contact fashion. An accessory tip of sapphire or hollow metal can be connected to the end of the wave guide for contact with the surgical site.

Second delivery system is a glass fiberoptic cable:

This cable comes in different diameter ranging from 200-1000 μm. The fiber fits snugly into a hand piece with the bare end protruding or with an attached sapphire or glass like tip. This system can be used in contact or non contact fashion. Most of the time it is used in contact fashion.

Clinically a laser used in contact fashion can provide easy access. In non contact fashion, the beam is aimed at the target at same distance away from it. But the disadvantage of this is lack of tactile sensation. In either mode the beam is focused by lenses within the laser itself. The laser device can emit the light energy in one of three basic modes.

Continuous wave: Beam is emitted continuously as long as the device is activated by pressing the foot switch.

Gated pulse mode: There are periodic alterations of the laser energy being on & off. (duration being millisecond)

Free running pulsed mode: Here large peaks of laser energy are emitted for short time (micro seconds) followed by a relatively long time in which laser is off. The important principle of any laser emission mode is that, the laser energy strikes the tissues for a certain period of time producing a thermal interaction. Hence we should see that, while using lasers, there shouldn't be any irreversible thermal damage to the target tissue as well as the surrounding tissue. If more heat is produced, it leads to delayed healing and postoperative discomfort. Hence a gentle air stream or an air current can be used to keep the area cool.

Laser Effects on Dental Hard Tissues

Thermal Effect

The thermal effect is the thermal vaporization of tissue by absorbing infrared laser light. The laser energy is converted into thermal energy or heat which destroys the tissues. The laser beam couples to the tissue surface, and this absorption leads to a heating with denaturation at about 45°C to 60°C. Above 60°C coagulation and necrosis can be observed accompanied by a desiccation of the tissue. At 100°C the water inside the tissue vaporizes. Carbonization and later pyrolysis (73wc) with vaporization of the bulky tissue terminate the thermal laser tissue interaction. The laser light will be absorbed and converted to thermal energy by stimulating the lattice vibrations of the tissue molecules. This leads to a heating of the surrounding tissues to a boiling of water followed by carbonization and tissue removal. Damage to the adjacent tissue is manifested by massive zones of carbonization, necrosis and thermally induced cracks.

Mechanical Effect

High energetic and short pulsed laser light can lead to a fast heating of the dental tissues in a very small area. The energy dissipates explosively in a volume expansion that may be accompanied by fast shock waves. These waves can lead to very high pressures so that adjacent tissue will be destroyed or damaged. To avoid micro cracks in dental tissues, the maximum laser energy density of all laser systems must be kept below a certain threshold.

Chemical Effect

The basis of the photochemical effect is the absorption of laser light without any thermal effect which leads to an alteration in the chemical and physical properties of the irradiated tissues.

Thermomechanical Effect

Due to the good absorption of laser in water as well as in hydroxyapatite, the laser radiation leads to fast heating of water inside. In the mineralized matrix there is an explosive volume expansion. In dentin, no cracks are seen, but more thermal damage like carbonization and necrosis are found. In enamel, cracks are always found.

Laser Effect on Dental Pulp

The pulp tissue response to lasers is evaluated in three forms

- Histologic analysis
- Radiographic analysis
- Laser Doppler flow meter measurement

Destructive effects of lasers on pulpal tissue have been delineated for several years [12, 13]. Historically the use of a continuous wave apparatus has been shown to generate significant thermal tissue damage in the oral cavity [14, 15]. Pulpal tissue cannot survive in an environment of elevated temperatures for long periods when tooth structure is irradiated with lasers [16].

Pulsing which has been used during soft tissue laser ablation has an effective mechanism for reducing the extent of collateral tissue damage. The use of a combination of air and water spray before, during or immediately after laser irradiation to enamel and dentin may be a more effective method for temperature control and reduction of heat transfer to the pulp and other vital structures surrounding the teeth. This air-water cooling may be used with laser systems such as CO_2, holmium and erbium. The application of an air and water spray has been found to provide adequate heat protection to the pulp equivalent to that of the common dental drill [17].

Unabated or uncontrolled laser irradiation of oral structures can cause pulpal inflammation with any type of laser [14, 18]. The undesirable side effects of laser can vary primarily with power and energy density and secondarily with the type of laser used. Little information is available regarding the intercellular response of dental pulp to several types of laser.

Continuous wave CO_2 laser can produce varying degrees of pulpal necrosis. Animal studies have demonstrated that laser irradiation of oral tissues induces increase in pulpal warming [16]. This is likely the reason for cell death. If pulp temperature is raised beyond 5°C level, research has shown that the odontoblastic layer may not be present. Odontoblastic alignment may also be acutely disrupted, displaying vertical and layering type of structure. The threshold response for pulp reaction appears to lie at energy densities somewhat less than 60 J/cm^2

Hazards of Lasers

The safe and appropriate use of lasers in the field of dentistry requires the conscious and cooperative efforts of all the groups to be effective. i.e. the dentist, educator, manufacturer and scientist.

Laser hazard classification according to ANSI & OSHA standards:

CLASS	DESCRIPTION
I	Low powered lasers that are safe to view
IIa	Low powered visible lasers that are hazardous only when viewed directly for longer than 1,000 seconds
IIb	Low powered visible lasers which has a dangerous viewing time of one fourth of a second
IIIa	Medium powered lasers or systems that are normally not hazardous if viewed for <0.25 seconds without magnifying optics.
IIIb	Medium powered lasers (0.5W maximum) that can be hazardous if viewed directly or viewed from reflective light for any duration.
IV	High powered lasers (> 0.5W) that produce ocular, skin and fire hazards. Hazardous from direct viewing and may produce hazardous diffuse reflections.

Types of Hazards

1) Environmental Hazards

This hazard involves the potential of airborne bio hazardous materials that may be released as a result of the surgical application of lasers. Inhaled airborne contaminants can be emitted in the form of smoke or plume generated through the thermal interaction or through the accidental escape of toxic chemicals and gases from the laser itself which may be hazards to the dentist and patients. Most of the surgical lasers in dentistry are capable of generation of smoke, toxic gases and chemicals. Inhalation of these gases and aerosols has been found to be potentially damaging to the respiratory system. Ablation of infected tissue poses an even greater hazard due to possible presence of infectious agents like HIV within the plume. The generation of smoke during laser surgery occurs as the result of dehydration of tissues and heating of solid matter to temperature sufficient for combustion. In this process oxygen combines with tissue elements to form a variety of byproducts. Greatest producers of smoke are CO_2 laser followed by Erbium and then Nd: YAG. Different chemicals are found after laser irradiation of soft tissues like formaldehyde, acrolein, cymates, cyclohexane, xyelene, acetone etc. We can avoid these hazards by wearing surgical masks, using high volume evacuators and also using surgical smoke evacuation equipment.

2) Combustion Hazard

With the flammable materials laser may produce significant combustion hazard. Flammable solids, liquids and gases used within the surgical setting can be easily ignited if exposed to the laser beam.

3) Electrical Hazard

Because class IV surgical lasers often use high electrical current, there are several electrical associated hazards like electrical shock hazard, electrical fire hazard and explosion hazard.

Insulated circuit, shielding, grounding and housing of high voltage electrical components provide adequate protection from electrical injury. The clinicians should never attempt to repair or remove safety panels from the laser.

Laser Safety

According to ANCI & OSHA four categories of control measures have been identified:

1) Engineering controls which consists of:
   - Protective housing
   - Interlocks
   - Beam Enclosures
   - Shutters
   - Service panels
   - Equipment labels
   - Warning system
2) Personal Protective Equipment which consists of:
   - Eye wear
   - Clothing
   - Surgical masks
   - Screens & Curtains
3) Administrative & procedural control which consists of:
   - Training & Education
   - Thorough knowledge of laser operation
   - Warnings signs
   - Protective devices
   - Medical surveillance
   - Incident reporting
   - Highly reflective instruments and those with mirrored surface should be avoided since they cause danger to non target tissue.
   - Appropriate power settings and time frames are essential to prevent undesirable effect on teeth and supporting structures.
4) Environmental control which consists of:
   - Use proper ventilation
   - Reticulating air filtration system
   - Change the filters of evacuation system regularly to maintain full airflow & to prevent the accumulation of harmful agents.

Laser treatment area should:

- have limited access except for operating personal
- have warning signs marked on entrance & door ways
- have protective laser curtains
- be kept dry
- have reticulating air filtration system

Shielding may be used as an effective method to avoid contact of the beam with tooth enamel when performing laser treatment on soft tissues. We can use wax spatula or pilchard periosteal elevator as a shield. The foot control should be covered with a metallic hood to prevent accidental activation of the laser beam. Most of the laser accidents and injuries can be prevented if appropriate measures are recognized and implemented.

Conclusion

Lasers which are constantly evolving can be customized to meet dental requirements and could become a very useful tool for dental practitioners. At present, applications of laser treatment have become well accepted methods with advantages to general dental practitioners. Lasers has advantages such as a bloodless operative field, minimal to absent postoperative pain and high patient acceptance which makes laser a highly advantageous alternative to conventional treatment. Dentistry had entered an exciting era of high technology. The dental laser offers the dentist not only a window, but a door into this high-tech, rewarding and potentially profitable arena. Looking to the future, it is expected that specific laser technologies will become an essential component of contemporary dental practice over the next decade.

References

[1] Einstein, A: Zur quanten theorie der strahlung (on the quantum theory of radiation). *Physiol Rev* 1917; 18:121-128.
[2] Gordan, JP; Zeiger, HJ; Townes, CH. The Maser new type of amplifier, frequency standard and spectrometer. *Physiol Rev* 1955; 99: 1264-1274.
[3] Schawlow, AL; Townes, CH. Infrared and optical masses. *Physiol Rev* 1958; 112: 1940-1949.
[4] Maiman, TH. Stimulated optical radiation in ruby. *Nature* 1960; 187: 493-494.
[5] Snitzer, E. Optical maser action of Nd+3 in a Barium crown glass. *Physiol Rev* 1961; 7: 444-446.
[6] Johnson, LF; Nassen, K. Proceedings of the Institute of Radio Engineers 1961; 49: 1704.
[7] Patel, CKN. Interpretation of CO2 optical maser experiments. *Physiol Rev* 1964; 12: 588.

[8] Bridges, WB. Laser oscillation in singly ionized argon in the visible spectrum. *Appl Phys Letters* 1964; 4-128.

[9] Pick, R. Using lasers in clinical dental practice. *J Am Dent Assoc* 1993; 124: 37-47.

[10] Myers, TD; Myers, WD; Stone, RM. First soft tissue study utilizing a pulsed Nd: YAG dental laser. *Northwest Dent* 1989; 68: 14-17.

[11] Dederich, DN. Laser/Tissue interaction. *J Am Dent Assoc* 1993; 124: 57-67.

[12] Goldman, L; Gray, JA; Goldman, J. Effect of laser beam impacts on teeth. *J Am Dent Assoc* 1965; 70: 601-606.

[13] Kinersly, T; Jarabak, JP; Phatak, NM et al. Laser effects on tissue materials related to dentistry. *J Am Dent Assoc* 1965; 70: 593-600.

[14] Launay, Y; Mordan, S; Corni, IA et al. Thermal effects of lasers on dental tissues. *Laser Surg Med* 1987; 7: 473-477.

[15] Lobene, RR; Bhussry, BR; Fine, S. Interaction of carbon dioxide laser radiation with enamel and dentin. *J Dent Res* 1968; 47: 311-317.

[16] Adrian, JC; Bernier, JL; Sprague, WG. Laser and Dental pulp. *J Am Dent Assoc* 1971; 83: 113-117.

[17] Miserendino, LT; Wigdo, M; Miserendino, CA. Evaluation of thermal cooling mechanisms for laser application to teeth. *Laser Surg Med* 1993; 13: 83-88.

[18] Stern, RH; Sognnaes, RF. Laser beam effects on dental hard tissues. *J Dent Res* 1964; 43: 73-75.