THE LASER RENAISSANCE: REVOLUTIONIZING DENTISTRY FOR THE MODERN AGE

Abstract

Traditional dental procedures have been transformed by lasers in dentistry, which provide accurate and minimally invasive solutions for a variety of applications. This chapter examines the various applications of lasers in dentistry, highlighting its effectiveness in managing both soft and hard tissues. Lasers are particularly good at preventing bleeding and improving vision during soft tissue treatments such as frenectomies and gingivectomies. Furthermore, periodontal therapy makes considerable use of lasers, which effectively disinfect periodontal pockets and stimulate tissue regeneration. Lasers are used in hard tissue applications to precisely ablate enamel, allowing cavities to be prepared with the least amount of harm to the neighboring good tooth structure. They are useful in caries removal because of their capacity to target carious lesions specifically, providing a cautious substitute for conventional drills. Additionally, lasers play a pivotal role in endodontic therapy, disinfecting root canals effectively and enhancing the success of root canal treatments. Beyond clinical applications, lasers in dentistry contribute to patient comfort by minimizing postoperative pain and reducing the need for anesthesia in certain procedures. While challenges such as cost and operator training persist, the continued integration of lasers into dental practice holds promise for advancing patient care, promoting faster healing, and shaping the future of dentistry towards more patient-friendly and efficient treatments.

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I. INTRODUCTION

Light amplification by stimulated emission of radiation is referred to as "LASER." It has potential to amplify and produce intense, highly directional monochromatic and coherent beam.

Gordon Gould initially used the term "laser" in 1957, although he did not patent it. Theodore Maiman later adopted it and established the acronym, leading to the creation of first Ruby Laser in the year 1960. [1] Ruby laser was used by Stern and Sognnaes in in-vitro study for the first time in 1964 and then by physicist Leon Goldman in vivo on dental tissues, in the year 1965. Ruby laser (wavelength 694nm) was used as a alternate for mechanical cutting, drilling in hard tissues treatments like caries excavation and cavity preparations. In 1976, the CO2 laser became the first laser to be FDA-cleared for oral use. Under the brand name "American Dental Laser," lasers for dental applications became commercially available in 1989. [2]

II. ELECTROMAGNETIC SPECTRUM

Electromagnetic spectrum for light is made up of visible and the invisible radiations. Cosmic radiations are produced by the radioactivity of the cosmos. Solar system has various radiation spectrum includes ultraviolet, visible, and infrared radiations.

The frequencies of electromagnetic waves also vary from as low as 30 Hz and as high as 10^{27}.Electromagnetic waves of higher frequencies have a shorter wavelength and more energy, whereas those of lower frequencies have a large wavelength and less energy.

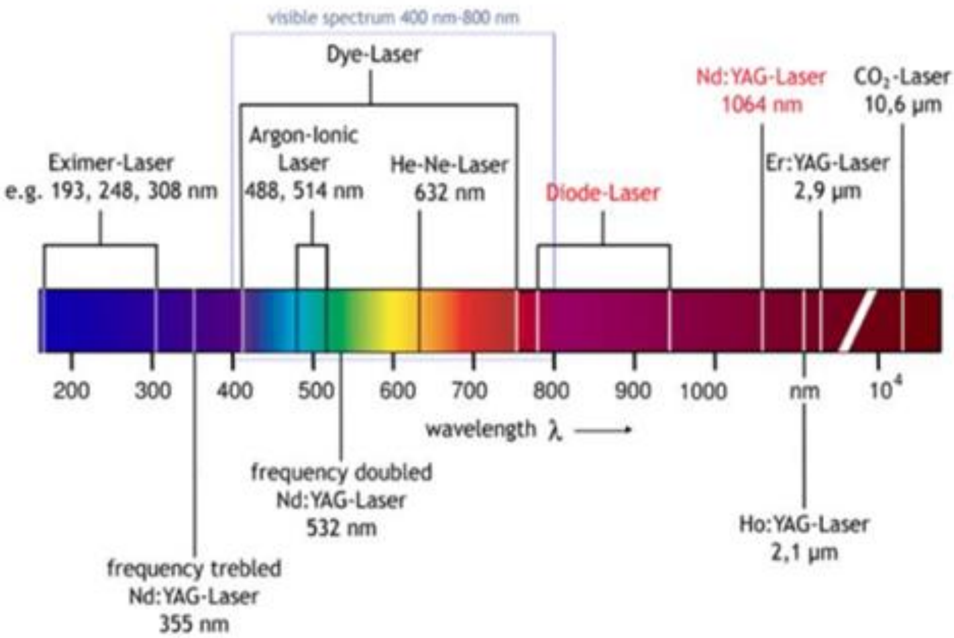

Figure 1

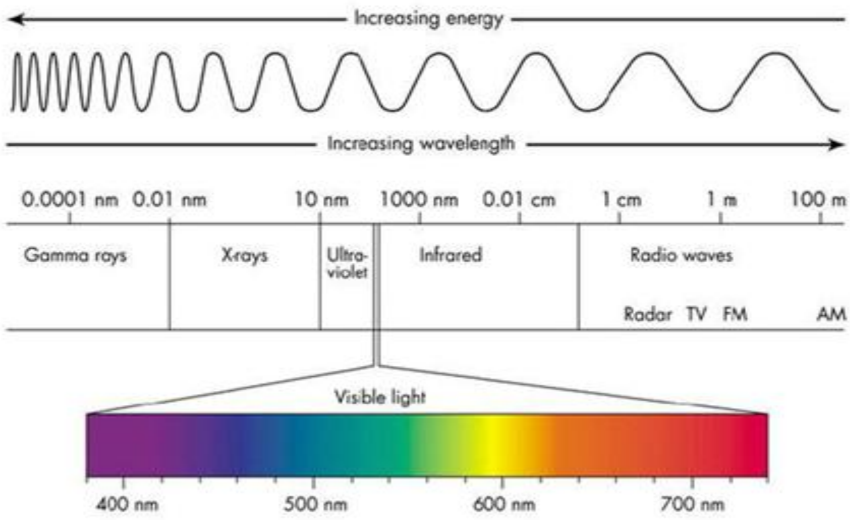

Figure 2

1. **Visible Spectrum of Light:** It is also called as "optical spectrum" of electromagnetic spectrum which a human eye can see. The visible light spectrum comprises a range that is approximately 0.4micrometres and 0.7 micrometres (400-700 nanometres).

2. **Ultraviolet Spectrum of Light:** Also called as invisible spectrum, The invisible spectrum is the region between 0.4 and 0.01 m that lies beyond violet region, which has a wavelength shorter than 0.4 meter (400 nanometre).

3. **Infrared Spectrum:** Electromagnetic radiation with a wavelength greater than visible light is known as infrared radiation. Red has the longest wavelength of all the colors of visible light, infrared means "below red." Its wavelength ranges from 750 nm to 1 mm.

- Infrared band is divided into smaller section:
- Far-infrared is (25 to 40) to (250–300) micrometres
- Mid-infrared is 5 to (25–40) micrometres
- Near-infrared is (0.7–1) to 5 micrometres.
- Characteristics of laser includes Coherence, Monochromatic, Brightness and intensity, Directionality, Collimation, Focusability

III. CLASSIFICATION OF DENTAL LASERS

Lasers were classified according to-

- Wavelengths- ultraviolet, visible light, infrared laser [3]
- Gas, solid-state, liquid, or semiconductor diode are some of the laser's physical components.
- Tissues on which it is used - soft or hard tissue laser
- level of risk to the skin or eyes after unintentional exposure

IV. ACCORDING TO PHYSICAL CONSTRUCTION AND TYPE OF LASING MEDIUM

Active medium	Physical construction	Wavelength (in nm)
Ar	Gaseous state	488,515 nanometres
He–Ne	Gaseousstate	633 nanometres
Nd:YAG	Solidstate	1064 nanometres
Er:YAG	Solidstate	2940 nanometres
Er, Cr:YSGG	Solidstate	2780 nanometres
CO2	Gas laser	9600nanometres,10300nanometres, 10600 nanometres
Diode	Semiconductor laser	635–980 nanometres

V. ACCORDING TO TISSUES ON WHICH IT IS USED

1. **Soft Tissues:** Diodes 445 > 1064 nanometres and Nd:YAG, Nd:YAP, CO_2 10,600 nanometres hard tissues: Er,Cr:YSGG, Er:YAG, CO_2 9300 nm

   There are four ways that laser energy might interact with tissues: through absorbing into tissues, passing through tissues, reflecting off tissues, or scattering on tissue surfaces.

VI. BASIC PARTS OF LASERS

In order to produce and emit the laser beam, a laser is made up of numerous fundamental components.

A laser's essential components are:

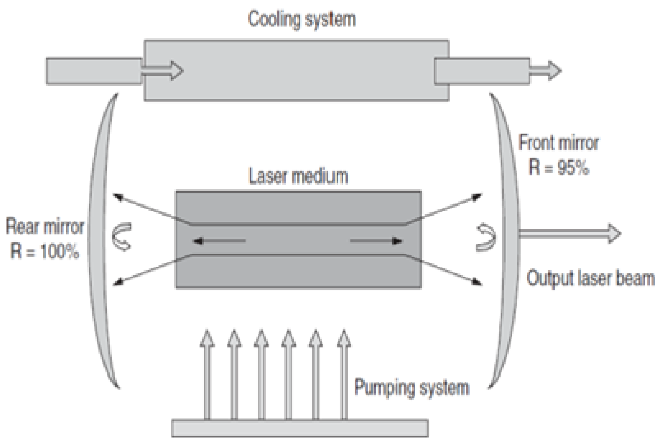

Figure 3

1. **Optical Resonator**: There are two mirrors at the corners of the cavity, one of which is entirely reflective and the other of which is partially reflective and permeable, together with active medium. Photons are amplified by the waterfall phenomenon, or

amplification, as they pass through the active medium and are reflected inside this optical cavity before exiting through the partially permeable mirror.

2. **Active Medium**: It is known as the laser's "heart." A semiconductor (diode) is an example of an active medium. It establishes the wavelength of various lasers. The atomic population of the active medium is activated by an external energy source, and it then provides the electrons needed for the energetic transition from one orbit to another, which results in the emission of laser photons.

3. **ENERGY Source:** The active medium's atoms are excited by the pumping source, which causes the population of electrons to reverse. Flash lamp, a diode laser, or an electric coil are used for representing this source of energy.

4. **Controller and Cooling System:** It evaluates the characteristics energy generation of the laser, theemission of laser mode (continuous waves, mechanical interruption, or pulse), the repetition frequency of the pulses, and the duration of single pulse emission.

5. **Delivery Unit:** Depending on variation in wavelength used, different delivery methods exist: the articulated arm, hollow fiber, and optical fiber.

6. **Hand Piece and Tips:** It should be small, very light in weight, and handy to use.

Figure 4:

VII. VARIOUS LASERS USED IN OPERAVTIVE AND ENDODONTICS

1. **Ar Laser (Argon):** Noble, inert argon is a chemical element that is remarkably stable. Inside the optical cavity, argon gas is utilized as the active medium. When bombarded by the pumping mechanism and the ionized molecules create a various wavelength, including three in blue spectrum (470–488 nanometres) and one in green spectrum (514 nanometres).

   - **Properties Includes [4]:**

     - gas/active medium: Ionized argon
     - Wavelength: 488 to 514 nm

- Method of pumping: Electrical discharge
- Emission mode: Continuous wave
- Output power: 100 mW to 50 W.

These wavelengths have shown bactericidal capabilities, particularly for *Prevotella and Porphyromonas,*[7] and are significantly absorbed by hemoglobin and melanin. Dentists are no longer being advertised with argon lasers, though.

2. **Neodymium: Yttrium Aluminum Garnet Laser:** Neodymium-doped yttrium aluminum garnet, also known as Nd:YAG (Nd: Y3 Al5 O12), is a crystal which is used for its lasing medium of solid state lasers. A crystal of solid yttrium, aluminum, and garnet (YAG) which is doped with the neodymium serves as the device's active medium. The stimulated neodymium YAG emits invisible photonics radiation at 1064 nanometres with a coaxial aimed at beam of low power (1 megawatt), usually red of 650 nanometres or green of 530 nanometres.

- **Application:**

  - Troughing of Gingiva
  - Contouring the gingiva for aesthetic purpose
  - Oral ulcers treatment
  - Removal of frenal attachment to the underlying bone
  - Removal of incipient carious lesion
  - PROPERTIES
  - Active medium: Neodymium-doped yttrium aluminum garnet.
  - Wavelength: 1064 nanometres
  - Method of pumping: Optical
  - Emission mode: Single or multimode
  - Output power: 1 J/pulse

3. **CO_2 Laser:** The CO2 laser is a type of gas active medium laser that moves CO2 molecules through a tube using an electrical discharge current. It is transmitted in a continuous or gated pulsed mode using a waveguide that resembles a hollow tube.[8]
The filling gas within the discharge tube consists primarily of: CO2—10 to 20%, N2—10 to 20%, H2 and/or xenon Helium

- **Applications:** Soft tissue

  - Incision of soft tissues and their ablation
  - Troughing of gingiva
  - Contouring the gingiva for aesthetic purpose
  - Removal of frenal attachment to the underlying bone
  - De-epithelization of the gingival tissues.
  - Hard tissue
  - Treatment of dentinal hypersensitivity
  - Dental hard tissue ablation
  - Treatment of tooth fracture
  - Prevention of dental caries as it promotes incorporation of fluoride ions into the enamel.

- **Properties:**

  - Active medium: Carbon dioxide and nitrogen.
  - Wavelength: 9.4 and 10.6 µm
  - Method of pumping: Electrical excitation.
  - Operation mode: Pulsed or continuous wave.
  - Power output: 1 to 10,000 Watt.

4. **Helium–Neon Laser**: Helium-Neon lasers, often known as He-Ne lasers, were initially demonstrated by Bell Labs' Ali Javan and colleagues in the year 1961 utilizing a combination of helium and the neon. Helium and neon gases are combined in a 5:1 to 20:1 ratio and are held at low pressure to form the active medium of helium neon lasers. [4]

   Application includes: Lowlevel laser therapy (LLLT) and curing dentin hypersensitivity.

- **Properties [4]**

  - Active medium: Helium and neon
  - Wavelength: 632.8 nm
  - Pumping technique: Release of electricity
  - Operation mode: Continuous Wave
  - Power output: 0.5 to 100 megawatts.

5. **Holmium: Yag Laser:** The holmium: YAG laser is yttrium aluminum garnet solid-state laser. That has been chrome-sensitized and doped with holmium and thulium ions. It is transmitted fiberopticallyin a pulsed free-running mode. This laser emits light at the wavelength of 2.1 meter (2100 nanometres), which is lies in near infrared region of non-ionizing radiation spectrum. [8]

   It is mainly used for:

- Troughing of gingiva
- Contouring the gingiva for aesthetic purpose
- Oral ulcers treatment
- Removal of frenal attachment to the underlying bone
- Gingivectomy Arthroscopic surgery.
- This laser does not react with any tissue pigment or hemoglobin.

- **Properties [4]**

  - Active medium: Holmium doped in a crystal of yttrium aluminum garnet.
  - Wavelength: 2.1 µm (2100 nm)
  - Mode of operation: Pulsed

6. **Erbium Lasers:** It is called as "Light saber of dentistry". It has the ability to remove soft tissue in addition to the ability to prepare enamel and dentin, remove cavities, bone, and cementum.

These lasers offer 2 different wavelengths but having similar properties: [9]

- Erbium, chromium: YSGG having wavelength of 2780 nanometres, and
- Erbium: YAG having wavelength of 2940 nanometres

Both of these lasers operate on non-ionizing, mid-infrared region of the spectrum, which is invisible. Unlike lasers of soft tissues (such diode and Nd:YAG), Er:YAG and Er, Cr:YSGG wavelengths could not be transmitted through quartz optical fibers. Other than quartz, "infrared fibers" can transfer the mid-infrared wavelengths required to provide energy oflaser at the surgical site.[10]

7. **Clinical Applications [11]**

- **Hard tissue**
  - Class I to VI cavity preparation.
  - Removal of caries
  - Hard tissue etching and roughening
  - Enameloplasty
  - Osteoplasty
  - Hard tissue ablation

- **Soft tissue**
  - Frenectomy, Gingivectomy and Gingivoplasty
  - Gingival troughing
  - Operculectomy
  - Hemostasis
  - Implant recovery
  - Pulpotomy and Pulpectomy
  - Crown lengthening

- **Endodontic Uses**
  - Access opening, root canal preparation debridement and cleaning (photoninduced photo-acoustic streaming, PIPS)
  - Apicectomy
  - Root end preparation
  - Removal of pathological and hyperplastic tissue.

- **Properties [4]**

  Er:YAG Laser

- Active medium: Erbium doped in a solid crystal of yttrium.
- Wavelength: 2940 nm
- Emission mode: Continuous wave/pulsed
- Delivery system: Optical fiber or waveguide

Er, Cr:YSGG

- Active medium: Erbium and chromium doped in solid crystal of yttrium scandium gallium garnet.
- Wavelength: 2780 nanometres
- Emission mode: Continuous wave/pulsed
- Delivery system: Optical fiber

7. **Diode Laser:** In a diode laser, the active medium is positioned in-between silicon wafers. Active media, such as GaAlAs, are crystalline by nature, making it feasible to selectively polish the crystal's ends to create fully and partially reflective surfaces. Photons are released from the active medium when current is discharged from one silicon wafer to the next across it.

- **Applications [2]**

- Treatment of dentinal hypersensitivity
- Photosensitization
- Wound healing
- For relieving postsurgical pain and Analgesia

VIII. LASERS USED IN DIAGNOSIS OF CARIES INCLUDES

- Quantitative laser fluorescence (QLF)
- Near-infrared fluorescence (DIAGNOdent)
- Multiphoton imaging
- Terahertz imaging
- Polarization-sensitive optical coherence tomography and optical coherence tomography (OCT and PS-OCT)
- Near-infrared photography (NIR)
- Photothermal radiometry and laser modulated luminescence (PTR and LUM)

IX. THE USE OF LASERS AS A DIAGNOSTIC TOOL IN RESEARCH

- Confocal Laser Scanning Microscopy (CLSM)
- Spectroscopic Examination of Dental Structure
- Laser-induced Breakdown Spectroscopy (LIBS)
- Raman Spectroscopic Analysis of Tooth Structure
- Fourier Transform Infrared (FT-IR) Spectroscopy
- Attenuated Total Reflectance-Infrared (ATR-IR) Spectroscopy

X. LASERS AND ESTHETICS

Lasers can be used for various esthetics procedures also, which includes:

1. **A Gingivectomy to Remove Tissue Overgrowth:** The laser (CO2 or diode) is utilized to incise the required gingival margin in a focused mode before excising or ablating the extra hyperplastic tissues.

2. **Cosmetic Reshaping of the Gingiva:** Laser (CO2 or diode) can be utilized carefully to mold the tissues at their optimal contour in cases involving asymmetry of the gingival tissues or excessive gingival tissue in one specific place.

3. **Frenectomy:** CO2, diode, argon, and Nd:YAG lasers aremost widely utilized lasers. The frenum can be abraded continuously or intermittently in a defocused mode or continuously and pointedly removed (or with a contact tip).

4. **Troughing of Gingiva:** Lasers like as CO2 and diode are helpful for gingival troughing. The laser point is positioned below the height of the gingival fissure and the tissue is "ledged" to disclose the margin of preparation.

5. **Laser Bleaching:** Lasers made of argon, carbon dioxide, nd:YAG, and er, cr: YSGG are frequently utilized. KTP, He-Ne, diode, and Er:YAG lasers are useful for bleaching. Laser bleaching can be done with either one laser alone or several lasers working together.

XI. LASERS IN ENDODONTICS

Olivi's classification of endodontic laser procedures [12]

Wavelength	Laser Technology	Chromophore Target	Interaction of Laser on Tissues	Effects of Laser
Visual Near-infrared	Irradiation via direct conventional	pigment of Bacteria	Diffusion	Photothermal
Mid infrared	Irradiation via direct conventional	Water content of dentin bacteria	Absorption	Photothermal
Visual Near-infrared	Direct irradiation using PAD	Photosensitizers	Absorption	Photochemical
Mid infrared	Indirect irradiation using LAI	Irrigants' water content	Absorption	Photothermal cavitation
Mid infrared	Indirect irradiation using PIPS	Irrigants' water content	Absorption	Photothermal photoacoustic cavitat

XII. CONCLUSION

Laser technology is state-of-the-art and offers promising results for a variety of dental applications. Although lasers have many advantages, they are not frequently employed for many treatments, especially in underdeveloped nations. Numerous obstacles, including high cost, method sensitivity, and a lack of training and updates among dental professionals, are responsible for this. In light of recent improvements brought about by ongoing research and technological progress, a notable increase in the use of lasers for dental applications is anticipated in the near future. Dental practitioners should seriously consider renewing their knowledge and abilities through continuing professional development (CPD), training programs, and literature updates in order to keep up with the quickly evolving laser technology.

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