Journal of Advanced Zoology
ISSN: 0253-7214
Volume 45 Issue 2 Year 2024 Page 354:364

Laser-A New Vision In Conservative Dentistry And Endodontics

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Abstract

This comprehensive review article explores the applications of lasers in conservative dentistry and endodontics. Covering diagnostic and therapeutic aspects, it delves into laser fluorescence for caries detection, cavity preparation, restorative material removal, tooth surface etching, and remineralization. Additionally, the review discusses laser applications in endodontics, including pulp vitality testing, pulpotomy, access cavity preparation, root canal irrigation, laser-activated irrigation, and photoactivated disinfection. Despite advancements, the article highlights the need for more clinical studies to establish laser superiority over traditional methods. The integration of lasers in these dental disciplines holds promise for enhanced precision, patient comfort, and therapeutic outcomes.

INTRODUCTION

"Laser" (Light Amplification by Stimulated Emission of Radiation) marks a transformative leap in dentistry, mitigating patient fears associated with traditional methods. Leveraging quantum mechanics, lasers emit coherent, monochromatic, and collimated light, concentrating energy in a targeted manner. With unique features, lasers stand out by providing a focused, single-wavelength beam, offering advantages in various dental procedures. Ongoing advancements in laser fiber technology enhance flexibility and durability, expanding applications in fields like endodontics. This innovation represents a significant shift in dentistry, ushering in cutting-edge treatments for a more comfortable patient experience.[1]

HISTORY OF LASER

The history of lasers in dentistry dates back to the mid-20th century, marked by the pioneering work of various researchers and scientists. The term "laser" itself, an acronym for Light Amplification by Stimulated Emission of Radiation, was coined by physicist Gordon Gould in 1959, setting the stage for the revolutionary technology.[2]

In 1960, physicist and engineer Theodore Maiman built the first working laser, using a synthetic ruby crystal. This groundbreaking development laid the foundation for exploring laser applications in various fields, including dentistry. Early experiments focused on investigating the interactions between laser light and dental tissues. By the 1970s, researchers were delving into the potential of lasers for dental procedures. Initial applications involved soft tissues, with early lasers demonstrating their efficacy in procedures such as gingivectomy and periodontal therapy. As technology progressed, researchers sought ways to adapt lasers for hard tissue applications, particularly in restorative dentistry.[2]

The 1980s witnessed significant advancements in laser dentistry, with the introduction of the first carbon dioxide (CO_2) lasers for dental use. These lasers proved effective for cutting soft tissues and became a valuable tool in oral surgery. Subsequent years saw the emergence of other types of lasers, such as the erbium family, offering more versatility in dental applications.[2]

Throughout the 1990s and early 2000s, laser technology continued to evolve, with researchers exploring its potential for applications like caries removal, teeth whitening, and endodontic procedures. Today, lasers are integral to modern dentistry, offering precise and minimally invasive solutions for a range of dental treatments. As ongoing research and technological advancements persist, the history of lasers in dentistry remains a dynamic narrative of innovation and progress.[3]

TIMELINE

In 1917, Albert Einstein laid the groundwork for laser technology by predicting the essential phenomenon of "Stimulated Emission," which forms the basis for the operation of all lasers. [3]

In 1939, Valentin Fabrikant theorized the application of stimulated emission for amplifying radiation.

The year 1950 saw Charles Townes, Nikolay Basov, and Alexander Prokhorov developing the quantum theory of stimulated emission, showcasing its application by demonstrating the stimulated emission of microwaves, an achievement that Searned them the Nobel Prize in Physics. [3]

In 1959, Columbia University graduate student Gordon Gould proposed the use of stimulated emission to amplify light. He introduced the concept of an optical resonator capable of generating a narrow beam of coherent light, coining the term LASER for "Light Amplification by Stimulated Emission of Radiation.

In 1960, Theodore Maiman constructed the first functional prototype of a laser at Hughes Research Laboratories in Malibu, California.

The year 1963 marked the development of the Carbon Dioxide (CO_2) laser by Kumar Patel at AT&T Bell Labs, offering improved cost-efficiency compared to the ruby laser and becoming the most popular laser type. [3]

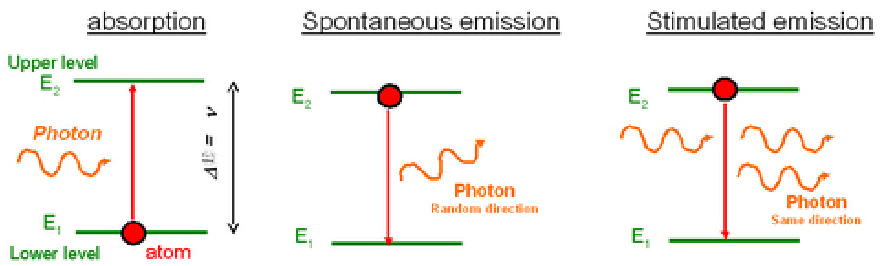
The 1970s witnessed the refinement of CO_2 lasers and the introduction of new laser types, leading to the initiation of "Laser Machining" applications. Laser-Work A.G. developed the first 2-axis laser system in 1975, primarily adopted by automobile and aircraft manufacturers for metal cutting and welding. [3]

The 1980s brought forth a new era of "Laser Materials Processing" with the introduction of small, affordable lasers like the Carbon Dioxide Slab Laser. This era expanded laser applications from metal processing to the treatment of organic materials such as plastic, rubber, and foam.[5]

LASER PHYSICS

Spontaneous Emission:

When an atom absorbs a photon of light, causing a shift in energy levels as an electron (e-) within the atom moves to a higher state, the absorbed photon ceases to exist. Subsequently, the atom enters an excited or pumped state, deviating from its initial resting or ground state. However, this excited state is inherently unstable, prompting the atom to undergo spontaneous decay back to its resting or ground state. During this process, the stored energy is released in the form of an emitted photon. Referred to as "spontaneous emission," this phenomenon occurs swiftly, with a brief interval between the absorption and re-emission of the photon.[4,7]



Stimulated Emission and Light Amplification:

When an atom exists in an excited or pumped state, a photon with the appropriate wavelength enters its electromagnetic field, inducing the transition of the excited electron to a lower energy state before spontaneous decay occurs. This transition is accompanied by the emission of stored energy in the form of a second photon. Importantly, the initial photon is not absorbed but continues its path, interacting with other excited atoms. The outcome of this process, known as "stimulated emission," is the generation of two photons with identical wavelengths moving in the same direction simultaneously, oscillating in phase. In a cluster of atoms where the number of excited atoms surpasses those in the resting state, a condition known as population inversion is established. This state is a prerequisite for the production of laser light.[6]

Emission Modes:
- Continuous Wave: The laser beam is transmitted at a constant power level for as long as the device remains active.
- Gated Pulse Mode: Laser energy is periodically turned on and off in a manner similar to the blinking of an eye. This mode is achieved through the opening and closing of the shutter in front of the beam path.[8]
- Free Running Pulsed Mode (Donat Wave Mode): The laser emits large peak energy of light for a short duration (microsecond), followed by an extended period when the laser is inactive.[9]

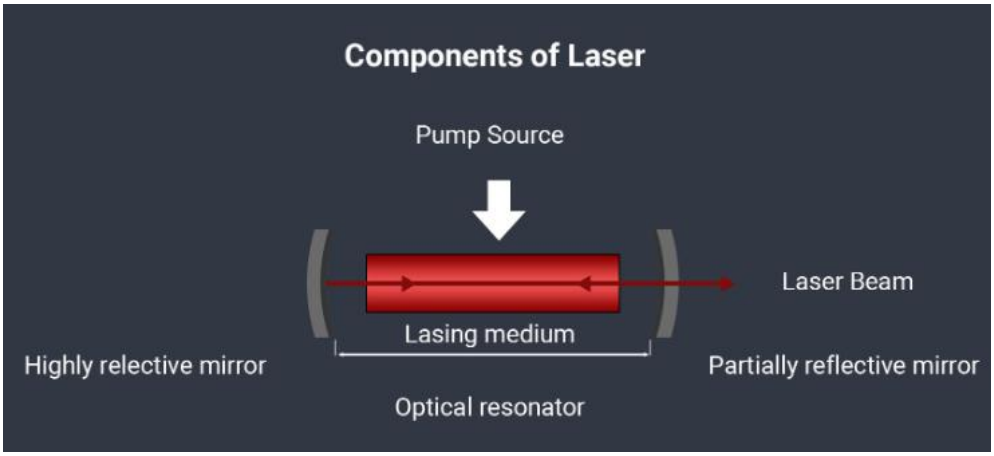
COMPONENTS OF LASERS

Basic Component Of Laser

There are 3 main parts of laser delivery system.

(1) Lasing or Active Medium
(2) Energy or Pumping Source
(3) Optical /ResonatingChamberOther parts include:-
(4) Controller (or microprocessor)
(5) Cooling system
(6) Delivery system
(7) Handpiece and tips[41]

The laser system comprises essential components for its operation. The active medium, found in varied forms like gas, solid, or liquid, absorbs external energy and releases it as photons. The energy source, vital for pumping atoms to higher energy levels, can be electrical, thermal, chemical, or optical. An optical chamber, with reflecting mirrors, fosters photon reflection for intense resonance. The controller, a microprocessor, manages laser characteristics and emission modes, while a cooling system dissipates heat. Delivery systems, like optic fibers, transmit laser light to the target. Angular or straight-ended handpieces convey light, with some having reflecting mirrors (tipless handpiece) or terminal tips for close-contact or root canal operations. The laser system's intricate design ensures effective and controlled energy delivery for diverse applications.[11,10]



Commonly Used Lasers in Conservative Dentistry and Endodontics:

1. **Carbon Dioxide Lasers:**
   - Gas Lasers

Advantages:
- Demonstrates a high affinity for water, allowing rapid removal of soft tissue.
- Ensures rapid hemostasis with shallow penetration.
- Commonly used in both major and minor surgical procedures.
- Improves the mechanical retention of sealant.

Disadvantages:
- Exhibits the highest absorbance among lasers.

- Large size and high cost.
- Causes greater destruction of hard tissues.

2. **Neodymium-Yttrium Aluminum Garnet Laser (Ne: YAG):**
- Solid State Lasers
  Advantages:
- Highly absorbed by pigmented tissues.
- Effective for cutting and coagulating dental soft tissues.
- Provides good hemostasis.
- Utilized in non-surgical sulcular debridement.
- *Disadvantages:*
- High cost and size.

3. **Erbium Laser:**
- Solid State Lasers
  Advantages:
- Erbium wavelengths exhibit a high affinity for hydroxyapatite and the highest water absorption.[12,13]
- Used for both soft and hard tissues.
  Disadvantages:
- High cost.
- Marginally prolonged treatment time but better results.

4. **Diode Lasers:**
- Solid State Lasers
  Advantages:
- Mainly absorbed by tissue pigment (melanin) and hemoglobin.
- Employed for soft tissue applications.[13]
- *Disadvantages:*
- Poorly absorbed by hydroxyapatite and water in enamel.

5. **Argon Laser:**
- Produces high-intensity visible blue light.
- Used for curing dental restorations, altering surface chemistry of enamel and root surfaces, and bleaching teeth.[14]

6. **Erbium: Chromium: Yttrium Scandium Gallium Garnet Laser (Er:Cr:YSGG):**
- Etches enamel surface.
- Removes smear layer.

7. **Erbium: Yttrium Aluminium Garnet Laser (Er:YAG):**
- Removes caries in enamel and dentin.
- Eliminates dislodged glass ionomer cement (GIC) and composite.[15]
- Desensitizes hypersensitivity in dentine.

8. **KTP Laser (Potassium-Titanyl-Phosphate):**
- Operates in the green band with a wavelength of 532 nm.
- Introduced to dentistry in the 1990s for soft tissue cutting and coagulation.[16,15]

9. **Medium-Infrared Lasers: Erbium YAG and Erbium, Chromium YSGG Laser:**
- Introduced in the late 1980s to the early 1990s for caries removal, aiming to substitute the drill.
- Specifically designed thin tips for root canal access.

Laser-Tissue Interaction:
Light energy emitted by a laser can engage in four distinct interactions with the target tissue, and these interactions are contingent upon the optical properties of the tissue and the wavelength employed. [16]
1. **Transmission:**
- The laser energy passes directly through the tissue without affecting the target tissue.

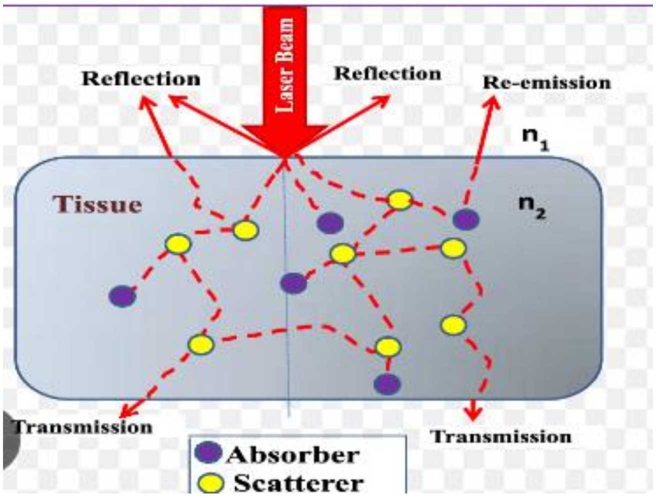
- For instance, Nd:YAG laser energy easily traverses water, while carbon dioxide is readily absorbed by tissue fluids.

2. **Absorption:**
  - This interaction is the desired effect, and the amount of energy absorbed by the tissue depends on its characteristics, such as pigmentation and water content, as well as the laser wavelength and emission mode.[17]
  - Diode and Nd:YAG lasers exhibit a high affinity for melanin and have minimal interaction with hemoglobin.
  - Longer wavelengths are more absorbed by water and hydroxyapatite, as seen with Erbium and carbon dioxide lasers.
  - Shorter wavelengths, approximately 500-1000nm, are readily absorbed in pigmented tissue.[17]

3. **Diffusion or Scattering:**
  - Scattering of laser light leads to the attenuation of energy and may result in no discernible beneficial biological effect.[18]

4. **Reflection:**
  - The laser beam diverges as the distance from the handpiece increases, and this divergence can pose potential hazards.

These interactions are dependent on the optical properties of the target tissue and the specific wavelength used in laser therapy. Understanding these interactions is crucial for optimizing the efficacy and safety of laser procedures in various clinical applications.[19]



Types Of Tissue Interaction

1. Photochemical- effects that lasers make to arouse chemical reactions,such as curing of the composite resin. They can also origin a breakdown in chemical bonds, such as in the process of photodynamic therapy.[11,20]
2. Photo ablation- When a laser is absorbed, it elevates the temperature and produces photochemical effects depending on the water content of the tissues. When a temperature of 00°C is extended, vaporization ofthe water within the tissue occurs, a process called Ablation. Removal of tissue by vaporization and super heating of tissue fluids, coagulation, and hemostasis.[13]
3. Tissue fluorescence- used as a diagnostic method to detect the light reactive substance in tissue. Eg.Diagnodent for caries detection
4. Vaporization & Carbonization- At temperatures below 100°C, but above almost 60°C, proteins begin to denature, without vaporization of the underlying tissue. On the other hand, at temperatures above 200°C, the tissue is dehydrated and then burned, resulting in an undesirable effect called Carbonization.[2]

The alteration in the target tissue brought about by the transfer of heat is termed photothermolysis. This process is further categorized, depending on temperature change, phase transfer, and incident energy levels, into photopyrolysis, photovaporolysis, and photoplasmolysis:[20]

1. **Photopyrolysis:**
  - In the temperature range of 60°C to 90°C, target tissue proteins undergo morphological changes that are predominantly permanent.

2. **Photovaporolysis:**
  - At 100°C, both inter- and intra-cellular water in soft tissue and interstitial water in hard tissue vaporize. This phase transfer leads to expansive volume changes, aiding the ablative effect of the laser by dissociating large tissue elements. This is particularly evident in the laser's application for cutting hard dental tissues.[21]

3. **Photoplasmolysis:**
  - Characterized by high temperatures and explosive expansion at micro-tissue and molecular levels, this phenomenon is observed in ultra-short pulsed lasers such as Nd:YAG and Er:YAG, with pulse widths of <100 µs. Photoplasmolysis is adjunctive to photothermolysis, where a plasma is formed due to the ionizing effects of the strong electric fields of light waves, reaching power densities >10^10 W/cm^2. This process occurs photonically in soft tissue and thermionically in hard tissue, producing flashes and popping sounds during laser use. While plasma formation can yield extremely high ablative energies, it can also act disruptively by 'shielding' the target from further incident light, serving as a 'super-absorber' of electromagnetic radiation. Within therapeutic levels of laser power used in dental procedures, photoplasmolysis is considered a rare occurrence.[22]

Thermal Relaxation:
The predictability of the conversion of electromagnetic energy to heat effects in target tissue relies on preventing unwanted changes through conductive thermal spread. Thermal relaxation describes the ability to control a progressively increasing heat loading of target tissue. Assuming fixed values of thermal and light diffusivity for any given tissue, thermal relaxation rates are proportional to the exposed tissue area and inversely proportional to the absorption coefficient of the tissue.[23]

Laser Absorption Characteristics:
Several factors influence the absorption of laser energy, including emission mode, duty cycle, incident power, power density, beam movement, endogenous and exogenous coolants such as blood flow, water, air, and pre-cooling of tissue. The use of correct incident wavelength and delivery parameters results in a central zone of tissue ablation surrounded by an area of irreversible protein denaturation (coagulation, eschar). Along a thermal gradient, a reversible, reactionary zone of edema develops, with the depth and extent of tissue change varying based on laser wavelength, being more superficial with longer wavelengths and deeper with shorter wavelengths.[24]

Application of Lasers in Conservative Dentistry

I. **Diagnostic Applications for Caries Detection:**
  - Laser fluorescence (LF) integrated with standard methods aids in occlusal caries detection. Diagnodent, using laser-induced fluorescence at a wavelength of 655nm, detects caries and calculus by assessing bacterial activity and displaying results digitally.[25]

II. **Laser Cavity Preparation:**
  - The "Laser Drill" successfully replaces conventional burs for cavity preparation. Lasers are employed for proximal carious lesions, performing box-only preparations without involving sound occlusal surfaces. In cases requiring direct pulp capping, Er:YAG laser, in a de-focused mode, partially necroses superficial tissue, creating a protective barrier around exposed pulp tissue.[26]
  - Guidelines for laser use: cutting at the tip, employing an up-and-down motion, and assisting in smear layer removal.
  - A systematic review by Jacobsen et al. suggests that erbium lasers are as effective as conventional instruments in removing dental caries. Patient preference favors laser ablation for comfort.[28]
  - Ultra-short pulsed lasers (USPLs) demonstrate promising results in efficiently cutting hard materials with less temperature fluctuation compared to erbium lasers.[27]

III. **Removal of Restorative Material:**

- Er:YAG laser effectively removes dental cements and composite resin restorations. Caution is advised against ablating amalgam restorations due to potential mercury vapor release. Limitations exist for gold crowns, cast restorations, and ceramic materials.[28]

IV. **Etching of Tooth Surface:**
- Laser etching, an alternative to acid etching, produces micro-explosions during hard tissue ablation. However, adhesion to dental hard tissues post-Er:YAG laser etching is inferior to conventional acid etching.[28]

V. **Laser in Re-Mineralization:**
- Laser irradiation induces enamel remineralization by causing physical fusion, reducing enamel solubility, and leading to ultra-structural alterations in enamel crystals.[29]

VI. **Laser in Dentinal Hypersensitivity:**
- Laser irradiation impacts nerve fibers within dental pulp or modifies dentin tubular structure, reducing dentinal hypersensitivity.

VII. **Laser in Dental Erosion:**
- Carbon dioxide lasers are used to prevent erosion by efficiently interacting with hydroxyapatite crystals, increasing enamel resistance to demineralization.[30]

VIII. **Photopolymerization:**
- Argon laser (488nm) is a promising source for polymerization initiation of composite resin, altering surface chemistry and enhancing mechanical properties

.
IX. **Bleaching:**
- Various lasers, including Nd:YAG, Argon, CO2, KTP-L, and Diode lasers, are utilized for dental bleaching applications.[31]

Application of Lasers in Endodontics
1. **Pulp Vitality Testing:**
- Laser Doppler flowmetry (LDF) was originally developed for assessing blood flow in microvascular systems, utilizing a helium–neon (He-Ne) laser emitting at 632.8 nm. The technique, based on the Doppler principle, involves measuring the frequency shift of light scattered by moving red blood cells.[32]
- Different wavelengths of semiconductor lasers, such as 780 nm, 780–820 nm, have also been employed for this purpose.
- Vascular supply serves as the most accurate marker of pulp vitality. Laser Doppler flowmetry (LDF) is a noninvasive, objective, and semi-quantitative method that measures pulpal blood flow by analyzing the frequency shift of laser light scattered by moving blood cells.[33]
- LDF aids in detecting transient ischemia episodes and identifying teeth at risk of adverse sequelae. However, it has limitations, including cost, availability, and challenges in teeth with large restorations where laser light may not reach the pulp.
- The working mechanism of Laser Doppler Flowmeter involves a laser diode emitting light onto tissue, where it is diffused and scattered by enamel prisms, dentine tubules, and capillaries of the pulp. The frequency shift of light scattered by moving red blood cells is then measured to determine pulpal blood flow.[34]

2. **Pulp Capping and Pulpotomy:**
- Melcer et al. (1987) initially explored laser treatment for exposed pulp tissues in dogs using the CO2 laser to achieve hemostasis. Subsequent studies by Ebihara et al. (1988, 1992) utilized the Nd:YAG laser in rats and dogs, demonstrating enhanced pulpal healing after laser irradiation.[35]
- CO2 lasers were found to be valuable aids in direct pulp capping in human patients, as reported by Moritz et al. (1998b). The first laser pulpotomy using the CO2 laser was performed in dogs by Shoji et al. (1985), with subsequent reports confirming successful outcomes in various studies.[36]
- Laser treatment in pulp therapy provides a bloodless field, ensuring vaporization and coagulation, sealing smaller blood vessels, and creating a sterile wound. Studies comparing CO2 laser direct pulp capping with calcium hydroxide revealed a higher success rate with the laser after 12 months.[36]

- While CO_2 lasers were effective for pulp capping procedures, Er:YAG and Nd:YAG lasers demonstrated success in forming dentine bridges and reparative dentine in different studies.

3. **Access Cavity:**
   - Beyond conventional rotative instruments, erbium lasers can be used for accessing the pulp chamber, capable of removing hard and soft dental tissues, including enamel, dentin, carious tissue, and pulp without direct contact.
   - The use of erbium lasers involves handpieces with terminal tips or tipless handpieces, with preferable diameters ranging from 600 to 1000 microns. Larger diameters provide higher energy and power during enamel ablation.[38,37]
   - During access cavity preparation, energy is gradually reduced from dentin to pulp. The high affinity of lasers with carious tissue and pulp, rich in water, aids in selective removal of carious dentin with less energy, minimizing the risk of a false path.[37]

4. **Root Canal Irrigation:**
   - Presently, Er:YAG, Nd:YAG, CO_2 lasers, and diode lasers are efficient for root canal disinfection and smear layer removal. Studies comparing Nd:YAG laser irradiation with NaOCl irrigation demonstrated significant bacteria reduction with laser irradiation, while NaOCl effectively disinfected the canals.[39,38]
   - Laser-activated irrigation (LAI) techniques, using erbium lasers such as ErCrYSGG and Er:YAG, involve laser energy to agitate and activate irrigants. Photon-induced photoacoustic streaming (PIPS) is a specific LAI technique utilizing specially designed laser fiber tips for effective irrigation throughout the root canal system.[40]
   - Photoactivated disinfection (PAD) employs photosensitizers activated by laser irradiation, producing a bactericidal effect without direct laser interaction with the dentin surface. - PIPS, or photon-induced photoacoustic streaming, is an advanced laser-activated irrigation technique using specific tip design, subablative energy, short pulse duration, easy tip positioning, and minimal root canal preparation.[41]

5. **Obturation:**
   - The major goal of modern root canal treatment is three-dimensional cleaning, disinfecting, and shaping along with effective sealing. Studies comparing apical leakage in lateral condensation, Nd:YAG laser-softened gutta-percha, and System-B techniques found no significant differences between groups, with slightly less leakage in the lateral condensation and System-B groups compared to laser-softened gutta-percha.

LASER HAZARDS

A hazard is a potential factor that can lead to harm. In the clinical setting, the use of lasers introduces various risks, with laser light being the most common. The Center for Devices and Radiological Health (CDRH) of the Food and Drug Administration (FDA) in the USA establishes standards for laser equipment manufacturing in the Code of Federal Regulations (CFR).[41]

1. **Ocular Hazards:**
   - Eye abrasion can occur through direct laser emission or iatrogenic reflection from mirror surfaces during dental procedures. Instruments in dentistry can create reflections, posing a risk of tissue injury to both clinicians and patients.

2. **Tissue Damage:**
   - Thermal interaction between laser radiant energy and tissue proteins can lead to injury in skin and other non-target tissues. Temperature elevations of 21ºC above normal body temperature can cause cell destruction by denaturing cellular enzymes and structural proteins, disrupting basic metabolic processes.[40]

3. **Respiratory Hazards:**
   - Surgical laser applications may generate airborne biohazard materials, representing a category of 'potential laser hazards' or 'non-beam hazards.'

4. **Combustion Hazards:**

- Lasers have the potential to cause combustion in the presence of flammable materials. The dental surgical setting may become hazardous if exposed to the laser beam in the presence of flammable solids, liquids, or gases.

5. **Electrical Hazards:**
   - Laser systems involve high potential and high-power electrical supplies, with the most serious accidents involving electrocution. Electrical hazards encompass shock hazards, fire hazards, or explosion hazards.

Laser Hazard Control Measures:
- In accordance with OSHA guidelines and ANSI standards, control measures for safe laser use in dentistry include:
  - *Engineering Controls:* These are built-in safety features within laser equipment, such as enclosures, interlocks, and beam stops, effectively reducing hazards.
  - *Personal Protective Equipment:* All individuals in the dental treatment room, including patients, must wear adequate eye protection meeting specified criteria for optical density.
  - *Procedural Controls:* Specific dental procedures, particularly those involving general anesthesia, require attention to details such as using appropriate intubation tubes and shielding nearby tissues. Regular checks on foot switches are crucial to prevent accidents.

By adhering to recommended control measures, many laser accidents can be easily avoided, ensuring a safer clinical environment.[29]

Conclusion

Recent progress in laser technology and delivery systems, alongside a deepened understanding of laser interactions with dental tissues, has broadened the scope of potential applications in dentistry. Clinicians are increasingly interested in integrating lasers into various dental procedures. However, the challenge lies in the scarcity of comprehensive clinical studies establishing the superiority of lasers over traditional treatments. The rapid evolution of laser systems, improved detection mechanisms, precise delivery systems, and advanced information processing in computers are collectively driving the integration of lasers into noninvasive diagnostics and selective therapeutics in dentistry. As these technologies advance, the landscape of laser applications in dentistry holds promising prospects for further innovation and refinement..

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