Dep. Medical physics

Medical Laser Applications

Introduction Lasers Pulsed

1. Introduction Lasers Pulsed

Definition and Key Characteristics

• A pulsed laser emits energy in the form of light pulses rather than a continuous beam.

• Pulse durations can range from nanoseconds (ns) to femtoseconds (fs).

Pulsed lasers are characterized by high peak powers and are widely used fields such as

o Material processing

o medical applications (e.g., laser surgery)

o Scientific research (e.g., spectroscopy, time- resolved studies)

Applications in Science and Technology

Pulsed lasers enable precise energy delivery in time-sensitive applications

- Examples include:
  - Micromachining delicate materials.
  - Generating high-intensity electric fields for particle acceleration.
  - Studying ultrafast processes in physics and chemistry

2. Understanding Power and Energy in Pulsed Lasers

Distinction Between (CW) and Pulsed Lasers

• Continuous-Wave (CW) Lasers: Emit a steady, continuous beam of light.

• Pulsed Lasers: Emit light in bursts, leading to significantly higher instantons power

Key Terminologies

1. **Pulse Energy (E):** The total energy contained in a single pulse, typically

measured. in (joules

2. **Peak Power (Ppeak):** is the maximum power achieved during a pulse. It is calculated as:

Ppeak = Energy / Pulse Duration

$$P_{peak} = E / \tau_p$$

Where:

- **E:** Pulse energy (J) - The total energy contained within a single pulse.
- **τ_p:** Pulse duration (s) - The length of time the pulse lasts.

3. Average Power (Pavg) : The time-averaged power output, calculated as:

$P_{avg} = E \times f_r$

where:

o E = Pulse energy (J)

o fr = Pulse repetition rate (Hz)

4. Mathematical Framework for Calculations

Energy Per Pulse

• The pulse energy can often be measured or derived from the laser specifications and is a fundamental quantity in calculations.

Power Peak Calculation

• Pulsed lasers often achieve very high peak powers due to the short duration of pulses

Example Calculation:

You provided a great example. A laser emits a 1 mJ pulse with a 10 ns pulse duration. Let's calculate the peak power:

Average Power Calculation:

You're also correct about average power. The average power is related to the pulse energy and the repetition rate. Here's the formula:

$P_{avg} = E * f_r$

Example of Average Power:

Let's say our laser from the previous example (1 mJ pulse energy) has a repetition rate of 1000 Hz (1 kHz). Then the average power would be:

A pulsed laser emits light at a pulse energy of 0.5 mJ and a pulse duration of 5 ns.

Calculate the peak power.

A. What is a Laser? • Laser stands for Light Amplification by Stimulated Emission of Radiation.

Characteristics of laser light:

Monochromatic: Single wavelength or color.

Coherent: All photons are in phase.

Directional: A highly focused beam.

B. Components of a Laser System

• Active Medium: Material that amplifies light (e.g., gas, solid, or liquid).

• Energy Source: Provides energy to excite the medium (e.g., electrical current)

• Optical Cavity: Mirrors that reflect light to amplify it further.

C. Types of Lasers

Gas Lasers: CO_2 lasers, He-Ne lasers.

Solid-State Lasers: Nd:YAG (neodymium-doped yttrium aluminum garnet • Semiconductor Lasers: Laser diodes.

Dye Lasers: Tunable across a range of wavelengths.

Laser Effects on Biological tissue

The thermal effect of lasers on biological tissue is a complex process resulting from three distinct phenomena:

Conversion of light to heat.

Transfer of heat.

the tissue reaction, which is related to the temperature and the heating

time.

2. Interaction of Lasers with Biological Tissues

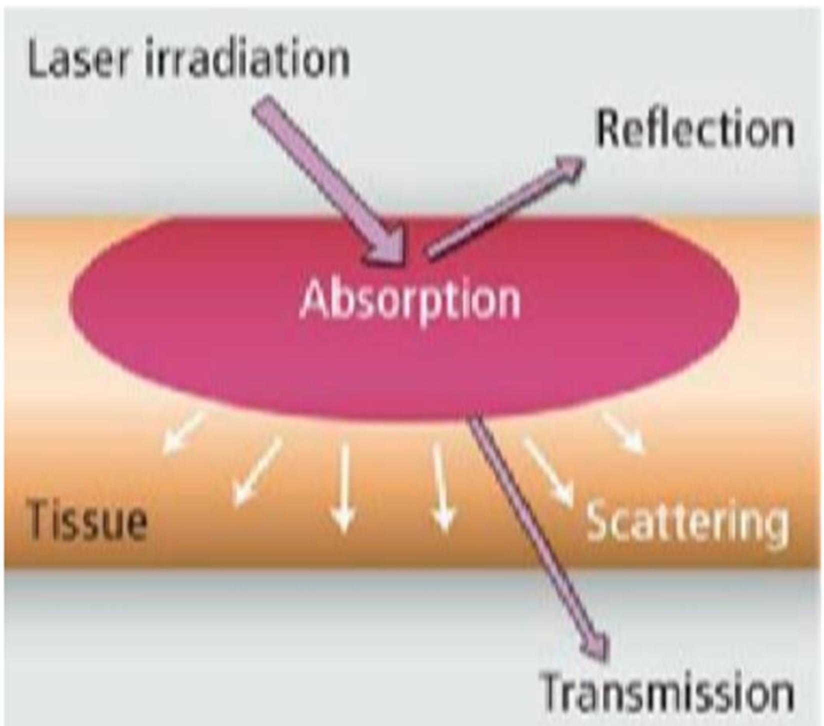
A. Mechanisms of Interaction

A laser beam is created and directed towards tissue to accomplish a particular job.

When energy hits the biological contact, it will interact in one of four ways:

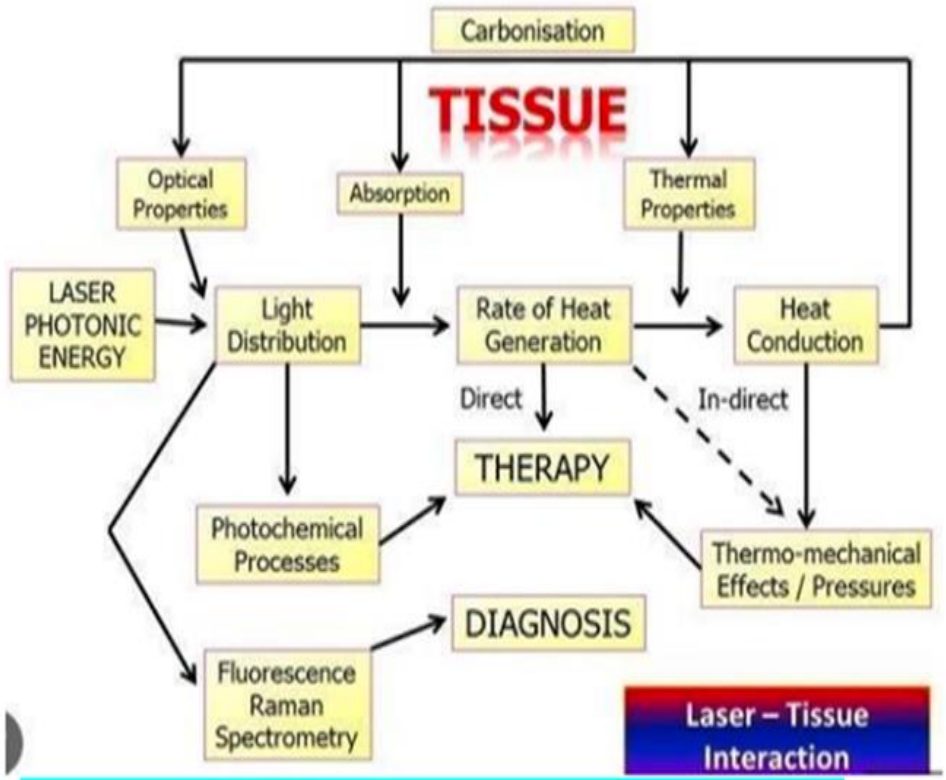
reflection, transmission, scattering, or absorption.

- Absorption: The tissue absorbs laser energy, leading to heat generation.
- Scattering: Redirection of light within tissue, which affects penetration depth.
- Reflection: A portion of the laser light is reflected at the tissue surface.
- Transmission: Some laser light passes through the tissue without interaction.



Laser absorbed by tissue may causes thermal effects:

- **Homeostasis: Any procedure that stop bleeding.**
- **Photocoagulation: Heating a blood vessel to point where the blood coagulates and blocks the vessel.**
- **Vaporization: To make incisions and vaporize tissue.**
- **Sonic: Membrane disruption**



B. Biological Effects

- Photothermal Effect: Heat generated to destroy targeted tissues.
- Photomechanical Effect: Shockwaves produced by rapid heating can disrupt cells
- Photochemical Effect: Interaction with photosensitive agents (e.g., in. (photodynamic therapy

3: Applications of Lasers in Cancer Treatment

A. Photothermal Therapy (PTT)

- Mechanism: Laser energy heats and destroys cancer cells.
- Common Lasers Used: Infrared and near-infrared lasers for deeper tissue penetration
- Applications: Skin cancer, prostate cancer.

B. Photodynamic Therapy (PDT)

Mechanism:

- A photosensitizing agent is administered and accumulates in cancer cells.
- Laser light activates the agent, producing reactive oxygen species (ROS)cells kill that.

Advantages:

- Minimally invasive.
- Selective targeting of cancer cells.
- Challenges
- Limited light penetration in deep tissues.

C. Laser-Induced Interstitial Thermotherapy (LITT)

Mechanism:

- A fiber optic laser probe is inserted directly into the tumor.
- Laser heats the tumor, causing localized destruction.

Applications: Liver, brain, and pancreatic cancers.

D .Laser Surgery

* Mechanism: High-intensity laser beams precisely cut or remove cancerous tissue

Advantages:

- Precision with minimal damage to surrounding tissue.
- Reduced bleeding and faster recovery.

Applications: Early-stage lung cancer, cervical cancer.

Advantages and Challenges of Laser Therapy

A. Advantages. Non-invasive or minimally invasive •

High precision and control

- Reduced risk of infection and shorter recovery times.
- Can be combined with other treatments (e.g., chemotherapy, radiation).

B. Challenges

- Limited penetration depth for certain wavelengths.
- Requires skilled operators
- Potential damage to surrounding healthy tissues if not carefully controlled.
- High initial cost of equipment

Advantages of Laser Surgery:

1-No technique touch.

2-Dry surgical field

3- Reduced blood loss

4-Reduced edema

5- Limited fibrosis and stenosis.

6-Precision

7- Reduced post-operative pain

8- It is effective, fast, safe.

9-Painless during its use especially when it is used in eye and dental treatment

4.Future Directions:

A. Advances in Laser Technology

* Development of tunable lasers for better targeting.

* Use of ultrafast lasers to minimize collateral damage.

B. Integration with Nanotechnology

- Nanoparticles as targeted delivery systems for heat or photosensitizing agents.
- Improved selectivity and efficacy in deep-seated tumors.

C. Personalized Medicine

Customized laser treatments based on genetic and molecular profiling of tumors

Conclusion

Lasers represent a powerful tool in the fight against cancer, leveraging physics to improve precision, efficacy, and patient outcomes. By understanding the principles of laser-tissue interaction and the various therapeutic techniques, we can appreciate the interdisciplinary nature of this field and its potential for future advancements

What is Laser Eye Surgery?

Definition: A medical procedure that uses lasers to reshape the cornea to improve vision.

Applications: Treats refractive errors such as myopia (nearsightedness), hyperopia (farsightedness), and astigmatism.

Goal of Laser Surgery

o Reshape the cornea to correct light focusing

Types of Lasers Used

o Excimer Laser: Ultraviolet (UV) light (193 nm) for ablation.

Precise removal of corneal tissue with minimal heat transfer.

o Femtosecond Laser: Infrared light for creating corneal flaps.

Produces short pulses with extremely high intensity

Laser-Tissue Interaction

A. Mechanisms of Action

- Photochemical Ablation: UV photons break molecular bonds in the corneal tissue.
- No thermal damage due to short pulse duration and low penetration depth
- Accuracy: Ablation depth of approximately 0.25 micrometers per puls

B. Precision and Control

wavefront analysis to guide treatment

o Importance of beam shaping and spot size control.

C. Thermal Effects and Safety

- Avoidance of collateral damage.
- Cooling systems to maintain corneal integrity.

Laser Eye Surgery Techniques

A. LASIK

- **Steps:** Corneal flap creation (femtosecond laser) → Excimer laser reshaping → Flap repositioning.

Recovery: Rapid visual improvement with minimal discomfort.

B. PRK

- **Steps:** Removal of the corneal epithelium → Excimer laser reshaping.
- **Recovery:** Longer healing time but avoids flap complications.

PRK stands for Photo Refractive Keratectomy.

It is a type of refractive eye surgery used to correct vision problems like l

- Myopia (nearsightedness)
- Hyperopia (farsightedness)
- Astigmatism

PRK reshapes the cornea using an excimer laser, allowing light entering the eye to focus correctly on the retina for improved vision Unlike LASIK, PRK does not involve creating a corneal flap, making it a good option for patients with thinner corneas or those at higher risk for flap complications.

Physics Challenges and Advancements

A. Wavefront-Guided Surgery

- Measures and corrects higher-order aberrations for. sharper vision.
- Relies on precise optical imaging techniques

B. Role of Physics

- Advances in laser technology and imaging to minimize risks.