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# *Medical Laser Applications*

Third Stage

Lec 11

# *Laser Interaction with Tissue*

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# Laser Interaction with Tissue

## 1. Introduction

Lasers play a central role in modern medicine, particularly in diagnosis, therapy, and surgery. Applications such as laser surgery, photodynamic therapy, ophthalmic procedures, dermatology, oncology, and biomedical imaging rely heavily on a clear understanding of how laser radiation interacts with biological tissues. For students of medical physics, laser–tissue interaction is a fundamental topic that connects physics, biology, and clinical practice.

The interaction between laser light and tissue depends on both **laser parameters** (such as wavelength, power, pulse duration, and beam diameter) and **tissue properties** (such as absorption, scattering, water content, and pigmentation). Different combinations of these factors lead to different biological effects, ranging from mild heating to precise tissue ablation.

This lecture provides a comprehensive explanation of the physical principles governing laser–tissue interaction and explains how these principles are applied in medicine.

## 2. Basic Properties of Laser Radiation

A laser is a device that emits light through the process of stimulated emission of radiation. Unlike conventional light sources, laser light has unique properties that make it suitable for medical applications.

### 2.1 Monochromaticity

Laser light consists of a very narrow range of wavelengths. This allows selective interaction with specific tissue components (chromophores) such as water, hemoglobin, or melanin.

## 2.2 Coherence

Laser waves are coherent, meaning that the photons are in phase with one another. This property allows the laser beam to be focused to a very small spot size, producing high energy density.

## 2.3 Directionality (Low Divergence)

Laser beams are highly collimated and spread very little over distance. This enables precise targeting of tissue with minimal damage to surrounding areas.

## 2.4 High Intensity

Lasers can deliver a large amount of energy in a short time, which is essential for cutting, coagulating, or ablating tissue.

# 3. Optical Properties of Biological Tissue

Biological tissues are optically complex media. When laser light strikes tissue, several processes may occur simultaneously.

## 3.1 Reflection

A small fraction of incident laser light is reflected at the tissue surface due to the mismatch between the refractive index of air and tissue. Reflection losses are generally low but can be clinically significant in sensitive procedures such as eye surgery.

## 3.2 Transmission

Some of the laser light penetrates into the tissue and travels through it. Transmission depends strongly on wavelength and tissue composition.

## 3.3 Absorption

Absorption is the most important process in laser–tissue interaction. When tissue absorbs laser energy, the photon energy is converted into other forms, mainly heat or chemical energy. The absorption coefficient ($\mu_a$) describes how strongly a tissue absorbs light at a specific wavelength.

### 3.4 Scattering

Scattering occurs when photons are deflected by microscopic structures within the tissue, such as cell membranes, organelles, and collagen fibers. Scattering limits the penetration depth of laser light and reduces spatial precision.

## 4. Tissue Chromophores

Chromophores are molecules in tissue that absorb laser light at specific wavelengths. The main chromophores in biological tissue are:

- **Water**: Dominant absorber in the infrared region
- **Hemoglobin**: Strong absorber in the visible region, especially blue and green light
- **Melanin**: Absorbs strongly in the visible and near-infrared regions
- **Proteins and lipids**: Absorb mainly in the ultraviolet region

Selective absorption by chromophores allows targeted medical treatments, such as selective photothermolysis in dermatology.

## 5. Mechanisms of Laser–Tissue Interaction

Depending on the laser parameters and tissue properties, different interaction mechanisms may dominate.

### 5.1 Photothermal Interaction

Photothermal effects occur when absorbed laser energy is converted into heat. This is the most common mechanism in medical laser applications.

As tissue temperature increases, different biological effects occur:

- **37–45 °C** : Mild hyperthermia, reversible cellular stress
- **45–60 °C** : Protein denaturation and enzyme inactivation
- **60–80 °C** : Coagulation and tissue necrosis
- **Above 100 °C** : Vaporization and tissue ablation

Photothermal interactions are used in laser surgery, tumor ablation, and coagulation of blood vessels.

## 5.2 Photochemical Interaction

Photochemical effects occur when laser light induces chemical reactions in tissue rather than heating it. These effects usually require low-intensity light and long exposure times.

A key example is **Photodynamic Therapy (PDT)**. In PDT, a photosensitizing drug is administered to the patient and accumulates preferentially in abnormal cells. When illuminated with laser light of a specific wavelength, the photosensitizer produces reactive oxygen species that destroy the targeted cells.

Photochemical interactions are widely used in oncology and ophthalmology.

## 5.3 Photomechanical and Photoacoustic Interaction

Photomechanical effects occur when short, high-intensity laser pulses cause rapid thermal expansion, generating mechanical stress or shock waves in tissue.

This mechanism is important in:

- Laser lithotripsy (breaking kidney stones)
- Photoacoustic imaging
- Precision microsurgery

The interaction is characterized by minimal thermal damage and strong mechanical disruption.

## 5.4 Photoablation

Photoablation occurs when high-energy photons (usually ultraviolet lasers) directly break molecular bonds in tissue. This process removes tissue with very little heat diffusion to surrounding areas.

Excimer lasers used in corneal refractive surgery (LASIK) are a classic example of photoablation.

## 6. Laser Parameters Affecting Tissue Interaction

Several laser parameters determine the nature and extent of tissue interaction:

- **Wavelength**: Determines which chromophores absorb the light
- **Power and Energy**: Control the amount of heat or damage produced
- **Pulse Duration**: Short pulses favor mechanical effects, long pulses favor thermal effects
- **Spot Size**: Determines energy density (fluence)
- **Repetition Rate**: Affects cumulative heating

The careful selection of these parameters is essential for safe and effective medical treatments.

## 7. Penetration Depth and Optical Window

Penetration depth depends on absorption and scattering. In biological tissues, the so-called **optical window** (approximately 650–1300 nm) allows deeper light penetration because absorption by water and hemoglobin is relatively low.
This wavelength range is widely used in biomedical imaging and laser therapy.

## 8. Medical Applications of Laser–Tissue Interaction

### 8.1 Surgical Applications

- Cutting and coagulation of soft tissue
- Minimally invasive procedures
- Reduced bleeding and infection risk

### 8.2 Therapeutic Applications

- Tumor ablation
- Photodynamic therapy
- Low-level laser therapy

### 8.3 Diagnostic Applications

- Optical coherence tomography (**OCT**)
- Fluorescence imaging
- Photoacoustic imaging

## 9. Safety Considerations and Bioeffects

Laser exposure can be hazardous if not properly controlled. Potential risks include:

- **Thermal burns**
- **Eye and retinal damage**
- **Unintended tissue necrosis**

Laser safety standards (such as **ANSI** and **IEC** classifications) define maximum permissible exposure levels and protective measures.

Medical physicists play a crucial role in ensuring laser safety through proper system design, dosimetry, and clinical protocols.

## 10. Conclusion

Laser–tissue interaction is a multidisciplinary topic that combines optics, thermodynamics, and biology. Understanding the underlying physical mechanisms allows medical physicists to optimize laser parameters for specific clinical applications while minimizing risks.

A solid foundation in this topic is essential for students preparing to work in medical research, clinical physics, or biomedical technology development.

# Discussion

**1. LASER stands for:**

A. Light Amplification by Stimulated Emission ☑

B. Light Absorbed Radiation

C. Laser Active Source

D. Light Atomic Signal Emission

E. Linear Amplified Radiation

**2. Laser coherence mainly allows:**

A. Wavelength tuning

B. Tight focusing ☑

C. High reflection

D. Deeper penetration

E. Lower absorption

**3. Laser monochromaticity means:**

A. High intensity

B. High power

C. Single wavelength ☑

D. Short pulse

E. Broad spectrum

**4. Low divergence refers to:**

A. High scattering

B. Energy loss

C. Beam absorption

D. Beam collimation ☑

E. Pulse shortening

**5. High laser intensity is required for:**

A. Imaging

B. Reflection

C. Diagnosis

D. Transmission

E. Tissue cutting ☑

**6. Reflection mainly occurs at:**

A. Tissue surface ☑

B. Cell nucleus

C. Blood vessels

D. Deep tissue

E. Organelles

**7. Laser transmission depends strongly on:**

A. Spot size

B. Wavelength ☑

C. Pulse rate

D. Beam angle

E. Power only

**8. Most important tissue interaction process:**

A. Transmission

B. Reflection

C. Absorption ☑

D. Refraction

E. Diffusion

**9. Absorbed laser energy converts mainly to:**

A. Pressure

B. Electricity

C. Sound

D. Heat ☑

E. Magnetism

**10. Absorption coefficient symbol:**

A. $\mu_s$

B. n

C. $\lambda$

D. d

E. $\mu_a$ ☑

**11. Scattering is caused by:**

A. Cell structures ☑

B. Water only

C. Blood flow

D. Laser power

E. Temperature

**12. Main infrared absorber in tissue:**

A. Melanin

B. Hemoglobin

C. Water ☑

D. Proteins

E. Lipids

**13. Hemoglobin absorbs strongly in:**

A. Infrared

B. Visible region ☑

C. Microwave

D. **X**-ray

E. Radio waves

**14. Melanin absorption occurs mainly in:**

A. **UV** only

B. Infrared only

C. Visible and **NIR** ☑

D. **X**-ray region

E. Microwave

**15. Selective photothermolysis depends on:**

A. Random heating

B. Mechanical stress

C. Chromophore targeting ☑

D. **UV** ionization

E. Shock waves

**16. Most common medical laser interaction:**

A. Photochemical

B. Photothermal ☑

C. Photoacoustic

D. Photoablation

E. Photomechanical

**17. Mild hyperthermia temperature range:**

A. 25–30 °C

B. 30–35 °C

C. 37–45 °C ☑

D. 50–60 °C

E. >100 °C

**18. Protein denaturation occurs at:**

A. 20–30 °C

B. 30–40 °C

C. 40–45 °C

D. 45–60 °C ☑

E. >100 °C

**19. Tissue vaporization begins near:**

A. 60 °C

B. 80 °C

C. 90 °C

D. 95 °C

E. 100 °C ☑

**20. Photochemical effects require:**

A. High power

B. Long exposure ☑

C. Short pulses

D. High temperature

E. **UV** only

**21. PDT abbreviation means:**

A. Photon Destruction Therapy

B. Pulsed Drug Treatment

C. Photodynamic Therapy ☑

D. Photo Diagnostic Tool

E. Photo Thermal Dose

**22. PDT cell damage is due to:**

A. Heat

B. Shock waves

C. Electrons

D. Mechanical stress

E. Reactive oxygen ☑

**23. Photomechanical interaction uses:**

A. Continuous beams

B. Long pulses

C. Low intensity

D. Rapid expansion ☑

E. Chemical reaction

**24. Laser lithotripsy mainly depends on:**

A. Thermal coagulation

B. Mechanical stress ☑

C. Photochemical action

D. **UV** ablation

E. Optical imaging

**25. Photoacoustic imaging combines light and:**

A. Electricity

B. Heat

C. Sound ☑

D. Magnetism

E. Pressure

**26. Photoablation commonly uses:**

A. Infrared lasers

B. Visible lasers

C. Microwave sources

D. Ultraviolet lasers ☑

E. Radio waves

**27. Excimer lasers are used in:**

A. Tumor ablation

B. PDT

C. Skin therapy

D. Lithotripsy

E. LASIK ☑

**28. Chromophore absorption depends on:**

A. Power

B. Wavelength ☑

C. Spot size

D. Repetition rate

E. Beam angle

**29. Short laser pulses favor:**

A. Thermal diffusion

B. Chemical effects

C. Mechanical effects ☑

D. Reflection

E. Transmission

**30. Energy density is controlled by:**

A. Spot size ☑

B. Wavelength

C. Refractive index

D. Absorption

E. Reflection

**31. Optical window range:**

A. 400–600 nm

B. 500–700 nm

C. 600–900 nm

D. 650–1300 nm ☑

E. >1500 nm

**32. Deeper penetration occurs when:**

A. Absorption is low ☑

B. Scattering is high

C. Reflection increases

D. Power is zero

E. Temperature rises

**33. OCT is mainly used for:**

A. Therapy

B. Surgery

C. Diagnosis ☑

D. Ablation

E. Drug delivery

**34. Reduced bleeding is an advantage of:**

A. Imaging lasers

B. Diagnostic lasers

C. Surgical lasers ☑

D. Low-power lasers

E. **UV** sources

**35. Low-level laser therapy causes:**

A. Cutting

B. Ablation

C. Vaporization

D. Mechanical damage

E. Biological stimulation ☑

**36. Most laser-sensitive organ:**

A. Skin

B. Muscle

C. Bone

D. Eye ☑

E. Liver

**37. Retinal damage is mainly due to:**

A. Reflection

B. Transmission

C. Scattering

D. Absorption ☑

E. Refraction

**38. ANSI and IEC define:**

A. Laser cost

B. Device design

C. Exposure limits ☑

D. Imaging quality

E. Tissue type

**39. Medical physicist role includes:**

A. Drug prescription

B. Laser safety ☑

C. Surgery

D. Nursing

E. Pathology

**40. Laser–tissue interaction combines:**

A. Biology only

B. Physics only

C. Chemistry only

D. Engineering only

E. Optics and biology ☑