Laser Applications in Dermatology & Orthopedics

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Dermatology is the branch of medicine dealing with the skin, nails, hair and its diseases (derived from Greek ‘derma’, which means skin).

- Acne
- Rosacea
- Eczema (Dermatitis)
- Skin Cancer
- Psoriasis
- Wart

**Therapies**

Therapies provided by dermatologists include, but are not restricted to:

- Cosmetic filler injections
- Hair removal with laser or other modalities
- Hair transplantation – a cosmetic procedure practiced by many
- Intralésional treatment – with steroid or chemotherapy
- **Laser therapy** – for both the management of birth marks, skin di
- **Photodynamic therapy** – for the treatment of skin cancer and pr
- **Phototherapy** – including the use of narrowband UVB, broadband
- **Tattoo removal** with laser
- **Tumescent liposuction** – liposuction was invented by a gynecok
- **Cryosurgery** – for the treatment of warts, skin cancers, and oth
- **Radiation therapy** – although rarely practiced by dermatologists.
- **Vitiligo surgery** – Including procedures like autologous melanoc
- **Allergy testing** – 'Patch testing' for contact dermatitis.
- Systemic therapies – including antibiotics, immunomodulators, a
- Topical therapies – dermatologists have the best understanding
Human Skin
Epidermis

- Outer layer of the skin
- Barrier to infection from environmental pathogens
- Regulates the amount of water released from the body
- Keratinocytes (95%), melanocytes
- Keratin and melanin are important protective proteins of skin
Dermis

- Layer between epidermis and subcutis
- Semi-solid mixture of collagen fibers, water, and highly viscous gel called ground substance
- Hair follicles, sweat glands, lymphatic vessels, blood vessels, and receptors
- Fibroblast, macrophage, and adipocytes
Subcutaneous Tissue (Hypodermis)

- Lowermost layer of the skin
- Loose connective tissue and fat, larger blood vessels and nerves
- Fibroblasts, adipose cells, macrophages
- Subcutaneous injection → because it is highly vascular, the tissue absorbs drugs quickly
Lasers in Dermatology

- In dermatology, thermal effects of laser irradiation are commonly used especially coagulation and vaporization

- Optical parameters of skin are strongly wavelength-dependent
  Air-skin interface is quite rough → scattering
  Absorption of light by chromophores such as hemoglobin and melanin
  Optical scattering by collagen fibers

- In clinical practice, mainly five types of lasers are being used: argon ion lasers, dye lasers, CO₂ lasers, Nd:YAG lasers, and ruby lasers
**Argon Laser**

- Radiation from the Argon laser is strongly absorbed by hemoglobin and melanin → Superficial treatments of highly vascularized skin
- Treatment of port wine stains (*naevi flammei*)
- Several sessions are necessary over a period of up to a few years

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**Fig. 2.4.** Absorption spectra of melanin in skin and hemoglobin (HbO₂) in blood. Relative absorption peaks of hemoglobin are at 280 nm, 420 nm, 540 nm, and 580 nm. Data according to Boulnois (1986)
Treatment of Port Wine Skin

With Argon Laser

- First, small test area of approximately 4 mm² is irradiated
  Suitable laser power is determined by gradually increasing it until the skin visibly pales
  → 2-5W, 0.02-0.1s

- After four weeks, the test area is checked for recanalization and scarring

- After another four weeks, a second test area is treated.
  If both tests lead to acceptable results, the whole stain is exposed

- Laser treatment may be repeated after a few years

- Disadvantage: painful

Fig. 4.62. (a) Preoperative state of a port wine stain. (b) Postoperative state of the same stain after several treatments with an argon ion laser (pulse duration: 0.3s, power: 2.5W, focal spot size: 2mm). Photographs kindly provided by Dr. Seipp (Darmstadt)
Treatment of Port Wine Skin

With Dye Laser
- Less painful and probably even more efficient
- Treatment of port wine skin and capillary hemangiomas
- Rhodamine dye lasers are used which emit at 570-590nm (0.5 ms and 4-10 J/cm²)
- About 20-60s after laser exposure, the color of the treated skin turns red, and after few minutes livid blue
- Less painful than argon laser but still, painful: mechanical impact during the light flash, stabbing pain, and longer lasting heat wave within the skin
- Advantage: can be performed among children

Pulsed Laser
- Can cause selective damage to pigmented structures in vivo (selective photothermolysis)
- Requires the presence of highly absorbing particles, e.g. pigments of the skin
CO$_2$ Laser

- Used for tissue vaporization

- Compared to conventional scalpel, it offers the possibility of precise tissue removal without touching the tissue → pain is significantly reduced

- External ulcers and refractory warts

https://youtu.be/onAENNj4BY8
CO₂ Laser

- Argon ion and CO₂ lasers gained attention in removing tattoos. Today, ruby lasers are commonly used.

- Depend on the dyes used in the tattoo.

https://www.youtube.com/watch?v=qVK3Z2aqAvY

[(Image of tattoo removal process)]
Nd:YAG Laser

- Significantly less scattered and absorbed in skin than radiation from the argon ion laser → Larger optical penetration depth
- Deeply located hemangiomas or semi-malignant skin tumors
- Never be used when treating skin surfaces

Hemangiomas

Wikipedia.org
Biostimulation

- Dermatology is one of the few medical disciplines where biostimulative effects of laser radiation have been reported.

- Mechanisms are not understood, most of the results are not reproducible. → Still, in controversy.
Photothermal Therapy (PTT)

- Thermal transducers are absorb specific wavelength of light (usually NIR)

- This brings to an excited stated where it then releases vibrational energy (heat), which is what kills the targeted cells

- Thermal transducers:
  - Gold nanoparticles (AuNP), graphene oxide (GO), polypyrrole, etc
Photothermal Therapy (PTT)

Raman Reporter-Coupled Ag<sub>core</sub>@Au<sub>shell</sub> Nanostars for in Vivo Improved Surface Enhanced Raman Scattering Imaging and Near-infrared-Triggered Photothermal Therapy in Breast Cancers

Leyong Zeng,‡§ Yuanwei Pan,‡ Shoujia Wang,§ Xin Wang,§ Xinmei Zhao,† Wenzhi Ren,‡ Guangming Lu,‡§ and Aiguo Wu,‡§
Photothermal Therapy (PTT)

In Vitro and In Vivo Near-Infrared Photothermal Therapy of Cancer Using Polypyrrole Organic Nanoparticles

Kai Yang, Huan Xu, Liang Cheng, Chunyang Sun, Jun Wang, and Zhuang Liu*

a

Poly (vinyl alcohol) • Iron ion • Polypyrrole nanoparticle

b

c

Number (%) vs. Size (nm)

Size (nm)

0 10 100 1000 10000

30

20

10

20

30

b

c

No Laser

PPy only (0.5 W/cm²)

PPy only (0.1 W/cm²)

PPy only (0.05 W/cm²)

Laser Irradiation

Control

PPy Injection

Control

PPy Injection

Absorbance

Wavelength (nm)

0.3 0.4 0.5 0.6 0.7 0.8 0.9 1.0

0.1

0.2

0.3

0.4

0.5

0.6

0.7

0.8

0.9

1.0

Time (s)

0 50 100 150 200 250 300 350

Relative tumor volume

0 1 2 3 4

5

6

7

8

9

10

11

12

13

14

15

16

17

18

19

20

PPy+0.6 W/cm²

PPy+0.1 W/cm²

PPy+0.25 W/cm²

PPy+0.05 W/cm²

Orthopedics

- Orthopedics is the branch of surgery concerned with conditions involving the musculoskeletal system (derived from Greek ‘orthos’ (correct, straight), and ‘paidion’ (child))

- Orthopedic surgeons use both surgical and nonsurgical means to treat musculoskeletal trauma, spine diseases, sports injuries, etc

- Standard tools are saws, milling-machines, and mechanical drills → operate in contact mode and induce mechanical vibration and hemorrhage

- Lasers can be a considerable alternative in orthopedic surgery (osteotomies)
Structure of Bone

- Mechanical support, protection of soft tissues, and supply of minerals and blood cells

- The hardness of bone results from a complex structure of hydroxyapatite \( \text{Ca}_{10}(\text{PO}_4)_6(\text{OH})_2 \) water, soluble agents, collagen, and proteins

- High water content is responsible for strong absorption of infrared radiation → \( \text{CO}_2 \), Er:YAG, and Ho:YAG lasers
CO₂ Laser

- Osteotomies performed with CO₂ lasers
- Delayed healing process compared with conventional osteotomies due to thermal damage of the bone rim
- However, thermal damages can be minimized by adjusting wavelength and pulse duration
- When selecting the laser transition at 9.6 μm, a pulse duration of 1.8 μs, and an energy density of 15 J/cm², thermally damaged zone is only 10-15 μm
Er:YAG Laser

- In the 1980s, researchers focused on laser radiation at a wavelength of 3 μm

- Wolbarsht (1984) compared the effects induced by CO2 lasers at 10.6 μm and HF* lasers at 2.9 μm, and concluded that latter one is better suited for orthopedics

- Er:YAG laser at a wavelength of 2.94 μm efficiently ablates both bone and cartilage
Ho:YAG Laser

- Emits at a wavelength of 2.12 μm
- Major advantage is that radiation can be efficiently transmitted through flexible fibers
- However, thermal effects are significantly enhanced
- In the case of Er:YAG laser, a lower energy density was chosen to obtain similar ablation depth as with the Ho:YAG laser
- Microsurgery of the stapes footplate in the inner ear

![Image of histologic sections]

Fig. 4.65. (a) Histologic section of bone after exposure to a Ho:YAG laser (pulse duration: 250 μs, energy density: 120 J/cm², bar: 100 μm). (b) Histologic section of bone after exposure to an Er:YAG laser (pulse duration: 250 μs, energy density: 35 J/cm², bar: 200 μm). Photographs kindly provided by Dr. Romano (Bern)
Excimer Laser

- High precision in removing tissues, but efficiency is much too low

- Osteotomies performed with XeCl lasers at 308 nm are associated with severe thermal damage

- Thermal effects are responsible for the delay in healing of the laser-induced bone excision
Arthroscopy

- Laser meniscectomy, i.e. the treatment of the meniscus using Nd:YAG and CO\textsubscript{2} lasers
- At that time, suitable delivery systems were not available
- CW mode of these lasers led to unacceptable thermal damage
- Significant improvements were not achieved until the use of contact probes consisting of ceramics
- Transmission through flexible fibers are mandatory for efficient surgical procedures

https://www.youtube.com/watch?v=pguNCtOwzEc
Thank You