CUTANEOUS LASERS

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January 30, 2004

Introduction

- The term “laser” is an acronym for “***l***ight ***a***mplification by ***s***timulated ***e***mission of ***r***adiation”

Introduction

- Albert Einstein first proposed the principle of laser operation in 1917 (“Theory of Stimulated Emission of Radiation”)
- 1950s and 1960s, laser technology was explored
- Leon Goldman (a dermatologist!) was the first to test a laser on human skin

Introduction

- Significant advances in laser technology have occurred in the past 2 decades, making laser therapy a valuable and highly versatile treatment for a number of skin conditions
- We will review how and why lasers work, and what lasers can be used for the treatment of various skin conditions

Physics

- Lasers involve light energy as defined by the **electromagnetic spectrum:**

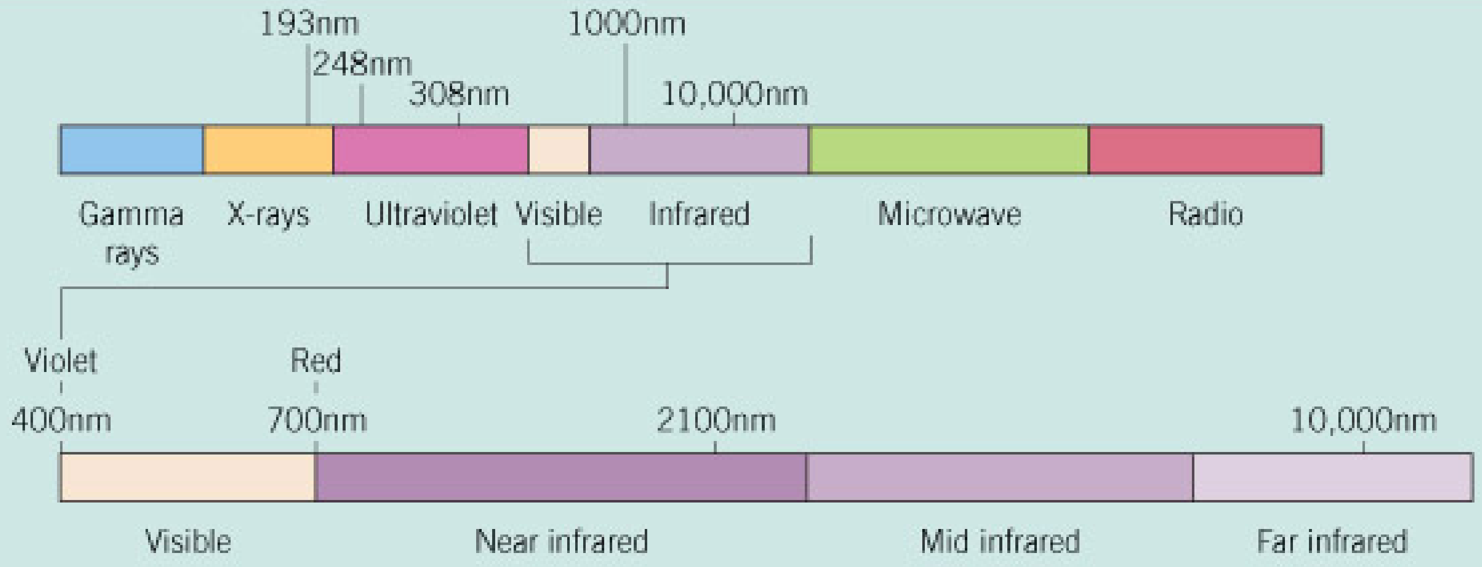
  <400 nm ultraviolet light

  400-700 nm visible light

  >700 nm near infrared light

- Electromagnetic radiation exhibits properties of both waves and particles (photons)

THE ELECTROMAGNETIC SPECTRUM



Laser Components

- 3 essential components to any laser:
  - Lasing medium
  - Resonant cavity
  - Energy source

Laser Components

- **Lasing medium**:
  - This is the source of laser radiation, and is often prominent in the name of the laser
  - Can be a gas (argon, carbon dioxide, excimer, etc), a liquid (pulsed dye), or a solid (ruby, alexandrite, Nd:YAG)

Laser Components

- **Resonant cavity:**
  - Contains the lasing medium and has 2 parallel reflective mirrors on either side
  - Mirrors return photons to the lasing medium, helping to increase the amount of energy that is produced

Laser Components

- **Energy source:**
  - This is what excites the lasing medium and drives the process
  - May also be mentioned in the name of the laser
  - Energy sources include a flash or continuous lamp, an electrical current, or another laser

Laser Physics

- Basically, the energy source “excites” the lasing medium
- When the energy source is on, electrons in the lasing medium move from the ground state into an excited state, and, as the electrons return to their lower energy ground state, energy in the form of a photon of light is released (**spontaneous emission**)

Laser Physics

- Once the photon of light is released, it moves into the resonant cavity, reflecting off one of the 2 parallel mirrors
- This photon then passes through the lasing medium again, hopefully striking one of the molecules of the lasing medium

Laser Physics

- If the reflected photon collides with an already excited electron, the energy of the electron is increased and 2 photons of light may be emitted as the electron returns to the ground state

Laser Physics

- This reflection of photons back into the lasing medium with the subsequent production of more photons accounts for the amplification of laser energy
- **Population inversion**: when more electrons are in the excited state than in the ground state

Laser Physics

- One of the 2 mirrors in the resonant cavity is partially reflective, and some of the laser light is able to pass through this mirror as a single beam
- The emitted beam of light can be **continuous**, **quasicontinuous**, or **pulsed**

Laser Physics

- **Continuous** lasers emit light as a single, steady beam with a constant level of energy
- **Quasicontinuous** lasers emit a beam as a series of small pulses, very closely spaced so that the biologic effect is that of a continuous laser

Laser Physics

- **Pulsed** lasers emit individual pulses with durations from nanoseconds to milliseconds
- Pulsed laser beams are created by pulsing the energy source (**flashlamp-pumped** lasers) or by using a mechanical or photooptical shutter (**Q-switched** lasers)

Laser Physics

- Properties of laser light
  - **monochromatic**: one wavelength, and this is dependent on the lasing medium
  - **coherent**: light waves are in phase both spatially and temporally
  - **collimated**: light waves are parallel and do not diverge, even at great distances

Laser Physics

- Energy
  - capacity to do work
  - measured in joules (J)

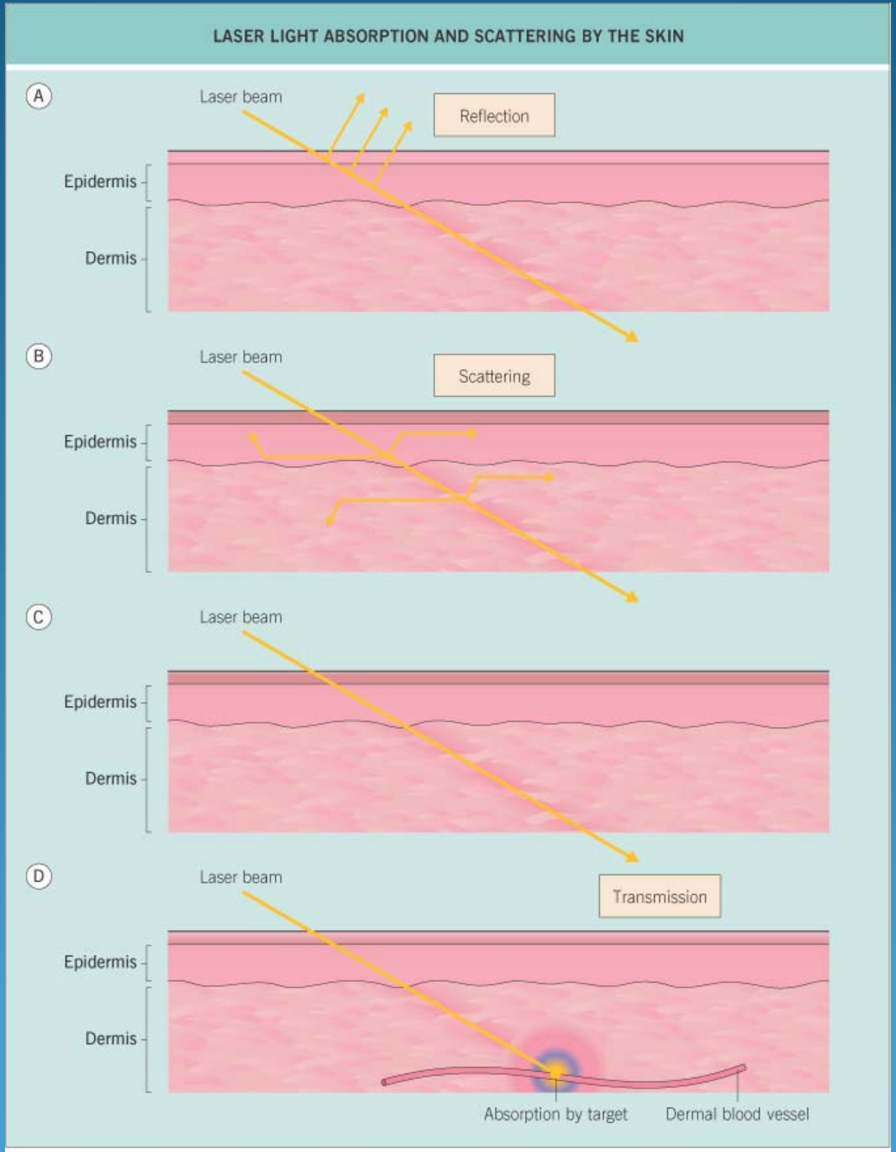
- Power
  - rate at which energy is delivered
  - measured in joules per second or watts (W)

Laser Physics

- Fluence
  - energy density
  - measured in joules per cm^2
- Irradiance
  - power density or power delivered to a defined area in a single pulse
  - measured in watts per cm^2

Laser Light and the Skin

- When a laser beam strikes the skin, 4 interactions can occur:
  - reflection
  - transmission
  - scattering
  - absorption



LASER LIGHT ABSORPTION AND SCATTERING BY THE SKIN
A
Laser beam
Reflection
Epidermis
Dermis
B
Laser beam
Scattering
Epidermis
Dermis
C
Laser beam
Epidermis
Dermis
D
Laser beam
Transmission
Epidermis
Dermis
Absorption by target
Dermal blood vessel

Laser Light and the Skin

- Laser light that is reflected or transmitted through the tissue has no biologic effect
- scattering occurs mainly in the dermis and can limit the depth of penetration of the light
- when light energy is absorbed, a biologic effect may occur

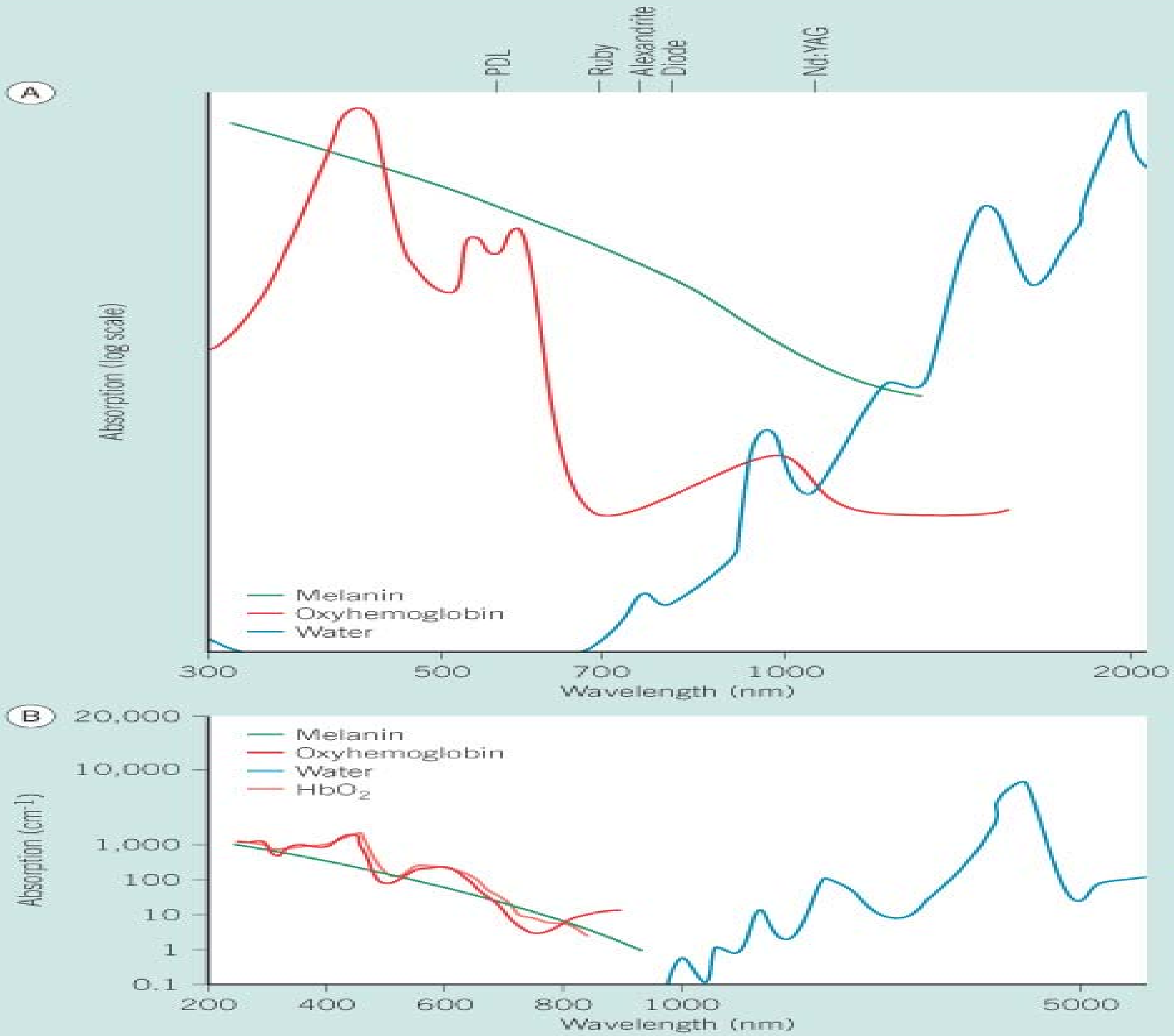
Laser Light and the Skin

- Absorption of light:
  - photon’s energy is absorbed by/transferred to a **chromophore**
  - a **chromophore** is an atom or molecule that gives color to a substance and can absorb light at a certain wavelength

Laser Light and the Skin

- 2 major **chromophores** in the skin are melanin and oxyhemoglobin
- melanin has a relatively broad absorption band
- oxyhemoglobin has 3 absorption peaks (418, 542, and 577 nm)
- water absorbs light in the near infrared portion of the electromagnetic spectrum

ABSORPTION SPECTRA



Laser Light and the Skin

- When a photon is absorbed by a chromophore, the light energy is converted to thermal energy
- the biologic effect is determined by the temperature reached within the tissue
  - cell injury occurs with a 5-10º C rise in temp
  - protein and DNA are denatured at temps of 100º C
  - water boils (vaporizes) at temps > 100º C

Laser Light and the Skin

- Thermal relaxation:
  - when a target tissue is heated by a laser, heat is dissipated to surrounding tissues
  - **thermal relaxation time** = time it takes for a target substance to cool to half the temperature to which it was heated **without** increasing the temperature of surrounding tissues

Laser Light and the Skin

- The thermal relaxation time varies according to the size of the target substance
  - melanosomes (<1 μm in size) have thermal relaxation times of <1 μsec
  - blood vessels (10 to 100 μm in size) have thermal relaxation times of 1-10 msec

Laser Light and the Skin

- Most selective thermal damage occurs when light energy is delivered to the target tissue faster than the rate at which the target tissue can cool down
- a pulse duration just shorter than the thermal relaxation time of the target substance will allow selective heating of the target, limiting thermal damage to surrounding tissues

Laser Light and the Skin

- This is the concept of **selective photothermolysis**, which is the key to therapeutic use of lasers
  - wavelength preferentially absorbed by the target
  - fluence (energy density) high enough to heat the target
  - pulse duration shorter than the target's thermal relaxation time

Laser Light and the Skin

- Selective photothermolysis was first applied for the treatment of port wine stains
- argon laser (514 nm) was first used, but was not selective for oxyhemoglobin and scarring and pigment changes occurred due to thermal damage of non-target tissues

Laser Light and the Skin

- The flashlamp-pumped pulsed dye laser (PDL) was designed initially with a wavelength of 577 nm, corresponding to one of the absorption peaks of oxyhemoglobin
- wavelength was increased to 585 nm, then to 595 nm, to allow greater depth of penetration

Laser Light and the Skin

- Pulse duration of 450 μsec was selected, and may be increased to 1 msec to target different sized blood vessels
- the concept of selective photothermolysis is integral to the therapeutic use of lasers and is key to selecting which laser to use for each medical condition

Lasers for Vascular Lesions

- Target chromophore: oxyhemoglobin
- optimal pulse width is related to the size of the target vessel (smaller vessel, smaller pulse width; larger vessel, larger pulse width)

Lasers for Vascular Lesions

- Argon laser (488 and 514 nm)
  - continuous beam with nonspecific thermal damage
  - melanin also absorbs light at these wavelengths, and hypopigmentation can result from treatment
  - argon laser is no longer routinely used for treating vascular lesions

Lasers for Vascular Lesions

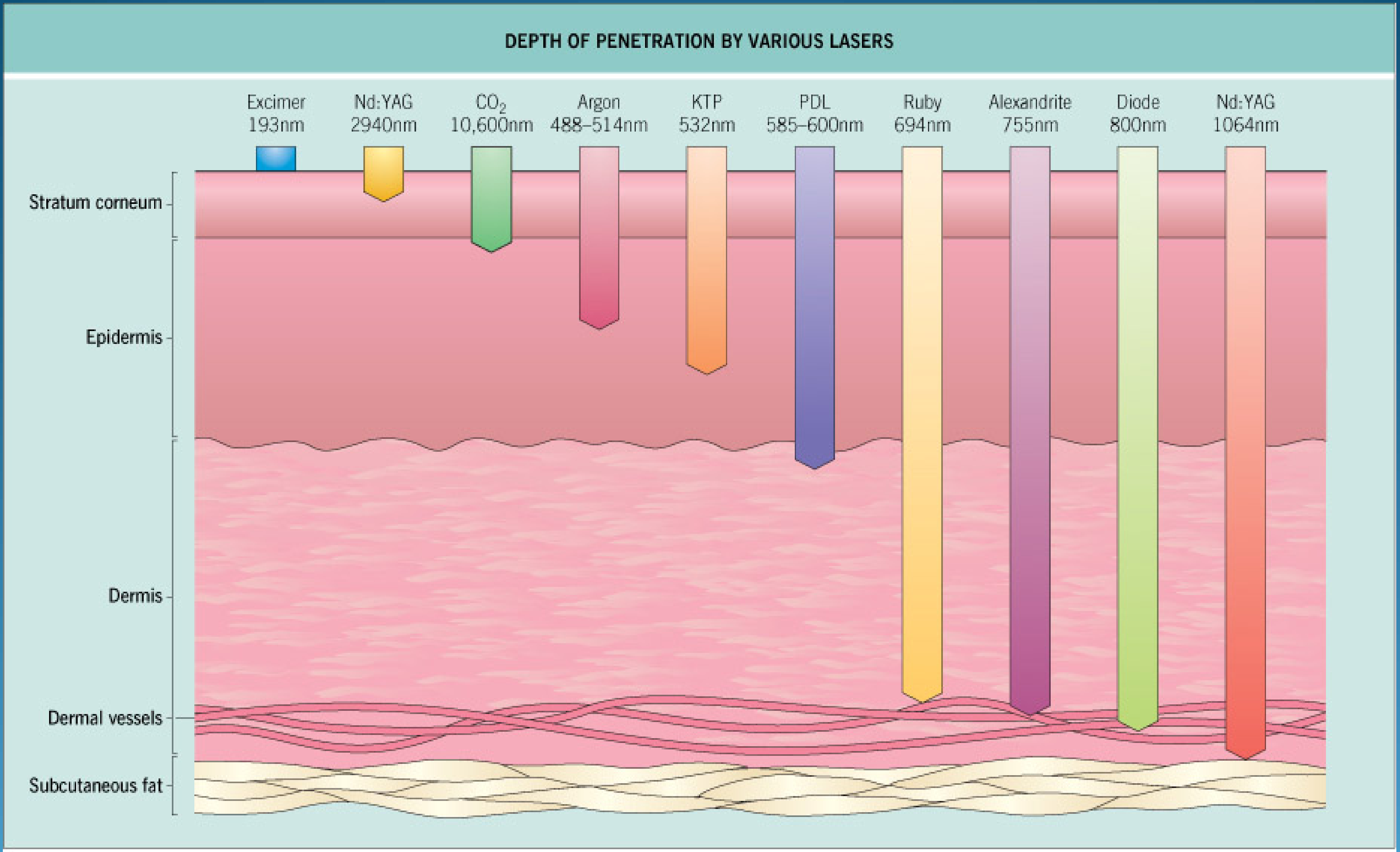
- Copper vapor laser
  - 578 nm (targets oxyhemoglobin)
  - quasicontinuous beam with resultant nonspecific thermal injury
  - can be used to treat thick port wine stains, angiokeratomas, pyogenic granulomas, and venous malformations

Lasers for Vascular Lesions

- Potassium titanyl phosphate (KTP) laser
  - this laser uses a Nd:YAG crystal (1064 nm) that is frequency doubled with a KTP crystal to produce a laser beam of 532 nm
  - current KTP lasers are Q-switched with pulse durations of 1 to 100 msec, and the longer pulse durations may help reduce purpura
  - used to treat superficial facial telangiectasias

Lasers for Vascular Lesions

- Pulsed dye laser (PDL)
  - flashlamp energy source
  - rhodamine dye lasing medium
  - early PDLs had wavelengths of 577 nm (corresponding to oxyhemoglobin absorption peak), but current PDLs have wavelengths of 585 to 595 nm to penetrate deeper into the skin


DEPTH OF PENETRATION BY VARIOUS LASERS
Excimer 193nm
Nd:YAG 2940nm
CO2 10,600nm
Argon 488–514nm
KTP 532nm
PDL 585–600nm
Ruby 694nm
Alexandrite 755nm
Diode 800nm
Nd:YAG 1064nm
Stratum corneum
Epidermis
Dermis
Dermal vessels
Subcutaneous fat

Lasers for Vascular Lesions

- PDL
  - typical pulse duration is 450 µsec for small telangiectasias
  - pulse duration can be increased to treat larger vessels
  - purpura may be seen after treatment and corresponds to clumped rbcs and fibrin within the treated vessels

Lasers for Vascular Lesions

- PDL
  - considered to be the treatment of choice for port wine stains, facial telangiectasias, superficial components of hemangiomas, and poikiloderma of Civatte
  - may also be used to treat warts, striae, and hypertrophic scars

Lasers for Pigmented Lesions

- Skin pigmentation is due melanin (endogenous) or dyes (exogenous, i.e. tattoos)
- goal of treatment is to destroy the unwanted pigment while preserving the normal or natural color of the skin
- consider the depth of pigment and size of the pigment particles when choosing the proper laser to use

Lasers for Pigmented Lesions

- Carbon dioxide laser (10,600 nm)
  - vaporizes water in tissues
  - nonspecific superficial destruction, but may be used to target individual lentigos

Lasers for Pigmented Lesions

- Q-switched ruby laser (694 nm)
  - ruby = aluminum oxide
  - very short pulse duration of 20 to 40 nanoseconds allows selective treatment of very small pigmented particles (melanosomes)
  - 694 nm penetrated well into the dermis

Lasers for Pigmented Lesions

- Q-switched alexandrite laser (755 nm)
  - pulse duration of 50 to 100 nanoseconds
  - penetrates deeper than the ruby laser, but otherwise has similar applications and clinical results

Lasers for Pigmented Lesions

- Q-switched Nd:YAG laser (1064 nm)
  - penetrates well into the dermis and can be used to treat lesions with deeply placed pigment (i.e. nevus of Ota or Ito)

Lasers for Pigmented Lesions

- Tattoo removal
  - first, a wavelength must be selected that is preferentially absorbed by the pigment
  - pulse duration must be shorter than the thermal relaxation time of the pigment particle
  - black tattoo pigments absorb all wavelengths, and therefore is the easiest pigment to remove

Lasers for Pigmented Lesions

- Tattoo removal
  - red pigments reflect red light, and therefore the ruby (694 nm) and alexandrite (755 nm) lasers are not effective in removing red tattoos
  - green pigment reflects green light, and therefore the frequency doubled Nd:YAG (532 nm) laser is not effective in removing green tattoos

Lasers for Pigmented Lesions

- ruby laser (694 nm): blue or black
- alexandrite (755 nm): green, blue, or black
- frequency doubled Nd:YAG (532 nm): red, orange
- short pulsed dye laser (510 nm): red, orange, yellow
- Q switched Nd:YAG (1064): deeper tattoo pigments

Lasers for Pigmented Lesions

- Tattoo removal
  - professional tattoos with many colors are the most difficult to treat and require the widest array of lasers at one's disposal
  - complications include transient pigment changes and scarring
  - hypopigmentation may be permanent
  - pink or red tattoo pigments may contain iron or titanium dioxide, which may darken immediately after treatment

Resurfacing Lasers

- Carbon dioxide laser
  - 10,600 nm (infrared)
  - preferentially absorbed by water, and resultant rapid heating of the water causes vaporization and nonspecific tissue destruction up to 100 μm
  - epidermis and superficial dermis are ablated

Resurfacing Lasers

- Carbon dioxide laser
  - thermal injury causes shrinkage and tightening of collagen bundles
  - used for improvement of photodamage, scarring, actinic cheilitis, actinic keratoses, rhinophyma, and any number of superficial epidermal lesions

Resurfacing Lasers

- Erbium:YAG laser (2940 nm)
  - 2940 nm wavelength is highly absorbed by water (more so than the carbon dioxide laser) and penetrates only 3 μm, allowing very precise ablation of the epidermis
  - thermal damage is less than the carbon dioxide laser, but less collagen tightening occurs

Resurfacing Lasers

- Combination therapy (carbon dioxide and erbium:YAG) can be done to achieve some collagen tightening with more superficial injury and shorter healing/recovery time

Hair Removal Lasers

- The target chromophore is melanin in the hair shaft
- as the hair shaft is heated, thermal energy damages the pleuripotent stem cells in the bulge region and matrix cells in the dermal papilla, thus preventing the hair from regrowing

Hair Removal Lasers

- The ruby, alexandrite, and Nd:YAG lasers are used for hair removal
- longer pulse durations are needed (the relatively large hair shaft has a long thermal relaxation time)
- the ruby laser has a risk of hypopigmentation due to absorption by epidermal melanin

Hair Removal Lasers

- Permanent hair removal is not often the case, just a delay in the regrowth of the next hair from the treated follicle
- cooling substances (gels, cryospray) are used to minimize the thermal damage to the perifollicular skin, hopefully minimizing the risks of scarring and pigmentary change

Other Laser Uses

- Warts
  - can be ablated with the carbon dioxide laser, but postoperative pain and scarring are common, as is recurrence
  - PDL may thermally ablate warts or may destroy superficial blood vessels feeding the wart

Other Laser Uses

- Hypertrophic scars and keloids
  - PDL can be an effective treatment
  - mechanism of action is not yet fully understood and may relate to destruction of vessels, alteration of collagen by thermal energy, or increases in the number of mast cells within the scar
  - best timing for treatment is not yet known

Other Laser Uses

- Striae
  - PDL is used to treat striae
  - may stimulate fibroblast proliferation and elastin production

Other Laser Uses

- Psoriasis
  - ultraviolet light is known to be an effective treatment for psoriasis
  - the excimer laser (308 nm, narrow band UVB range) has been shown to be safe and effective for treating psoriatic plaques