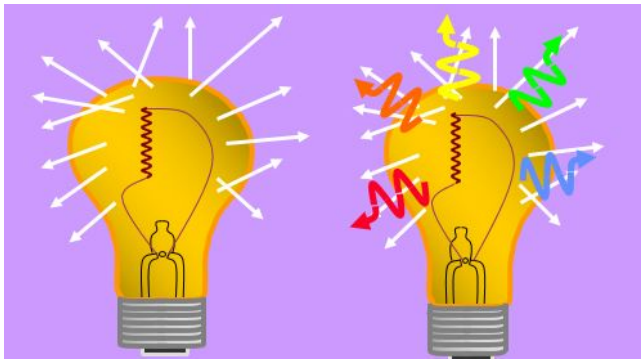
COURSE 11: DYNAMICS OF LASER THERAPY

Dr. Stuart Nelson

Introduction: Dynamics of laser therapy

Laser therapy is the standard of care for the treatment of many vascular lesions. Though laser therapy is the primary curative approach for many superficial vascular lesions, primarily Port Wine Stains (capillary vascular malformations)and early proliferative infantile hemangiomas, the basic biophysics of laser therapy is not universally understood. As a result, outcomes vary among practitioners.



Without a basic understanding of biophysics, there will continue to be nconsistent outcomes. The ultimate goal of every practitioner who elects to treat a vascular lesion with a laser device should be to achieve the optimal outcome. In order to achieve this goal, it is critical that all practitioners understand the basic biophysics of these devices.This module establishes a foundational understanding of how the laser is used to effectively treat cutaneous vascular lesions. Once the biophysics of these devices is fully understood, these same principles can be applied to future devices.

The goal of this module is to provide a general understanding of the biophysics of laser light interaction with human skin and its relationship to the treatment of vascular lesions in order to establish best practice standards for this very specialized treatment modality.

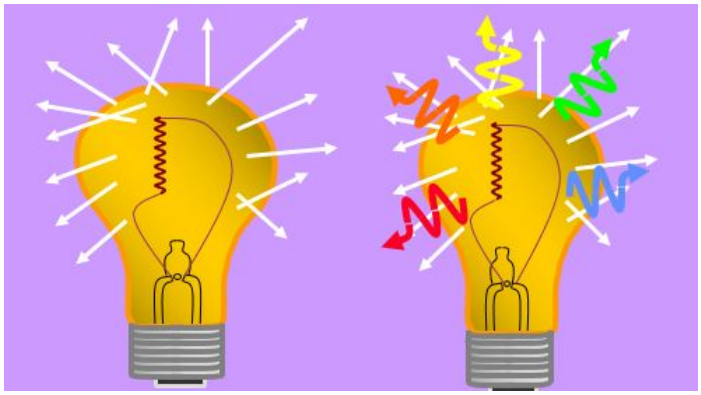
Objectives

Upon successful completion of this activity, participants should be able to:

- Explain how the laser is different from ordinary light
- Define the acronym for LASER
- Describe various laser parameters
- Identify how laser light is converted into useful energy
- Identify which chromophore in human skin is being targeted during laser exposure
- Identify lasers appropriate for the treatment of vascular lesions
- Explain the relationship of thermal relaxation time to pulse duration of laser exposure
- Describe a key factor in how optimal laser duration is selected
- Assess whether the Infantile Hemangioma (IH) should be treated with pulsed dye laser

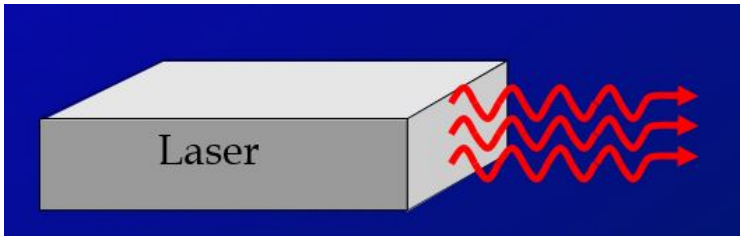
Light bulb vs. laser

Light bulb



- Polychromatic (many colors) = white
- Incoherent distribution/direction
- Not intense

Laser

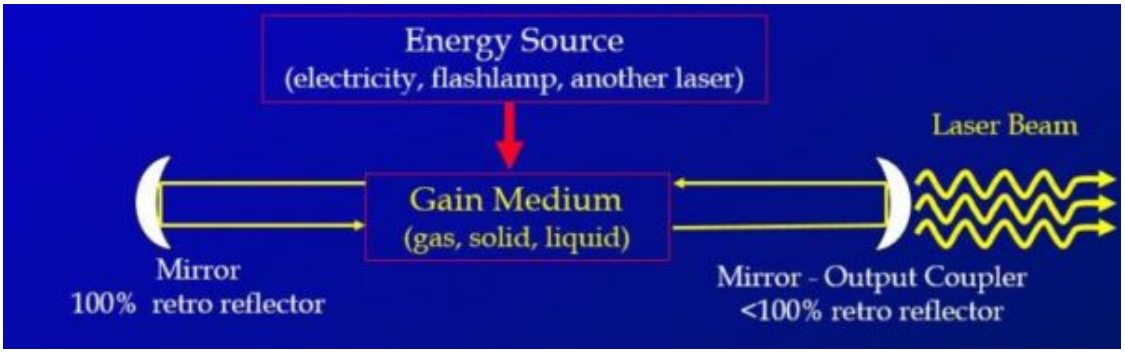


- Monochromatic (one color)
- Coherent (all in phase + parallel)
- Intense

How lasers work

Laser stands for

- Light
- Amplification by
- Stimulated
- Emission of
- Radiation

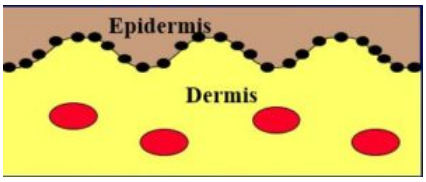


Lasers need an energy source, gain medium (usually this is how the laser is named), and mirrors (retroreflector, output coupler)

Laser parameters

- Wavelength – fixed function of the laser
- Pulse duration – how long the skin is exposed to the laser
- Light dosage – amount of energy delivered to the skin surface
- Spot size – diameter of the beam
- Repetition rate – number of pulses delivered per second

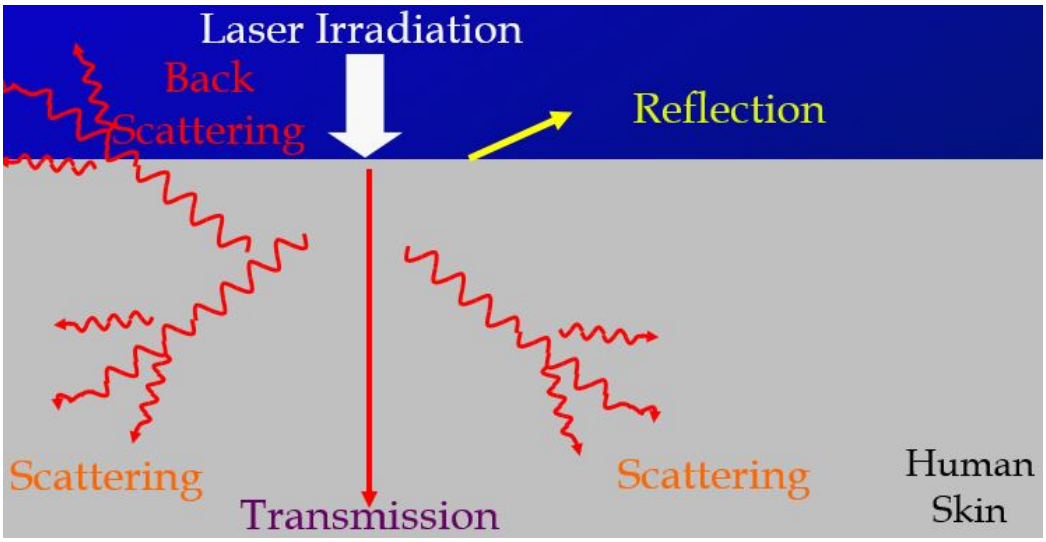
Laser treatment of vascular skin lesions

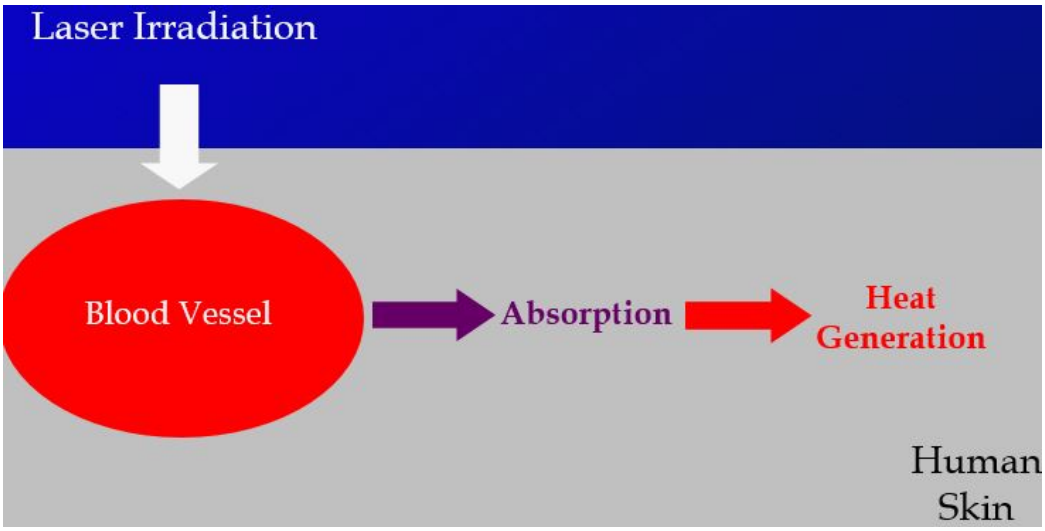


Laser treatment targets subsurface blood vessels without injuring the epidermis and other structures.

How is photon energy converted to useful tissue energy?

Laser treatment of vascular skin lesions

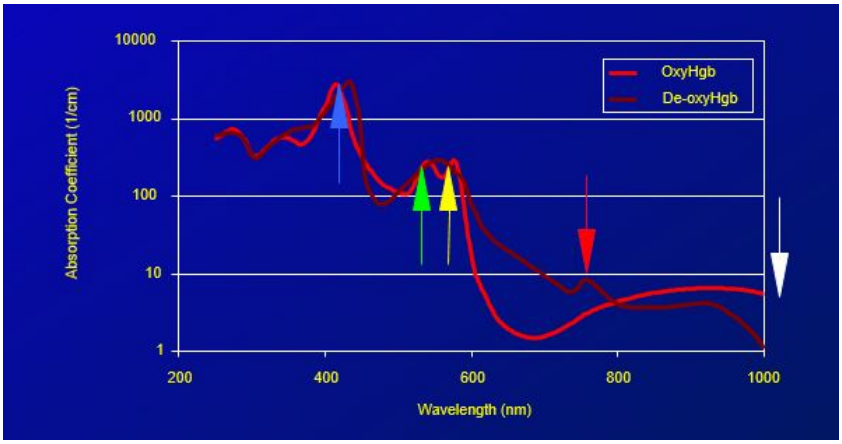




Laser wavelength (λ)

- Determined by the medium inside the device undergoing stimulated emission
- Generally expressed in nanometers (nm; 10^{-9} m)
- Key to targeting certain atoms or molecules in tissue to produce some kind of clinical effect

Absorption spectrum of hemoglobin as a function of laser wavelength



Pulsed dye lasers (577 – 595 nm)

Pros:

- Has been the standard for years
- Can treat large areas quickly
- Cryogen spray cooling
- May use 2-3 separate passes
- Induces diminution in diffuse redness and telangiectasia
- Treatment of choice for port wine stain

Cons:

- Can cause purpura
- Several treatments required
- Painful
- Causes considerable edema and erythema

Millisecond green lasers 532 nm

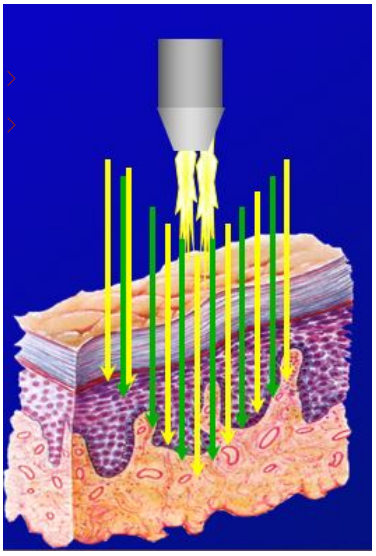
Pros:

- Variable spot sizes; large beams allow treatment of full face
- Small beams target individual vessels
- No purpura produced
- Contact cooling
- If few areas treated, only transient erythema

Cons:

- Must use air brush technique if using the smaller spot sizes
- Moderately painful and may cause considerable edema
- Significant melanin absorption; avoid tanned and dark skin phototypes
- Contact cooling must be assured

Laser treatment of vascular skin lesions

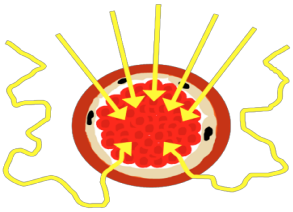


The following wavelengths are appropriate for treating vascular lesions:

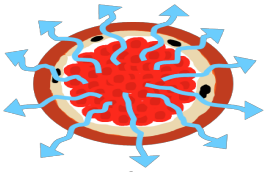
Green (laser wavelength (λ) = 500-550 nm) or

Yellow (laser wavelength (λ)= 570-600 nm)

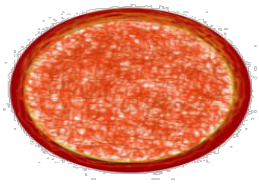
Light absorption with subsequent heat generation



Absorption of photon energy by intravascular hemoglobin



Conversion of photon to kinetic energy with subsequent heat diffusion



Thermal denaturation of blood and vascular wall components

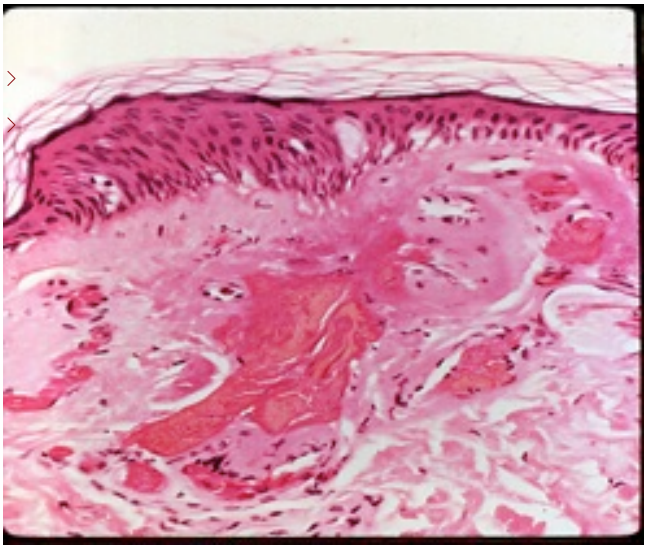
Pulse duration of laser exposure

- How long the skin is exposed to the laser
- Generally expressed in milliseconds (ms; 10^{-3} ms)
- Key to confining energy to just the targeted blood vessel

Selective photothermolysis and pulse duration (t_p) of laser exposure

- Thermal Relaxation Time (τ_r)
- How quickly targets cool to 50% of the temperature immediately after laser exposure
- $\tau_r = d^2 / 16X = t_p$
- τ_r is directly proportional to squared diameter (d^2) of target
- Pulse duration (t_p) of laser exposure should be shorter than τr to confine heating to just the targeted blood vessel

Selective photothermolysis of blood vessels



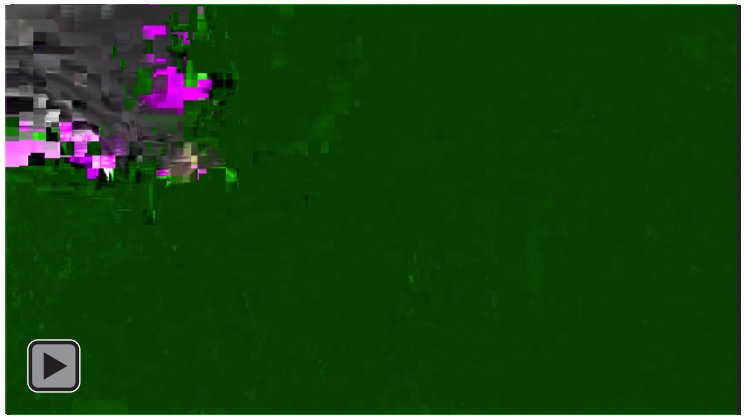
Heating confined to heating targeted blood vessel

Green and yellow lasers (λ = 532 and 595 nm)

10-300 μm blood vessels

Optimal τr = 0.45 – 50 ms

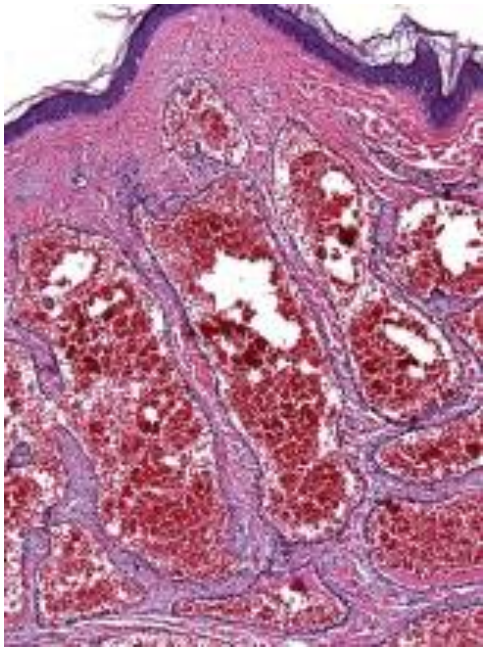
Pulsed dye laser treatment of port wine stain



Before treatment

1 day after treatment with purpura formation which will last 7 – 10 days

Port wine stain (PWS) birthmarks



- “Capillary vascular malformation”
- Lesions present at birth
- 3 per 1,000 live births
- 950,000 people in US have PWS
- 22 million people worldwide have PWS
- Two-thirds are facial lesions

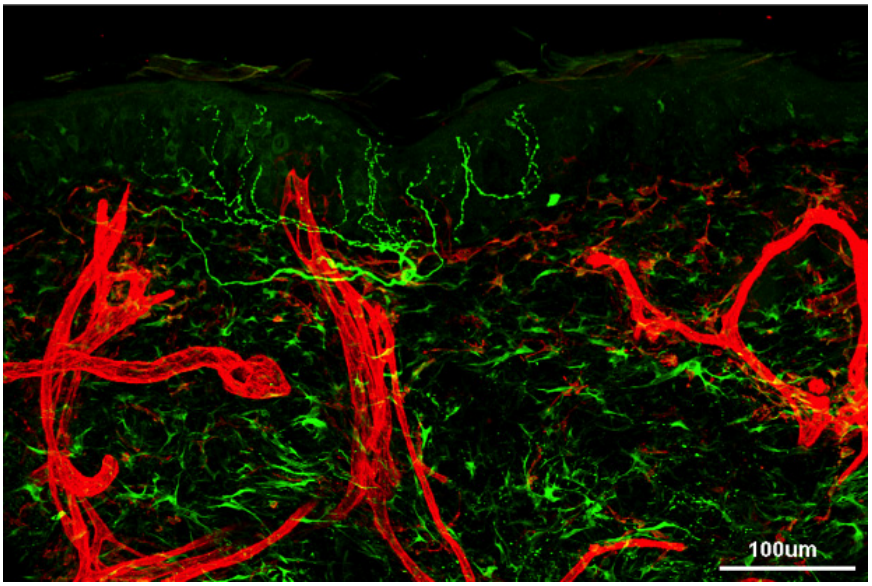
PWS are composed of dilated blood vessels in the dermis with a normal overlying epidermis

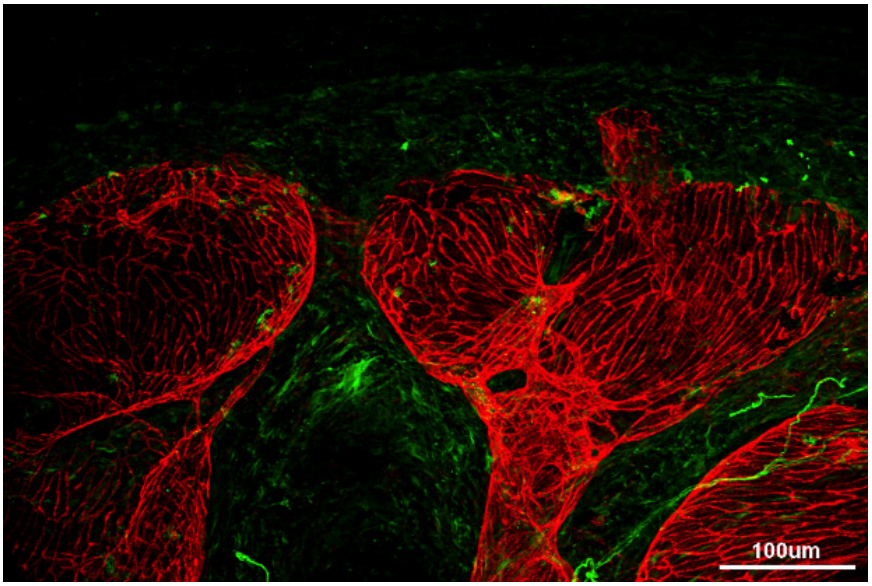
Pulsed dye laser therapy of PWS in infants and young children

Pre-treatment

Same patient, after 7 treatments

Each PWS is unique; port wine stains are enormously complex lesions





PWS blood vessel diameter and depth vary on an individual basis, and even vary from site to site on the same patient

PWS blood vessel heterogeneity can have a profound influence on selection of optimal laser pulse duration

Blood Vessel Size (μm)	Optimal Pulse Duration
10	60 μs
60	1.5 ms
150	12 ms
300	50 ms

Hemangiomas

To laser or not to laser?

Phase	Approximate Age	What's happening?
Growth	Newborn to 14 months (avg. 8 months)	Hemangioma is growing rapidly (puffs out) and the color is bright red
Resting	8-14 months	No change in size and skin is less shiny
Shrinking (Involution)	One to five years	Lesion shrinks and color changes to purple and gray and may fade completely

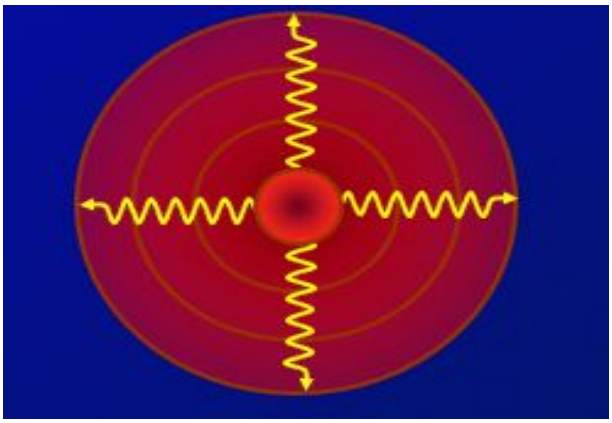
Batta K et al, Lancet. 2002;360:521–527

- Randomized trial of pulsed dye laser therapy vs. no treatment in 121 infants (1-14 weeks)
- Significantly more hemangiomas were cleared completely in treated group at 1 yr
- Side effects higher in treated group

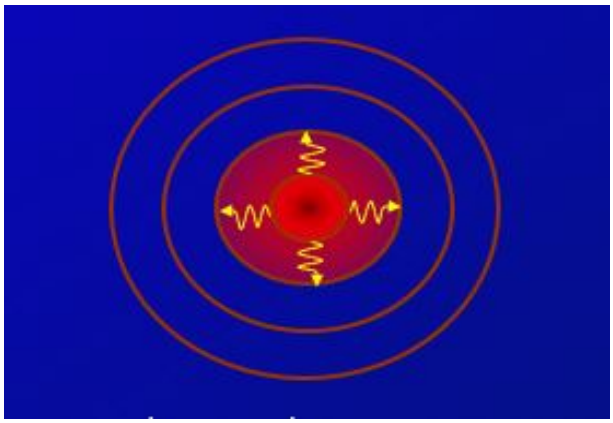
585 nm, 3-5 mm spot-size, 450 μs PDL, 10-12 J/cm^2, no cooling

The PDL

The PDL (based on the concept of selective photothermolysis) was not designed to treat hemangiomas. 1983: Selective Photothermolysis (Anderson and Parrish)



Tumor of Blood Vessels Bulk heating by multiple absorbing blood vessels within hemangioma



Single Blood Vessel Isolated small blood vessel heating

Proliferative infantile hemangioma treated by pulsed dye laser (PDL)

Before PDL treatment

After 1st PDL treatment

After 3rd PDL treatment

After 10th PDL treatment

Patient was treated by pulsed dye laser alone before the propranolol discovery.

Should pulsed dye laser treatment be considered first line of therapy for hemangiomas?

Successful laser therapy requires prompt referral from our pediatric colleagues.

10 days

2 months

Caveats for pulsed dye laser treatment of hemangiomas in infants and young children

- Flat, smooth lesions less than 3 mm thick
- Use low energy densities (< 5 J/cm^2)
- Use short pulse durations (0.45 – 1.5 ms)
- Use large spot sizes (10 – 12 mm)
- Repeat treatments every 2-4 weeks
- Epidermal cooling is essential
- Experience treating infants

Course 11: Lesson Quiz

1. What chromophore in human skin is targeted by the laser to treat pediatric patients with vascular birthmarks?
    A. Melanin
    B. Bilirubin
    C. Fat
    D. Hemoglobin

2. LASER is an acronym for
    A. Light alpha scatter by energy resistance
    B. Laser atomic spectrum and energy radiatio
    C. Light amplification and stimulated energy resource
    D. Light amplification by stimulated emission of radiation

3. Why is the thermal relaxation time key to pulse duration of laser exposure?
    A. It maximizes the number of blood vessels destroyed during laser exposure.
    B. It confines the energy to the targeted blood vessel.
    C. It allows the unlimited penetration of light into human skin.
    D. It restricts energy to the epidermis.

4. Which of the following is NOT a laser parameter?
    A. Vessel depth
    B. Wavelength
    C. Pulse duration
    D. Spot size

5. Laser light is
    A. Visible, pulsed, collimated
    B. Monochromatic, coherent, intense
    C. Coherent, continuous, multifocal
    D. Collimated, colored, multimodal

6. Which factor is key to treating an Infantile hemangioma with a laser?
    A. Lesion must concurrently be treated with some form of beta blocker.
    B. Lesion must be greater than 5 mm thick.
    C. Lesion should be flat, smooth, and less than 3 mm thick.
    D. Lesion should be ulcerated at time of treatment.

7. The laser repetition rate is defined as

A. Number of pulses delivered per millisecond
B. Number of pulses delivered per second
C. Rate of energy produced by the laser
D. Rate at which the laser is amplified

8. A key factor in determining the selection of optimal laser duration is

A. Blood vessel size
B. Response of blood vessels to temperature changes
C. Age of the patient
D. Skin type of the patient

9. Based on wavelength, which are the optimal lasers to treat pediatric vascular birthmarks?

A. Green and yellow millisecond lasers
B. Near-infrared lasers
C. Mid-infrared lasers
D. Ultraviolet excimer lasers

10. What photo physical interaction must occur in order for light energy to be useful in the treatment of pediatric patients with vascular birthmarks?

A. Fluorescence
B. Reflection
C. Absorption
D. Transmission

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Dr. J. Stuart Nelson, is Medical Director of the Beckman Laser Institute and Medical Clinic, and Professor of Surgery and Biomedical Engineering at the University of California Irvine Medical Center. He is also the Director of the Vascular Birthmarks and Malformations Diagnostic and Treatment Center.

Dr. Nelson's university-based clinical practice and research combines his expertise in engineering, optics, medicine, and surgery.

In addition to Dr. Nelson's faculty, research, teaching, and clinical responsibilities, he developed the "Dynamic Cooling Device" which, in conjunction with pulsed dye laser technology, has become the standard of care for the treatment of cutaneous vascular malformations. Worldwide, this methodology developed has now been incorporated into more than 25,000 laser devices. Dr. Nelson has published more than 340 scientific articles and 15 book chapters. He served as President of the American Society for Laser Medicine and Surgery (ASLMS) 2001-2002 and Editor-in-Chief of the ASLMS journal Lasers in Surgery and Medicine 2005-2015.

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Course 11: Lesson Quiz Answer Key

1. D
2. D
3. B
4. A
5. B
6. C
7. B
8. A
9. A
10. C