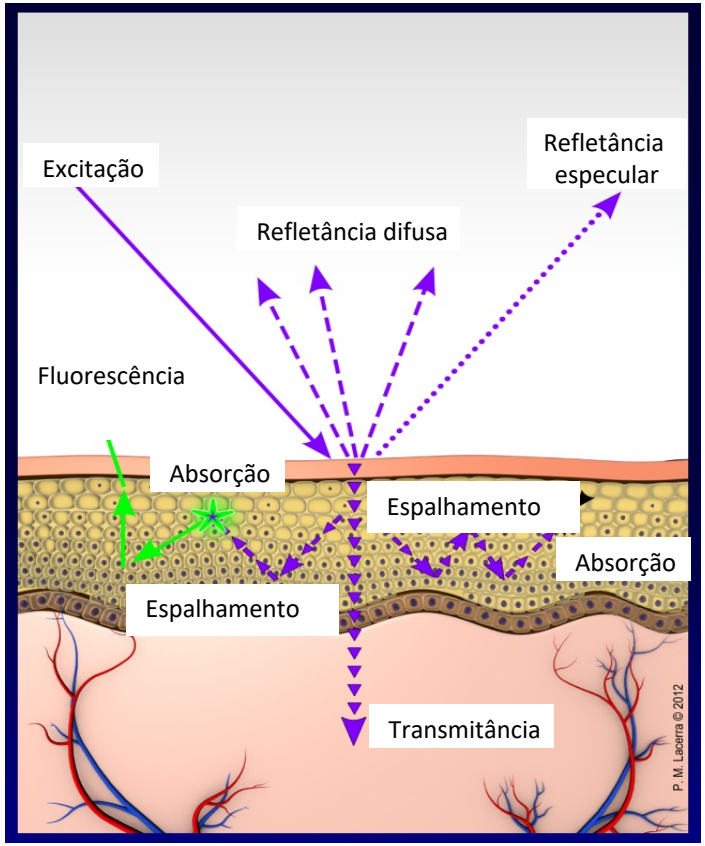
Interação da luz com sistemas biológicos

LUZ

TECIDO



Características da fonte de luz

- Tipo de emissão
- Comprimento de onda
- Potência média, irradiância
- Tempo de interação

EFEITOS

- Fotoquímico
- Fototérmico
- Não-lineares

(fotodisruptivo, fotoablativo, ablação induzida por plasma)

Água: espectro de absorção

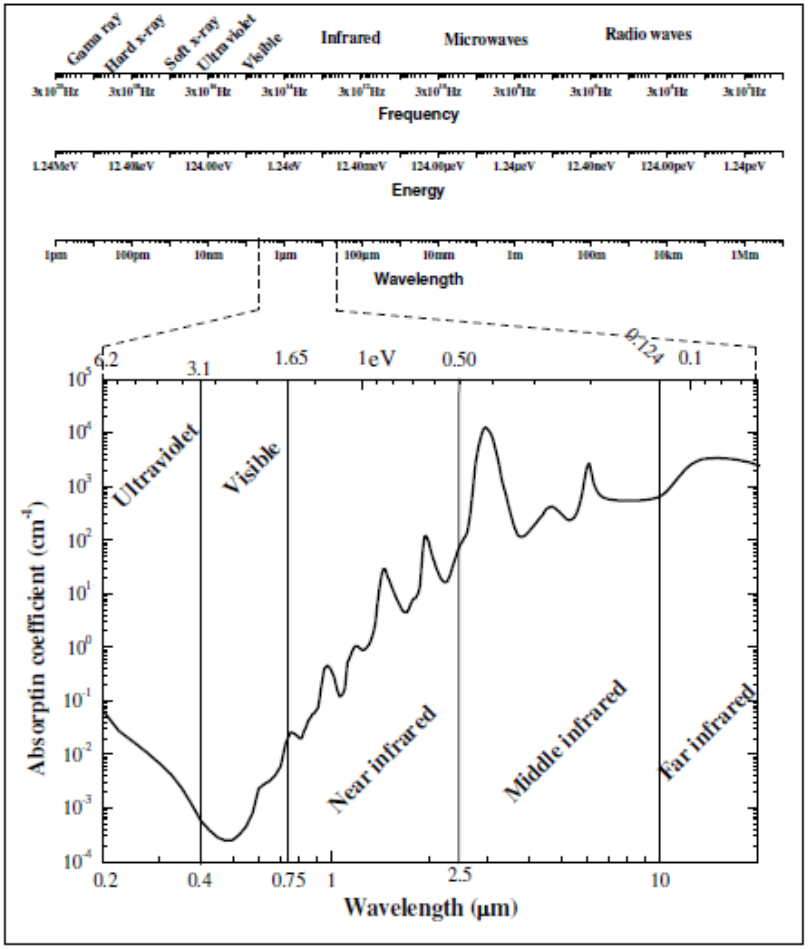


Figure 2 – Electromagnetic spectrum. The first upper scale represents the frequency of wave oscillation. The higher values represent the gamma ray and hard x-ray; when the frequency is decreased there are the soft x-ray, ultraviolet, visible, infrared, microwaves, and radio waves. The second scale represents the respective photon energy and the third gives the wavelength of the photon. The main interest in laser applications is the ultraviolet, visible, and infrared radiation; these three spectral regions are better visualized in the graphic and compared with the water absorption spectrum [6].

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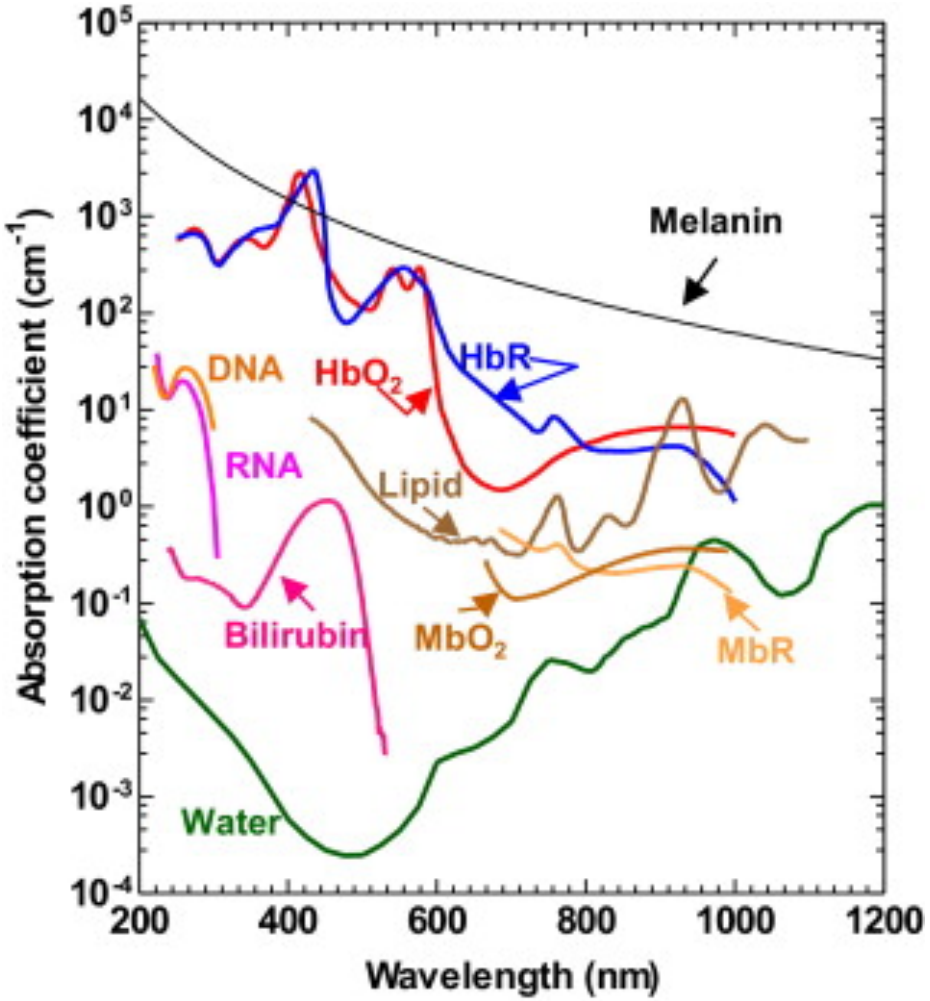
Coeficiente de absorção - biomoléculas



Junjie Yao and Lihong V. Wang. Laser & Photonics Rev, 2013

Energia dos diferentes tipos de radiação

Comprimento de onda (m)	Energia do fóton (eV)	Radiação
superior a 3×10^{-1}	inferior a $4{,}1 \times 10^{-6}$	Ondas de radiofrequência
3×10^{-1} → 3×10^{-3}	$4{,}1 \times 10^{-6}$ → $4{,}1 \times 10^{-4}$	Micro-ondas
3×10^{-3} → $7{,}6 \times 10^{-7}$	$4{,}1 \times 10^{-4}$ → 1,6	Infravermelha
$7{,}6 \times 10^{-7}$ → 4×10^{-7}	1,6 → 3,1	Luz visível
4×10^{-7} → 10^{-8}	3,1 → 123,2	Ultravioleta
inferior a 10^{-8}	superior a 123,2	Raios X e γ

A-400 → 320nm
B-320 → 290 nm
C-290 → 200nm

Table 2 – Laser systems for medical applications with their wavelengths and photon energy.

Laser systems	Wavelengths (nm)	Photon energy (eV)
Excimer - F_2	157	7.9
Excimer - ArF	193	6.4
Excimer - KrCl	222	5.6
Excimer - KrF	248	5.0
Excimer - XeCl	308	4.0
Nitrogen	337	3.7
Excimer - XeF	351	3.5
Double ionized argon	351/363	3.5/3.4
Argon	488/514.5	2.5/2.4
Metal-Vapour-Copper	510/578	2.4/2.1
Metal-Vapour-Gold	312/628	4.0/2.0
Krypton	530.9/568.2	2.3/2.1
Helium-Neon	543/594/604/612/632.8	2.28/2.09/2.05/2.03/1.96
Helium-Neon	1152/3391	1.08/0.37
Ruby	694	1.79
Alexandrite	720-800	1.72-1.55
Dye	400-900	3.1-1.38
Diode	600-1000	2.07-1.24
Ti:sapphire	700-1000	1.77-1.24
Neodymium (Nd:YAG)	1064/532/355/266	1.16/2.33/3.49/4.66
Neodymium (Nd:YLF)	1053	1.18
Holmium - Ho:YLF	2060	0.602
Holmium - Ho:YAG	2120	0.584
Erbium - Ct:Tm:Er:YAG	2640	0.470
Erbium - Er:YSGG	2780	0.446
Erbium - Cr:Er:YSGG	2790	0.444
Erbium - Er:YLF	2800	0.443
Erbium - Er:YAG	2940	0.422
Carbon dioxide	9000-11000	0.138-0.113
Free electron laser	800-6000	1.55-0.207

Table 3 – The main interatomic bond energies present in biological molecules. The bond energy can be broken by the direct absorption of a photon; this process is named photoablation and is accomplished mainly by lasers with emission in the ultraviolet region; wavelengths with photon energy higher than the bond energy.

Chemical bond	Energy (eV)
H bond	0.19
N – N	1.62
O – O	2.18
N – O	2.18
C – S	2.70
C – N	3.06
C – C	3.62
C – O	3.62
H – N	4.06
H – C	4.31
N = N	4.31
H – H	4.49
H – O	4.81
N = O	5.00
O = O	5.12
C = N	6.37
C = C	6.37
C = O	7.68
C ≡ C	8.68
C ≡ N	9.24
N ≡ N	9.80

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Table 4 – Dependence of biological effects on the temperature in heated soft tissues [3] and hard tissues [9]. These values are an approximation because the presence of these effects is not restricted to a specific temperature but also to a range of temperature and they are also dependent on the characteristics of the tissue.

Temperature (C)	**Biological changes in soft tissues**
45	Hyperthermia
50	Reduction in enzyme activity; Cell immobility
60	Protein denaturation, coagulation
80	Permeabilization of membranes
100-140	Tissue vaporization
150	Carbonization
Temperature (C)	**Biological changes in hard tissues**
140	Elimination of adsorbed water
200	Collagen denaturaion
300-400	Organic material loss
400-1000	Carbonate loss
200-800	Cyanate formation
800-1000	Cyanate loss
200-1000	Changes in Hydroxyapatite structure
600	(Ca_3PO_4)-β and (Ca_3PO_4)-α formation
1100	$Ca_4(PO_4)_2O$ formation
1300	Elimination of structural water
1300	Hydroxyapatite melting

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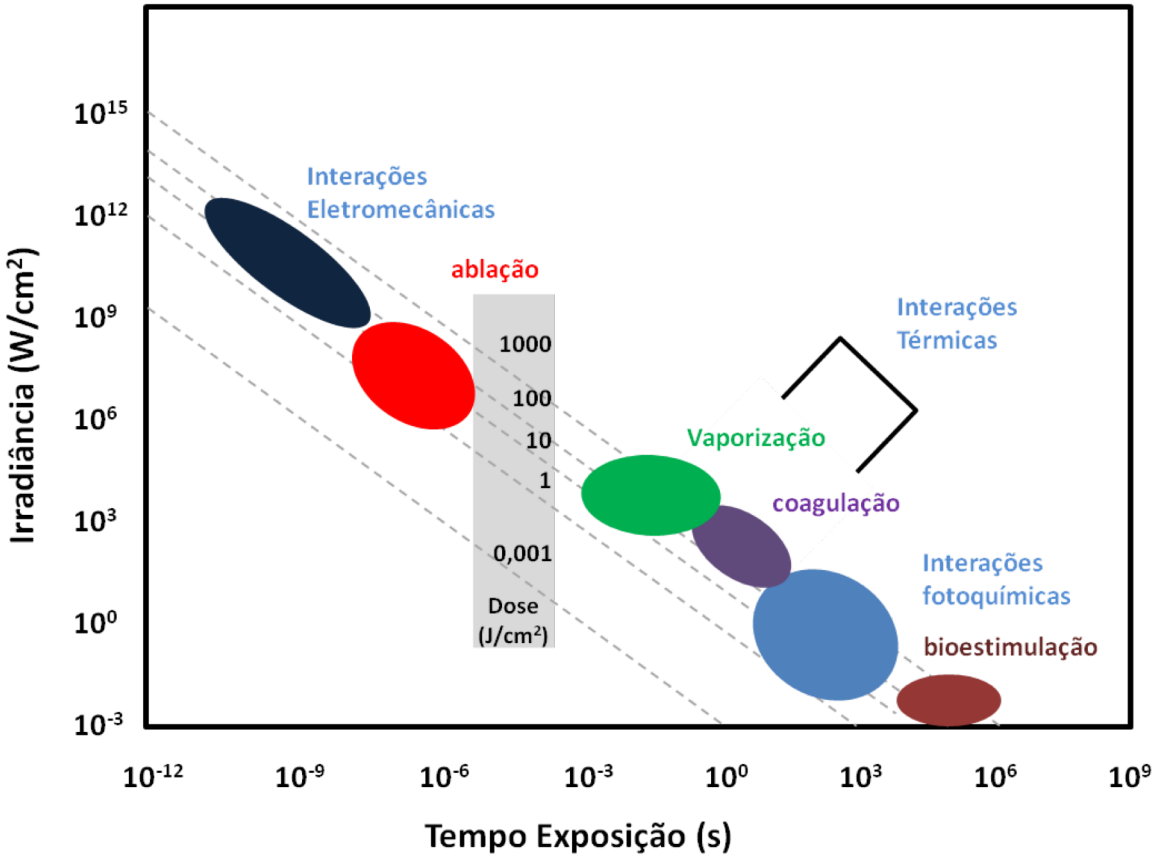
Parâmetros importantes da irradiação

- Comprimento de onda (λ): nm
- Potência óptica média: W
- Duração da interação (cw ou largura do pulso): s
- Irradiância de luz (intensidade, densidade de potência): W/cm^2
- Energia entregue (por ponto ou total): J (Joules)
- Fluência (densidade de energia): J/cm^2
- Diâmetro do feixe (área de interação): cm^2
- Formato do feixe (geometria de acoplamento)



Mapa de interações de lasers com tecido biológico aplicado a medicina. O eixo das ordenadas mostra a irradiância (W/cm^2) e o eixo das abscissas mostra o tempo de interação da luz. As diagonais pontilhadas apresentam a doses de energia típicas (J/cm^2). As figuras geométricas apresentam os tipo de interação e os parâmetros utilizados em diversos relatos clínicos e aplicações experimentais. (Adaptado de Boulnois, 1986[5])

Duração da interação e irradiância - efeitos

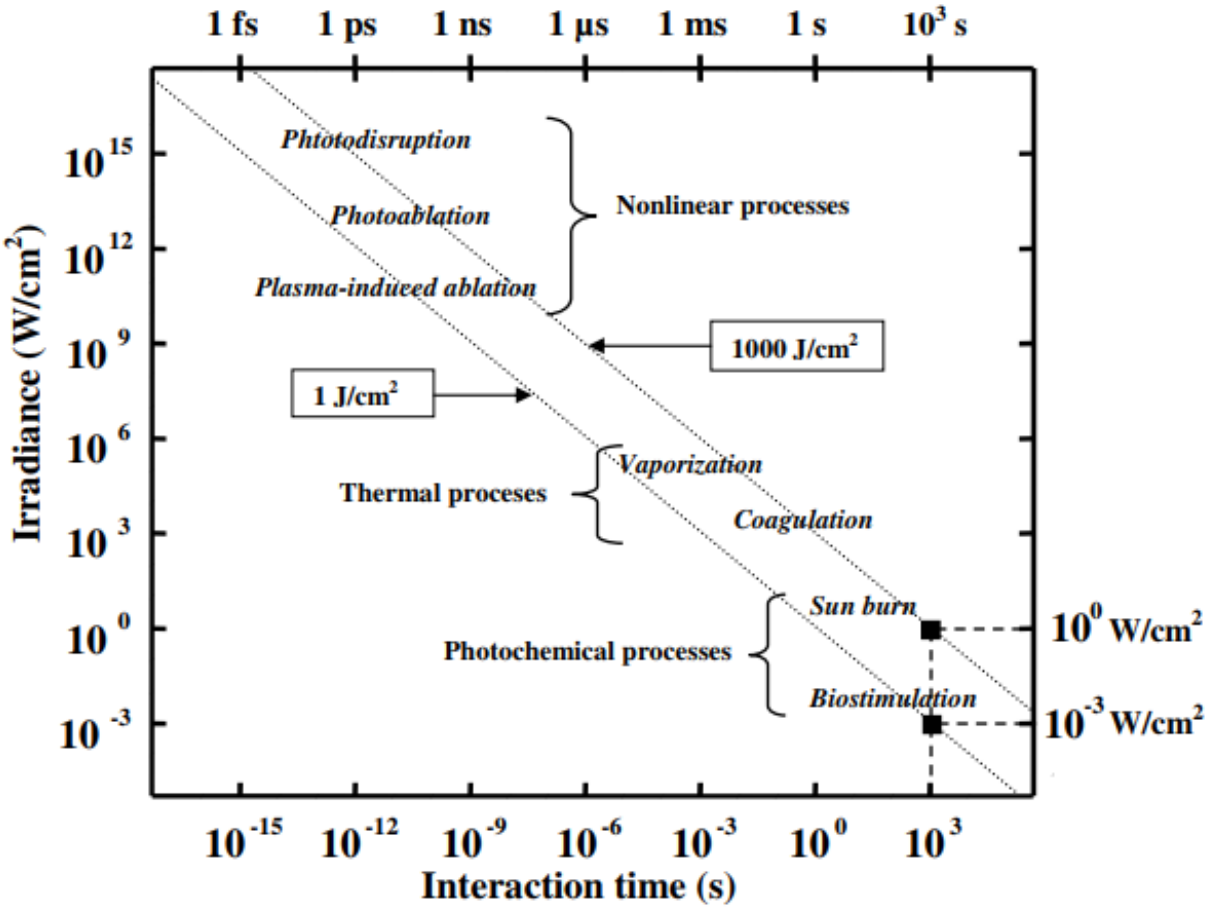


Figure 15 – The interaction of laser radiation will be determined by the duration of the interaction and the irradiance values. For example, photochemical interaction mechanisms are dominant for low irradiance, longterm exposure, while nonlinear effects occuring for short pulse, high irradiance exposure (adapted from [7]).

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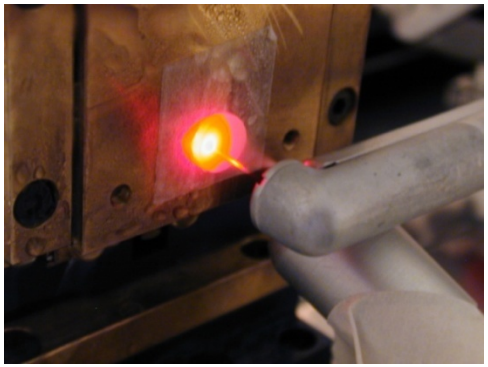
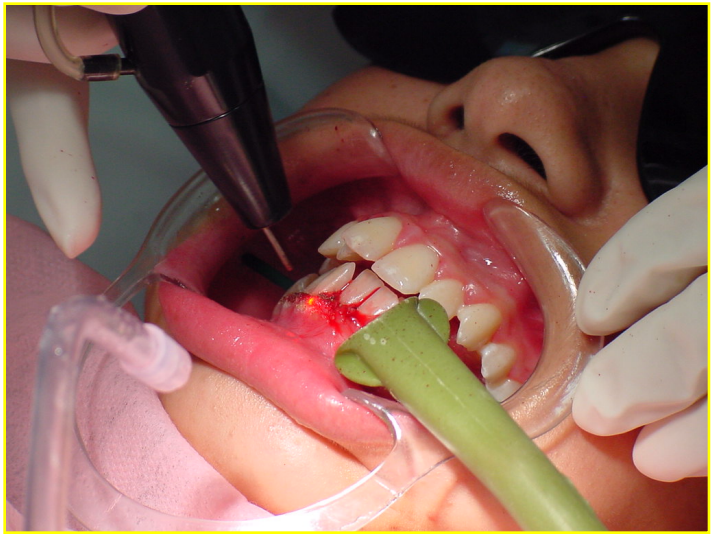
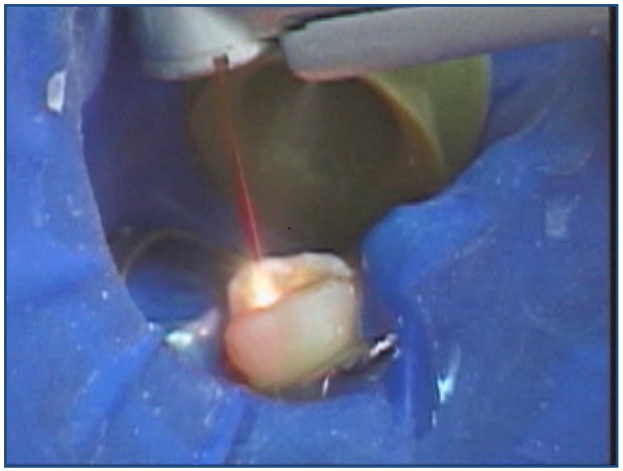
Efeito fototérmico - laser cirúrgico

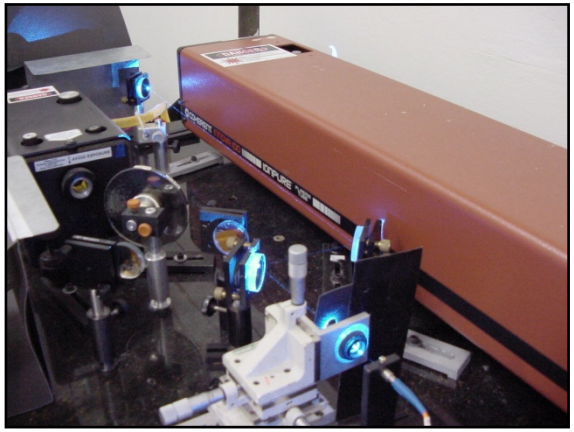
- Alta concentração de energia
- Absorção por biomoléculas ou água
- Corte, vaporização, carbonização de componentes biológicos

- Lasers cirúrgicos: funcionam como um “bisturi óptico”.
  - Alta irradiância: muita energia







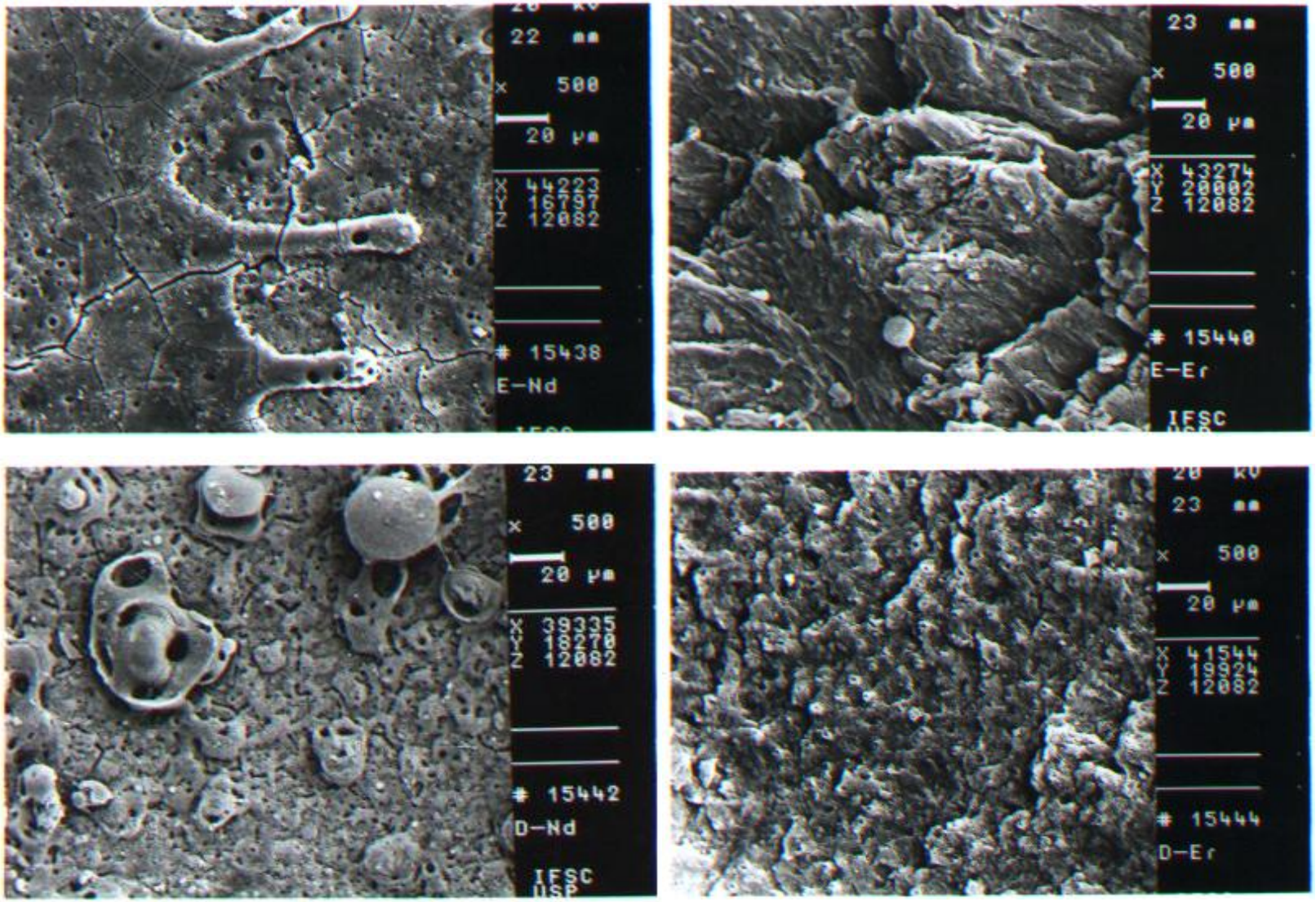


Nd:YAG

Er:YAG

esmalte

dentina



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Efeitos térmicos

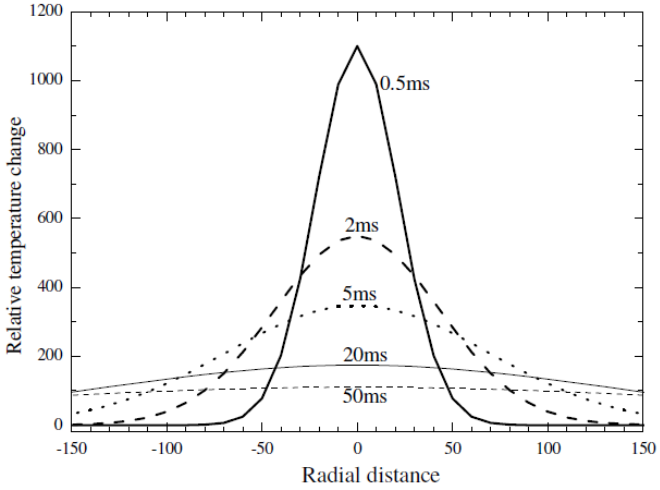

Figure 17 – Relative temperature progression at different distance from the irradiation site. The temperature profile can be visualized for different times after the irradiation has stopped: 0.5ms; 2ms; 5ms; 20ms; and 50ms. The temperature and time delay are only representative values for the temporal and spatial visualization; the real temperature and time depends on the irradiation parameters and on the thermal properties of the tissue.

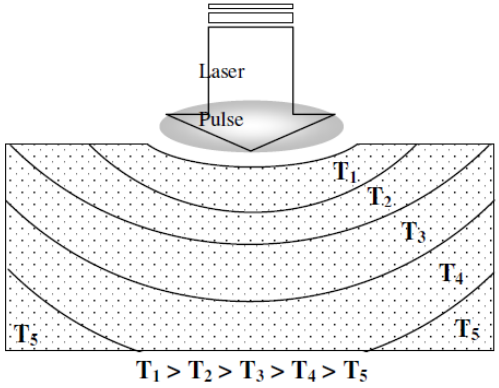

Figure 18 – Spatial distribution of temperature into a tissue block. In this diagram part of the tissue is removed (by vaporization, ablation), and the remaining tissue is submitted to thermal effects with the higher temperature localized in the first layer surrounding the removed tissue and the lower temperature in the deeper tissue. The time and temperature at each layer depend on the irradiation parameters and on the thermal properties of the tissue.

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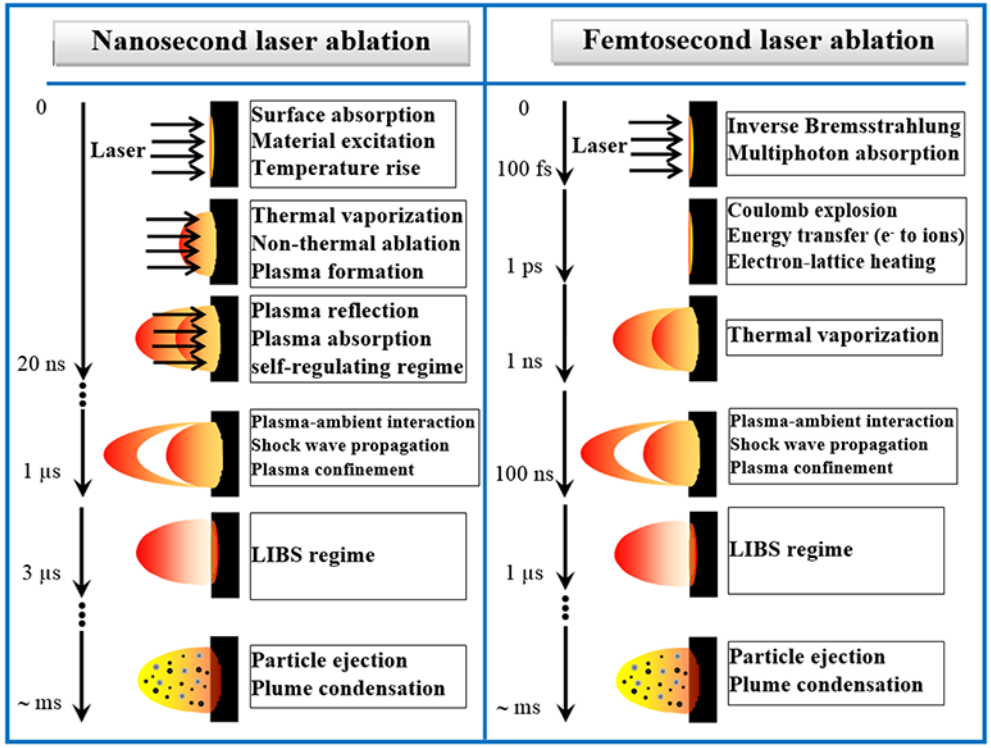
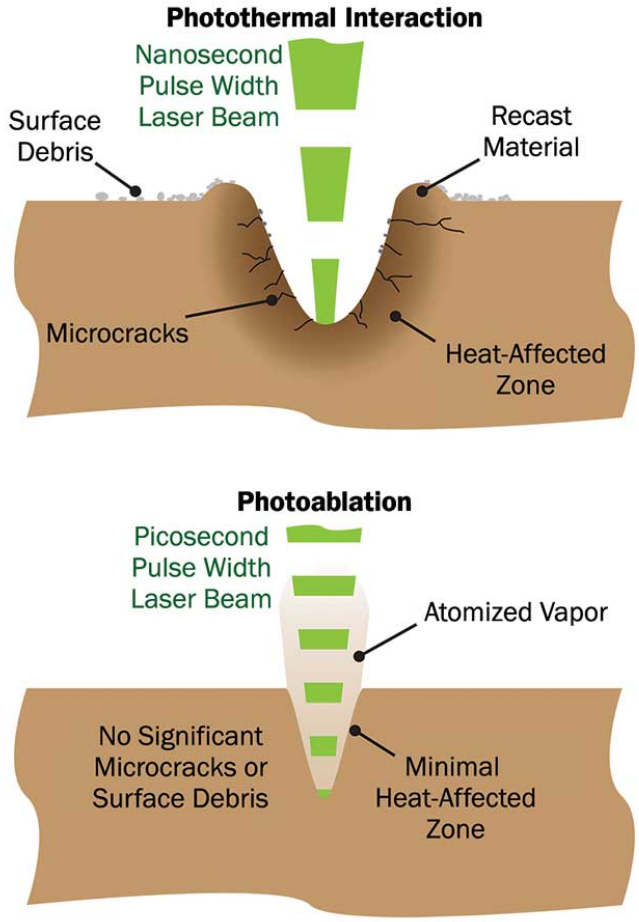
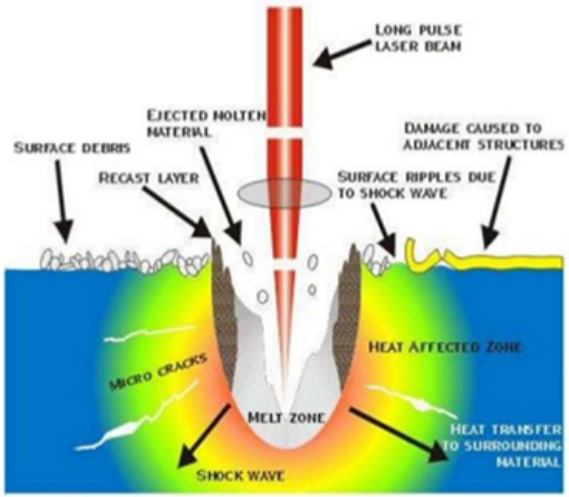
Largura de pulso

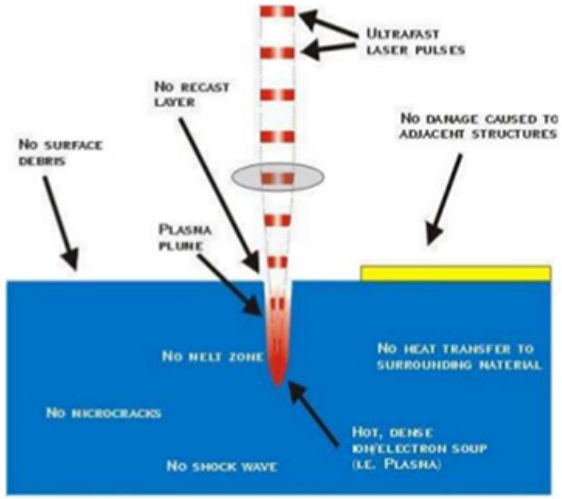


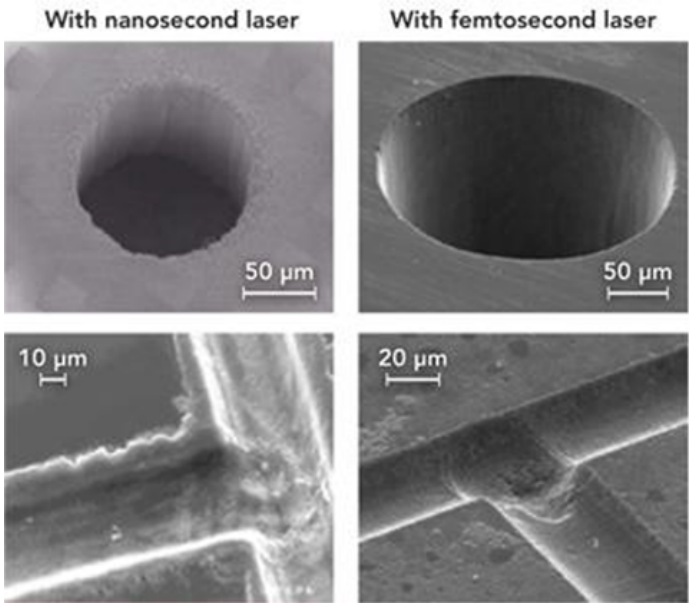


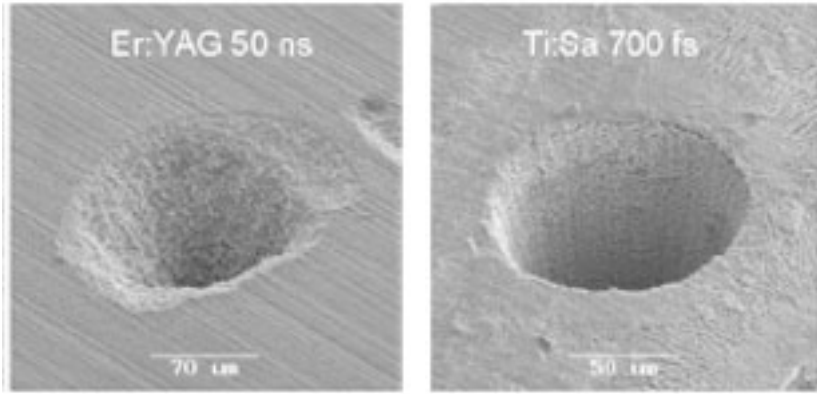
Long pulse



Short pulse



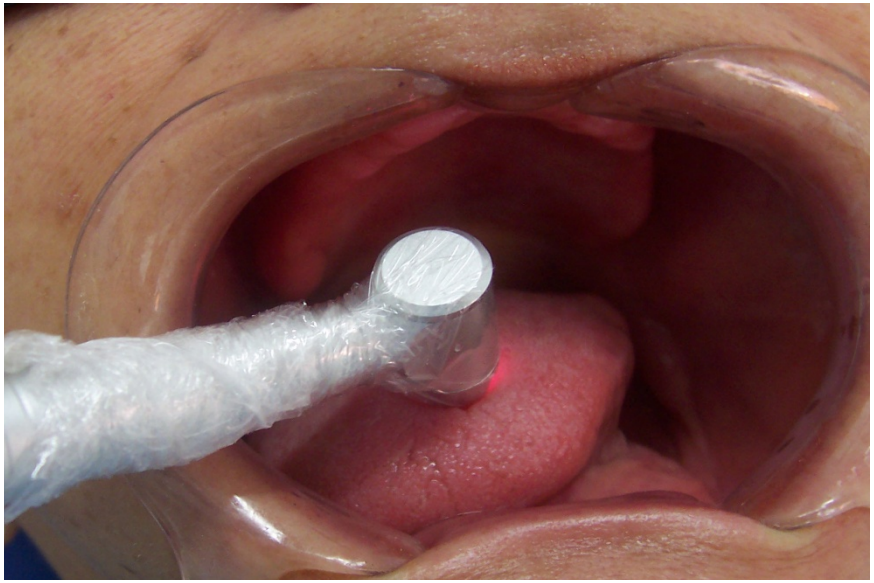




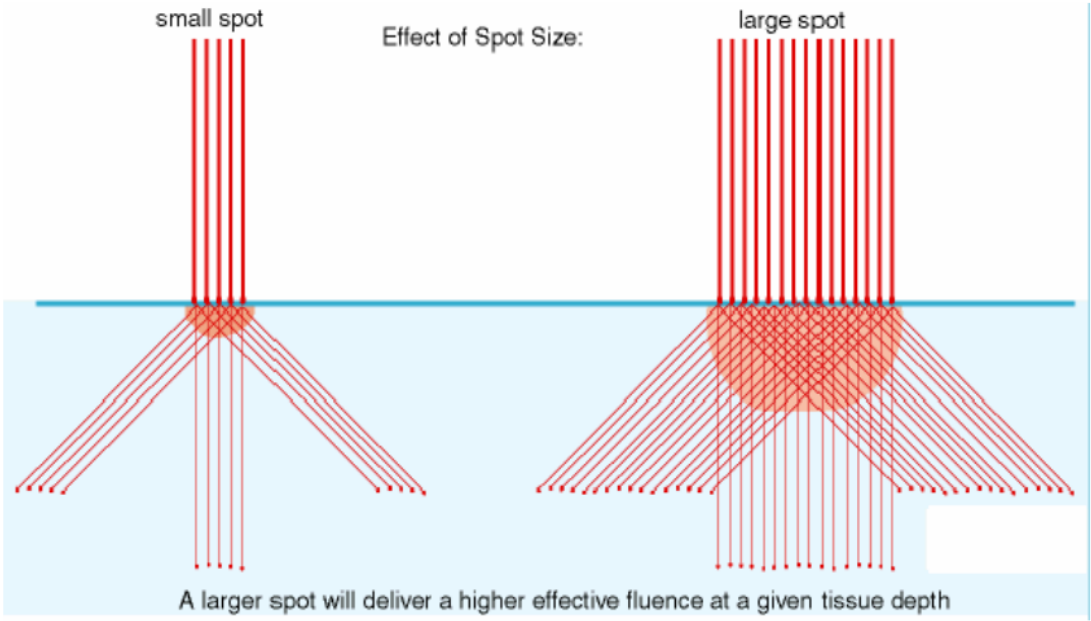
(Vidro)

Fototerapia de baixa intensidade

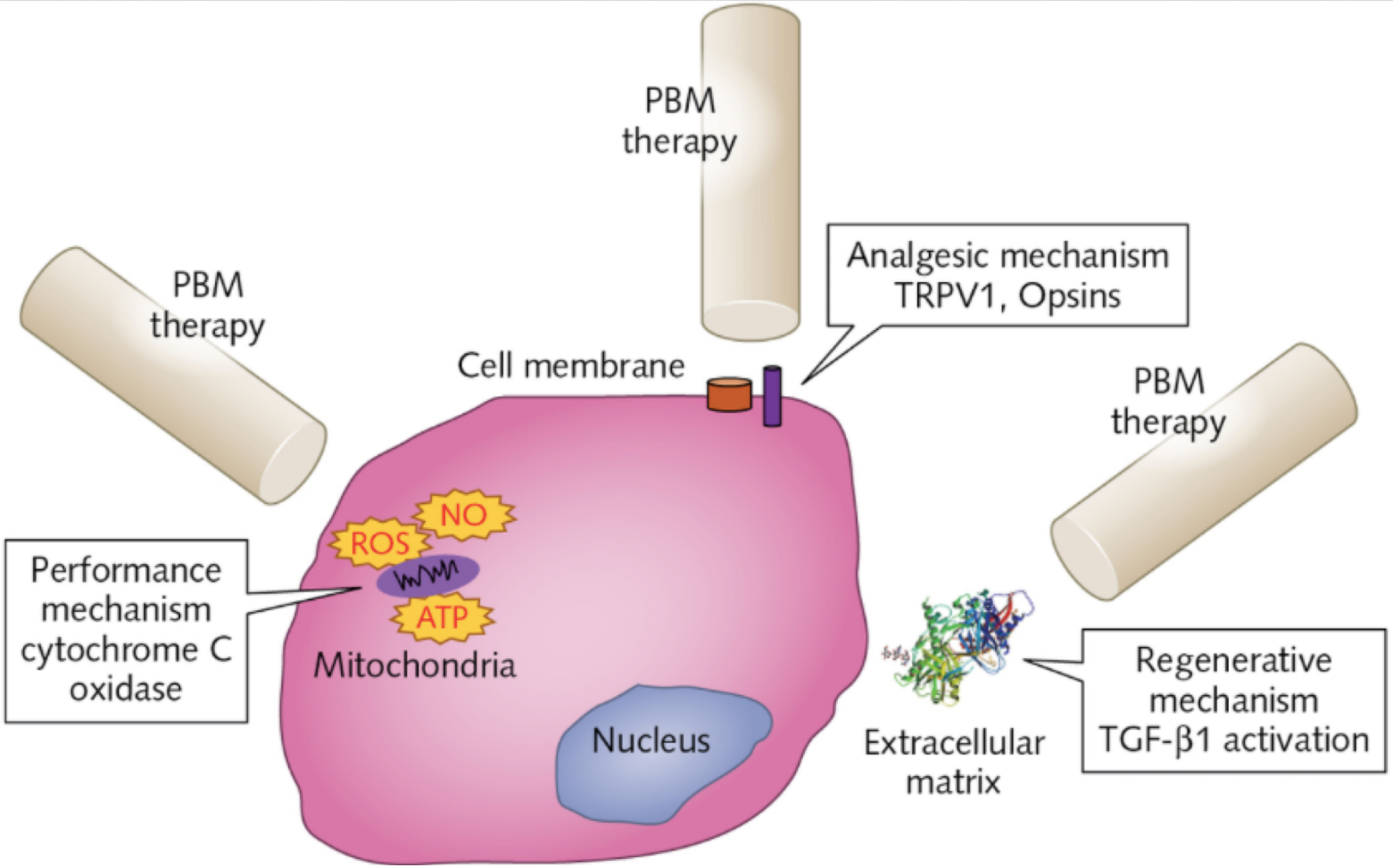
- Modulação de reação metabólicas
  - Principais cromóforos biológicos: proteínas de membrana celular e da mitocôndria
  - Efeitos clínicos: controle da dor, aceleração da cicatrização, redução da resposta inflamatória



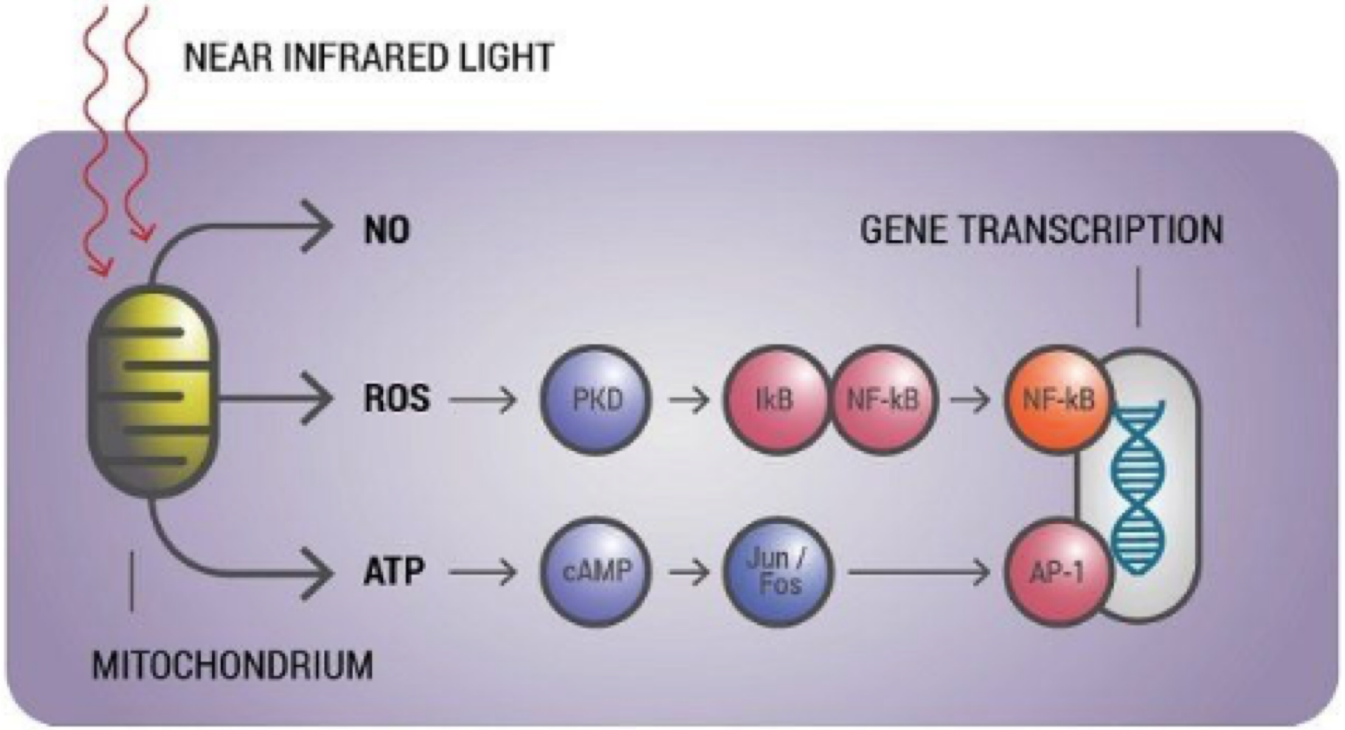
Efeito do formato do feixe



Mecanismos celulares da fotobiomodulação

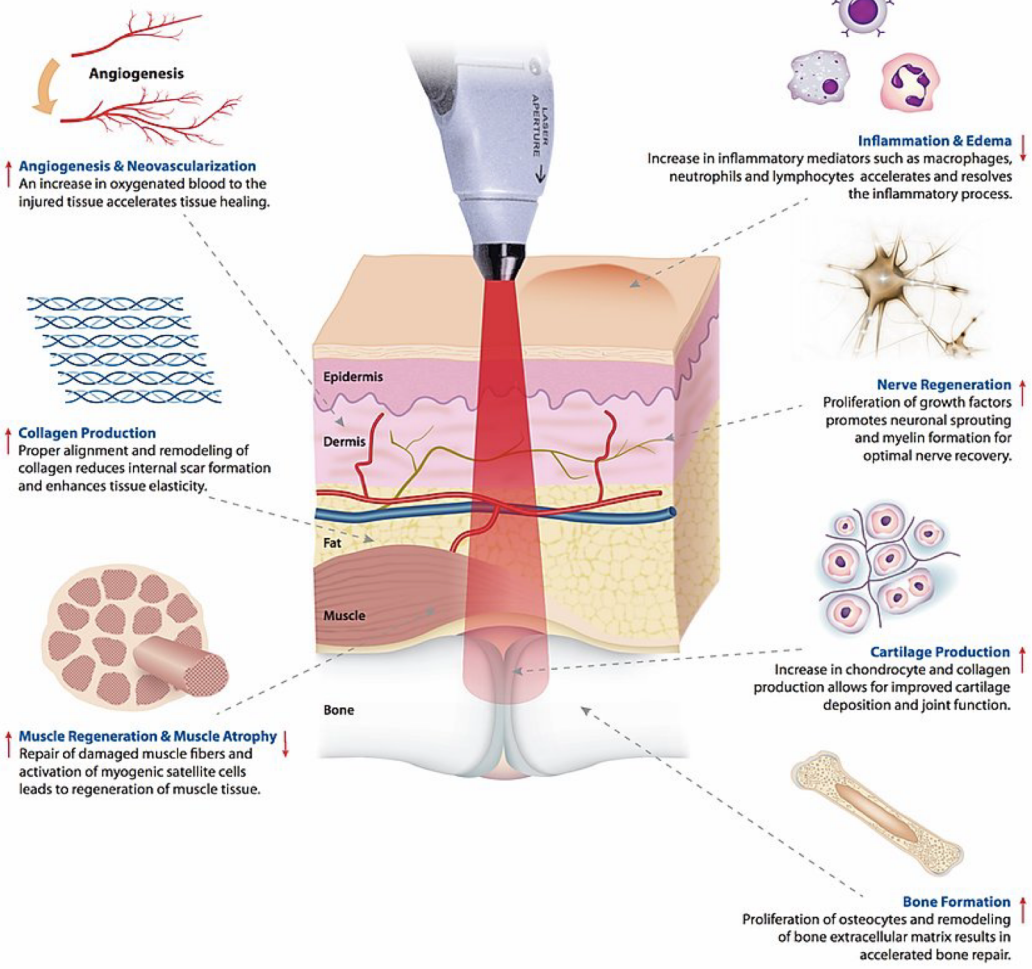


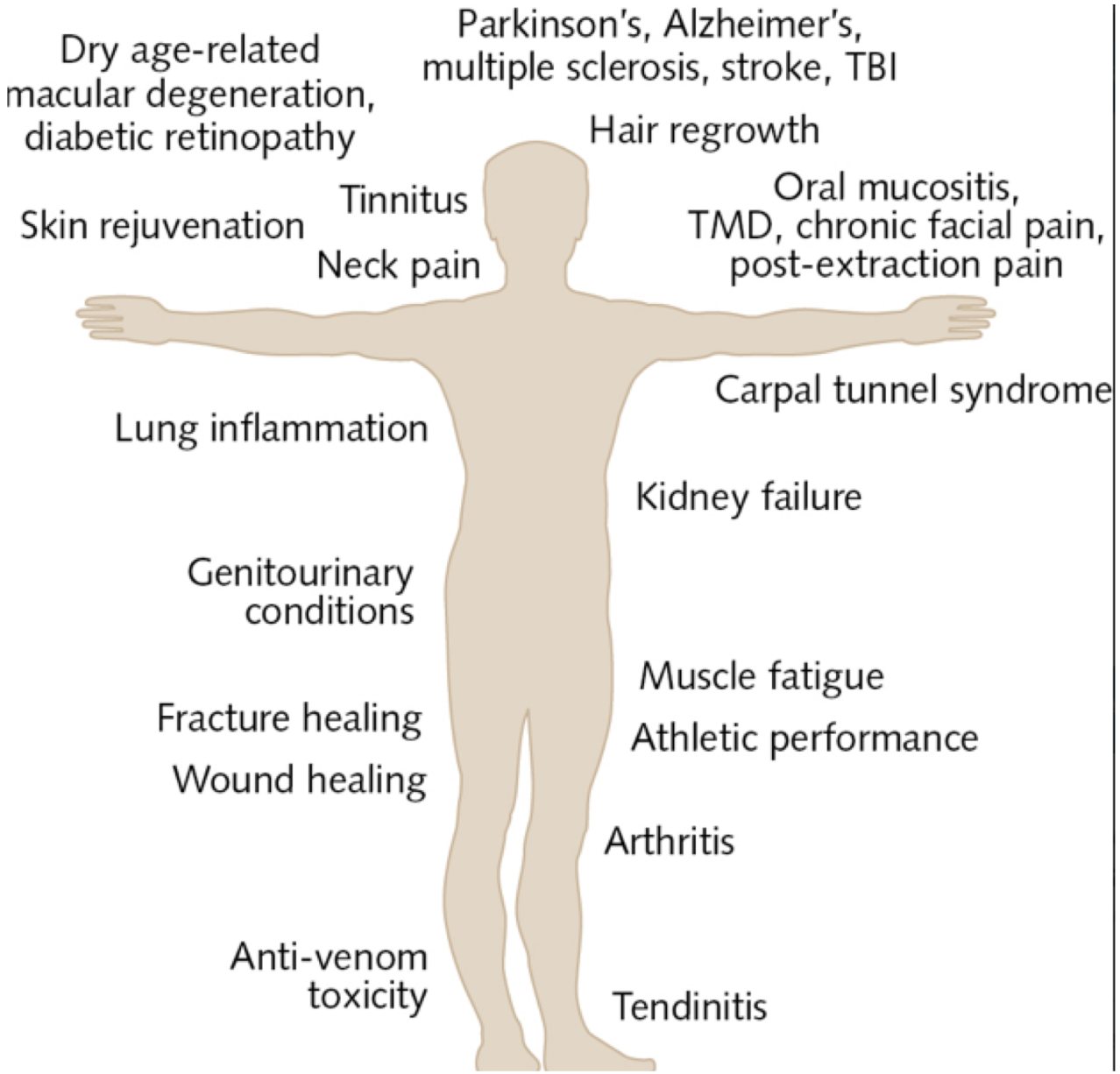
CELLULAR MECHANISMS



Reference: "Basic Photomedicine", Ying-Ying Huang, Pawel Mroz, and Michael R. Hamblin,

CLINICAL EFFECTS OF LASER THERAPY




Dry age-related macular degeneration, diabetic retinopathy
Parkinson's, Alzheimer's, multiple sclerosis, stroke, TBI
Hair regrowth
Skin rejuvenation
Tinnitus
Neck pain
Oral mucositis, TMD, chronic facial pain, post-extraction pain
Carpal tunnel syndrome
Lung inflammation
Kidney failure
Genitourinary conditions
Muscle fatigue
Fracture healing
Athletic performance
Wound healing
Arthritis
Anti-venom toxicity
Tendinitis