Ablative Fractional Laser Physics

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April 2011

Basic Parameters
Laser Types
Pulse Modes

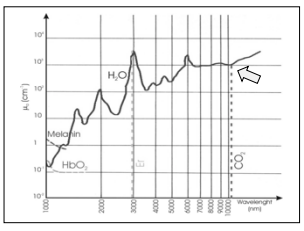
Skin Resurfacing History

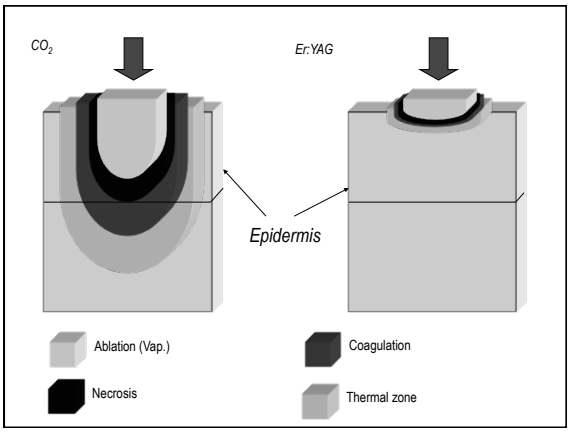
Ablative	Non-ablative
1992 CO2 Skin Resurfacing	
1996 Er:YAG Skin Resurfacing	**1996** 1320nm Non-ablative Laser
	2000 IPL Photorejuvenation
	2005 Fractional IR
2008 Fractional Resurfacing	

Skin Resurfacing History

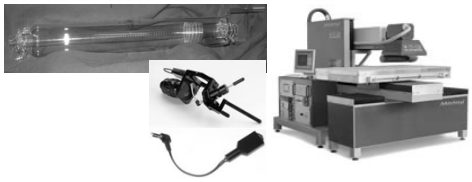
Carbon dioxide laser (CO2) has the optimal water absorption properties for laser skin resurfacing

- 10,600 nm
- Effective for vaporization
- Significant, coagulation effect
- Thermal zones may be created and managed





Versatility of CO_2 Lasers



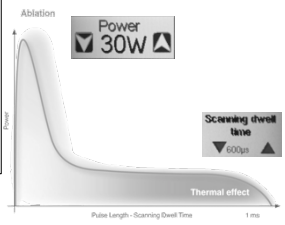
- 25 year evolution of CO_2 lasers, systems, and accessories for aesthetic and medical uses.
- Broad range of technology: 20 watts to 6,000 watts, DC, RF, Fast flow.
- Industrial, aesthetic, surgical, and dental systems

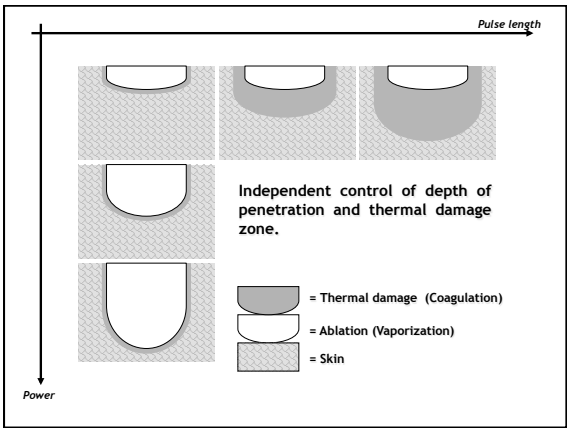
Control of Thermal Zone

Operator can independently adjust ablation depth and thermal zone.

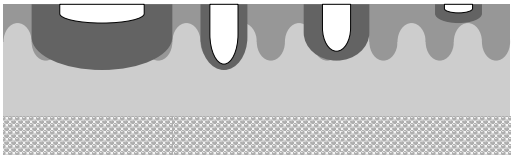
Benefits:

- Control of ablation depth
- Control of thermal damage (hemostasis, collagen shrinkage)
- Intactness of the surrounding tissue

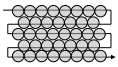




Treatment techniques



Standard Skin Resurfacing



Parameters

Power | **Dwell time**

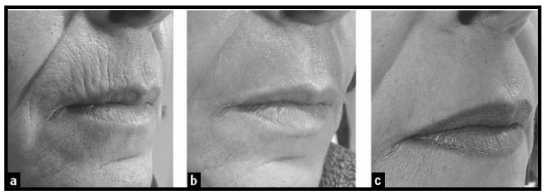
Collagen shrinkage
Neo collagenesis

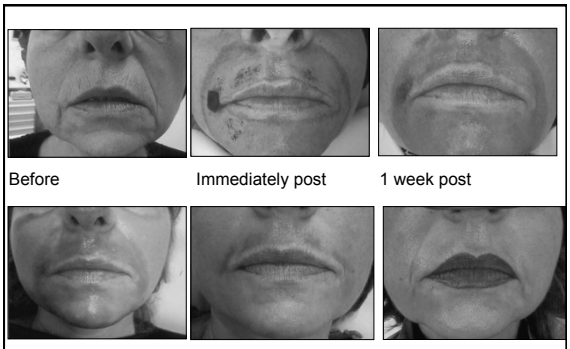
Normal and homogeneous epithelial regeneration
No photo-aging and no dyschromia

No scars

Surrounding tissue integrity

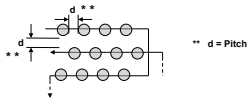
Resurfacing Mode





Resurfacing Mode

Fractional
Skin Resurfacing



Parameters

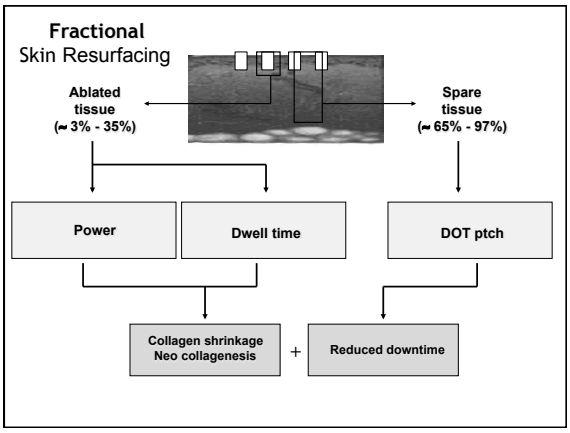
New

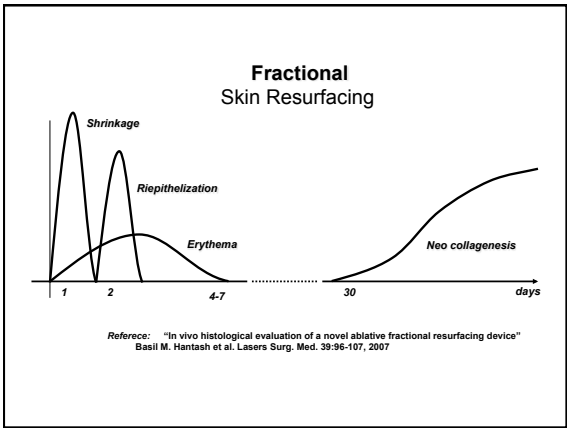
Power | **Dwell time** | **DOT Pitch**

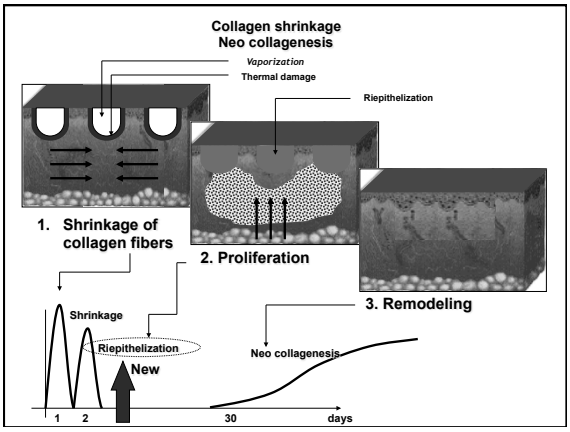
Normal and homogeneous epithelial regeneration
Neither hyper nor hypopigmentation – No scarring

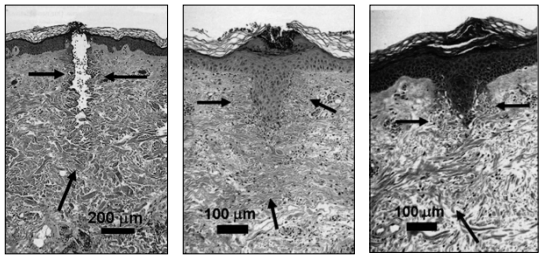
Reduced downtime

Collagen shrinkage
Neo collagenesis


Fractional
Skin Resurfacing
Ablated tissue (≈ 3% - 35%)
Spare tissue (≈ 65% - 97%)
Power
Dwell time
DOT ptch
Collagen shrinkage Neo collagenesis
+
Reduced downtime

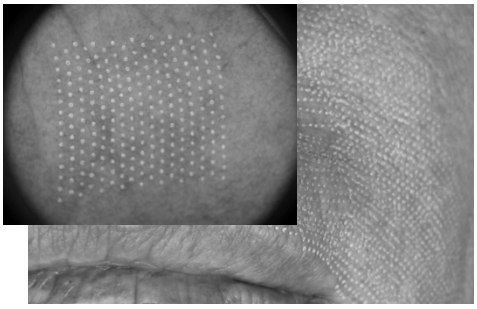

Fractional
Skin Resurfacing
Shrinkage
Riepithelization
Erythema
Neo collagenesis
1
2
4-7
30
days
Referece: "In vivo histological evaluation of a novel ablative fractional resurfacing device"
Basil M. Hantash et al. Lasers Surg. Med. 39:96-107, 2007

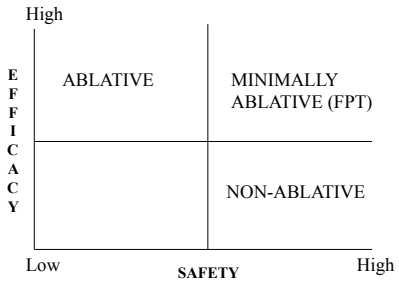

Collagen shrinkage
Neo collagenesis
Vaporization
Thermal damage
Riepithelization
1. Shrinkage of collagen fibers
2. Proliferation
3. Remodeling
Shrinkage
Riepithelization
New
Neo collagenesis
1
2
30
days



Immediately after | 2 days after | 7 days after

In FPT, heat is delivered to the tissue in columns rather than in layers





Physics Terms

Power – watt (W) – rate of work, rate of energy conversion.
Irradiance – W/cm^2 – power per unit area at a surface, power density.

Energy – joule (J) – amount of work done.
Fluence – J/cm^2 – measurement of energy flow across a unit area.

Thermal Conductivity – $W/cm/^\circ C$ – unit of the ability to conduct heat.
Heat Capacity – $J/cm^3/^\circ C$ – ability to store heat for a unit temperature rise.

Thermal Diffusivity – cm^2/s – ability for a material to adjust its temperature to its surrounding. Ratio of Thermal Conductivity to Heat Capacity.
Thermal Relaxation Time – s – the time for the temperature difference between and object and the initial temperature of its surroundings to decrease by 1/e.

*the symbols for watt (W) and joule (J) should be capitalized.

Fractional Laser Treatment

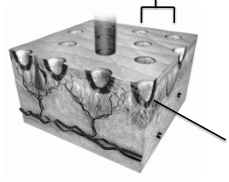
A fraction of the skin area is treated with an array of relatively small spots.

frac·tion·al
-of, relating to, or being a fraction
- relatively small: inconsiderable

frac·tion·ate
- to divide or break up
- divide into different portions

Note: the term fractionated is sometimes used, however it is a less accurate description of the process. Dividing a treatment area into cosmetic units for full resurfacing could also be considered as a fractionated treatment by definition.

Fractional Tissue Parameters



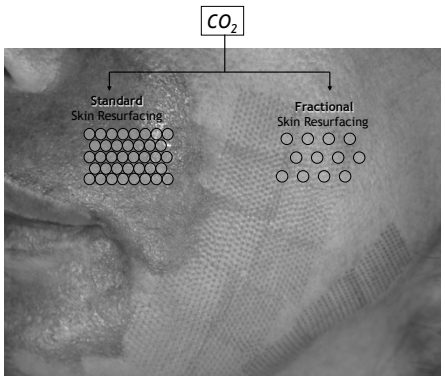
Pitch – dot spacing, sometimes **density** or (dots/area) is used.

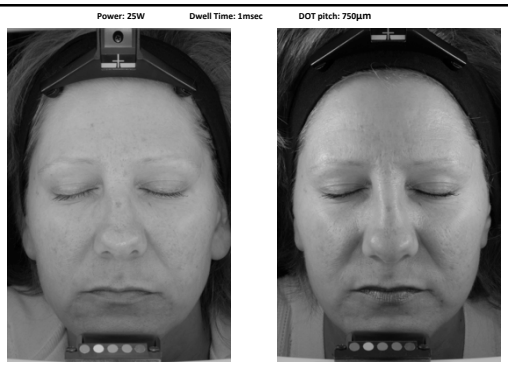
Spot size – no standard definition
- diameter of the ablation channel,
- diameter of the total injury
- diameter of the laser beam

Ablation depth

Thermal Damage Zone (TDZ) or Coagulation – comprises the necrotic zone and as well as viable thermally modified tissue.

Note: These parameters define the basic treatment. Two different lasers will give similar results if they have similar values for these four parameters.





BEFORE 2008_03_11 AFTER 2008_04_02

Courtesy Deborah Sarnoff, MD

Spot Size

Can be defined in different ways

Diameter of Injury

a. Diameter of ablation channel
- Common understanding
- Difficult to measure and may vary with laser power

b. Diameter of total injury
- More significant clinically than ablation diameter
- More difficult to measure and define

Diameter of Laser Beam

a. *Diameter containing > 90% of energy – good for most beams

b. $1/e^2$ power point
- not appropriate for many beam shapes including flat top beams

c. Diameter determined by observed impact
- subjective and inappropriate for gaussian-like beams.

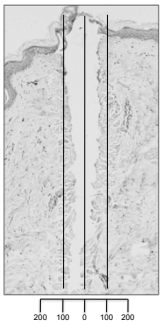
Note: Laser diameter (a.) is precise and reproducible, and a good parameter for comparing devices. It is very close to the diameter of ablation and easier to measure for comparing devices.

Spot Size

The image shows the ablation channel width of about 150 µm created with the Smartxide DOT ex-vivo in tissue with a 5 micropulse burst (Stack 5 setting) in fractional scanning mode.

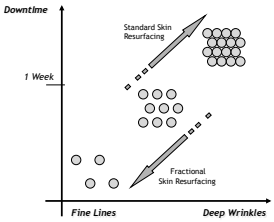
Channel sizes < 300µm heal quickly and are unnoticeable.

Channel sizes > 300µm can sometimes leave noticeable patterns long after healing.



Note: Spot size is less important clinically than percentage of area covered including the amount of thermal coagulation.

Pitch or Density



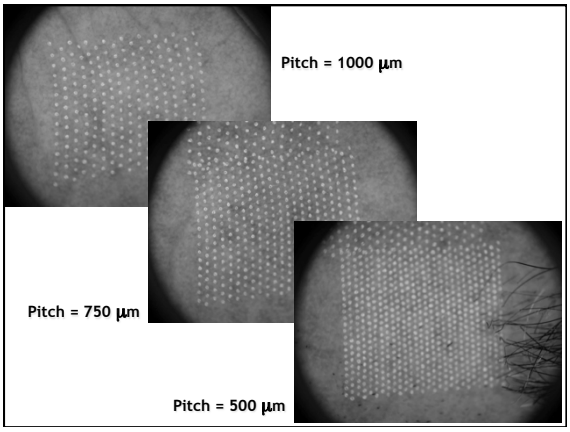
Pitch – dot spacing in microns or mm
Density – dots per unit area ≈ 1/pitch^2

Area treated ≈ (Spot Area) X (Density)

More area treated >
More dramatic results >
Longer recovery

Note: A wide range of spot density options is important to match the ideal treatment to the condition.

Reference: "In vivo histological evaluation of a novel ablative fractional resurfacing device" Basil M. Hantash et al. Lasers Surg. Med. 39:96-107, 2007



Laser Control Parameters

Parameters that Control Tissue Ablation

Beam size
- Measurable and correlates with the diameter of the ablated channel.

Power to tissue, or irradiance
- Determines the rate of ablation.
- High power beams vaporize tissue faster than low power beams.

Dwell time
- Determines the loss of heat due to conduction
- Determines the depth of ablation if beam power is known

Dot pitch
- Controls the amount of area treated for a given spot size

Laser Derived Parameters

Measured or calculated parameters

Pulse Energy - the **Power** and the **Dwell Time.**
- Correlated with the total amount of work done to tissue.
- Either the Dwell Time or the Power must also be known to understand the **Clinical Significance** of Pulse Energy.
- **Any laser can deliver any pulse energy if left on tissue long enough.**

Average Power - the **average** of the beam power including **ON** and **OFF** time.
- This has little to no **Clinical Significance** and is related to the maximum wall plug power required by the system.
- Most laser devices specify the maximum average power that can be delivered.
- **Usable average power is much less than the rated average power and is limited by treatment, delivery systems, and usability.**

Note: Pulse Energy and Average Power are not reliable indicators of relative device performance.

Trade Names & Marketing Terms

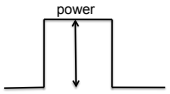
Superpulse, Ultrapulse, Chopped-Pulse, Gated-Pulse, CW are marketing or trade terms.

- Almost all medical CO_2 lasers can operate in both CW and Pulsed modes.
- The critical parameters are:
  Pulse height (power) and Pulse width (time)
- Some lasers can have modulated pulses for added features.

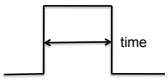
Laser Pulse Shape

There are two Significant Physics Parameters

1. **Pulse Height** – Irradiance (Power/Area)
   Determines ablation rate, or rate of thermal energy deposited, and is the power to tissue.



2. **Pulse Width** – Dwell Time on Tissue
   Governs the amount of energy used, or work performed on tissue at a specific irradiance level.



Pulsed CO_2 Laser Classification

CO_2 lasers can be classified by pulse capability

TYPES of PULSING

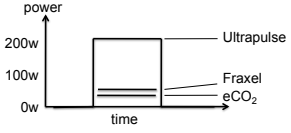
1. Gated-CW (chopped-CW)
2. Variable-CW
3. Enhanced Pulse
4. Modulated Pulse

Pulsed CO_2 Laser Classification

Gated- or chopped-CW

- Pulsed by gating on and off.
- Laser runs at nominal fixed power when on.
- Energy delivered is determined by gated on-time.

Typical operation of RF-excited lasers such as Lutronic ***eCO$_2$*** and Fraxel ***re:Pair,*** and the Lumenis ***UltraPulse ,*** which is a 200 watt CW laser that can be gated on for up to a millisecond.

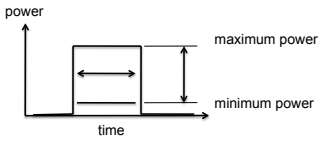


Pulsed CO_2 Laser Classification

Variable-CW

- Pulsed by gating on and off
- Laser power can be varied for additional control
- Typical operation of DC-excited lasers.

More control over parameters than typical RF-excited lasers.

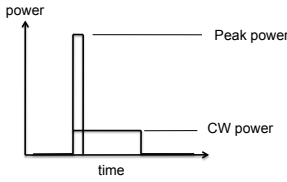


Pulsed CO_2 Laser Classification

Enhanced Pulse

- Sometimes referred to as ***Superpulse***.
- Laser tube gas volume is larger than needed for CW operation.
- Tube can deliver very high powers for very short times.

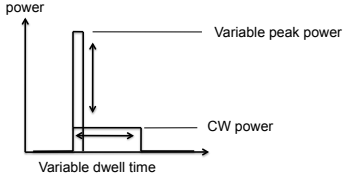
Typical of some DC-excited tubes such as ***Smartxide DOT***



Pulsed CO_2 Laser Classification

Modulated Pulse

- Custom pulse shape superimposing more than one mode of operation.
- ***DEKA SmartPulse*** uses an enhanced pulse for high-power ablation and variable-CW energy for coagulation.
- *Sciton* ***Contour*** and *Lumenis* ***Derma-K*** are examples of early modulated lasers for full resurfacing.



Misconception

Selective photothermolysis can be used to describe the residual thermal damage for CO_2 lasers.

The theory is not applicable. For 3 reasons:

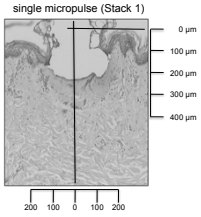
1. The energy from a CO_2 laser is mostly non-selective in tissue.
2. Much of the target is removed from surrounding tissue as well as the energy that the target absorbed.
3. A directly-heated tissue layer and a conductively-heated tissue layer remain after ablation and subsequently heats deeper layers of tissue.

This is a far more complex process* than the model described by the theory of selective photothermolysis.

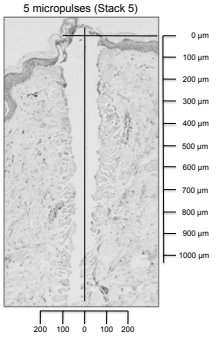
* McKenzie, *"A three-zone model of soft-tissue damage by a CO_2 laser."* Phys.Med. Biol. 1986, **9**:967-983.

Depth of Ablation

single micropulse (Stack 1)



5 micropulses (Stack 5)



The Smartxide DOT is a high performance CO_2 fractional system that can give consistent ablation channels to over 1mm in depth.

Depth is correlated with peak power and pulse width.

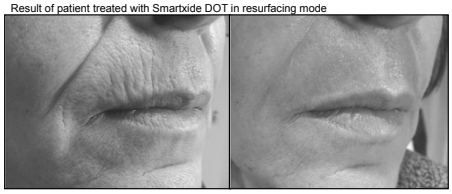
Note: Anecdotal correlation of depth with efficacy

How Deep is Enough?

Laser Resurfacing depth:

- 20 to 150 µm of ablation*
- 20 to 150 µm thermal damage*

Result of patient treated with Smartxide DOT in resurfacing mode

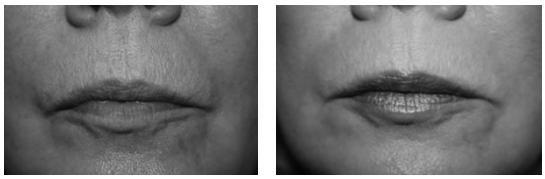


Depths of 300µm can give dramatic clinical results

* Kauvar A, *Histology of Laser Resurfacing*. Lasers in Derm, 1997,15:459-465

Transform Your Patients

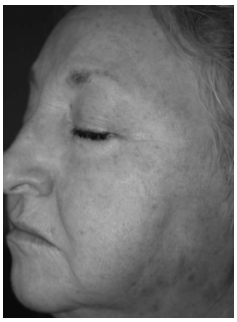
Upper Lip: 30W – 1000 Dwell – 500 Spacing



Used with permission of C. William Hanke, MD

30W – 1000 Dwell - 500 Spacing

PRE 7-2-08



POST 7-24-08

Courtesy of C. William Hanke, MD

Misconception

Deeper is better. Depths of 700µm or greater are required for CO_2 fractional resurfacing.

Many examples contradict this. A controlled study is needed.

1. Dramatic CO_2 resurfacing results obtained at < 700 µm.

2. Results with Smartxide DOT up to 400 µm with added thermal damage show good patient improvement.

Acne scars, burn scars and other conditions may require deeper treatment, but so far there is no indication that deeper is better.

Device Recommendations

Parameter	Range	Requirement
Laser type	CO_2	perfect match to requirements many other surgical uses
Spot size	< 400µm	faster recovery, no visible pattern
Ablation depth	> 1000µm	possible benefit for scars
Ablation time	< 100 µs	efficient controlled ablation
Power	enhanced	high peak power for efficient ablation
Spot density	0 – 100% adjustable	requires only 1 pass tailor treatment to patient
Delivery	scanner	controlled placement, reproducible, flexibility, speed, minimal tissue contact
Tx time	15 min	economics, pt throughput for full face, or neck and chest
Consumable	none	economic, consumables add no benefit

Thank You

Questions?