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An Overview on Fractional CO_2 Laser in Dermatology

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Abstract

Tremendous advances have been made in the medical application of the laser in the past few decades. Many diseases in the dermatological field are now indications for laser treatment that qualify for reimbursement by many national health insurance systems. Among laser types, the carbon dioxide (CO2) laser remains an important system for the dermatologist. The lasers used in photo surgery have wavelengths that differ according to their intended use and are of various types, but the CO2 laser is one of the most widely used lasers in the dermatology field. With its wavelength in the mid-infrared at 10,600 nm, CO2 laser energy is well-absorbed in water. As skin contains a very high water percentage, this makes the CO 2 laser ideal for precise, safe ablation with good hemostasis. In addition to its efficacy in ablating benign raised lesions, the CO2 laser has been reported to be effective in the field of esthetic dermatology in the revision of acne scars as well as in photo rejuvenation. With the addition of fractionation of the beam of energy into myriad micro beams, the fractional CO 2 laser has offered a bridge between the frankly full ablative indications and the nonablative skin rejuvenation systems of the 2000s in the rejuvenation of photo aged skin on and off the face.

Keywords: CO_2 Laser, dermatology, fractional laser.

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1. Introduction

The laser is the acronym from Light Amplification by Stimulated Emission of Radiation. Main characteristics of laser light are the monochromatic character, collimation and coherent beam [1]. The role of minimally invasive treatments in dermatology is to achieve maximum result with the minimal thermal injury to the skin. The original theory for selective photo thermolysis (SPTL) means using laser energy at high peak powers and short pulse widths to destroy the intended target alone while inflicting as little damage as possible on the surrounding tissue [2]. Three key conditions must be met to achieve this: 1) The target must contain chromophores that absorb a specific laser wavelength; 2) These chromophores should not be found in the surrounding tissue; and 3) Minimization of damage to surrounding tissue is achieved through high peak powers and short pulse widths of laser energy in millisecond, microsecond or nanosecond domain. CO_2 laser does not meet criteria for SPTL because its chromosphere, water, exists uniformly in soft tissue, not just in target zone. CO_2 laser surgery could therefore be described as tissue-selective since only target tissue is ablated with minimal involvement of surrounding normal tissue.

The advantage of this is that the CO_2 laser is not pigment-selective, and so both pigmented and non-pigmented skin lesions can be targeted with the CO_2 wavelength [1]. Selective laser thermal injury was developed for skin remodeling resulting in superficial ablation of the skin, characterized by islands of spared skin, from which recovery after laser treatment start, which is known as fractional photothermolysis (FP) [3]. Traditional, non-fractionated, fully ablative lasers with carbon dioxide (CO_2), and erbium: yttrium–aluminum– garnet (Er: YAG) lasers have been for years the gold standard in laser resurfacing. They target intracellular water as a chromophore, leading to epidermal and superficial dermal vaporization and ablation of up to 200 µm in depth. Although clinically effective, the associated down time and potential side effects, including persistent erythema, permanent hypopigmentation, infection, and even scarring, led to search for alternative treatment approaches [4]. Development of FP attempts to achieve comparable clinical results to ablative lasers but with fewer adverse effects and down time [3]. 1,550 nm erbium-doped fiber non-ablative laser is first fractional laser approved for clinical use.

By creating an array of microscopic treatment zones (MTZs) with controlled width, depth and density, a percentage of skin is thermally coagulated and treated in each session, whilst leaving the stratum corneum intact. The adjacent viable tissues surrounding these MTZs allow for rapid reepithelialization and hence less patient down time. This technology has proven effective for numerous dermatological conditions, including photo aging, scars, dyschromia, and poikiloderma [5]. The concept of fractional photothermolysis has since been extended to ablative lasers with the intention of achieving more efficacious results than non-ablative lasers, but with fewer side effects and more rapid recovery compared to traditional ablative laser treatment [6]. CO_2 laser is the powerful weapon in the treatment of many dermatological diseases wrinkles, scars, dilated pores, stretch marks, benign growths on the skin. Therefore it's a good opportunity for the rejuvenation of the skin. Ablative laser resurfacing of the skin is safe and semi-invasive; however careful approach is necessary for adjusting treatment parameters for the minimalisation of the complication and optimization of the results [7].

2. Mechanism of action

Ablative fractional resurfacing (AFR) with 10,600 nm CO_2 laser utilizes fractionated laser beams to produce an array of microscopic columns of controlled deep dermal tissue volumetric ablation and vaporization, which are surrounded by thermally induced annular coagulation zones of denatured collagen with interspersed regions of untreated tissue [8]. Much greater depth of penetration, ranging from 300 µm to over 1 mm, can be achieved when energy is delivered fractionally [9]. The subsequent robust dermal remodeling is reflected by the greater degree of tissue contraction and collagen production compared to non-ablative fractional treatment [10]. The denaturation temperature of collagen is conventionally stated to be 66.8˚C, although this varies. Once denatured by laser-generated heat, collagen rapidly contracts as fibers shrink to one-third of their length. The shrinkage of collagen is the primary mechanism of skin tightening, although vaporization of intracellular water and ablation contribute as well. Next, a wound-healing phase is initiated characterized by extremely high levels of collagenases (matrix metalloproteinases), which degrade the fragmented collagenous matrix [11]. Rapid reconstitution of the epidermis from adjacent epidermal cells contrasts with healing after traditional resurfacing in which new epidermis is derived from cells that migrate from adnexal structures.

A prolonged period of dermal neocollagenesis of up to at least 6 months follows [12]. Ablative fractional resurfacing with CO_2 lasers appear to have a better safety profile compared to traditional ablative lasers. This is due to the interspersed untreated cutaneous tissues allowing for complete reepithelialization in 3–6 days, compared to 2–3 weeks with traditional ablative lasers [10]. To achieve ablation without excessive thermal damage, a fluence of 5 J/cm^2must be delivered within a pulse duration of <1 ms, the generally agreed upon thermal relaxation time of skin [13]. The mechanism of action of Fractional CO_2 laser in treatment of AA is thought to be; induction of T cell apoptosis, arresting hair follicles in telogen stage and promoting anagen stage and denovo neogenesis of hair follicles from non-hair follicle stem cells [14]. Anagen inductions also could be related to Wnt/β-catenin signaling pathways reported after fractional laser in a murine model study [15]. Meanwhile, laser induction of thermal effect on papillary dermis stimulating hair regrowth [16]. Furthermore, generating micro thermal treatment zones by fractional lasers can provide channels for a uniform and controlled transepidermal drug delivery for traditional topical medications as corticosteroids [17].

The CO_2 laser remains an efficient, precise and safe system for the dermatologist. Technological advances in CO_2 laser construction have meant smaller spot sizes and greater precision for laser surgery, and more flexibility in tip sizes and protocols for fractional CO_2 laser treatment. The range of dermatological applications of the CO_2 laser is expected to continue to increase in future [1]. Fractional CO_2 laser therapy and micro needling are safe and effective treatments for AA, according to modest studies. Many hypotheses have been put up as to why hair regrowth occurs following skin resurfacing operations. There aren't enough clinical data to draw any firm conclusions about the effectiveness of these new treatment modalities. The combination of therapies with topical drug administration has potential to be effective because of enhanced drug delivery [18]. Fractional laser therapy stimulates hair regeneration by causing skin to heat up. Fractional lasers have both a direct and indirect therapeutic effect on hair follicle via transepidermal drug delivery of 5 FU. Topical 5 FU for resistant AA can now be delivered via fractional carbon dioxide laser–assisted drug delivery [18].

3. Basic considerations for fractional CO_2 laser

- Spot size: spot size of laser refers to diameter of irradiated beam, varies from 125 µm to 1.25 mm. As spot gets bigger re-epithelization process takes longer, which in turn causes a longer downtime, therefore, it is important to make spot small to facilitate safe treatment and fewer inconveniences.
- Laser beam irradiation method: micro lens array method in which the beam goes through the lens and is simultaneously irradiated after being divided into several fine beams that treats the parts by stamping micro beams, the other one is also a stamping method, but uses optical scanner to scan a very small laser spot across the skin.
- Density: is an important parameter and determines the amount of surface area that treated. Density is equivalent to treated area divided by the total surface area, extending from 5% surface area coverage to 100%, depending on device.
- Characteristics of the beam: 1) power, 2) pitch, 3) dwell time, and 4) micro spot diameter [19]. *The first* parameter is the power (wattage), which is the energy delivery per micro beam. This varies from 5 to 100 mJ/micro beam per device. The power output and penetration depth directly proportional for a set micro spot diameter. *The second* parameter is pitch or micro spot spacing. As pitch or spacing is decreased, the density or surface area of skin treated increases. Some devices have adjustable pitch, whereas others are fixed. *The third* parameter is dwell time or pulse duration of each micro pulse which correlates with the degree of thermal injury at a given micro beam fluence. *Finally*, the micro beam diameter, which is fixed for each device, and plays an important role in penetration depth [20]. As power output is increased, ablative penetration depth is increased. As dwell time or pulse duration is increased, so rises the degree of collateral thermal injury that is incurred. Ideally, for reasons of maintaining adequate hemostasis and potentially inducing greater neocollagenesis, a combination of both ablative and thermal injury appears to be desirable. Micro spot density is inverse of micro spot pitch or spacing. As the pitch or spacing is decreased, density of micro lesions and treated surface area increases. As pitch or micro spot spacing is increased, the density of treated skin decreases, and this correlates with decreased patient discomfort and faster recover time [20].

4. Clinical applications of fractional CO_2 laser

Laser induces regeneration by vaporizing aging tissue at epidermis and dermis. It can effectively lead to regrowth and re modelling in process, so it can be applied broadly to a variety of issues (scar, pigmentation, texture so on) at epidermis and dermis and it is also effective to improve aging skin laser can treat from 0.2mm in depth to 1mm or more at dermis. CO_2 fractional laser can be utilized to various indications of epidermis and dermis as in (Table 1) [19].

5. Clinical findings after fractional CO_2 laser treatment

Immediately following pulsing with fractional ablative Laser Skin Resurfacing (LSR), white <1-mm macules appear on skin surface. They change within minutes to erythematous macules, which correlate clinically with mild to moderate erythema. With several devices, pinpoint or multifocal hemorrhage may occur immediately post treatment. Postoperative erythema may increase in subsequent 1 to 3 days. If low power employed, erythema may be mild and resolve within 1 day; at high power settings and dwell times, erythema may be pronounced with accompanying edema for up to 7 days or more. In cases where periprocedural hemorrhage occurs, crusting expected, typically resolving within 7 days [20]. Procedure is more painful than nonablative fractional, but less than traditional ablative LSR. Each device may employed across a spectrum of settings from gentle to aggressive, with increasing power, dwell time, and micro spot density resulting in increasing discomfort and recovery time. Clinical outcomes from fractional CO_2 LSR depend on 4 key parameters, as well system and number of treatment sessions [20].

6. Histological findings after fractional CO_2 laser treatment

Histological evaluations of fractional CO_2 LSR have demonstrated the direct correlation between energy output and ablative depth of penetration [21]. The wound healing during the first 30 days following treatment with a fractional ablative CO_2 laser demonstrated granulation tissue at 1 to 3 days, followed by progressive neocollagenesis and dermal remodeling to 30 days post treatment. Neocollagenesis continued for several months post treatment, as had been demonstrated for standard ablative CO_2 LSR [22].

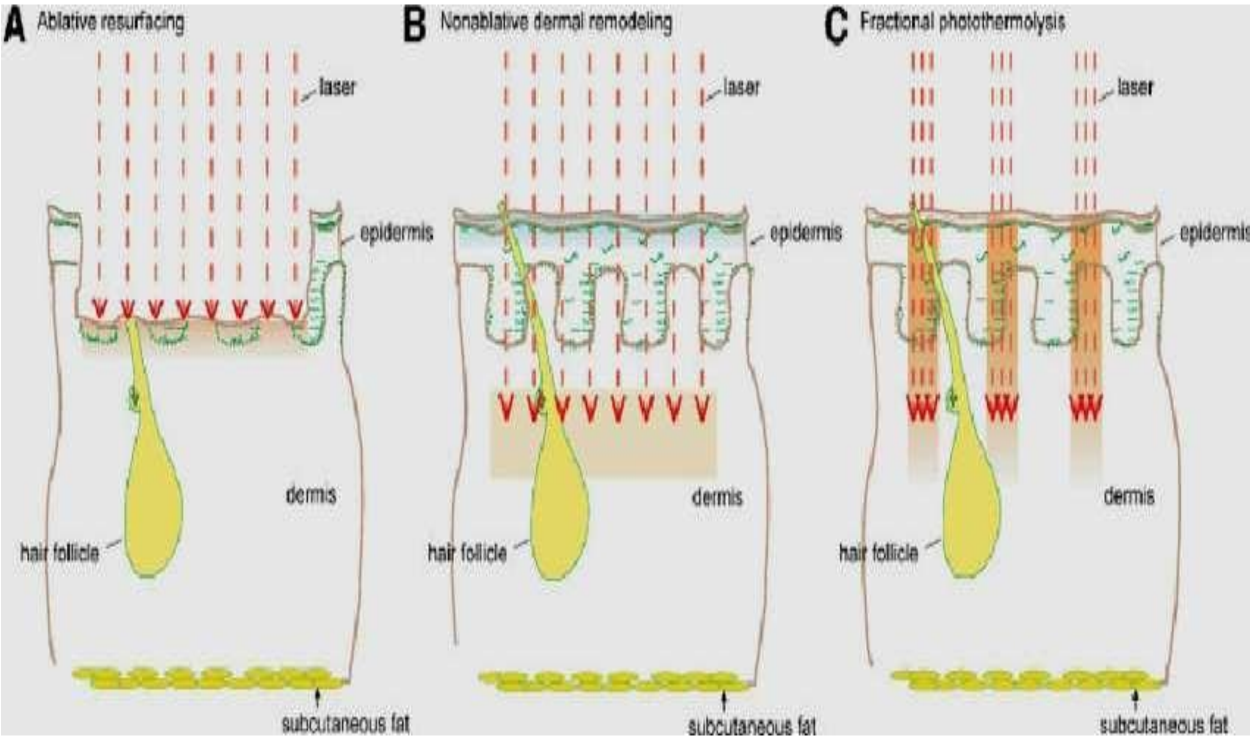

Figure 1: Comparison of ablative skin resurfacing (ASR), non-ablative dermal remodeling (NDR), and fractional photothermolysis (FP). A: ASR removes the epidermis and causes residual thermal damage within the dermis. Reepithelialization is delayed because of relative long migratory path lengths for keratinocytes that repopulate from skin appendages. B: NDR creates a layer of thermal damage below the surface without causing epidermal removal or damage. C: FP is the distribution of microscopically small volumes of thermal damage, MTZ, within the skin. Epidermal repair is fast due to small wounds and short migratory paths for keratinocytes [3].

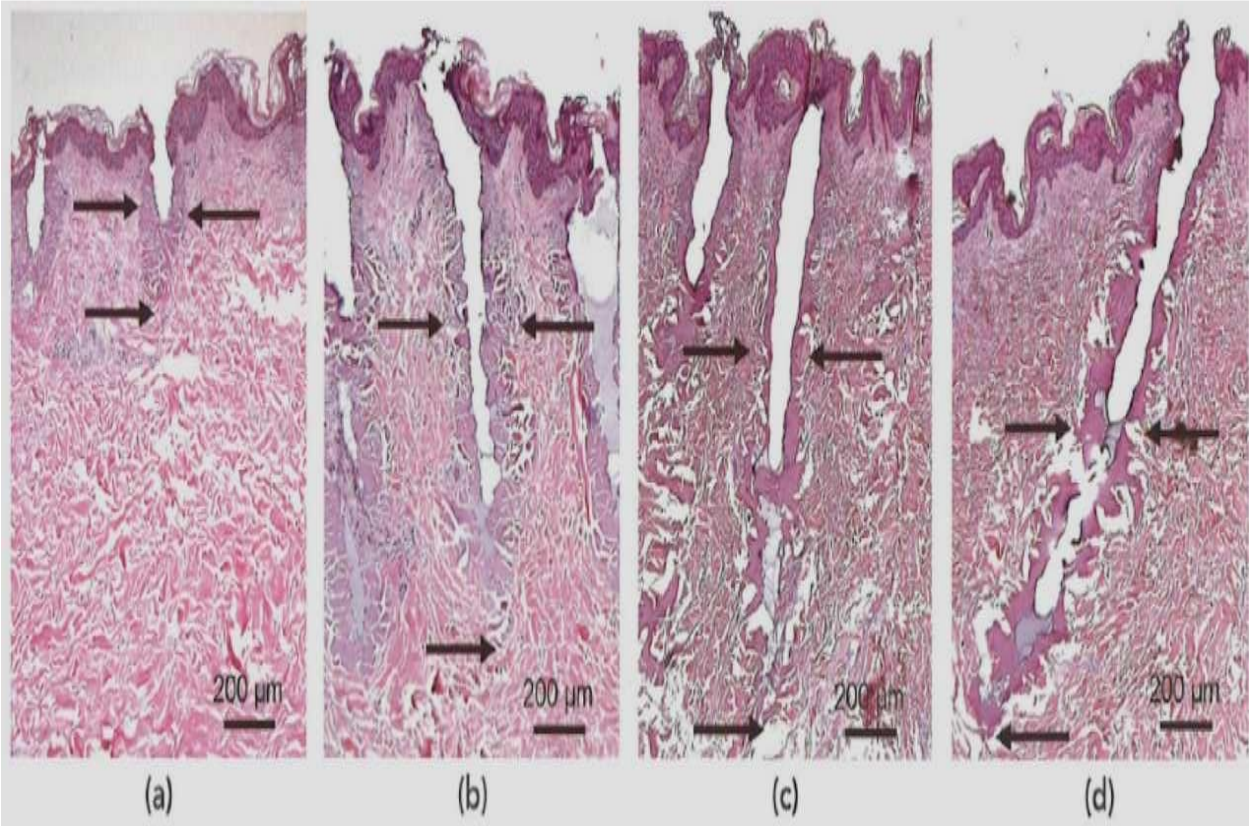

Figure 2: Histologic findings immediately following fractional CO_2 laser resurfacing. (a): immediately following irradiation,(b):columns of ablation (vaporization) are evident,(c):extending from the epidermis into the dermis with adjacent collateral thermal denaturation of collagen.(d):The depth of penetration of the column correlates with the energy output of the device [20].

Table 1: Clinical applications of fractional CO_2 laser **[**19].

1. Superficial problem
◆ Pigmentary lesions
◆ Pore
◆ Texture & aging skin
◆ Laxity(hand, neck)
◆ Wrinkles
2. Surface and deeper structure
◆ Scar
◆ Striae distensa
3. Dermal problem
◆ Pigmentary lesions: refractory PIH, tattoo

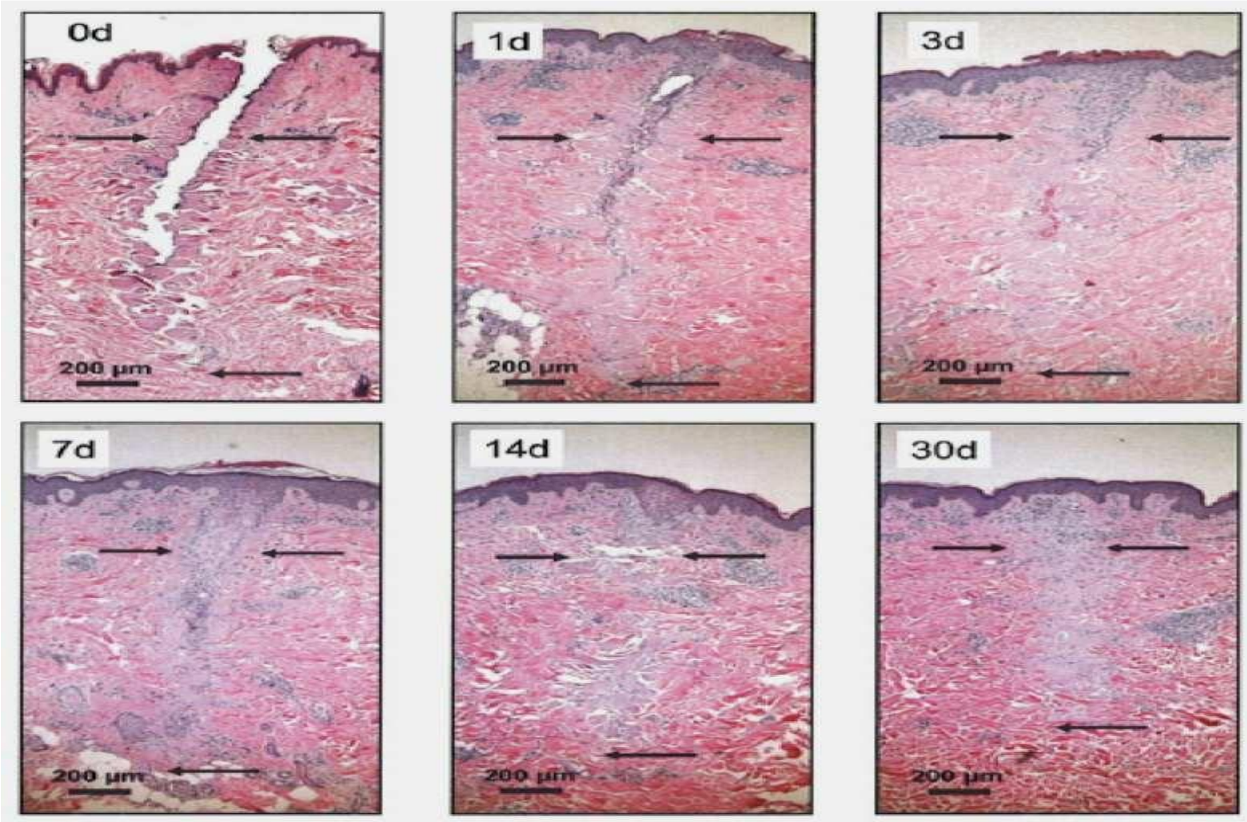

Figure 3: Histologic findings over 30 days following fractional CO_2 laser resurfacing. Over the 30 days, the ablative column is replaced by granulation tissue, which then results in neocollagenesis evident by postoperative day 30 [20].

Table 2: Complications of fractional laser skin resurfacing [23].

Degree of Severity		
Mild	Moderate	Severe
Prolonged erythema	Infection	Hypertrophic scarring
Acne and milia	Pigmentary alteration	Ectropion formation
Delayed purpura	Anesthesia toxicity	Disseminated infection
Superficial erosions	Eruptive keratoacanthomas	
Contact dermatitis		
Recall phenomenon		

4. Side effects and complications

Adverse events include erythema, edema, crusting, depigmentation, infection, and scarring. Risk of infection is higher than for nonablative LSR, but lower than that of traditional LSR. The risk of herpes simplex virus reactivation necessitates premedication with antivirals. Good postoperative wound care is essential. Postoperative erythema, may manifest in a dot like pattern, may persist for weeks or months following fractional ablative LSR. With deeper penetrating devices, postoperative erythema, in a dot like pattern, typically lasts an average of 3 months, but subtle erythematous micro macules may persist for up to 12 months. A recall phenomenon, where redness reappears with histamine release or increased blood flow, as during exercise. Post procedural dermatitis, eczematous dermatitis, and allergic contact dermatitis. Acneiform eruptions, either due to the thermal effect or occlusive hydrophobic wound dressings, may also occur [23]. Postinflammatory hyperpigmentation is commonly observed in treatment of patients with darker skin photo types. Treatment options to speed its resolution include topical bleaching agents (hydroquinone, kojic acid); retinoic, azelaic, ascorbic, glycolic acid products; and broad-spectrum sunscreens to prevent further ultraviolet light-induced melanin synthesis. Regardless of intrinsic skin photo type, patients with suntans should avoid treatment until their tans fade to reduce likelihood of laser induced melanocytic stimulation with subsequent postoperative hyperpigmentation [24].

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