Fractional lasers; NAFL and AFL

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Fractional lasers, by virtue of rapid healing, provide a means to reduce the complications and downtime associated with ablation lasers, while maintaining a laser thermal effect superior to that of non-ablative rejuvenation (NAR) lasers. Therapeutic effects of non-ablative fractional lasers (NAFL) are achieved by irradiation of multiple micro-treatment zones on the skin. Compared to NAFL, the micro-columnar ablation effect of ablative fractional lasers (AFL) provides superior skin elasticity improvements and skin contraction. Fractional lasers are effective for both aging facial skin rejuvenation and scar improvement. Early treatment of acute stage scars is recommended for better results. With a thorough understanding of the characteristics of NAFL and AFL, clinicians can properly apply each type of laser for satisfactory rejuvenation and scar treatment.

Key words
Fractional laser; Scar; Rejuvenation
INTRODUCTION

The development of fractional lasers

Laser resurfacing, which removes the outer layer of the skin to promote skin regeneration, has been in active use since the mid-1990s. Laser resurfacing also employs the effect of heat to increase skin elasticity along with regeneration. Ablative lasers efficiently resurface the skin while safely controlling penetration depth, and post-operative care is easy for the patient. These lasers can remove lesions from the skin surface, regenerate aging skin, smooth out elevations and depressions in scars, and increase skin elasticity, with an overall effect of marked skin rejuvenation [Fig. 1A].1,2

However, such ablative lasers do have their shortcomings. Post-procedural wound healing usually requires at least one week, and the erythema and pigmentation that can occur after laser skin resurfacing can result in social downtime that discomforts patients. Complications such as infection or hypertrophic scarring can also arise. Compared to CO2 lasers, the effect of Er:YAG lasers with less thermal damage on surrounding tissue leads to quicker healing, with earlier subsidence of erythema and less pigmentation, but even with these lasers, deep peeling can cause the same discomforts as in CO2 lasers.3,4

Non-ablative infrared lasers were developed as a method to minimize social downtime while still increasing skin elasticity and regenerating the skin dermis. The infrared wavelength of these lasers penetrate deep into the dermis layer. Low-output Nd:YAG lasers were also used to avoid the drawbacks of ablative lasers, using heat effect to regenerate only the dermis, while preserving the epidermis by use of a cooling apparatus. Since these devices induce rejuvenation without resurfacing skin, they were named NAR (Non-Ablative Rejuvenation) lasers [Fig. 1B]. Although theoretically ideal, the efficacy of these lasers did not fulfill expectations, and their use fell into a decline.

The disappointing results of non-ablative infrared lasers called for more powerful devices, and as Manstein5 presented the concept of fractional photothermolysis in 2004, the Fraxel® laser was developed and put to use. Although the term ‘Fraxel’ is used like a common noun to describe a general type of laser, originally it was a name given to a specific laser developed by Reliant company, and the accurate title for these so-called ‘Fraxel’ lasers should be ‘fractional lasers’ or ‘micro-focal ablative lasers’ [Fig. 1C].

The first fractional laser was a 1,550 nm Erbium glass laser, which transferred heat to the epidermis and dermis through tiny microbeams [with diameters smaller than 100 µm]. Epithelization originating from the unharmed tissue surrounding the irradiated area was finished within 1-2 days, and dermal regeneration also ensued within 1 week. Post-procedural erythema was also limited to a

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Fig. 1. Four different lasers. (A) resurfacing laser, (B) NAR, (C) NAFL, (D) AFL.
few hours, which meant almost zero social downtime. Although these early fractional lasers were more effective than the non-ablative infrared lasers, ablative lasers with fractional properties such as the CO2 fractional and Erbium fractional laser were developed in succession, to fulfill the demand for more powerful effects. These AFLs (Ablative Fractional Laser) [Fig. 1D] vaporize micro-diameter columns of the epidermis and dermis and exert heat effect on the surrounding tissue for a stronger effect than NAFLs (Non-Ablative Fractional Laser), albeit with a downtime of about 2-3 days.1-6

**MATERIALS AND METHODS**

**NAFL; non-ablative fractional laser**

‘Fractional’ literally means a fraction, or portion, of the entire surface. Whereas skin resurfacing deals with the whole surface of the skin, fractional lasers conserve most of the skin while effecting portions and parts of it, irradiating the skin with narrow and deep-penetrating laser beams for therapeutic effects. Fractional lasers, developed along the concept of fractional photothermolysis, employ up to 400 micro-sized beams with diameters of 50-100 μm in 1 cm² of target skin; this amounts to only 5-10% of the skin being directly irradiated by laser.7 The penetration depth of fractional lasers can be controlled by altering the energy strength of the laser beams. Weaker power (mJ/beam) settings have less penetration; with higher power settings, penetration depth increases, and laser heat can be transmitted down to a depth of 400 μm, into the upper dermis. Er:Glass fractional lasers have a near-infrared wavelength of 1,550 nm, with penetration down to the dermis layer.

The MTZ (microscopic treatment zone) refers to the area of tissue directly receiving heat from the laser beams. The innermost core area of the MTZ is the zone which receives the most heat, with irreversible damage leading to tissue necrosis, and rapid regeneration from the surrounding intact tissue. The area around the central core of the beam is heated to a lesser degree, with reversible tissue changes [Fig. 2A].

The deep but narrow irradiation of fractional laser beams necrotize the epidermis, but rapid re-epithelization follows; complete epithelization usually occurs within 24 hours. The necrotized epithelium remains for a few days, acting as a barrier against external microbes. The irradiated dermis also undergoes necrosis; while certain parts of the necrotized dermis are resorbed, other portions of the necrotic debris are pushed toward the skin surface and excreted, as MEND (microscopic epidermal necrotic debris).8

Fractional lasers can be used in dynamic mode, which irradiates continuously as the operator moves the hand piece, and in stamp mode, which treats only a fixed area. Engulfing a target area measured in cm² with hundreds to thousands of micro-beams, fractional lasers can repeatedly irradiate therapy sites. Topical anesthetic creams are usually used for pain reduction before treatment sessions.

Skin irradiated by fractional lasers instantly becomes

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**Fig. 2.** Histology of NAFL (A, Fraxel®) and AFL (B, eCO2®). MTZ, micro treatment zone; MAZ, micro ablative zone; MEND, micro epidermal necrosis zone; MCZ, micro coagulation zone. (supplement from Reliant Co., and Lutronic Co.).
erythema and edematous; both of these conditions subside within hours. Usually no specific wound care is needed, although applying cool air or wet gauze to the skin does comfort the patient. Makeup can be applied to the therapeutic area on the next day, with almost no social downtime, which is one of the greatest advantages of NAFL. Pigmentation can occur in Asians with predispositions to similar problems such as melasma, but to a much lesser extent than with resurfacing lasers.9

These non-ablative fractional lasers include Erbium Glass lasers (1,550 nm), Nd:YAG lasers (1,440 nm) and Thulium lasers (1,927 nm).

AFL; ablative fractional laser

Although the therapeutic effect on skin elasticity of NAFLs was superior to that of nonablative near-infrared lasers, their efficacy was lesser than that of resurfacing lasers. This gave rise to a demand for ablative fractional lasers which could reduce the social downtime and complication rates of resurfacing lasers, ensure rapid healing similar to NAFLs, and still retain the efficacy of resurfacing lasers. CO2 fractional lasers, which add fractional aspects to conventional CO2 lasers, have been introduced since 2007, and fractional versions of the skin-resurfacing lasers have also followed.10

AFLs (Ablative Fractional Laser) have the advantages of both skin resurfacing lasers and fractional lasers, attaining intermediate characteristics somewhere in the middle of these two different types. AFL beams resurface deep but narrow columns of skin, with rapid wound healing occurring from surrounding areas. The micro-beams of AFL have diameters between 50 μm to 100 μm, with pulse densities of 50-200 pulse/cm². Higher pulse energy (mJ) translates to deeper penetration with a maximal penetration depth of 2,000 μm (2 mm), down to the deep dermis, effecting the entire skin layer.

When AFL is used on skin, the epidermis penetrated by the beams is instantly vaporized in micro-columns reaching down into the dermis, as if the skin were struck by a conventional resurfacing layer; these columns are called micro-ablative columns (MAC) (Fig. 2B). The areas surrounding these columns do not reach temperatures over 100 degrees Celsius and therefore are not vaporized; the areas immediately adjacent to the MACs form thin layers of irreversible necrosis, while tissue more distant from the MACs display reversible skin contraction (tightening).

The epithelial columns vaporized by AFL begin regeneration within several hours, and complete re-epithelization is usually achieved within 2 days. The partially vaporized and necrotized dermis is replaced by new dermal tissue; remodelling occurs within 2-4 weeks, with collagen fibers increasing for up to 2-3 months.11,12

Some oozing may appear up to the next day after AFL treatment, but patients are permitted to wash their faces from this day on, and from the post-treatment second day, normal activities including wearing makeup are permitted; therefore, AFL can be considered as an ideal weekend procedure with minimal social downtime. Post-procedural erythema with AFL does persist longer than in NAFL, but still has a shorter duration than in laser skin resurfacing. Depth and duration of erythema vary according to pulse energy levels.

Pain associated with AFL is more intense compared to that of NAFL; when treating small areas, topical anesthetic cream is applied, but when large areas of skin are targeted, local block anesthesia or sedation may be required.

Complications other than erythema or pigmentation rarely occur after AFL; although skin infections have been reported, the prevalence is much lower than in laser skin resurfacing. Post-procedural pigmentation also is much rarer and lighter than in skin resurfacing lasers, but prescribing lightening creams in advance for 4-8 weeks to prevent hyperpigmentation may be recommended in individuals with darker skin or predispositions such as melasma. Common complications of skin resurfacing lasers such as hypertrophic scarring, hypopigmentation or decoloration do not occur with AFL; this may be attributed to rapid epithelization from intact skin surrounding the micro-ablative columns.13

Unlike NAFL, skin tightening during AFL treatment can be visualized with the naked eye, with a generous improvement in skin elasticity. Generally speaking, AFL can be considered as having intermediate properties between NAFL and resurfacing lasers, including aspects such as skin tightening effect, complications, and social downtime. When repetitive sessions are desired, AFL can be repeated every 2 months in the facial area, and every 3 months in other body areas and extremities; such repetitive therapy can enhance the effects of AFL.

Apart from fractional CO2 lasers (10,600 nm), Er:YAG fractional lasers (2,940 nm) and Er:YSGG fractional lasers (2,790 nm) also are classified as AFL. As Er:YAG lasers have higher affinity for water compared to CO2 lasers, with less penetration consequentially, Er:YAG fractional lasers also display lesser penetration and vaporization than CO2 fractional lasers (Fig. 3). Er:YSGG fractional lasers are similar to Er:YAG fractional lasers in nature.
The rejuvenation effect of fractional lasers is achieved through tightening of aged facial skin and increased elasticity, which improves wrinkles; reducing melanin-related senile lesions such as lentigo also decreases skin spots and blotches, resulting in a cleaner, and younger-looking, complexion. Generally speaking, rejuvenation effect is greatest with skin resurfacing lasers, followed by AFL, NAFL, and non-ablative rejuvenation lasers.6,14 Although many studies on the rejuvenation effect of lasers have been reported, degrees of improvement differ from report to report, and few studies present objective comparative data. For this reason, the author conducted animal studies to objectively compare and prove the effects of fractional lasers.15-19

20 mm × 20 mm areas were tattooed on the abdomens of white rats, and irradiated with NAFL and AFL for comparison with control groups. In the NAFL group, an Er:Glass fractional laser (1,550 nm, Mosaic®, Lutronic Co.) was used at 40 mJ, 100 pulse/cm² for 3 passes, for a total energy of 12,000 mJ. In the AFL group, a CO₂ fractional laser (10,600 nm, eCO2®, Lutronic Co.) was used at 80 mJ, 150 pulse/cm² for one pass, and an identical total energy amount of 12,000 mJ. Fractional laser therapy was repeated 4 times at 3-week intervals, and 4 months after each final laser session, changes in skin surface area and histology were examined (J Plast Reconst Aesth Surg, 2012; 65, 1305-1311. Skin-tightening effect of fractional lasers: comparison of non-ablative and ablative fractional lasers in animal model).20

The results displayed no immediate skin surface area shrinkage in NAFL but a 4.3% decrease at 6 months, and an immediate decrease of 11.5% in AFL which would wax and wane, until maintaining a 9% decrease at 6 months. Histological findings of the epidermis exhibited recovery of normal tissue nearly identical to pre-procedural epidermis, whereas in the dermis collagen fibers were thickened and arrayed parallel to the skin surface, increasing skin elasticity; findings after AFL were more similar to post-skin resurfacing laser findings compared to NAFL. Collagen levels of subtype I and III were initially decreased after fractional laser, but gradually increased, with no change in the component ratio.

Electron microscope findings of the collagen fibrils displayed a 4.6% decrease of fibril diameter and 0.8% decrease of length after NAFL treatment; fibril diameters decreased 14.8% with a 5.2% decrease of length after AFL, with more dense collagen fibrils in the AFL group compared to the NAFL group. These findings translate to a greater increase in skin elasticity with AFL compared to NAFL.

2) Aging spot and pigmentation disorders

Pigmentation disorders also improve after fractional laser treatment. Although the immediate effect is less than with skin resurfacing lasers, repetitive treatments improve the results. Since fractional lasers follow the concept of selective, or partial, resurfacing, only 10-20% of the target area actually is effected; hence the overall effect is weaker than skin resurfacing lasers.

Liver spots such as seborrheic keratosis, solar keratosis and solar lentigo commonly seen in aging skin are improved as the epidermis is shedded. Deeper dermal pigmentation lesions also improve as the fractional laser beams penetrate into the dermis and destroy micro-columns, with subsequent resorption of necrotized microtissue or surface shedding of MEND.21 Melanin pigments, which mainly lay in the epidermal-dermal border, are faded by fractional laser, as are deep dermal melasma or Ota nevi. However, when the objective is to treat only pigmentation disorders, Q-switch lasers designed specifically for melasma, pigments, tattoos and such are superior to fractional lasers. Although fractional lasers can improve rhytids and liver spots in aging skin through rejuvenation effects, PIH (post-inflammatory hyperpigmentation) can occur in melasma or sensitive skin types. It is for this reason that lasers must be chosen and used selectively, with concomitant skin care.
After fractional laser treatment, melanin rapidly migrates and regenerates, safely recovering skin color without the severe discoloration or hypopigmentation that sometimes follows laser skin resurfacing. Fractional laser not only removes abnormally excessive melanin pigment but also induces melanocyte migration and melanin pigment formation in hypopigmented skin. These properties lend to superior results with refractory discolored skin lesions.22

Effect on scars

1) Atrophic scars, depressed scars
Acne, chicken pox or smallpox-induced inflammation gives rise to reddish edema in the acute phase, but as the lesion settles into the chronic phase, the inflammation subsides with scar tissue formation in the deep dermis and a crater-like depression on the skin surface. Skin resurfacing lasers are effective in these cases, but deep dermal scarring is difficult to resolve, and patients are frequently unsatisfied with the results. Resurfacing to excessive depths can leave complications such as hypertrophic scarring or discoloration, and the social consequences of erythema persisting for several months must also be considered.

NAFLs are largely ineffective on atrophic scars, with unsatisfactory results even after several sessions. On the other hand, AFL can be as effective as skin resurfacing laser with repetitive treatment sessions; AFL is also safer than resurfacing laser with more rapid recovery and less social downtime, making it suitable as a weekend procedure.23,24

The author has previously conducted clinical studies to verify the effect of fractional lasers on acne scars. Photographic analysis of the results of NAFL and AFL on volunteers with acne scars revealed an improvement of 2.16 points out of 10 with an average of 4.4 treatment sessions with NAFL (Er:GLASS), and 5.19 points improvement with an average of 3.4 sessions with AFL (CO2 fractional); AFL achieved better results even with fewer therapeutic sessions.1

Laser skin resurfacing should be recommended initially for severe acne scars or pockmarks; for patients desiring further improvement of scars after laser resurfacing, AFL can be recommended after erythema subsides. While deep resurfacing laser treatment can only be repeated after 6-12 months, and only up to 2-3 sessions, AFL, which is safer with a more rapid recovery time, can be repeated for more than 5-6 sessions at 2-3 months’ interval.

2) Hypertrophic scars
The previous rule of thumb was to wait 6 to 12 months for scar maturation before attempting any type of scar revision. However, the application of laser therapy to scars has dramatically changed this paradigm.

Wound healing proceeds through an inflammation phase to a proliferation phase, which is followed by a maturation or remodeling phase after several months. During the inflammation phase, cells such as leukocytes and platelets increase and secrete inflammatory cytokines. The proliferation phase is hallmark by capillary proliferation, blood flow increase, and collagen fiber accumulation. The proliferated collagen layer decreases in the maturation phase, irregular collagen fibrils are rearranged methodically, and the firm elevated scar softens and flattens out.

NAFLs have longer wavelengths than AFLs, penetrate deeper into the dermis, and suppress collagen proliferation while reducing blood flow more effectively, while also inducing remodeling of the proliferated collagen fibril layer. Through these processes, fractional lasers both suppress the proliferation phase of scars and hasten the maturation phase. Early erythematous scars are best treated with NAFL, while AFLs are better for chronic non-erythematous scars [Fig. 4].

NAFL treatment on acute-stage acne can suppress sebum excretion and alleviate inflammation, just as low-output lasers are used for acute acne treatment. The long wavelength of fractional lasers effectively restrain sebaceous glands by penetrating into dermis depth. NAFLs also reduce blood flow by virtue of heat effect on capillaries, which helps control acne formation.

AFL treatment vaporizes microcolumns of tissue, pro-

Fig. 4. NAFL treatment of post operative hypertrophic scar on abdomen.
moting skin regeneration. Subsequent skin tightening and elasticity increase improves skin irregularities; the skin color and tone also becomes more uniform with surrounding areas, which improves the general appearance of scars (Fig. 5).125

3) Other scars

Stretch marks occur on locations such as the abdomen, thighs, and upper arms, which, unlike the face, have limited skin appendages, precluding and limiting the efficacy of deep laser resurfacing. Stretch marks are the result of rapid stretching of the skin, usually associated with pregnancy, rapid weight changes, or surgically implanted tissue expanders. In the early phases of stretch mark formation, as an acute reaction, they may take on the erythematous appearance of hypertrophic scars. During this period, capillaries proliferate and collagen layers accumulate; hypoxia-inducing vascular therapy lasers are used to treat these marks at this stage. Pulse dye lasers, long pulse lasers, IPL, and NAFL are effective during this period.

Chronic stretch marks are no longer erythematous and can be targeted for laser scar therapy. IPL and pulse dye lasers have little effect at this stage; powerful fractional lasers that penetrate deep into the dermis and induce skin contraction are recommended. Both NAFL and AFL effectively improve stretch marks by conducting heat through narrow but deep channels, which, while regenerating from the surrounding tissue, shrink and contract, ameliorating the scar.26

Using AFL on burn scars vaporizes microportions of scar tissue, which subsequently regenerate from surrounding tissue, smoothing out uneven skin surfaces. Burn scars frequently display blotched irregular skin colors, which also can be improved by fractional laser treatment, fading hyperpigmentation and darkening hypopigmentation through melanocyte and melanin migration. Since burn scar tissue is different from normal tissue, the power output settings should be lowered to a weak 10-20 mJ/pulse with longer intervals when using fractional lasers.

4) Early treatment of scars

Rapid wound healing ensues in skin irradiated by fractional lasers. Various cytokines are secreted, which increase, among other things, the concentration of TGF-beta, fibroblasts and collagen type I; keratinocytes migrate from basal layers of the epidermis to the surface layers. Melanocytes of the basal epidermal layer are initially destroyed, but are soon regenerated from surrounding tissue to produce normal melanin pigments. Vaporized and necrotized dermal tissue is replaced by normal tissue within 1-2 weeks, with an increase in dermal collagen fibers.

Although scar therapy was originally delayed until scar maturation, the introduction of fractional lasers demonstrated that earlier intervention with these lasers led to better results. This is especially true for postoperative hypertrophic scars with erythema and prominent elevation (Fig. 4). Neck surgical scars left after thyroid cancer resection can be improved greatly with fractional laser treatment. Generally, NAFL can be used 2 weeks after surgery, with intervals of 3-4 weeks between sessions. Scars that are no longer erythematous, or chronic scars, should be treated with AFL with 2-3 month intervals for good results.

Hypertrophic scars occur when the proliferation phase of scar formation and healing is prolonged. Abnormally
enhanced capillary proliferation and collagen layer thickening result in an erythematous and prominently bulging scar. Applying NAFL at this stage reduces scar blood flow and inhibits collagen fiber proliferation for a therapeutic effect. Fractional laser treatment yields superior results compared to conventional scar management methods including steroid creams, taping, silicone gels, compressive garments and scar care ointments, and thus are strongly recommended. NAFL is also effective for the acute stages of acne, when sebum secretion is hyperactive and inflammation is present.

Comparison of NAFL and AFL

While non-ablative fractional Er:GLASS and Nd:YAG lasers have wavelengths of 1,550 nm and 1,440 nm within the infrared spectrum, ablative fractional CO2 and Er:YAG lasers have longer wavelengths of 10,600 and 2,940 nm. NAFL have deeper penetration depths, however AFL can also reach the dermis at higher output levels.

Wound healing is more rapid in NAFL, with re-epithelialization occurring within 24 hours, compared to AFL which requires 2 days. AFL also causes exudate to ooze from the treated area with small amounts of bleeding for 1-2 days, unlike NAFL which causes no oozing. At identical power output settings, AFL causes more pain than NAFL; NAFL-induced pain can also increase with repeated passes. Vaporization, which does not occur in NAFL, accompanies AFL treatment as does smoke from vaporized skin tissue. Post-procedural erythema subsides within 1-2 days after NAFL, compared to erythema in AFL which can persist up to 2-4 weeks.

The prevalence of PIH after NAFL is less than 10%, and when it does occur, is still less prominent than with AFL, with a PIH occurrence of 20%. Patients can wash their faces and apply makeup immediately after NAFL treatment with no social downtime, whereas AFL requires 2-3 days’ time to apply makeup, making it better suited for over-the-weekend procedures. Immediate skin shrinkage and contraction, not visible in NAFL, is regularly demonstrated with AFL treatment.

When treating aging facial skin, AFL is more effective than NAFL; skin elasticity and senile plaques both are more improved with AFL (Table 1).

CONCLUSION

The characteristics of AFL are somewhere in between those of NAFL and skin resurfacing lasers. The skin shrinkage and elasticity enhancement effects of AFL are superior to those of NAFL; however, AFL does give more discomfort to patients in several aspects. Considering these facts, clinicians should carefully select from resurfacing lasers, AFLs and NAFLs according to patient conditions and desires.

REFERENCES


