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The use of lasers and light sources in skin rejuvenation

Nicolette Nadene Houreld, D.Tech Biomedical Technology*

Laser Research Center, Faculty of Health Sciences, University of Johannesburg, South Africa

Abstract Smooth, wrinkle-free skin is associated with supposed attractiveness, youthfulness, and health, while rhytids have a negative impact on one's perceived appearance, image, and self-esteem. Noninvasive esthetic procedures such as laser or light therapy have been used to achieve and attain a more youthful appearance. Currently, there is a wide range of lasers and devices available for the regeneration and healing of skin. Lasers and light sources for skin rejuvenation involve the removal of aged skin tissue via thermal heat from high-powered lasers, stimulating the surrounding tissues to recover through natural wound-healing processes. In contrast, photobiomodulation, which makes use of low energy lasers or light emitting diodes, uses no heat and has shown positive effects in the reduction of wrinkles and improving skin laxity.

Introduction

The treatment of photoaged skin can be divided into two types. Type I involves the treatment of irregular pigmentation, ectatic vessels and erythema, and pilosebaceous changes; Type II involves the improvement of dermal and subcutaneous senescence.[1]

Skin rejuvenation is a procedure that involves restoring the look of youthfulness. In the past, this involved invasive procedures, including face-lifts. The demand for skin rejuvenation products and noninvasive procedures has dramatically increased over the last decade, initiating several advances in the field. There is public demand for procedures that allow for faster healing and a more natural look with reduced downtime and side effects, as well as a treatment for a broader range of skin types. One such therapy involves the use of lasers and other light sources. Lasers (an acronym for light amplification by stimulated emission radiation) became popular for skin rejuvenation in the 1980s following an explanation of selective photothermolysis.[2] Laser devices for treatment of type I vascular or pigment irregularities include lasers emitting light at wavelengths of 532, 585, 595, 755, 800, and 1,064 nm, as well as filtered light generated by intense pulsed light (IPL) systems. Lasers emitting at wavelengths of 1,320, 1,450, and 1,540 nm, which targets water, and pulsed dye lasers (PDL), which target oxyhemoglobin, are employed for type II rejuvenation.[3]

In 2017, dermatologic surgeons carried out more than 8 million cosmetic treatments in the United States, a 19% increase from 2016. There was an escalation in the number of skin resurfacing treatments involving laser, light, and energy-based procedures (3.27 million).[4] This reveals the public's desire to look and feel more attractive and younger. The strategy of using lasers and light sources for skin rejuvenation involves the removal of aged skin tissue, thereby inducing tissue damage via thermal heat from high-powered lasers. This then stimulates the surrounding tissues to recover through the natural

* Corresponding author. Tel: +27 11 559 6833.
E-mail address: nhoureld@uj.ac.za.

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wound-healing process. The types of lasers involved include ablative lasers, nonablative lasers, and fractional ablative lasers. The introduction of photobiomodulation (PBM), which makes use of low energy lasers or light emitting diodes (LEDs), has also shown positive effects in the reduction of wrinkles and improvement of skin laxity. There are limitations to the treatment and the techniques, and the possible associated risks and results, particularly with high-powered lasers, should be understood.

Laser skin resurfacing and chemical peels both reduce fine lines and rough skin; however, chemical peels do not work as efficiently for deep wrinkles and sagging skin, and lasers have the added advantage of continued improvements over a period of weeks as a result of stimulated collagen production. Chemical peels work in the same way as laser resurfacing does, by inducing immunohistologic features resembling wound healing and are categorized based upon the depth of destruction.[5] Superficial peels are indicated for photoaging (superficial wrinkles), pigmentary disorders (superficial), and acne; they exfoliate the epidermis without destroying the basal layer.

Medium peels are indicated for treating fine lines and wrinkles, pigmentary disorders (contraindicated for melasma), and superficial atrophic scars; they penetrate the epidermis to the papillary dermis.[5] Deep peels reach the midreticular dermis and are indicated for the treatment of severe photoaging, pigmentary disorders, and scars.[5,6]

Deep wrinkles or hyperpigmentation are not amendable to chemical peels, even more so for men's skin due to its thickness[7]; moreover, the risk of heart failure that may be associated with deep chemical peels limits its clinical usefulness and value. For these reasons, laser resurfacing is generally preferred over chemical peels.[6]

Tissue optics

The physical properties of skin, including optical, chemical, and mechanical, as well as the concentration and distribution of components that make up the tissue, influences the interaction of laser light with tissue. When incident light comes into contact with skin, four outcomes are possible:

- Reflection: the photons bounce off the skin, and there is no light-tissue interaction. This accounts for about 3% of all incident light.[8]
- Scattering: shorter wavelengths are scattered more, while longer wavelengths have a deeper penetration. The optical window of skin (range of wavelengths which optimally penetrate skin) is from 620 to 1,200 nm.[9]
- Absorption: wavelengths <620 nm are predominantly absorbed by melanin and hemoglobin, and wavelengths >1,200 nm are principally absorbed by water in the epidermis and superficial dermis.[10] It is only during absorption that the photons engage and interact with the target chromophores and tissue.
- Transmission (Figure 1): the photons are dispersed in various directions within the tissue, without interacting with the tissue. When photons are transmitted, they pass through the tissue completely unhindered; thus, there is no light-tissue interaction.

Laser-tissue interaction

When laser light interacts with biologic tissue, three reactions are possible:

- Photochemical: the absorbed photons from low-powered irradiation interact with cells at a molecular level, causing a chemical reaction within the cells. This may activate or inactivate certain cellular pathways and processes. During photochemical reactions, there is no increase in local temperature. Slight increases in temperature, of approximately 45°C to 50°C, result in hyperthermia, reduction in enzyme activity, and cell immobility.[11]
- Photothermal: absorbed photon energy is converted to heat. Photothermal reactions are associated with an increase in local temperature. If local temperature increases to such an extent, denaturization, necrosis, and even vaporization and spallation (splintering of the tissue), and tissue ablation (breaking of chemical bonds) may result. When tissue reaches temperatures of approximately 60°C, denaturation of proteins and collagen occurs, resulting in the tissue coagulation and cell necrosis.[11]
- Photoplasmal: if the power irradiance is extremely high (in the order of 10^8 or 10^9 W/cm^2), photoplasmal reactions will occur, resulting in plasma formation associated with high electric fields, dielectric breakdown, shockwave formation, and tissue rupture.[8] Water vaporizes at a temperature of around 100°C. During this vaporization phase, local tissue temperature is not altered, but instead gas bubbles are formed. The dissemination and spreading of these bubbles accompanied with the alteration of their volume causes thermal decomposition of tissue.[11]

Photothermolysis

To understand how lasers are effective in skin rejuvenation and carry out their effects, one needs to understand the principle of photothermolysis. Photothermolysis is a technique employed to target tissue in a specific area without damaging surrounding tissue. This is possible because different wavelengths have different depths of penetration into tissue (longer wavelengths have deeper penetration depth) and are absorbed by different chromophores (a chemical group that absorbs light at a specific wavelength, eg, melanin, oxyhemoglobin, water, tattoo ink, etc). The photon (light) energy is absorbed

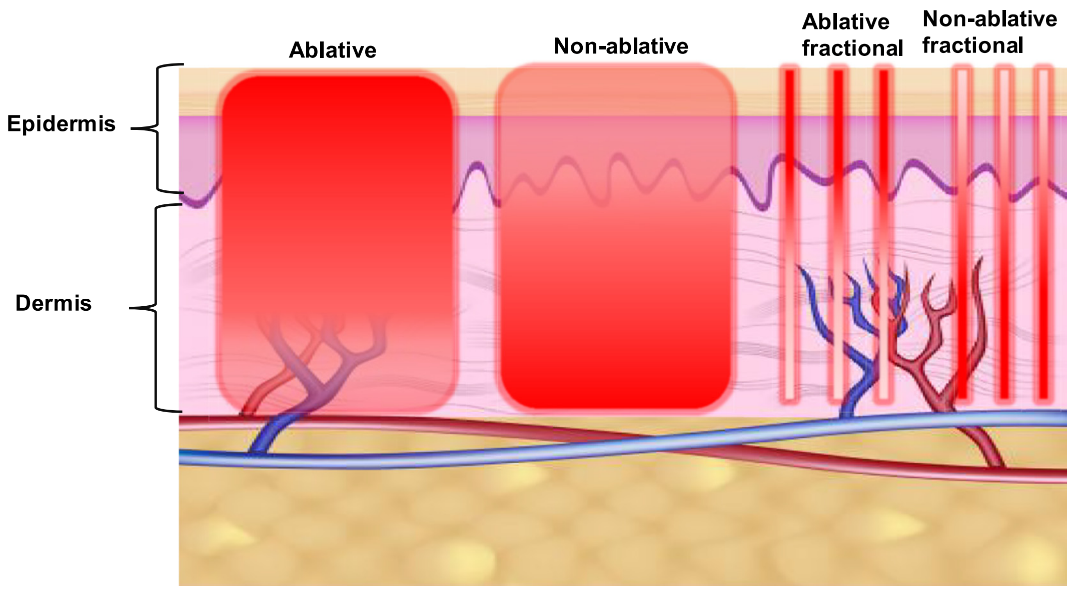

Fig. 1 When incident light comes into contact with skin, four outcomes are possible, which are dependent on the optical properties of the tissue. These outcomes include **(a)** reflection, **(b)** scattering, **(c)** absorption, and **(d)** transmission.

by the target chromophore and converted to heat, thus destroying the target chromophore and tissue. Target tissue needs to be given sufficient time to cool to allow for heat dissipation, known as thermal relaxation time (TRT). TRT, which is tissue and chromophore specific, is defined as the time taken for the target chromophore to dissipate 50% of the thermal energy to the surrounding tissue. The TRT for the epidermis is 3 to 10 ms, and 1 μs for melanosomes.[10] Consequently, the physical properties of incident radiation (wavelength, fluence, and pulse width and duration) and time between pulses, is an important factor to consider in skin rejuvenation. The pulse duration must be less than the TRT; this will ensure that the heat generated in the target chromophore does not dissipate until the target is damaged.[12]

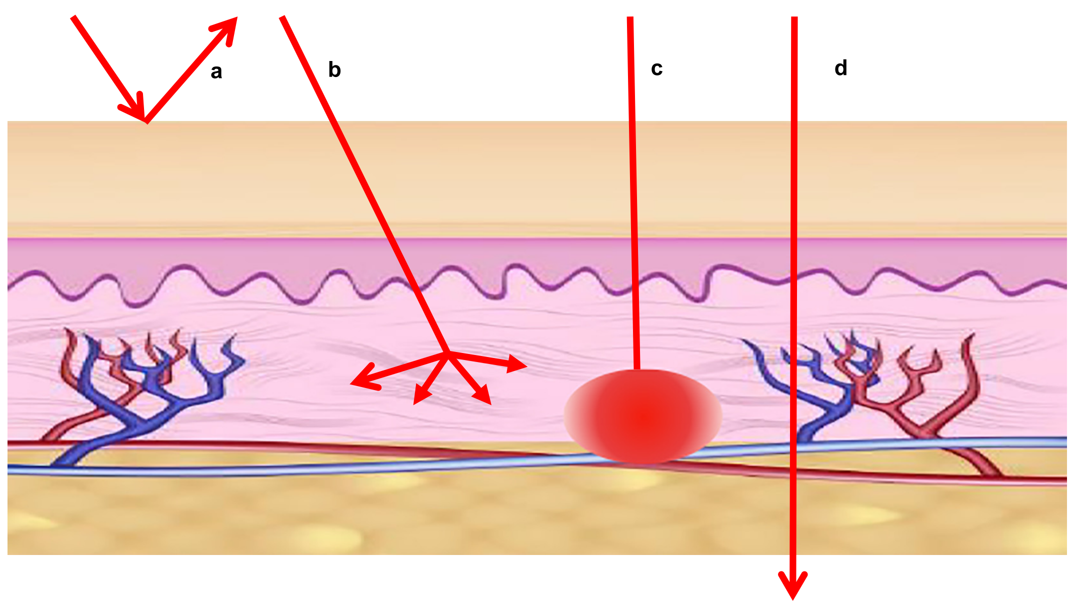

Fig. 2 Lasers typically used in skin rejuvenation include ablative, nonablative, and fractional lasers. Ablative lasers destroy the upper epidermis and heat the underlying dermis, while nonablative lasers do not damage the dermal layer through skin surface cooling but result in heating and denaturation of dermal proteins. Fractional lasers, either ablative or nonablative, form cylindrical zones of tissue thermal damage, with undamaged areas in between.

Lasers used in skin rejuvenation

Lasers typically employed in skin rejuvenation include ablative, nonablative, and fractional lasers (Figure 2). Ablative lasers destroy the epidermis and heat the dermis, are typically applied to resurface and rejuvenate the skin, and are used in treating rhytides, dyspigmentation, and scars.[10] Nonablative lasers spare the epidermis through cooling but still allow for the heating and denaturation of dermal proteins, including collagen, which stimulates collagen production and tightens underlying skin. There is a decreased recovery time as compared with ablative lasers, as well as less risk of adverse events such as scarring, dyspigmentation, and infection.

Fractional lasers provide a link between ablative and nonablative technologies, and they are associated with decreased risks. These devices depend on high-fluence irradiation to form multiple vertical cylinders of thermal damage, known as microthermal zones, with undamaged areas or islands in between that accelerate recovery. Microthermal zones can measure 1.5 mm in depth and 100 to 400 mm in width, and there may be up to 6,400 treatment zones per squared centimeter.[10] The period of healing, as well as associated risks such as discoloration, scarring, depigmentation, and infections, have been significantly reduced through the introduction and use of fractional lasers, making them a more popular choice.[13]

Caution needs to be taken when performing laser resurfacing on patients with Fitzpatrick skin types III to VI, who are at increased risk for hyperpigmentation, hypopigmentation, and dermal scarring. Pigmented skin has the ability to absorb 40% more photons than nonpigmented skin, and as a result, thermal injury extends beyond targeted areas.[14] Hence, the majority of clinicians who make use of ablative lasers in such patients use them with low-power settings and limit the number of passes.[15] Although nonablative lasers are more promising, they have yet to yield significant long-term results.[14]

Ablative lasers

Ablative lasers thermally ablate and vaporize the entire epidermis, also leading to thermal damage of the superficial portion of the dermis, thereby stimulating a wound-healing response, where there is collagen remodeling and rebuilding of the extracellular matrix, making for new smoother and tighter skin. This part of the dermis is coagulated to a depth of around 150 to 300 microns.[10,16] The most commonly used ablative lasers include the carbon dioxide (CO_2) laser (10,600 nm), erbium: yttrium-aluminum-garnet (Er:YAG) laser (2,940 nm), and erbium-doped yttrium scandium gallium garnet laser (2,790 nm).[17]

Nonablative lasers

Nonablative lasers are less destructive than ablative lasers and tighten the skin by stimulating collagen production in the dermis; the epidermis is protected through skin cooling. Dermal thermal damage leads to dermal collagen denaturation and triggers the wound-healing response that results in new collagen fibers being laid down and the extracellular matrix being remodeled.[14,18] Downtime associated with these lasers is decreased, as well as adverse effects such as scarring, dyspigmentation, and infection, and there is modest edema and erythema.[10,16,19] Nonablative lasers show reduced efficacy as compared with ablative lasers and are aimed at patients with moderate photoaging and realistic expectations.[18] Typical nonablative lasers include IPL sources (550-1,200 nm), high-dose PDL (585/595 nm), low-dose PDLs (589/595 nm), pulsed potassium titanyl phosphate lasers (532 nm), neodymium yttriumaluminum-garnet (Nd:YAG) lasers (1,064 nm and 1,320 nm), diode lasers (1,450 nm), erbium glass lasers (1,540 nm), Alexandrite lasers, and Er:YAG lasers.[16,19,20]

Fractionated lasers

Fractional lasers can be either ablative or nonablative. Nonablative fractional lasers comprise wavelengths of 1,440, 1,540, 1,550, and 1,565 nm, and the lasers used in ablative fractional treatments are Er:YAG of 2,940 nm and CO_2 of 10,600 nm.[21] Erbium glass lasers (1,540-1,550 nm) create columns at the depth of about 1 mm, while Er:YAG lasers (2,940 nm) and CO_2 lasers (10,600 nm) create columns approximately 90 μm and 2.5 mm in depth, respectively.[13] The first fractional lasers were nonablative, influencing the dermis but leaving the epidermis untouched, being described in 2007. The blend of dermal and epidermal damage prompted a more robust healing and fibroplasia process.[22] With the use of fractional lasers, the epidermis desquamates superficially after a short period of tissue erythema and edema. There is an improvement in skin tension, the skin appears smoother, and the color becomes more uniform.[13] Improvements in skin smoothness is typically seen several months after treatment, as collagen remodeling takes place during the several months postprocedure.

Generally, several nonablative laser sessions are required to achieve the same results of a single session with an ablative laser. A study in 2014 compared the effect of multiple fractional nonablative laser sessions (using a 1,540 nm erbium) with a single fractional ablative laser session (using a 2,940 nm erbium) on photoaging.[23] Eighteen patients with a mean age of 55.9 years received three sessions of nonablative fractional erbium laser (1,540 nm) on one side of the face (50 mJ/mB, 15 ms, two passes), and one session of ablative fractional erbium laser (2,940 nm) on the other side (5 mJ/mB, 0.25 ms, two passes). There was clinical improvement in both sides of the face in all patients, with no significant difference. Histopathologic study showed new collagen and elastic fiber organization, with edema being more prominent in skin treated with the fractional ablative erbium laser. Multiple (three) sessions with a fractional nonablative laser were clinically equivalent to a single treatment with a fractional ablative erbium laser. The healing process for the nonablative fractional erbium laser

(1,540 nm) was faster than for the ablative fractional erbium laser (2,940 nm) and produced less intense erythema, edema, and desquamation.[23] Despite the fact that undesired effects are less intense with nonablative fractional lasers, more treatments are necessary to achieve the same results.

Three to five procedures, in 4-week intervals, should be performed to optimize effects. A 47-year-old patient was treated on three occasions at 4 to 6 week intervals with a fractional CO_2 laser (35 mJ, density of 100 ablation columns of 300 μm × 1 cm^2).[13] Healing occurred without complications, and treatment resulted in harmonization of the skin color, increased flexibility, and a significant reduction of wrinkles. A new trend presently employed is to use two different lasers in one session. This is aimed at intensification of the therapeutic effects in as short a time as possible. Examples of this include combining a deep penetrating CO_2 laser (10,600 nm) and an Er:YAG laser (2,940 nm) operating on the surface, or a nonablative (1,550 nm) laser and a Er:YAG ablative laser (2,940 nm).[13]

Ablative fractional lasers in combination with IPL are safe and effective for photoaging skin.[24] Women aged 40 to 60 years old and with Fitzpatrick skin types III and IV received IPL treatments (590 or 640 nm, depending on skin type; double pulse mode; pulse durations, 4.0 to 4.5 ms; pulse delays, 30 to 35 ms; and energy density, 14 to 17 J/cm^2) on one side of the face, and IPL in combination with ablative fractional lasers (CO_2 laser; single pass; pulse width, 1.2 ms; spot size, 250 mm; fluence, 84 mJ/pixel, and 10% treatment density) on the opposite side. Participants were treated with IPL on three occasions over 90 days (day 0, day 30, and day 90), while those who received combination therapy were treated with IPL on day 0, ablative fractional laser on day 30, and IPL again on day 90. Participants were seen 30 days after the last treatment. Both treatment regimens reduced pore size, decreased red areas, increased skin elasticity, and improved pigmentation. The combination treatment of IPL and ablative fractional laser significantly reduced the appearance of wrinkles and improved skin texture.[24]

In an evidence-based review for the use of nonablative fractional lasers in Fitzpatrick skin types IV-VI,[25] there is strong evidence that nonablative fractional lasers are effective for skin rejuvenation in skin of color.

Contraindications

A number of contraindications exist for skin rejuvenation with lasers and IPL. These include psoriasis and lichen planus (active phase of the disease), active infectious lesions such as Herpes simplex infection or dermatophytosis, active neoplastic disease, proneness to scarring, use of phototoxic substances, treatment with retinoids within 6 months after treatment, pregnancy, tanning for up to 8 weeks after treatment, epilepsy (procedures using visible spectrum waves, ie, 400-780 nm), inability to giving informed consent, and unrealistic expectations.[2]

PBM for skin rejuvenation

PBM, formally known as low level laser therapy, usually employs light in the red and near-infrared spectrum to modulate biologic activity. It has been used in a wide range of medical applications and is increasingly being used as an esthetic procedure. PBM makes use of low-power intensity light from various sources (lasers, LEDs, and broadband light), to induce a nonthermal, photophysical, and photochemical reaction.[26] As with photothermolysis, PBM is reliant on the absorption of photon energy by chromophores. Instead of photon energy being converted into damaging heat energy, photon absorption converts light into signals that can stimulate biologic processes, such as collagen production.[24] Near-infrared irradiation has been shown to increase the amount of dermal fibroblast collagen and clinically improve skin texture.[27] Increased dermal collagen density and long-term epidermal smoothness without scar formation in rat skin has been reported.[28]

A recent study has demonstrated how far-infrared (FIR) radiation (with wavelengths in the range of 3~25 μm) can inhibit skin photoaging induced by UVB) in NIH 3T3 mouse embryonic fibroblasts and SKH-1 hairless mice.[29] In NIH 3T3 fibroblast cells, FIR radiation inhibited UVB-induced matrix metalloproteinase (MMP)-1 and MMP-9, and increased collagen type I. MMP are proteinases which breakdown and destroy various types of collagens. There was additionally an increase in autophagy (a process by which UVB damaged cells will be destroyed and removed), which was induced via inactivation of the Akt/mTOR cell signaling pathway. In UVB-induced skin photoaging in SKH-1 hairless mouse, FIR resulted in thinner epidermal layers and increased abundance and density of collagen fibers.[29]

The efficacy and safety of nonthermal photorejuvenation has been studied in a randomized, controlled clinical trial using different types of polychromatic light sources.[30] Low-pressure lamps emitted within the range of 611 to 650 nm and were compared with midpressure lamps in combination with spectrally selective reflectors and filter systems that eliminated emissions in wavelengths <570 and >850 nm. Participants (n = 136, between 27 and 79 years of age) were divided into three groups: (1) the control group, who did not receive any treatment; (2) the low-pressure lamp group; and (3) the midpressure lamp group. Participants were treated with PBM twice a week and received a total of 30 treatments. Measurements (digital photographs; clinical measurements, which included ultrasonographic collagen density, and digital profilometry; and patient satisfaction questionnaires) were taken at baseline and after 15 and 30 treatments. The results showed a significant improvement in skin complexion and subjective feeling and an increase in collagen density in the intervention groups as compared with the untreated, control group. There was no difference between the two light sources. No severe adverse events were registered. PBM appears to be a safe and effective nonthermal treatment for skin rejuvenation with high patient satisfaction rates and is suitable for full-body treatments.[30]

Fifty Japanese patients were treated with a near-infrared irradiation 1,064-nm Nd:YAG laser, having an energy fluence of 14 J/cm^2, pulse duration of 0.3 or 1.0 ms, and a repetition rate of 7 Hz.[31] Patients received three rounds of treatment with a 4-week interval, without any topical anesthetics or oral analgesics. Measured outcomes included digital photographs and facial surface analysis. Improvements in skin texture, wrinkles, and dilated pores were evaluated. All objective computer assessments showed significant improvement. Skin specimens were also obtained at 30 and 90 days postirradiation for histologic evaluation and revealed an increase in the amount of elastin in Fitzpatrick skin type III and IV biopsies. There was also epidermal thickening on day 30, and epidermal smoothness persisted for up to 90 days. No treatment-related adverse events were observed, and patients reported a high-level of satisfaction.[31]

Conclusions

Aging skin is the result of decreased collagen production and reduced structural integrity. A large proportion of the adult population has a profound desire to maintain a youthful skin appearance, and this desire has driven and fueled a multibillion-dollar industry. Treatment for aging skin stimulate and promote the production of new collagen, elastin, and glycosaminoglycans, providing improvement to the skin's appearance.

Lasers are increasingly used as alternatives to chemical peels. The use of lasers in the cosmetic and dermatology fields have had a significant impact on the treatment of cutaneous conditions and skin rejuvenation, with the use of high-powered lasers (ablative, nonablative, and fractional lasers) and IPL devices possibly leading to adverse unwanted effects and downtime; however, with technologic advancement, these have been significantly reduced. Ablative lasers provide superior results but at a price, with increased recovery times and far greater risk of adverse events. Nonablative lasers provide sufficient and modest results with a reduced recovery time and less side effects. Fractional lasers combine the pros of ablative and nonablative lasers, with quicker recovery times and results approaching those of ablative technologies; however, a series of treatments is required. The use of PBM provides a nonthermal alternative form of treatment for skin rejuvenation, and there is a multitude of devices that can be used at home, reducing the need for clinical visits and treatments. PBM offers a safe, consistent, and long-term effect for skin rejuvenation; however, repeated treatments are required to maintain effects. The wide selection of laser and light technologies offers a multitude of options to achieve the desired effects that best suits the patient. However, the choice of lasers and treatment parameters should be cautiously chosen according to the patient's skin phototype.

Disclosures

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