Laser Hair Removal: A Review

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BACKGROUND Unwanted hair growth is a common aesthetic problem. Laser hair removal has emerged as a leading treatment option for long-term depilation.

OBJECTIVES To extensively review the literature on laser hair removal pertaining to its theoretical basis, current laser and light-based devices, and their complications. Special treatment recommendations for darker skin types were considered.

MATERIALS AND METHODS A comprehensive literature search related to the long-pulse alexandrite (755 nm), long-pulse diode (810 nm), long-pulse neodymium-doped yttrium aluminum garnet (Nd:YAG; 1,064 nm), and intense pulsed light (IPL) system, as well as newer home-use devices, was conducted.

RESULTS The literature supports the use of the alexandrite, diode, Nd:YAG and IPL devices for long-term hair removal. Because of its longer wavelength, the Nd:YAG is the best laser system to use for pigmented skin. Further research is needed regarding the safety and efficacy of home-use devices.

CONCLUSION Current in-office laser hair removal devices effectively provide a durable solution for unwanted hair removal.

The authors have indicated no significant interest with commercial supporters.

Unwanted hair is a common aesthetic problem in many cultures. Hirsutism, excess hair growth in androgen-dependent areas, and hypertrichosis, greater hair density at any body site, may affect psychologic health by causing depression and anxiety. Hair removal through shaving, waxing, plucking, chemical depilatories, and electrolysis can improve one's quality of life,[1] but many of these techniques provide temporary solutions to unwanted hair. Although electrolysis may permanently remove hair, it is a slow and operator-dependent procedure with variable efficacy.[2,3]

Laser treatment has emerged as the criterion standard in hair depilation. It provides a longer-lasting hair-free period than other methods. In 1996, the 694-nm ruby laser was the first laser device formally studied for hair removal.[4] Long treatment times, lasting from a few minutes for the face to several hours for the back, limited its practical use. Shortly thereafter, the quality-switched neodymium-doped yttrium aluminium garnet (Nd:YAG) laser in combination with a carbon-based topical suspension became the first laser hair removal treatment that the Food and Drug Administration (FDA) approved. Upon laser-induced heating, the carbon particles served to selectively damage the hair follicles in contact.[5] Hair regrowth was delayed by up to 3 months but not permanently.[6] Today's laser devices provide longer-lasting results due to targeted destruction of the germinative cells in hair follicle bulge.

Anderson and Parrish's principle of selective photothermolysis explains the mechanism behind such light-based therapies.[7] Lasers emit light onto the

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skin surface that is reflected, scattered, transmitted, or absorbed. At specific peak wavelengths in the red to near-infrared range of electromagnetic radiation (600–1100 nm), absorbed light energy heats the target chromophore in the skin. The most common chromophores are melanin, oxyhemoglobin, tattoo pigment, water, and collagen. Selective tissue destruction occurs when optimal parameters of wavelength, fluence, and pulse duration confine heating and subsequent injury to the desired chromophore without dissipation to surrounding tissues. The hair follicle is a unique structure in that there is spatial separation of the chromophore (melanin) within the hair shaft and the biological "target" stem cells in the bulge region. Wavelengths of 600 to 1100 nm favor absorption by melanin in the hair matrix. Long-pulse ruby (694 nm), long-pulse alexandrite (755 nm), long-pulse diode (810 nm), long-pulse Nd:YAG (1,064 nm), and intense pulsed light (IPL) (590–1200 nm) destroy hair photothermally by emitting wavelengths within this range. Melanin absorbs light better at lower wavelengths (Figure 1). Melanin absorbs light energy, converts it into heat, and then diffuses it, which causes collateral damage to the bulge cells. Fluence and pulse duration influence the amount of heat absorbed. Fluence, or energy density (J/cm^2), determines the peak temperature reached within the target structure. Pulse duration is the length of time spent at a given temperature. The most selective thermal damage occurs when the pulse duration approaches the thermal relaxation time (TRT) of the target chromophore. TRT is defined as the time necessary for the heated tissue to cool to half its peak temperature. If the pulse duration is longer than the TRT, heat dissipates from the chromophore before irreversible thermal damage occurs; if the pulse duration is much shorter than the TRT, excessive damage may occur; and if the laser exposure time is just shorter than the TRT, the chromophore cannot disperse its heat, and thermal damage is confined to the target.[8]

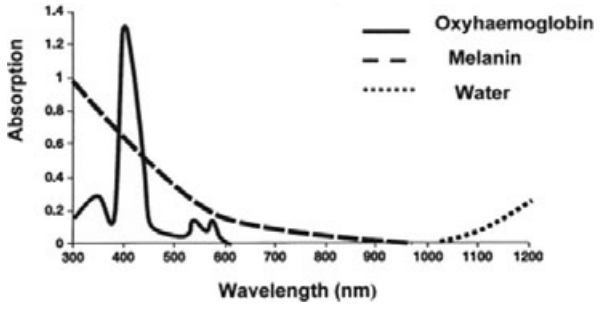

Figure 1. Absorption spectra of skin chromophores. From Reference 8. Reprinted with permission.

Thermal relaxation time is directly related to the chromophore's size. Smaller targets such as tattoo pigment and melanin heat and cool more quickly than larger structures such as blood vessels. Quality-switched lasers operate in the nanosecond range and are used to target these smaller chromophores. Long-pulse lasers perform in the millisecond range, best approximating the TRT of hair follicles (10–100 ms).[9,10]

Epidermal melanin competitively absorbs the same wavelengths used for hair removal. In darker-skinned individuals, the greater epidermal melanin content competes with the hair follicle for light absorption, increasing the risk of thermal blisters and hyperpigmentation. Moreover, a reduction in the total amount of energy that is able to reach the melanin deep in the hair shaft decreases the overall efficacy per pulse. For these reasons, the ideal candidate for laser hair removal would have fair, untanned skin and dark hair.[11]

Lasers with longer wavelengths such as the diode (810 nm) and Nd:YAG (1,064 nm) effect less epidermal melanin absorption and fewer potential adverse events than those with shorter wavelengths. The long-pulse Nd:YAG laser provides effective and durable hair loss at 6 months after treatment in darker skin types (skin phototypes IV-VI) with no signs of dyspigmentation or burns [12] (Figure 2). The Nd:YAG laser is considered the best laser to use when treating darkly pigmented skin such as skin phototypes IV to VI. The IPL and alexandrite (755 nm) laser, which do not penetrate as deeply, are more suitable for lighter skin types I to III

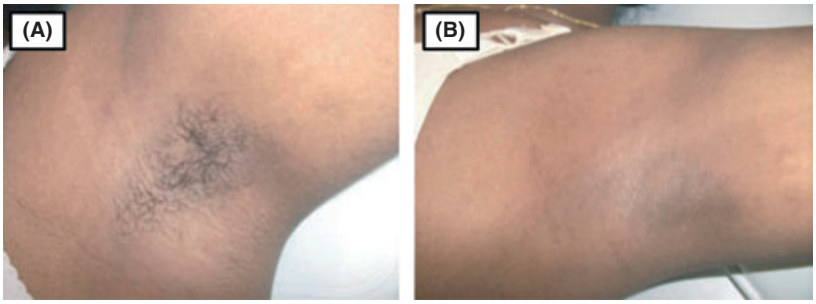

Figure 2. Axillary hair in an individual with darker skin before (A) and after (B) treatment using a long-pulse 1,064-nm neodymium-doped yttrium aluminum garnet laser. From Reference 12. Reprinted with permission.

TABLE 1. Suggested Skin Type–Based Laser Recommendations and Initial Treatment Parameters

Laser	*Wavelength, nm*	*Skin Type*	*Fluence, J/cm²*	*Pulse Duration, ms*
Long-pulse alexandrite[19–23]	755	I, II, III	15–25	5–20
Diode[15,29,30,34,37–43]	800–810	III, IV, V	5–15	5–30
Neodymium-doped yttrium aluminum garnet[44–47,50]	1064	IV, V, VI	30–50	20–30
Intense pulsed light (IPL)	590–1200	Typically I, II; depends on device	Depends on skin type	Depends on skin type

Initial treatment parameters should start at a more-conservative dosing when treating facial skin.
There will be variation in suggested parameters from different devices even in the same category (e.g., different Alexandrite lasers may have disparate parameters). These are simply general guidelines.

because there is a greater risk of epidermal melanin activation with shorter wavelengths (Table 1).

The mechanism of action of laser hair removal is reflected in the immediate histologic changes in the skin, as well as its effects on the hair growth cycle. Microscopically, treated follicles display immediate changes of keratinocyte swelling, scattered apoptotic and necrotic keratinocytes, and full-thickness necrosis of the follicles depending on the amount of energy absorbed. Permanent hair removal with complete dropout of follicles is achieved in only 15% to 30% of treated hairs at each treatment at optimal parameters. More commonly, temporary hair loss occurs through induction of a telogen-like state in which the hair follicles are at "rest" and no hair growth is occurring. Histologically, most follicles are in the telogen phase 1 month after treatment, whereas fibrosis with a foreign body giant cell reaction replaces others.[13] There is a period of alopecia lasting from several weeks to a few months until a portion of hair follicles recover and commence another anagen cycle.[14] Validating this observation, after one treatment with the diode laser, hair regrowth ranged from 22% to 31% 1 month follow-up and then plateaued at 65% to 75% from 3-month to 20-month follow-up.[15]

Herein, we review the laser and light-based devices used for hair removal and their potential complications. The discussion will include the long-pulse alexandrite, long-pulse diode, long-pulse Nd:YAG, IPL system, and newer home-use devices. We conclude with an approach to relevant patient selection criteria and various treatment considerations that a proceduralist should understand before using lasers for hair removal.

Alexandrite Laser

In 1997, Finkel and colleagues first reported effective hair removal on the face, arms, legs, and bikini line

with the long-pulse 755-nm alexandrite laser.[16] Long-term efficacy for the long-pulsed alexandrite laser ranges from 65% to 80.6%.[17,18] Equivalent hair removal for up to 6 months can be achieved using the alexandrite laser with pulse durations of 5, 10, and 20 ms.[19] Noninferiority studies demonstrate equivalent efficacy of the alexandrite laser and other similar laser devices. Bouzari and colleagues did not find any significant difference in efficacy between the alexandrite and diode lasers when treating patients with skin types I to V.[20] Similarly, Handrick and Alster found equivalent clinical and histologic responses using a long-pulse alexandrite and long-pulse diode laser in treating skin types I to IV, although the diode had more side effects than the alexandrite laser.[21] Treating patients with skin types I to IV sequentially with the diode followed by alexandrite laser did not produce greater mean hair reduction than an equivalent number of treatments with the alexandrite laser alone, although the former was associated with more side effects of folliculitis, erythema, and blistering.[22] The long-pulse alexandrite laser and long-pulse diode laser have been shown to have similar efficacy whether used individually or sequentially when treating skin types I to IV. Because the alexandrite laser is capable of shorter pulse durations than the diode laser, the alexandrite laser may be better suited for treating fine vellus hairs.

The long- and short-pulse alexandrite lasers show no statistically significant difference from IPL in efficacy in skin types II to IV. Transient side effects including erythema, edema, and paradoxical hair growth were greatest with the long-pulse alexandrite and least with the IPL system.[23] In summary, the alexandrite laser effectively removes hair with results comparable with those of the diode laser and IPL devices. We suggest using the alexandrite laser on skin types I to III because of the paucity of competing epidermal melanin and low risk of laser-induced dyspigmentation or burns.

Diode

The hair count reduction reported with the long-pulse 810-nm diode laser ranges from 22% to 59%.[15,24–28] In skin treated with the diode laser, histologic analysis showed a statistically significant reduction in hair density and thickness.[29]

Lasers with longer wavelengths such as the diode and the 1,064-nm Nd:YAG lasers are preferred when treating darker skin types because they result in fewer side effects such as pain and postinflammatory hyperpigmentation than lasers with shorter wavelengths. Longer wavelengths induce less epidermal melanin absorption. Efficacy of hair removal between the diode and the Nd:YAG lasers is inconsistent among studies. Li and colleagues showed greater hair removal efficacy using the diode laser (78.6%) than with the long-pulse Nd:YAG laser (64.5%),[31] whereas Chan and colleagues did not find a difference.[30] The diode laser was less painful than the Nd:YAG when treating Asian skin.[30–32] Most studies have found few and transient side effects using the diode laser to treat patients with skin types III to V.

Studies using the diode laser have recently suggested a shift away from the criterion standard high-fluence devices in favor of a low-fluence (5–15 J/cm^2) approach. The latter provides comparable hair reduction, less discomfort, and fewer adverse effects even when treating phototype V skin and tanned individuals.[33–39] The most common side effects were slight and transient erythema and pigmentary changes. No long-term adverse effects were noted. The mechanism of hair removal using low-fluence devices may be through an induction of hair miniaturization of coarse terminal hairs. In contrast to photodestruction of stem cells using the conventional technique, low-fluence lasers may also trigger photomodulation of germinative cells, leading to altered hair growth.[13] Individuals with skin phototypes III to V can be effectively and safely treated at low fluences (5–15 J/cm^2) using the diode laser.

Neodymium-Doped Yttrium Aluminum Garnet

The 1,064-nm Nd:YAG laser is considered the best laser for hair removal in patients with darker

skin.[40–43] The longer wavelength of the Nd:YAG allows for less epidermal melanin absorption. Patients with skin types IV to VI can tolerate higher fluences with minimal adverse events such as epidermal burns or dyspigmentation. The long-pulse Nd:YAG laser did not demonstrate significant long-term adverse events at high fluences of 50, 80, and 100 J/cm^2 when treating skin phototypes II to IV; only two subjects treated at the highest fluence developed nonscarring blisters. Greater fluence did not result in greater hair reduction, with similar efficacy in hair reduction demonstrated in the three treatment groups (27–29%) at 3-month follow-up.[44] In contrast, Rogachefsky and colleagues, treating primarily subjects with skin type II with the Nd:YAG, found that higher fluences (60–80 J/cm^2) and longer pulse durations (50 ms) were correlated with lower hair counts.[45] The subjects' skin phototype may explain the disparity in the amount of hair reduction between the two studies. In the former study, subjects with darker skin types require a higher fluence to achieve hair loss because the epidermal melanin absorbs some of the energy. Greater fluence did not linearly correlate with greater hair loss. In the latter study and in general, subjects with lighter skin had less competing epidermal melanin. At a given fluence, a greater proportion of laser energy is able to penetrate to the bulge stem cells than in individuals with darker skin. Therefore, in lighter-skinned individuals, greater fluence results in a more-linear correlation with the degree of hair loss. In the Rogachefsky study, the most acute reactions of erythema, perifollicular edema, and pain were associated with greater fluences. As might be predicted, more adverse events occurred at higher energies and longer pulse durations in both studies.

The Nd:YAG laser and IPL device were compared in a recent within-patient, right–left, assessor-blinded study treating the axillary hair of 39 women with skin types IV to VI. There was statistically significantly greater reduction in hair counts on the laser side (79.4%) than on the IPL side (54.4%) at 6-month follow-up.[12] Only temporary adverse effects were reported for either side. Despite more pain and inflammation, the Nd:YAG laser produced greater hair reduction and a higher level of patient satisfaction than the IPL system. Because there is less risk of epidermal melanin absorption, we recommend using the Nd:YAG on individuals with skin type IV to VI.

Intense Pulsed Light

In contrast to laser light, which is monochromatic (produces a single wavelength or narrow band of wavelengths) and has high power density and minimal coherence (divergence), the IPL device uses a xenon polychromatic broadband flashlamp with optical filters to generate noncoherent light beams in the visible to infrared spectrum (500–1,200 nm). Based on the type of cut-off filters used, an IPL device emits a defined range of wavelengths to reach the desired depth of the target structures. Similar to lasers, IPL technology is based on the principle of selective photothermolysis. Because of its ability to emit a spectrum of wavelengths, a single light exposure can excite multiple chromophores in the skin (hemoglobin, water, and melanin) at one time. Thus, in the hands of an inexperienced physician or nonmedical personnel, complications from nonspecific thermal damage could easily ensue.

Advantages and disadvantages arise from the distinct differences in technical qualities and operation between an IPL device and a laser. An advantage of IPL is its lower cost. In addition, the large spot size of an IPL device makes it easy to treat large surface areas such as the back, chest, and legs. Treatment duration for a given area is shorter than for a smaller spot size. A disadvantage is the heavy weight of the IPL handpiece, which houses the lamp and lamp-cooling device. This can be bulky and somewhat difficult to maneuver. When using the device, an optical coupling gel application and direct skin contact with the handpiece is required, hindering visualization of the immediate local reaction. Furthermore, the immediate inducible perifollicular edema and erythema seen with lasers is infrequently

encountered with the IPL, which makes it difficult to accurately place the next pulse immediately adjacent to the previous pulse and may inadvertently cause patches of skin to be left untreated. Finally, IPL devices have been shown to emit inconsistent fluence and wavelengths from pulse to pulse, making clinical results unpredictable.[46] The mechanism of generating light and the range of wavelengths emitted from the IPL is inherently different from that of lasers, conferring a distinct set of advantages and disadvantages. The low wavelengths emitted in the spectrum of light from an IPL device can disadvantageously target epidermal melanin, so IPL devices with a light range that starts in the lower wavelength range are not recommended for darker skin.

Few studies have compared the efficacy of IPL devices with that of lasers. Amin and colleagues compared IPL with a red filter, IPL with a yellow filter, a diode laser, and an alexandrite laser in 10 patients with skin types I to III. Evaluation at 1, 3, and 6 months did not reveal a statistically significant difference in efficacy between the four devices at each time point, although the IPL device was less painful than the alexandrite laser.[47] Another study compared six split-face treatments of the diode laser with IPL in 31 hirsute women with normal testosterone levels. Six-month follow-up demonstrated hair reduction of 40% for IPL and 34% for diode laser, but the difference was not statistically significant. There was also no difference in patient assessment of hairiness or satisfaction. Pain was consistently greater with IPL than diode laser.[48] Although IPL devices vary greatly in their efficacy, in these studies, the IPL device used has efficiency in hair removal similar to that of the alexandrite and diode lasers and is typically used to treat patients with skin types I and II.

Home-Use Devices

Devices designed for home use have recently gained in popularity because of their lower cost than a professional service and the convenience and luxury of depilating in the privacy of one's own home. Safety concerns inherently arise because of the shift from professional oversight to inexperienced personal use. Currently, the FDA requires compliance with certain standards and regulations for light-based home-use devices sold in the United States.[49] These devices are based on IPL and laser technologies but operate at lower fluences than comparable in-office devices. The 810-nm diode Tria laser (Tria Beauty, Inc., Dublin, CA) and 475 to 1,200 nm IPL Silk'n device (Home Skinovations, Kfar Saba, Israel) are the current FDA-approved hair removal systems.

Despite these regulations, safety and prevention of accidental injury to eyes and skin of the user and those nearby is the primary concern. Although manufacturers may include protective eyewear with the packaging, there is no guarantee that the consumer will wear the glasses during the procedure. One safety feature on most home-use devices is a skin contact sensor that prevents the beam from firing when not on the skin. Light is supposedly self-contained within the device, and special protective goggles are not required, but if eye precautions are breached, irreversible corneal burns, lens cataracts, and retinal damage may result.

A few studies have assessed the ocular safety of U.S.-sold devices in accordance with the FDA Center for Devices and Radiologic Health Laser Notice No. 50, but abroad, Eadie and colleagues tested the optical radiation hazard of the iPulse Personal IPL device (CyDen LTD, Swansea, UK) in accordance with International Electrotechnical Commission TR 60825–9 and the International Committee on Non-Ionizing Radiation Protection Guidelines on Limits of Exposure to Broad-band Incoherent Optical Radiation. They found that this device was within the international limits for ocular exposure.[50] Another international study by Town and Ash compared three IPL home devices, iPulse Personal, Silk'n/SensEpil, and Satin/Lux/Lumea (Philips, Netherlands), with the International Electrotechnical Commission TR 60825–9 standard. The measured optical output varied significantly between the three systems. At its two highest settings, the

Silk'nSensEpil was hazardous to the naked eye were the skin contact safety mechanism to fail.[51] Further studies are needed to assess the ocular safety of home-devices sold within the United States.

Aside from ocular damage, unintentional misuse by individuals with darker skin type or a tan or inappropriate treatment of moles or tattoos may lead to thermal burns. In a study comparing 77 "appropriate" users with naturally light brown to black hair and skin types I to IV to 44 "inappropriate" users with naturally white, gray, red, or blond hair and skin type V or VI, the 810-nm Tria diode laser (SpectraGenics, Inc, Pleasanton, CA) induced blisters in 8% (1/12) of users with skin type V and 33% (10/30) of users with skin type VI. Subjects with lighter skin types did not exhibit any blistering. Users with darker skin types described more pain than those with lighter skin (mean pain score 2.3 vs 2.0 on the first visit).[52] Although the small sample size may overemphasize the effect, the risk of thermal skin damage is greater in darker skin types. A newer model of the Silk'n device (SensEpil) contains a built-in sensor that prevents treatment of skin types V or VI. It is hoped that this added safety feature will prevent the adverse outcomes seen when treating darker-pigmented individuals.

Although there is not a perfect solution to these safety concerns, the clinical efficacy of these home-use devices is promising. Wheeland's study using the Tria diode laser produced an average hair reduction of 41% after three treatments at 6-month follow-up.[52] Multiple studies using the Silk'n IPL device show modest hair reduction 3 and 6 months after treatment. Mulholland treated 34 individuals three times with a 64% average reduction 3 months after the last treatment.[53] Another study of 20 women with skin types I to IV demonstrated hair reduction averaging 43% across all body regions 6 months after three treatments. Hair loss was maintained with only a 10% to 20% increase in hair growth between 1 and 6 months after treatment.[54] Gold and colleagues studied 22 women receiving six biweekly treatments. Overall hair reduction was 78% at 1-month follow-up and 72% at 3-month follow-up.[55] In the most recent study, 10 adults with skin types I to IV received four to six biweekly treatments. Mean hair reduction was less impressive than in the previous studies: 36% at 4 weeks and 10% at 6 weeks.[56] Effective hair reduction in home-use devices may approach the low end of the range seen with in-office laser and light source treatments.

Complications of Photoepilation and Their Treatment

Skin type, body location, seasonal changes, and patient history of recent sun exposure determine complications of photoepilation. More-sun-protected sites, such as the axillary and inguinal areas, tend to develop complications less frequently than sun-exposed sites. Side effects are usually minor and transient. The most common skin reactions include pain, transient erythema (Figure 3), and perifollicular edema,[57] although more-severe side effects of thermal burns, blisters, hyperpigmentation, persistent hypopigmentation,[58] and permanent scarring can also occur.[59] Other uncommon side effects include induction or aggravation of acne, rosacea-like rash, premature graying of hair, tunneling of hair under the skin, prolonged diffuse redness and edema of the face, and inflammatory and pigmentary changes of preexisting nevi.[60] Severe, persistent urticaria may occur in patients who had previously tolerated a similar procedure

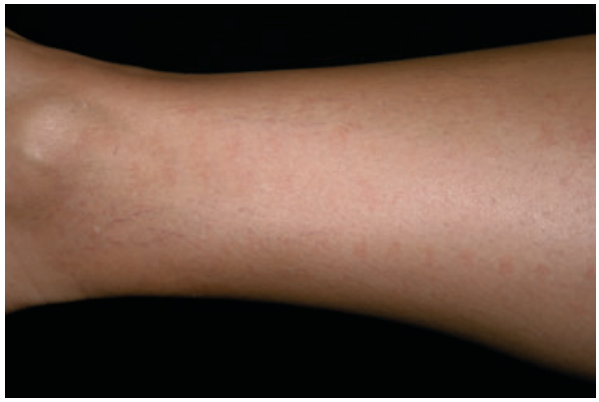

Figure 3. Faint erythema immediately after laser hair removal.

and do not have a history of urticaria with physical stimuli. This pathogenesis is unclear but may be attributed to an allergic reaction to the cryogen cooling spray or sensitivity to specific wavelengths of light.[61] Lastly, long-term hyperhidrosis may result after treatment of axillary hair with the Nd: YAG laser, perhaps due to a stimulatory rather than destructive effect on eccrine sweat glands.[62] It is important for clinicians to be aware of and communicate common and uncommon skin reactions to patients (Table 2).

Ocular injury is another potential complication of laser hair removal. At wavelengths in the visible (400–720 nm) and near-infrared (720–1,400 nm) range, intraocular penetration may cause retinal burns and visual damage. Special eye protection for all persons near the procedure should be worn. Periocular (eyebrow and eyelid) laser epilation should be avoided. Cataracts, iritis, iris atrophy, pupillary distortion, uveitis, photophobia, posterior synechiae, and visual field defects have all been reported despite use of metal protective lenses when treating this region.[63–69]

Paradoxical hypertrichosis is a rare side effect seen in 0.6% to 10% of patients treated with IPL devices and diode and alexandrite lasers.[70–77] This phenomenon is more commonly seen with the alexandrite and IPL devices and can affect treated and surrounding areas. Although the exact mechanism is unknown, one theory proposes that the laser or light source stimulates new hair growth through synchronization of dormant hair follicles into terminal anagen hair growth. Overall hair density appears to be greater than the previously asynchronous hair growth.[70] Another hypothesis is that suboptimal fluences may induce terminal hairs from vellus hairs.[78] Risk factors for this complication include darker skin types (III–VI) commonly of Mediterranean, Middle Eastern, Asian, and South Asian descent; dark, thick hair; and underlying hormonal conditions. Despite initial hypertrichosis, continued treatment with laser therapy to the affected area will eventually reduce the hair growth.

A novel technology developed to alleviate pain and discomfort during laser treatments is a pneumatic skin flattening (PSF) device based on the "gate theory" of pain transmission in which activation of non-nociceptive nerves (non-pain transmitting fibers) interferes with and inhibits the signal transmission of pain.[79] The PSF device suctions the skin into the handpiece and creates compression between a contact window and the skin, stimulating tactile and pressure receptors that block transmission of pain sensation during treatment. Moreover, the compression mechanism temporarily expels blood from dermal vasculature, reducing the amount of competing chromophore (hemoglobin) from the skin. Consequently, greater laser energy is transmitted to melanin in the hair shaft while minimizing nonselective tissue heating. The PSF system demonstrates hair removal efficacy equivalent to that of other lasers with different cooling mechanisms with less pain.[80–83] It is also faster than treatment using a sapphire-cooled handpiece.[84] In the future, devices with the PSF technology may be preferred over the current epidermal cooling devices because the former are less painful and more efficient.

Cooling mechanisms (forced cold air, contact cooling, or a delayed cooling device) use cold air or liquid nitrogen to lower the skin's surface temperature and protect the epidermal melanin, preventing unwanted hyperpigmentation or burns. A forced cold air device applies a continuous stream of chilled air 6 to 10 inches from the skin 90º to the direction of movement of the laser handpiece. It has an analgesic effect and reduces patient discomfort.[85] Because the cooled air partially protects the epidermal melanin, there are fewer side effects, including shorter-duration, less-intensive erythema and less crusting and edema. Higher laser fluences can also be tolerated.[86] Another type of cooling device is contact cooling, as is often used with IPL devices. This method has several benefits: allowing greater tolerance of high fluences; compressing and positioning the follicular unit closer to the skin surface and into a region of higher fluence; imparting partial anesthesia; and decreasing internal reflection due to

TABLE 2. Summary of Side Effects, Prevention, and Treatment Options

Side Effects	*Prevention*	*Treatment Options*
Pain	Topical anesthetic creams, forced cooled air at treatment site, local anesthesia	Application of ice packs immediately after procedure
Transient erythema and perifollicular edema	None; an appropriate treatment endpoint is to achieve transient erythema and perifollicular edema	Application of ice packs immediately after procedure; topical steroids, if necessary
Dyspigmentation	Strict sun avoidance and protection for a minimum of 6 weeks before and after each treatment; use of lasers with longer wavelengths, conservative fluences, longer pulse durations, and efficient cooling systems; selection of appropriate laser device, particularly in darker-skinned individuals	Hyperpigmentation: sun avoidance and protection, topical steroids (early in treatment), hydroquinone, mild chemical peels Hypopigmentation: sun avoidance, 1,550-nm nonablative fractionated laser[103–105]
Hypertrophic or keloidal scars	Avoidance in patients with history of easy scarring, hypertrophic scars, or keloids	Steroid injections and excision[106,107] laser and intense pulsed light,[108] low-density nonablative fractional resurfacing in early scars,[109] carbon dioxide laser
Thermal burns (blistering, ulceration)	Trimming hairs to prevent unintentional laser exposure of untrimmed hairs and adjacent cutaneous burn that is a particular risk with contact cooling devices; selection of appropriate laser device, particularly in darker-skinned individuals; avoidance of pigmented lesions or tattoos	Supportive care: topical emollients, analgesics
Ocular damage (cataracts, iritis, iris atrophy, pupillary distortion, uveitis, photophobia, posterior synechiae, retinal burns, and visual field defects[57–63]	Wearing wavelength-specific goggles by the patient and all persons in the room; not treating in periocular zone	Referral to ophthalmology
Reactivation of herpes simplex virus	Valacyclovir 500 mg by mouth twice daily for 10–14 days starting day before procedure (Beeson[95])	Valacyclovir 1 g by mouth twice daily for 7 days[110]
Chrysiasis[91,92]	Routine screening for previous gold the rapy	Long-pulse ruby[93] and pulsed dye laser[94]
De novo growth of thick hair or activation of hair follicles outside boundaries of area treated	Unknown	Subsequent laser hair removal treatments
Potentiation of thin to vellus hairs in treated areas	Avoidance of areas of thin or vellus hairs, although may be challenging because hairs of different thickness often intermingled with each other in same treatment area; seen more commonly in skin types III–VI	Subsequent laser hair removal treatments
Induction or aggravation of acne	Unknown; more common in younger individuals	Traditional treatment options (local or systemic antibiotics) for temporary relief; systemic isotretinoin therapy

TABLE 2. Continued

Side Effects	*Prevention*	*Treatment Options*
De novo rosacea-like rash	Unknown	Unknown definitive treatment options but reasonable to use traditional rosacea treatments
Premature graying of hair	Unknown	Irreversible; unknown definitive treatment options
Tunneling of hair under skin	Unknown; more common in submandibular area and especially with use of high fluences	Early management through superficial incision followed by forceps extraction under adequate magnification before subsequent laser sessions; not treatable with further laser sessions, which can cause fragmentation of the hair simulating minor iatrogenic tattoo.
Prolonged diffuse redness and edema of face	Unknown; typically seen in fair-skinned (types II or III) individuals	Reduction of dose and immediate post-treatment application of cold compresses with or without systemic nonsteroidal anti-inflammatory medication
Inflammatory and pigmentary changes of preexisting nevi	Unknown	Biopsy may be indicated because of concern regarding malignant transformation
Persistent urticaria[58]	Unknown preventative measures; no previous history of cold or heat urticaria	Trial of topical steroids; lasts for approximately 1 week
Hyperhidrosis after 1,064-nm neodymium-doped yttrium aluminum garnet laser treatment[59]	Unknown	Standard-of-care treatment for hyperhidrosis: aluminum chloride, botulinum toxin injection

index matching of the sapphire plate with the skin surface.[4] Although contact cooling can be helpful, the operator must make sure to keep the entire handpiece flush with the skin. This is of particular concern in areas where it is difficult to maintain complete contact with the skin. Delayed cooling devices impart a brief spray of liquid nitrogen onto the skin milliseconds before the laser beam contacts the skin. Like contact cooling, the delayed cooling device allows for a greater tolerance of high fluences and provides partial anesthesia. Because this type of cooling does not compress the skin, the operator has better visualization of the treatment area. It is also easier to use over uneven surface areas. If the cryogen spray area is misaligned and does not completely overlap with the laser treatment zone, distinctive sickle-shaped or crescent shaped hyperpigmentation will result[87] (Figure 4). A cooling device is essential in all skin types but is especially critical with darker skin types to minimize adverse events.

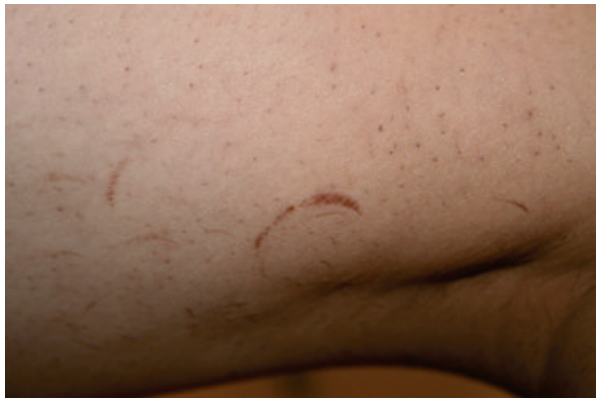

Figure 4. Crescent-shaped hyperpigmentation due to misalignment of the cryogen spray in a laser using a delayed cooling device.

Complications in Darker Skin Types

Patients with darker skin types are more at risk of side effects such as dyspigmentation and scarring because of their greater epidermal melanin content. Using longer wavelengths, longer pulse durations, conservative fluences, and more-efficient cooling systems can minimize these complications in individuals with darker skin. Epidermal melanin absorbs longer wavelengths lasers such as the Nd:YAG less efficiently, which makes them less damaging. The Nd:YAG is the best laser system to use for pigmented skin. Small structures such as epidermal melanin also cool faster than large structures such as hair follicles. Longer pulse durations can effectively heat hair follicles while epidermal melanin has cooled and is thermally protected.

Effective cooling is important for all skin phototypes, as mentioned previously, but is especially critical in those with more epidermal melanin (darker phototypes), but excess epidermal cooling without sufficient offsetting energy from the laser can increase the risk of postinflammatory hyperpigmentation in darker-skinned individuals[88,89] (Figure 4). Its mechanism is not well understood, but laser-induced inflammation may stimulate the melanocytes to become more hypersensitive to the cold temperature of the cryogen spray.

A low complication rate in darker-skinned individuals is seen after treatment with the Nd:YAG and diode laser and, with rigorous preventative measures, the Alexandrite laser. A survey of 50 subjects with skin type VI treated using the long-pulse Nd:YAG indicated high patient satisfaction in terms of hair reduction. The majority would recommend it to other patients. Minimal complications were experienced, with most cases reporting transient erythema. Only three cases had transient hyperpigmentation.[90] The diode laser could be safely used in individuals with skin types V and VI, with reported postoperative side effects being mild crusting and transient hypo- and hyperpigmentation.[91,92] In another study, 150 individuals with skin types IV to VI were treated using the alexandrite laser, with complications developing in 15 of 550 (2.7%) treatment sites. The most common side effect was blistering, with a smaller incidence of folliculitis, transient hyperpigmentation, and excoriation. Scarring was not observed. The authors attributed the low incidence of adverse effects to preventative measures. Patients were instructed to practice rigorous sun protection before and after treatment, were pretreated with hydroquinone and glycolic acid, and were given postlaser topical corticosteroids. During treatments, direct thermal tissue damage was minimized through determination of the minimal fluence parameter that would provoke mild perifollicular erythema, appropriate selection of an epidermal cooling device, and avoidance of overlapping pulses.[93] Such an intensive regimen may hinder adherence and be impractical for the average patient. The long-pulse Nd:YAG is the best laser system to use for darker-pigmented individuals, but the Nd:YAG and diode lasers both have few transient side effects without such stringent preventative measures before, during, and after treatment than are necessary when using the alexandrite laser in this select population.

Laser Treatment

Patient Selection

Pretreatment evaluation should include a thorough medical history. A history of endocrine abnormalities or menstrual dysfunction should prompt a thorough examination to unveil a systemic and treatable cause of hirsutism. Likewise, a patient with sudden onset of lanugo-type hypertrichosis should be evaluated for a paraneoplastic syndrome.[94] Recurrent infections with herpes simplex virus (HSV) at or around the mouth or genital area warrants appropriate prophylactic treatment with valacyclovir 500 mg twice daily for 10 to 14 days starting the day before the procedure.[95] A history of keloids or hypertrophic scars should be investigated to avoid overly aggressive treatment. Hairs should be trimmed or shaved to minimize the smoke plume during treatment and prevent hair from becoming

trapped underneath a contact cooling device. If hair is present on the skin surface, the laser will target the exposed hair and induce a thermal cutaneous burn (Figure 5).

Individuals should be screened for previous gold or isotretinoin therapy. A history of taking gold salts, historically used for treatment of diseases such as rheumatoid arthritis, is a contraindication to laser therapy. The combination of laser treatment and gold intake can induce chrysiasis, a type of cutaneous hyperpigmentation.[96,97] Treatment of chrysiasis is limited, with only a few case reports documenting improvement using the long-pulsed ruby [98] and pulsed dye [99] lasers. Laser hair removal while taking isotretinoin is controversial. Although recent studies suggest that it may be safe,[100,101] there may be a risk of phototoxicity, skin fragility, and impaired tissue repair, with a delay in reepithelialization and scar formation. We recommend a washout period of at least 6 to 12 months before laser exposure.

An important part of the consultation visit is to establish realistic patient expectations, detail potentially adverse outcomes, and discuss the cost of the procedure. Patients should understand that multiple (approximately 4–6) treatments will be necessary for long-term hair removal, although this does not guarantee a permanent solution, because treated hairs may regrow some years later. A single laser treatment typically yields a 2- to 6-month growth delay. Hair regrowth is generally more sparse, with individual hairs being thinner and paler.[102] Patients should also be aware that hairs do not fall out immediately after treatment but are shed over a period of days to weeks. Sun avoidance should be strictly enforced before the procedure, because patients cannot be treated if at all tan. Epidermal melanin competes for absorption of light energy and confers a risk of side effects such as hypo- or hyperpigmentation (Figure 6), blistering, ulceration, and scarring. Because melanin in the hair shaft is essential for effective laser removal, individuals with white, blonde, or red hair, histologically correlating to a lack of melanin, paucity of melanin, or presence of eumelanin, are not good candidates for laser hair removal. Waxing, plucking, threading, or any epilation method that pulls out the entire hair shaft should be avoided between treatments or for at least 4 weeks before a treatment.

Treatment Considerations

Pretreatment with topical anesthetics varies between patients and specific anatomic sites. More-sensitive areas such as the upper lip and inguinal region may require a 30-minute to 1-hour incubation with a topical anesthetic cream such as lidocaine, prilocaine, Betacaine, or tetracaine. Other less commonly used anesthetic methods include application of

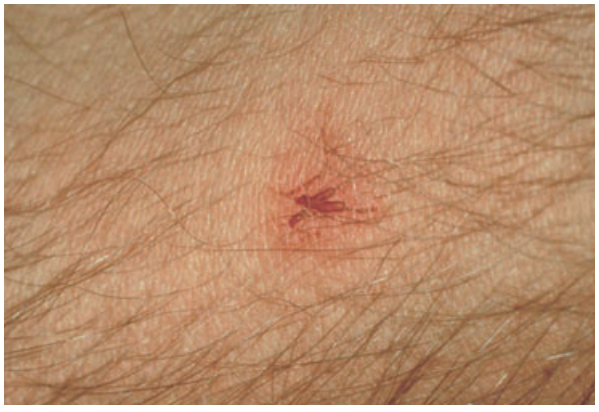

Figure 5. A burn sustained after laser hair removal using a contact cooling handpiece. The unshaven hair on the skin's surface absorbs light and creates a burn. Courtesy of Dr. Thomas Rohrer.

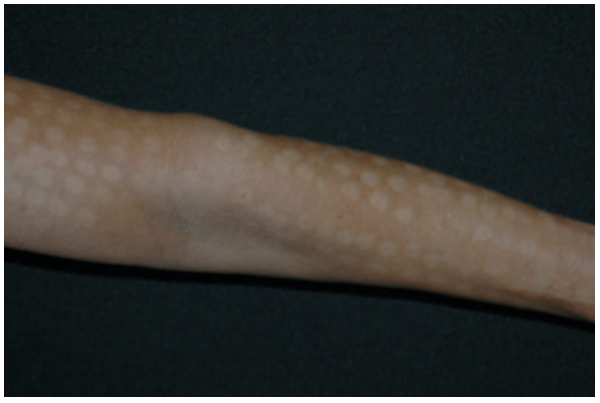

Figure 6. Persistent hypopigmentation after laser hair removal in a suntanned patient.

forced cooled air to the treatment site, local infiltration of anesthesia, regional nerve block, or a combination thereof.

Most importantly, before starting the procedure, proper eye protection is critical for the patient, proceduralist, and any observers in the treatment room. Each device requires the use of specific goggles unique to that machine's particular wavelength. Therefore, goggles are not interchangeable between laser or IPL devices of other wavelengths. Additionally, because of the risk of ocular damage, treatments should not be performed in the periocular zone.

At the start of the procedure, a test spot on an inconspicuous area should be performed before the full treatment. Adjustments to the laser's parameters should be made to achieve perifollicular edema or faint erythema as an appropriate endpoint. The proceduralist should avoid treating pigmented lesions or tattoos, which can easily induce burns.

After the procedure, ice packs should be applied to the treated area to reduce pain and swelling. Erythema and edema can be seen immediately after treatment. Topical steroids may be given at the discretion of the practitioner, but if the patient sustains burns during the procedure, high-potency topical steroids should be applied immediately afterward and for the next several days. If hyperpigmentation ensues, hydroquinone and topical steroids can be applied daily in combination with mild chemical peels as necessary. Hypopigmentation should be addressed with sun avoidance and potentially with treatment with a 1,550-nm nonablative fractionated laser.[103–105] Patients should practice strict sun avoidance for a minimum of 6 weeks before and after each treatment. Subsequent treatments to a given area may be repeated every 4 weeks.

Conclusion

Laser hair removal devices effectively provide a durable and efficient method for unwanted hair removal. Possessing a detailed understanding of each laser's properties is critical for the clinician to accurately customize individual treatments to the unique patient. Laser technology within the scope of hair removal continues to evolve from its beginnings in the mid-1990s. Current research is directed toward optimizing safety, efficacy, and comfort for patients of all skin types. In the future, these improvements will probably have longer-lasting treatment results while minimizing untoward side effects.

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