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INVITED REVIEW ARTICLE

Laser hair removal

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ABSTRACT: The extended theory of selective photothermolysis enables the laser surgeon to target and destroy hair follicles, thereby leading to hair removal. Today, laser hair removal (LHR) is the most commonly requested cosmetic procedure in the world and is routinely performed by dermatologists, other physicians, and non-physician personnel with variable efficacy. The ideal candidate for LHR is fair skinned with dark terminal hair; however, LHR can today be successfully performed in all skin types. Knowledge of hair follicle anatomy and physiology, proper patient selection and preoperative preparation, principles of laser safety, familiarity with the various laser/light devices, and a thorough understanding of laser–tissue interactions are vital to optimizing treatment efficacy while minimizing complications and side effects.

KEYWORDS: laser hair removal, photoepilation, selective photothermolysis

Introduction

History of laser hair removal

The ability of lasers to nonspecifically damage hair follicles was noted nearly 50 years ago in the first reports on the use of lasers on human skin (1,2). However, it was not until the theory of selective photothermolysis was proposed by Anderson and Parrish at the Wellman Center for Photomedicine at Harvard Medical School, that the concept of selectively targeting a particular chromophore based on its absorption spectra and size was realized (3). Several years later, this group also reported the first successful use of a normal-mode ruby laser for long-term and permanent hair removal (4,5).

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Alternative methods for hair removal

Today, removing unwanted body hair is an increasingly prevalent trend in our society, and photoepilation by laser or other light-based technology is the fastest-growing procedure in cosmetic dermatology (6). Other methods for removing unwanted hair include bleaching, plucking, shaving, waxing, and chemical depilatories. Threading is a common practice in some cultures. None of these methods provide a permanent solution to unwanted hair, and can be inconvenient and tedious (7,8). Electrolysis is a method for hair removal in which a fine needle deep into the hair follicle destroys the follicle via electrical current, thus allowing for permanent hair removal of both terminal and nonterminal hair, as well as of both pigmented and non-pigmented hair (9,10). However, this technique is extremely operator dependent and efficacy in achieving permanent hair removal is variable among patients (9,10). Thus, it is often impractical in terms of treating large areas. Eflornithine is a topical inhibitor of ornithine decarboxylase that slows the rate of hair growth and is effective for unwanted facial hair (8), and is currently indicated for the removal of unwanted facial hair in women. Eflornithine can be combined with lasers and intense pulsed light (IPL) for hair removal (11,12).

The hair follicle

Hair anatomy

The hair follicle is an intricate, hormonally active structure with a programmed growth pattern (FIG. 1). It is anatomically divided into the infundibulum (hair follicle orifice to insertion of the sebaceous gland), isthmus (insertion of the sebaceous gland to the insertion of the arrector pili muscle), and inferior (insertion of the arrector pili to the base of the hair follicle) segments. The dermal papilla, a neurovascular structure that supplies the cells of the proliferating matrix at the base of the follicle, helps form the hair shaft.

Hair growth

Each hair follicle consists of a permanent (upper) and nonpermanent (lower) part, with the follicular bulge forming the lowermost aspect of the permanent part. In periods of active growth (anagen) the rapidly developing bulbar matrix cells differentiate into the hair shaft and the hair lengthens. A transition period follows in which the bulbar part of the hair follicle undergoes degradation through apoptosis (catagen). A resting period (telogen) phase ensues, and regrowth is started once again in early anagen. Stem cells within the hair follicle regenerate the follicle within or near the hair bulb matrix. Slow-cycling stem cells have also been found in the follicular bulge arising off the outer root sheath at the site of arrector pili muscle attachment. The duration of each growth phase is body site dependent.

Hair types

There are three main types of hair: lanugo, vellus, and terminal hairs. Lanugo hairs are fine hairs that cover a fetus and are shed in the neonatal period. Vellus hairs are nonpigmented, and have a diameter of roughly 30 µm. Terminal hair shafts range from 150 to 300 µm in cross-sectional diameter. The type of hair produced by an individual follicle

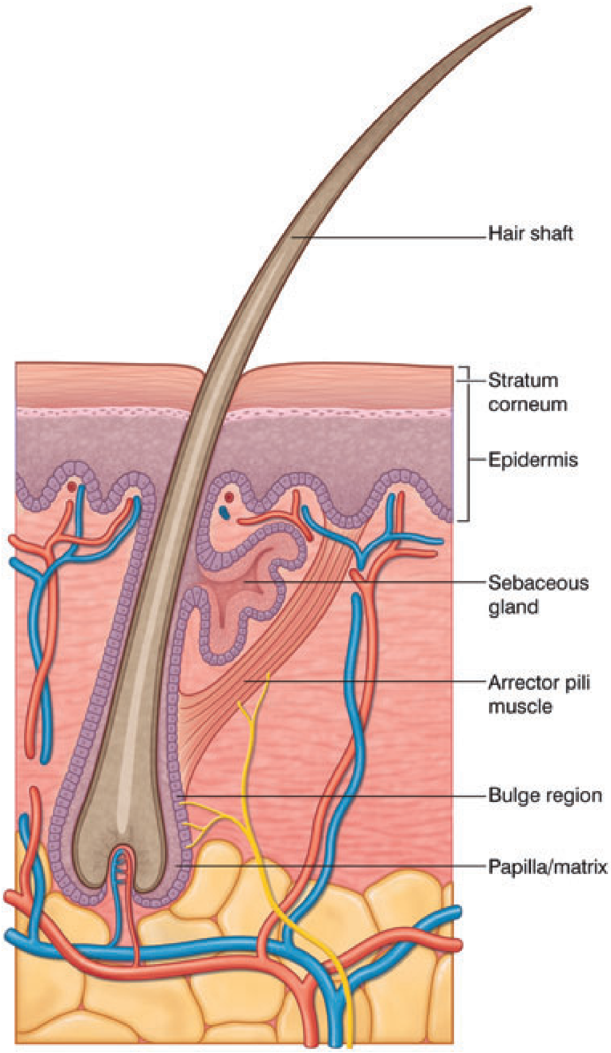

FIG. 1. Hair follicle anatomy (reproduced from Tsao SS and Hruza GJ. Laser hair removal. In: Robinson JK, Hanke CW, Sengelmann RD, and Siegel DM, eds. Surgery of The Skin. Philadelphia: Elsevier Mosby, 2005: 575–588).

is capable of change (e.g., vellus to terminal hair at puberty or terminal to vellus hair in androgenic alopecia).

Hair color

Hair color is determined by the amount of pigment in the hair shaft. Melanocytes produce two types of melanin: eumelanin, a brown-black pigment; and pheomelanin, a red pigment. Melanocytes are located in the upper portion of the hair bulb and outer root sheath of the infundibulum.

Classification of excess hair

Excessive and unwanted body hair ranges in severity, depending on cultural mores, and can usually be classified as either hypertrichosis or hirsutism (13). Hirsutism is defined as the abnormal growth of terminal hair in women in male-pattern (androgen-dependent) sites, such as the face and chest. Hypertrichosis refers to excess hair growth at any body site that is not androgen-dependent (13).

Mechanism of LHR

The theory of selective photothermolysis enables one to selectively target pigmented hair follicles by using the melanin of the hair shaft as a chromophore (3). Melanin is capable of functioning as a chromophore for wavelengths in the red and near-infrared portion of the electromagnetic spectrum (14). However, to achieve permanent hair removal, the biological "target" is likely the follicular stem cells located in the bulge region and/or dermal papilla. Based on the slight spatial separation of the chromophore and desired target, an extended theory of selective photothermolysis was proposed which requires diffusion of heat from the chromophore to the desired target for destruction (15). This requires a laser pulse duration that is longer in duration than if the actual chromophore and desired target were identical. Temporary LHR can result when the follicular stem cells are not completely destroyed, primarily through induction of a catagen-like state in pigmented hair follicles. Temporary LHR is much easier to achieve than permanent removal, using lower fluences. Long-term hair removal depends on hair color, skin color, and tolerated fluence. Roughly 15–30% long-term hair loss may be observed with each treatment when optimal treatment parameters are used (16). A list of laser and light devices that are commercially available at the time of this publication for hair removal are summarized in Table 1.

Key factors in optimizing treatment

The ability to selectively target hair follicles with lasers and light sources has revolutionized the ability to eliminate unwanted hair temporarily and permanently in many individuals. As laser technology advances, the ability to treat individuals of all skin types and all hair colors broadens. Proper patient selection, preoperative preparation, informed consent, understanding of the principles of laser safety, and laser and light source selection are key to the success of laser treatment. An understanding of hair anatomy, growth and physiology, together with a thorough understanding of laser–tissue interaction, in particular within the context of choosing optimal laser parameters for effective LHR, should be acquired before using lasers for hair removal.

Patient selection

Despite the seemingly cosmetic nature of LHR, a complete medical history, physical examination and informed consent, including setting realistic patient expectations and potentials risks, should be preformed prior to any laser treatment. Any patient with evidence for endocrine or menstrual dysfunction should be appropriately worked up. Similarly, patients with an explosive onset of hypertrichosis should be evaluated for paraneoplastic etiologies. Treatment of a pregnant woman for nonurgent conditions is discouraged, although there is no evidence suggesting a potential risk to pregnant women undergoing LHR. The past medical history should be reviewed to identify patients with photosensitive conditions, such as the autoimmune connective tissue disorders, or disorders prone to the Koebner phenomenon. A history of recurrent cutaneous infections at or in the vicinity of treatment area might warrant the use of prophylactic medications. Any past history of keloid or hypertrophic scar formation should be elicited as well. Previous methods for hair removal, including any past laser treatments, should be reviewed. Any methods of epilation, such as waxing or tweezing, that entirely remove the target chromophore, render LHR ineffective for at least 2 weeks. Although there is little evidence for the time frame a patient must wait after complete epilation of the hair shaft and laser treatment, we recommend a minimum of 6 weeks. Shaving and depilatory creams can be used up to the day of the laser treatment as they do not remove the entire hair shaft.

A thorough medication history should be obtained. Any history of gold intake is a contraindication for laser therapy. The use of any photosensitizing medications or over-the-counter supplements should also delay treatment until these medications can be safely discontinued. There is controversy as to whether patients on isotretinoin should be treated with laser, although conventionally most practitioners recommend a 6-month to 1-year washout period prior to laser treatment (17–19). Topical retinoids used in the treatment area should be discontinued 1–2 days prior to treatment.

The physical exam should evaluate the patient's Fitzpatrick skin phototype. This will help

Table 1. Commercially available lasers and light sources for hair removal[a]

Laser/light source	Wavelength (nm)	System name	Pulse duration (ms)	Fluence (J/cm^2)	Spot size (mm)	Other features
Long-pulsed ruby	694	None				
Long-pulsed alexandrite	755	Apogee (Cynosure)	0.5–300	25–50	5–15	Cold air or integrated cooling; can add 1064 nm Nd : Yag module to form Apogee Elite
		Arion (Quantel Derma)	5–140	Up to 40	6–16	Cold air unit
		ClearScan Yag (Sciton)	Up to 200	Up to 140	3, 6 and 30 × 30	Contact cooling
		Coolglide (Cutera)	0.1–300	5–300	10	Contact cooling
		Elite (Cyanosure)	0.5–300	25–50	5–15	Cold air cooling; available with 1064 nm Nd : Yag; EliteMPX model can simultaneously treat with 755 nm Alexandrite and 1064 nm Nd : Yag
		EpiCare LP/LPX (Light Age)	3–300	22–40	7–16	
		GentleLASE (Candela)	3	Up to 100	6–18	Dynamic cooling
		GentleMax (Candela)	0.25–300	Up to 600	1.5–18	Dynamic cooling, comes with 1064 Nd : Yag
		Ultrawave 755/II/III (AMC Aesthetics and Advance Aesthetic Concepts)	Up to 100	Up to 125	Up to 16	Available with 532, 1064, and 1320 nm Nd : Yag
Diode	800–810	F1 Diode (Opusmed)	15–40	up to 40	5, 7	Chiller tip
	808, 980	Leda (Quantel Derma)	6–60	Up to 60	50 × 12, 10 × 12	Contact cooling
	810, 940	MeDioStar XT (Aesclepion)	5–500	Up to 90	6,12	Integrated scanner with cold air cooling device
	800	LightSheer Duet (Lumenis)	5–400	10–100, 4.5–12	9 × 9, 22 × 35	Chilltip for smaller handpiece; vacuum skin flattening for larger handpiece
	810	Soprano XL (Alma Lasers)	10–1350	Up to 120	12 × 10	Contact cooling
Long-pulsed Nd : Yag	1064	Acclaim (Cynosure)	0.4–300	35–600	1.5–15	Cold air or integrated cooling; can add 755 nm Alexandrite module to form Apogee Elite (Cynosure)
		ClearScan Yag (Sciton)	0.3–200	Up to 400	3,6 and 30 × 30	Contact cooling
		CoolGlide CV/XEO/Excel/ Vantage (Cutera)	0.1–300	Up to 300	3–10	Contact cooling
		Cynergy (Cynosure)	0.3–300	Up to 600	1.5–15	Cold air

Table 1. *Continued*

Laser/light source	Wavelength (nm)	System name	Pulse duration (ms)	Fluence (J/cm^2)	Spot size (mm)	Other features
		Dualis XP, XP Plus and XS Max (Fotona)	5–200	Up to 600	2–10	n/a
		GentleYAG (Candela, Wayland, MA)	0.25–300	Up to 600	1.5–18	Dynamic cooling
		Gemini (Iridex)	1–100	Up to 990	2, 10	Available with 532 nm KTP
		LightPod Neo (Aerolase)	0.65–1.5	Up to 312	2	Built-in cooling system
		Lyra (Iridex)	20–100	5–900	1–5, 10	Contact cooling
		MultiFlex (Ellipse, Atlanta, GA)	n/a	Up to 600	1.5–5	Equipped with IPL device
		Mydon (Quantel)	0.5–90	10–450	1.5–10	Intergrated air cooling
		NaturaLase 1064/LP (Focus Medical)	0.5–100	Up to 400	3–15	Intergrated air cooling
		Profile (Sciton)	0.1–10,000	Up to 75	n/a	Contact cooling; 2940 nm Er : Yag and 410–1400 nm flashlamp in same device
		SmartEpil (Deka)	Up to 20	11	2.5,4,5,6	
		SP Plus (Fotona)	Up to 300	Up to 600	1–42	
		Synchro_FT (Deka)	2–30	Up to 50	2.5–13	Available with IPL handpiece
		Ultrawave II/III (AMC Aesthetics, and Advance Aesthetic Concepts)	up to 300	5–500	Up to 12	Pulsed cryogen cooling
		Varia (CoolTouch)	0.6	Up to 500	2–10	Dynamic cryogen cooling
Intense-pulsed light sources	520–1200	Axiom (Viora)	25–75 and 2.2–12.5	Up to 39	50 × 25, 35 × 15, 20 × 10	Built in cooling system
	420–1400	BBL (Sciton)	Up to 200	Up to 30	15 × 45	Built in cooling system
	560–590	Cynergy (Cynosure)	0.3–300	Up to 600	n/a	Built in cooling system
	400–1200	Duet/SkinStation/SpaTouch II (Radiancy)	3–10	35	22 × 55	
	600–950	Ellipse I2PL/MultiFlex (Ellipse)	2.5–88.5	4–26	10 × 48	MultiFlex model with long-pulsed Nd : Yag
	400–1400	EsteLux (Palomar Medical Technologies)	10–100	Up to 28	n/a	
	650–950	Harmony XL (Alma Lasers)	30–50	Up to 40	30 × 30	Available with 755 nm alexandrite and 1064 and 1320 nm Nd : Yag
	530–1200	iPulse (Dermavista)	5–120	Up to 20	89 sq	Air cooling

Table 1. *Continued*

Laser/light source	Wavelength (nm)	System name	Pulse duration (ms)	Fluence (J/cm^2)	Spot size (mm)	Other features
	390–1200	Med Flash II (General Project)	Up to 100	Up to 45	n/a	
	525–1200	MediLux/StarLux Y, Ys, R, Rs (Palomar)	5–500	Up to 70	28 × 12, 46 × 16	1064 Nd : Yag handpiece for StarLux 500
	500–1200	MiniSilk_FT (Deka)	3–8	Up to 160	48 × 13, 23 × 13	Contact cooling
	400–1200	Mistral (Radiancy)	Up to 80	4–15	25 × 50, 13 × 50, 13 × 35, 12 × 12	
	640–1400	NannoLight MP50 (Sybaritic)	1–30	2.8–50	40 × 8	Nd : Yag handpiece; optional cooling
	640–1200	NaturaLight (Solamed)	Up to 500	Up to 50	10 × 40	
	750–1100	Solera Opus (Cutera)	Auto	3–24	10 × 30	
	550–950	PhotoSilk/PhotoLight/MiniSilk (Cyanosure)	Up to 30	10–340	21 × 10, 46 × 10, 46 × 18	Nd : Yag handpiece
	770–1100	ProWave (Cutera)	Auto	5–35	10 × 30	
	500–1200	Quadra Q4 (DermaMed)	48	10–20	33 × 15	Built in cooling system
	695–1200	Quantum HR (Lumenis)	15–100	25–45	34 × 8	
	560–950	SmoothCool (Eclipse)	1–60	10–45	8 × 34	Automatic temperature control system
	530–1200	Trios (Viora)	25	Up to 22	15 × 50	
Fluorescent pulsed light	615–920	OmniLight/NovaLight (Medical Bio Care)	2–500	Up to 90	7 × 15, 10 × 20, 30 × 30	Sapphire tip cooling
Optical energy combined with RF electrical energy	580–980	eMax//eLight (Syneron)	Up to 100	Up to 50 optical; up to 50 J/cm^3 RF	12 × 15	Contact cooling
Diode combined with RF electrical energy	800	eLaser (Syneron)	Up to 100	Up to 50 optical; up to 50 J/cm^3 RF	12 × 15	Contact cooling
	810	MeDioStar Effect (Aesclepion, Jena, Germany)	Up to 500	Up to 90	10,12,14	Acoustic wave technology; integrated scanner with cold air cooling device; 940 nm simultaneously

[a]This table is intended only as a reference aid. The authors have made every attempt to provide an exhaustive list of available devices for laser hair removal but do not guarantee comprehensiveness.

IPL, intense pulsed light; KTP, potassium titanyl phosphate; RF, radiofrequency.

determine which lasers and light sources are safe to use for that patient (Table 1), because epidermal melanin in darkly pigmented patients can compete with the melanin within hair follicles as the target chromophore. Importantly, every patient should always be evaluated for the presence of a tan, and if present, laser treatment should be delayed or the treatment parameters appropriately adjusted until the tan has faded. Finally, the patient's hair color should be noted as the chromophore for LHR is melanin. Black and brown hair contain sufficient amounts of melanin to serve as a chromophore for LHR. In contrast, the lack of melanin, paucity of melanin, or presence of eumelanin in the hair follicle, which clinically correlates to white, gray, or red/blonde hair, is predictive of a poor response to laser hair removal. For patients with little to no melanin in their hair follicles, attempts have been made to use an exogenous chromophore that can be topically delivered to the hair follicles, thereby making the removal of white, gray, red, and blonde hair hypothetically possible. This concept was first demonstrated with a topical carbon solution dissolved in mineral oil (20). However, we have noticed very little efficacy of topical chromophores in our vast experience.

Informed consent

An explanation of the potential risks of LHR should be reviewed as part of the informed consent process. The risks include but are not limited to temporary and permanent hypo/hyperpigmentation, blister formation, scar formation, ulceration, hive-like response, bruising, infection, acne flare, and folliculitis. For those patients with Fitzpatrick skin type IV or greater or of Mediterranean, Middle Eastern, Asian or South Asian descent, the low risk of paradoxical hypertrichosis (conversion of vellus hairs to terminal hairs), especially when treating the lateral face and jaw, should be reviewed (21–24). Patients should be counseled that permanent and complete hair removal is not likely but that with multiple treatments, significant long-term reduction can be achieved. Hirsute women with hormonal abnormalities may require continued maintenance therapy and should be advised of this possibility. Procedural pain is expected with LHR but can be minimized with topical anesthetics. Erythema and edema are also expected with treatment and may last up to 1 week. Patients should be aware of the need for strict sun avoidance for a minimum of 6 weeks before and after each treatment.

Preoperative preparation and laser safety

The need for topical anesthesia is variable among patients and particular anatomic sites. Various topical anesthetics including lidocaine, lidocaine/prilocaine, and other amide/ester anesthetic combinations can be used to diminish the procedural discomfort, and should be applied 30 minutes to 1 hour before treatment under occlusion. Care should be taken when using lidocaine or prilocaine to apply these medications to a limited area to diminish the risk of lidocaine toxicity or methemoglobulinemia, respectively.

Patients should be placed in a room with a treatment chair that makes the desired treatment area easily accessible. The room should be adequately cooled to keep the laser device from overheating and be free of any hanging mirrors or uncovered windows. A fire extinguisher should be readily available, especially if oxygen is being used. Having a vacuum device on hand during treatment can minimize the plume and unpleasant odor created by each laser pulse. Because the retina contains melanin which can be damaged by all LHR devices, proper eye protection is absolutely critical for both the patient and laser surgeon. Each device requires the use of protective goggles that are unique to the device's particular wavelengths. Goggles can not be interchangeably used with laser or IPL devices of other wavelengths. Furthermore, because of the risk of retinal damage, it is the authors' strong opinion that one should never treat a patient for LHR within the bony orbit.

Device variables

Wavelength. The chromophore for laser hair removal is melanin. Within the hair follicle, melanin is principally located within the hair shaft, although the outer root sheath and matrix area also contain melanin. Melanin is capable of functioning as a chromophore for wavelengths in the red and near-infrared portion of the electromagnetic spectrum (14), and can be targeted by ruby, alexandrite, diode, and Nd : Yag lasers, as well as IPL devices.

The long-pulsed ruby laser (694 nm) was the first device used to selectively target hair follicles (5), and result in long-term (follow-up at 2 years) hair loss (6 mm spot size, 270 μs pulse duration and fluences 30–60 J/cm^2) (4). The long-pulsed ruby laser can be safely used in Fitzpatrick skin phototypes I–III. A large multicenter trial of nearly 200 patients showed that the majority of patients had >75% hair loss on 6-month follow-up after an average of four treatments (25). At the time of press, there are no long-pulsed ruby lasers that are commercially available in the United States (Table 1).

The long-pulsed alexandrite (755 nm) laser has been shown to be effective for hair removal in multiple studies (26). The long-pulsed alexandrite laser can be safely used in Fitzpatrick skin phototypes I–IV; although some experts limit the use of the long-pulsed alexandrite laser to Fitzpatrick skin phototypes I–III. A few studies have demonstrated the safety of the long-pulsed alexandrite laser in a large cohort of patients with Fitzpatrick skin phototypes IV–VI (27,28). A recent randomized, investigator-blinded clinical trial of subjects with Fitzpatrick skin phototypes III–IV treated with a long-pulsed alexandrite laser (12 and 18 mm spot size, 1.5 ms pulse duration and fluences of 20 or 40 J/cm^2) for four sessions at 8-week intervals showed 76–84% hair reduction 18 months after the last treatment (29) provides the best evidence for long-term hair removal efficacy with the alexandrite laser. A randomized controlled trial of 144 Asian subjects with Fitzpatrick skin types III–V with a long-pulsed alexandrite laser (12.5 mm spot size, pulse duration of 40 ms, fluences of 16–24 J/cm^2) found that subjects with three treatments had a 55% hair reduction compared with subjects treated twice with a 44% hair reduction and subjects treated once had a 32% hair reduction at 9 months follow-up (30). Combination treatment of alexandrite and Nd : Yag lasers provide no added benefit over the alexandrite laser alone (31). The commercially available long-pulsed alexandrite devices are summarized in Table 1.

The long-pulsed diode (800–810 nm) laser has also been extensively used for LHR (26,32). The diode laser can be safely used in patients with Fitzpatrick skin phototypes I–V. Two long-term nonrandomized controlled studies showing roughly 40% hair reduction at a mean follow-up of 20 months after one or two treatments (9-mm spot size, pulse duration of 5–30 ms, fluences of 15–40 J/cm^2) (33), and 84% hair reduction at 1-year follow-up after four treatments (9-mm spot size, pulse duration of 5–30 ms, fluences of 12–40 J/cm^2) (34) demonstrate the efficacy of the diode laser for long-term hair removal.

The long-pulsed Nd : Yag laser has been thought to offer the best combination of safety and efficacy for Fitzpatrick skin phototype VI patients. To our knowledge, the evidence for long-term hair reduction with the Nd : Yag laser is not as convincing as other LHR devices, although a nonrandomized trial reported a 70–90% reduction of facial, axillary, and leg hair growth 1 year after three monthly treatments with an Nd : Yag laser (5-mm spot size, pulse duration of 50 ms, fluences of 40–50 J/cm^2) (35). A small study of axillary LHR comparing long-pulsed alexandrite, diode, and Nd : Yag lasers showed that both the alexandrite and diode lasers were significantly more efficacious than the Nd : Yag laser for LHR (36).

IPL is composed of polychromatic, noncoherent light ranging from 400 to 1200 nm. Various filters can be used to target particular chromophores, including melanin. Long-term (>1 year) hair removal has not been convincingly demonstrated to date. Various reports have demonstrated some short-term efficacy (37,38). One study of patients treated with a single IPL session reported 75% hair removal one year after treatment (39). Two studies providing a head to head comparison of IPL versus either the long-pulsed alexandrite laser (40), or Nd : Yag laser(41) both found the IPL to be inferior to laser devices for hair removal.

Fluence. Fluence is defined as the amount of energy delivered per unit area and is expressed as J/cm^2. Higher fluences have been correlated with greater permanent hair removal; (5,42) however, they are also more likely to cause untoward side effects. Recommended treatment fluences are often provided with each individual laser device for non-experienced operators. However, a more appropriate method of determining the optimal treatment fluence for a given patient is to evaluate for the desired clinical endpoint of perifollicular erythema and edema (FIG. 2). The highest possible tolerated fluence which yields this endpoint,

FIG. 2. Appropriate clinical endpoint of perifollicular erythema and edema.

without any adverse effects, is often the best fluence for treatment.

Pulse duration. Pulse duration is defined as the duration in seconds of laser exposure. The theory of selective photothermolysis(3) enables the laser surgeon to select an optimal pulse duration based on the thermal relaxation time (TRT). Terminal hairs are roughly 300 μm in diameter, and thus the calculated TRT of a terminal hair follicle is roughly 100 ms. However, unlike many other laser applications, the hair follicle is distinct in that there is a spatial separation of the chromophore (melanin) within the hair shaft and the biological "target" stem cells in the bulge and bulb areas of the follicle. The expanded theory of selective photothermolysis(15) takes this spatial separation into account and proposes a thermal damage time, which is thought to be longer than the TRT. Shorter pulse widths are also capable of removing hair, but are probably not as effective in producing permanent hair removal. Longer pulse widths are likely more selective for melanin within the hair follicle and can minimize epidermal damage as the pulse widths are greater than the TRT of the melanosomes and melanocytes within the epidermis.

Spot size. The spot size is the diameter in millimeters of the laser beam. Larger spot sizes are preferable to smaller spot sizes. As photons within a laser beam penetrate the dermis, they are scattered by collagen fibers, and those that are scattered outside the area of the laser beam are essentially wasted. Photons are more likely to be scattered outside of the beam area for smaller spot sizes, whereas in a larger spot size, the photons are likely to remain within the beam area following scatter (S. Kilmer and R. Anderson, unpublished data). Using the largest possible spot size also minimizes the number of pulses it takes to cover a treatment area, thereby translating to faster treatment courses. A double-blind, randomized control trial of a long-pulsed alexandrite device for LHR of the axillary region comparing 18- and a 12-mm spot sizes at otherwise identical treatment parameters showed a 10% greater reduction in hair counts with the larger spot size (43).

Skin cooling. The presence of epidermal melanin, particularly in darker skin types, presents a competing chromophore to hair follicle melanin, which can be damaged during LHR. Cooling of the skin surface can be used to minimize epidermal damage, while permitting treatment with higher fluences (44). All of the skin cooling methods function by acting as a heat sink and removing heat from the skin surface. The least effective type of cooling is the use of an aqueous cold gel which passively extracts heats from the skin and then is not capable of further skin cooling. Alternatively, cooling with forced chilled air can provide cooling to the skin before, during, and after a laser pulse. However, today, most of the commercially LHR devices have a built-in skin cooling system, which either consists of contact cooling or dynamic cooling with a cryogen spray. Contact cooling, usually with a sapphire tip, provides skin cooling just before and during a laser pulse. It is most useful for treatments with longer pulse durations (>10 ms) (45). Dynamic cooling with cryogen liquid spray (46) precools the skin with a millisecond spray of cryogen just before the laser pulse. A second spray can be delivered just after the laser pulse for post-cooling, but parallel cooling during the laser pulse is not possible as the cryogen spray interferes with the laser beam. Dynamic cooling is best suited for use with pulse durations shorter than 5 ms.

Post-procedure care

It is expected for the patient to have perifollicular erythema and edema in the treatment area following LHR. This generally persists for 2 days but can last for up to 1 week. Ice and application of a topical corticosteroid can be used to shorten the duration of these desired clinical findings. Patients will often find that a single treatment of LHR with shorter pulse durations results in nearly total epilation of the hair follicles in the treatment area. It is important to counsel the patient that a majority of these hairs will likely regrow, and this isn't considered a treatment failure. Generally, only about 15% of hairs are permanently removed with each laser treatment. On the other hand, LHR treatments with longer pulse durations may leave behind many hairs which appear to "grow" following treatment. It is important to reassure the patient that these "growing" hairs are dislodged from the hair follicle and require 1–2 weeks to be completely shed. Nearly any method of epilation can be used to hasten their removal.

The importance of strict sun precaution following LHR treatments can not be overemphasized. This can be achieved by the use of topical sunscreens, ultraviolet light impermeable garments, and sun avoidance.

Complications

The most common complication of LHR is pigmentary alteration, including hyper- and hypo-

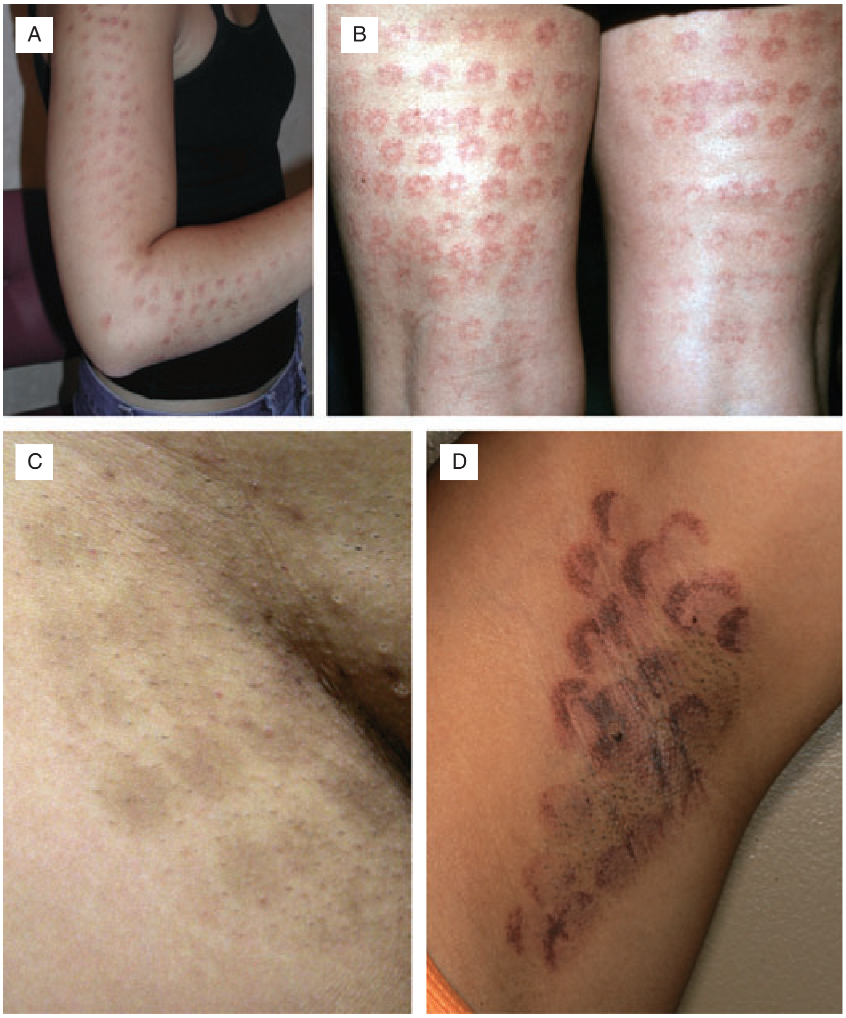

FIG. 3. **(A, B, C, and D) Examples of laser hair removal-induced hyperpigmentation**.

pigmentation (FIGS 3 and 4). This may result either from selecting a non-optimal wavelength, pulse duration, fluence, nonfunctional epidermal cooling, or by treating a tanned patient. Pigmentary alterations may also occur even when optimal treatment parameters are used. These changes are often transient and improve with time, although permanent hypopigmentation can occur (FIG. 4). Zones of untreated hairs can result from a lack of overlapping between laser pulses (FIG. 5). Scarring is an exceedingly rare complication but can occur when excessive fluences are used.

Treatment of vellus hairs, especially of the lateral cheeks and chin area, may result in the induction of terminal hairs, a phenomenon known as paradoxical hypertrichosis (FIG. 6). This has been reported to occur more commonly in females of Mediterranean, Middle Eastern, Asian, and South Asian descent (21–24).

Conclusion

Future directions

Advances in pain control. A novel technique to reduce laser hair removal-associated pain is pneumatic skin flattening (PSF) (47). PSF works by coupling a vacuum chamber to generate negative pressure and flatten the skin against the handpiece treatment window. Based on the gate theory of pain transmission, it stimulates pressure receptors in the skin immediately prior to firing of the laser pulse, thereby blocking activation of pain fibers. PSF is just beginning to be incorporated into commercially available lasers (Table 1).

Home use laser and light source devices for hair removal. In recent years, a number of devices have been developed that seek to provide patients with

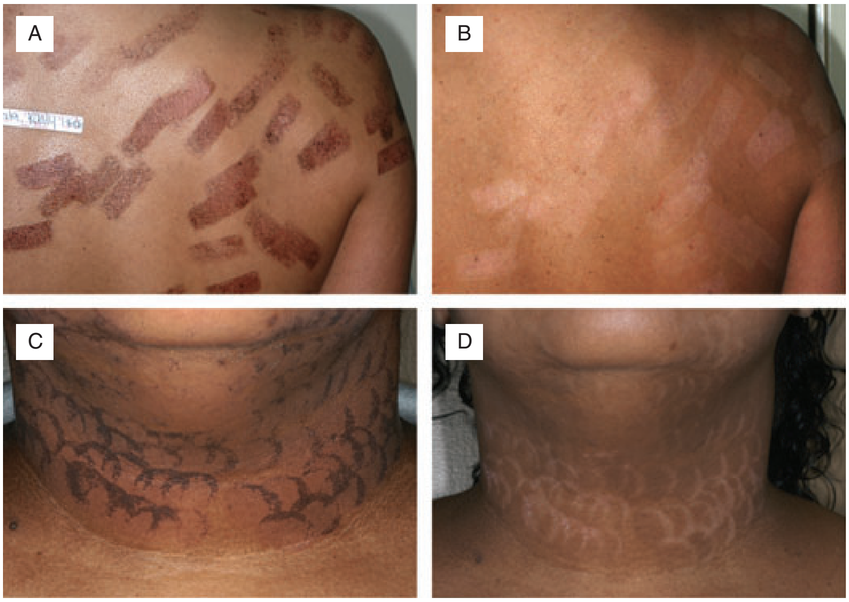

FIG. 4. **Permanent hypopigmentation resulting from laser hair removal. (A) Temporary hyperpigmentation in a Fitzpatrick skin phototype IV treated with an intense pulsed light device for hair removal. (B) One month later, the hyperpigmented patches were replaced with persisting hypopigmented patches. (C) Temporary hyperpigmentation in a Fitzpatrick skin phototype VI patient treated with an Nd : Yag device. (D) Two weeks later, the annular hyperpigmented patches were replaced with persisting hypopigmented patches.**

FIG. 5. **Zones of untreated skin resulting from poor operator technique.**

the ability to achieve hair removal at home. These devices are based on IPL, laser and thermal technologies that target the hair follicle for destruction. These devices include Spa Touch (Radiancy, Orangeburg, NY, USA), Tria (SpectraGenics, Dublin, CA, USA), and no!no! (Radiancy).

The evidence behind such devices is scant and limited to small noncontrolled studies (48–50). In addition, the risk for devastating eye injuries with improper use of laser- and IPL-based devices and lack of medical training raises a dilemma of how much autonomy a patient should have with potentially harmful devices. Nonetheless, the appeal of having a personal device to remove unwanted hair in the privacy of one's home without the expense and inconvenience of multiple dermatologist or spa visits will likely drive the development of additional home-use devices.

Alternative technologies for hair removal. Photodynamic therapy with aminolevulinic acid has been shown in a small pilot study to result in up to 40% hair loss with a single treatment, although wax epilation was performed prior to treatment in this study (51).

Electro-Optical Synergy (ELOS) technology combines electrical (conducted radiofrequency (RF)) and optical (laser/light) energies (52). A handful of devices based on this technology have

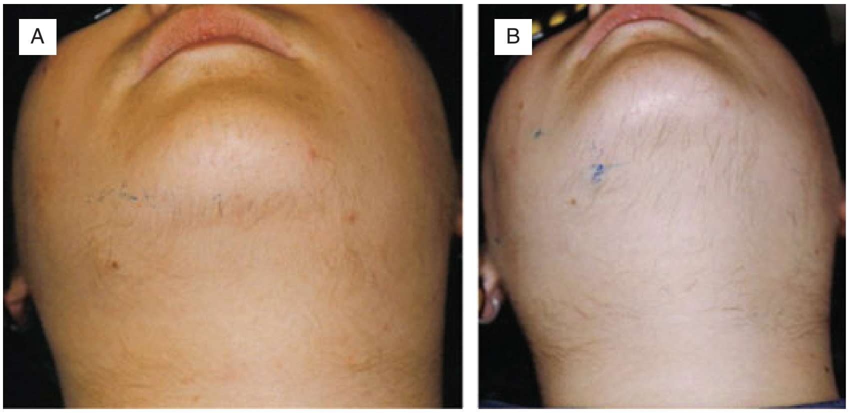

FIG. 6. **Paradoxical hypertrichosis. (A) Baseline appearance of chin and neck. (B) Apparent increase in pigmented hair density following treatment with a long-pulsed alexandrite laser (images provided courtesy of Andrea Willey, MD and Nerea Landa, MD).**

been produced (Table 1). The theory behind ELOS is based on the optical component (laser or IPL) heating the hair shaft, which then is thought to concentrate the bipolar RF energy to the surrounding hair follicle. Based on this combination, lower fluences are needed for the optical component, thereby suggesting it might be well tolerated in all Fitzpatrick skin phototypes, and potentially effective in the removal of white and poorly pigmented hair. A study of 40 patients (Fitzpatrick skin phenotypes II–V) with varied facial and nonfacial hair colors were treated with combined IPL/RF ELOS technology. An average clearance of 75% was observed at 18 months following four treatments. No significant adverse sequelae were noted and there was no treatment differences between patients of varying skin types or hair color (53). Pre-treatment with aminolevulinic acid prior to use of a combined IPL and RF device has been shown to further augment the removal of terminal white hairs (54).

In conclusion, hair removal has made a dramatic shift from an art to a science based on the theory of selective photothermolysis. Since the first reports of selective hair removal in 1996 by Anderson and colleagues (5), there has been a tremendous explosion in the number of devices used for LHR and making LHR the most commonly requested cosmetic procedure in the world. This review provides the reader with the fundamentals of hair follicle anatomy and physiology, pearls for patient selection and preoperative preparation, principles of laser safety, an introduction to the various laser/light devices, and a discussion of laser–tissue interactions that are vital to optimizing treatment efficacy while minimizing complications and side effects.

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