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REVIEW ARTICLE

Laser and Light Treatments for Hair Reduction in Fitzpatrick Skin Types IV–VI: A Comprehensive Review of the Literature

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Abstract Unwanted facial and body hair presents as a common finding in many patients, such as females with hirsutism. With advances in laser and light technology, a clinically significant reduction in hair can be achieved in patients with light skin. However, in patients with darker skin, Fitzpatrick skin types (FST) IV–VI, the higher melanin content of the skin interferes with the proposed mechanism of laser-induced selective photothermolysis, which is to target the melanin in the hair follicle to cause permanent destruction of hair bulge stem cells. Many prospective and retrospective studies have been conducted with laser and light hair-removal devices, but most exclude patients with darkly pigmented skin, considering them a high-risk group for unwanted side effects, including pigmentation changes, blisters, and crust formation. We reviewed the published literature to obtain studies that focused on hair reduction for darker skin types. The existing literature for this patient population identifies longer wavelengths as a key element of the treatment protocol and indicates neodymium-doped yttrium aluminum garnet (Nd:YAG), diode, alexandrite, and ruby lasers as well as certain intense pulsed light sources for safe hair reduction with minimal side effects in patients with FST IV–VI, so long as energy settings and wavelengths are appropriate. Based on the findings in this review, safe and effective hair reduction for patients with FST IV–VI is achievable under proper treatment protocols and energy settings.

Key Points

Advancements in laser and light technology have led to successful hair reduction by selective photothermolysis, which theorizes that targeting melanin in the hair follicle causes thermal damage to the nearby stem cells responsible for hair regrowth.

Dark skin types (Fitzpatrick skin types IV–VI) present a complication in laser and light therapy, as the melanin in the epidermis competes with the target chromophore and can lead to undesirable skin pigmentation changes and other adverse effects.

Successful hair reduction without permanent adverse effects is possible with laser and light technology in dark skin types, particularly with the use of longer wavelengths and multiple treatment sessions.

1 Introduction

Since the introduction of laser hair removal in the late 1990s, its ability to successfully and permanently reduce unwanted hair with minimal side effects has improved dramatically [2]. However, much of the research has been conducted on lighter skin types, and patients with darker skin have been excluded from many relevant studies. Thus, the treatment protocols and laser parameters suitable for these patients remain largely unknown. Research that does include patients with dark skin types indicates that the higher melanin content of the epidermis competes with the target chromophore of the light or laser, which is the melanin in the hair shaft of the hair follicle. This specific

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targeting of a chromophore is the basis for the theory of selective photothermolysis [3, 4]. To achieve permanent clinical results, the heat must then diffuse to the nearby bulge region of follicular stem cells, which regenerate hair follicles during the anagen, or active growth, phase of the hair growth cycle [5]. While the stem cells lack melanin themselves and therefore cannot effectively absorb light, they are damaged by this diffusion of heat from the hair shaft, which is rich in melanin and thus very effectively targeted within a therapeutic range of wavelengths of light [6]. In patients with dark skin, the epidermal melanin interferes with this proposed mechanism of action. Rather than reaching the target melanin in the hair shaft, light is absorbed in the epidermis where it is then converted to heat. Subsequently, these patients experience poorer clinical outcomes and a higher rate of thermally induced adverse effects, including hypo- or hyperpigmentation, blistering, and crust formation, which can last months after treatment or even be permanent [7]. These additional adverse effects have led many studies to exclude this particular subset of patients.

Frequently used in dermatologic practice as the standard for classifying skin, the Fitzpatrick skin phototype system [1] is based on both color and response to sun exposure, the latter of which is the defining element of skin type. This classification was first developed by Thomas B. Fitzpatrick in 1975 and currently describes six phototypes, ranging from type I (burns easily, never tans; ivory white constitutive color) to type VI (never burns, tans profusely, dark brown or black constitutive color). This systematic classification is further detailed in Table 1 [8].

Hair removal by laser or light therapy is often selected by female patients with hirsutism or hypertrichosis, often after simpler methods such as bleaching, tweezing, or waxing prove ineffective. Unwanted hair can have negative psychological and social implications for patients, as it often presents on exposed, easily visible areas, including the upper lip, chin, and neck in addition to more covered anatomic regions, including the axilla, back, and bikini area [9]. Although laser hair removal has traditionally been limited to lighter skin types, more recent advances that allow for a more comprehensive customization of treatment settings have paved the way for safe reduction in hair regrowth in darker skin without undesirable changes in pigmentation. According to one survey of more than 200 people of color, more than 50% were unaware that laser hair removal treatments were at all safe for pigmented skin types [10]. With recent advancements in laser and light technology and the development and US FDA approval of at-home devices, hair removal should be more efficacious and more accessible for patients of all skin types.

1.1 Lasers and Light

It is theorized that lasers use selective photothermolysis to target melanin in the hair follicle matrix. As the melanin absorbs light within its absorption spectrum, converts it to heat, and diffuses the energy locally, thermal damage affects the nearby stem cells in the hair bulge and prevents future hair regrowth. In patients with Fitzpatrick skin type (FST) I–II, with a lower epidermal melanin content, lasers and light emitting higher wavelengths, ranging from 600 to 1100 nm, can allow for the light to be successfully absorbed by the follicular melanin without epidermal interference [2]. But with the higher epidermal melanin concentration of FST III–VI individuals, some of this energy at lower wavelengths is absorbed in the epidermis, lessening absorption in the region of the hair follicle and therefore causing unwanted pigmentary changes and poorer outcomes. Additionally, laser fluences in individuals with darker skin must be kept lower than the typical values for patients with lighter skin so as to avoid burns. The pulse width should be significantly less than the thermal relaxation time for matrix cells in order to achieve selective and effective photoepilation [6].

The neodymium-doped yttrium aluminum garnet (Nd:YAG) laser typically has a wavelength of 1064 nm, whereas diode lasers generally have wavelengths of 800 or

Table 1 Fitzpatrick skin types

Phototype	Constitutive color	Sunburn and tanning history
I	Ivory white	Burns easily, never tans. No immediate pigment darkening or delayed tanning
II	White	Burns easily, tans minimally with difficulty. Weak immediate pigment darkening and minimal/weak delayed tanning
III	White	Burns moderately, tans moderately and uniformly. Definite immediate pigment darkening and low delayed tanning
IV	Beige–olive, lightly tanned	Burns minimally, tans moderately and easily. Moderate immediate pigment darkening and moderate delayed tanning
V	Moderate brown	Rarely burns, tans profusely. Intense immediate pigment darkening and strong, intense delayed tanning
VI	Dark brown or black	Never burns, tans profusely. Intense immediate pigment darkening and strong, intense delayed tanning

Modified from Freedberg et al. [47]

810 nm. Both lasers have been used in individuals with dark skin and have shown impressive reductions in hair regrowth in this selected cohort. The long-pulse 755-nm alexandrite laser is lower than those of the Nd:YAG and diode lasers but is considered high enough on the spectrum of melanin light absorption to be considered appropriate for darker skin types [11]. The FDA has approved a fluence of up to 40 J/cm^2 for the treatment of patients with fair skin, but for patients with darker skin it should be used at fluences of just $\leq$25 J/cm^2 to prevent thermal damage [12]. Lastly, the 694-nm ruby laser has been minimally studied in dark-skinned patients since it is typically indicated for lighter-skinned individuals.

Intense pulse light (IPL) is similar to lasers in that its mechanism of action is also selective photothermolysis, although it is polychromatic whereas lasers are monochromatic. The wavelength is set within the absorption spectrum of melanin, and thermal damage to the stem cells in the hair bulge ensues, thereby reducing hair regrowth. Patients with darker skin types are often contraindicated users of at-home IPL systems, which are typically more affordable and more easily accessible, making successful and affordable hair removal a mounting challenge [13].

This review examines multiple laser and light sources studied for hair removal, including the Nd:YAG laser, diode laser, 755-nm alexandrite laser, 694-nm ruby laser, and IPL, and summarizes their implications for safety and efficacy in patients with FST III–VI.

2 Methods

A broad literature search in PubMed was performed in July 2016 to compile all available published articles that studied laser or light treatment for hair removal specifically in patients with FST IV–VI. The search terms employed included hair removal, laser, light, pulsed dye laser, Nd:YAG, Er:YAG, carbon dioxide, excimer, fractional, and photodynamic therapy. Only articles published in the English language and involving humans were included. Subsequently, titles and abstracts were screened for relevance and for thorough examination of clinical results in FST IV–VI patients. Prospective clinical trials, retrospective chart reviews, and comparative studies were included. Individual case reports were excluded. Two authors (RAF, ASA) selected the remaining articles to ultimately include in this review.

3 Results

The preliminary broad search returned 879 published articles. After filtering the search to English language only and humans only, 708 titles and abstracts were screened for relevance. Articles that either completely excluded patients with, or only included fewer than five patients with, FST IV–VI were considered irrelevant to this review. Of the screened articles, 32 were chosen for the review, including six randomized controlled trials (RCTs), four retrospective data collections, and six comparative studies. Tables 2, 3, 4, 5, 6 and 7 display the study types and designs, patient sex and skin type, treatment protocols, results, and adverse effects for all 32 studies included in this review.

3.1 Neodymium-Doped Yttrium Aluminum Garnet (Nd:YAG)

In a survey of 50 African American patients treated with a long-pulsed Nd:YAG laser for reduction of unwanted hair, the average satisfaction score was 84.2; 100% of those surveyed preferred the laser to alternative treatments [14].

Nepalese patients with FST III–V ($n = 60$) received seven treatments at 4-week intervals to achieve desired results with a 1064-nm Nd:YAG, with a fluence of 50 J/cm^2 and a long-pulse duration of 50 ms. No side effects were mentioned in the study. Satisfaction scores of satisfactory, good, or excellent were reported by 88.7% of participants, with 50% hair reduction considered a successful result [15].

A retrospective study of 150 patients with FST IV–VI evaluated the results of hair removal with a 1064-nm Nd:YAG laser with a mean fluence of 22.3 J/cm^2. An average of nine treatment sessions occurred, at intervals of 4–6 weeks, and fluence gradually increased until adverse effects or discomfort were noted. The mean hair reduction achieved was 54.3%. In total, 86% of patients reported no adverse effects, 8% reported hyperpigmentation, and 2.7% reported skin burns, all of which healed with no permanent scarring or long-term complications [16].

Nanda and Bansal [17] performed a prospective study in 200 FST IV–V patients with a long-pulsed 1064-nm Nd:YAG with starting fluences of 44/55 J/cm^2 for FST IV and 40/50 J/cm^2 for FST V, which were increased by 5 J/cm^2 at every treatment session if there were no complaints of discomfort or adverse effects. Starting at the third session, fluences of 75/45 and 70/40 J/cm^2 were used for FST IV and V, respectively. All patients completed six to eight sessions at 4- to 6-week intervals. At 6 months after the final session, 50% improvement was seen in 68.7% of patients treated on the lower face, 89.69% of those treated on the chin, and 59% of those treated on the upper lip. No burns or hyperpigmentation were reported; only superficial crusts were seen in 2% of patients, which healed within 2 weeks [17].

A shorter-pulsed 1064-nm Nd:YAG laser was used in five patients with FST V and one with FST III to determine whether shorter pulse durations could achieve the same

Table 2 Nd:YAG lasers for epilation in patients with Fitzpatrick skin type IV–VI: treatment protocols, results and adverse effects

Study	Study type	Treatment	Sessions and intervals	Pts (*n*); sex (F/M)	Skin type	Anatomic location	% mean hair reduction	Adverse effects
Karn et al. [15] 2014	Prospective (NB)	Wavelength: 1064 nm Energy settings: 50 J/cm^2 Pulse duration: 50 ms	7 sessions, 4-wk intervals	60 (60/0)	III–V (breakdown NR)	Face	At least 50% in 88.7% of subjects	NR
Rao and Sankar [16] 2011	Retrospective (NB)	Wavelength: 1064 nm Energy settings: 22.3 J/cm^2 Pulse duration: 30 ms	9 sessions, 4- to 6-wk intervals	150 (135/15)	7 IV, 141 V, 2 VI	Face, axilla, legs	54.3%	Transient hyperpigmentation, burns
Nanda and Bansal [17] 2010	Prospective (NB)	Wavelength: 1064 nm Energy settings: 44/45–75/45 J/cm^2 (FST IV); 40/50–70/40 J/cm^2 (FST V) Pulse duration: NR	6–8 sessions, 4- to 6-wk intervals	200 (200/0)	160 IV, 40 V	Face	50% in 68.7% on face, 89.7% on chin, 59% on upper lip	Transient superficial crusts
Khatri et al. [18] 2009	Prospective, RCT (NB)	Wavelength: 1064 nm Energy settings: 21 (low) or 36 (high) J/cm^2 Pulse duration: 0.65 ms	4 sessions, 4-wk intervals	6 (6/0)	5 V, 1 III	Axilla	72% in low fluence, 76% in high fluence	NR
Fournier [19] 2008	Prospective, RCT (NB)	Wavelength: 1064 nm Energy settings: 36–44 J/cm^2 Pulse duration: 20–30 ms	1 or 2 sessions, 12-wk intervals	28 (NR)	5 IV, 4 V, 1 VI	Axilla	79%	NR
Tanzi and Alster [20] 2004	Prospective (NB)	Wavelength: 1964 nm Energy settings: 30–60 J/cm^2 Pulse duration: 10–30 ms	3 sessions, 4- to 6-wk intervals	36 (NR)	12 III–IV, 12 V–VI	NR	41–46% on facial sites, 48–53% on non-facial sites	Temporary hyperpigmentation
Alster et al. [21] 2001	Prospective, clinical and histological trial (NB)	Wavelength: 1064 nm Energy settings: 10 J/cm^2 Pulse duration: 50 ms	3 sessions, 4-wk intervals	25 (20/0)	5 IV, 13 V, 2 VI	Face, axilla, legs	80% in axillary sites	Transient pigment changes
Mittal et al. [22] 2008	Prospective (NB)	Wavelength: 1064 nm Energy settings: 30–50 J/cm^2 Pulse duration: 15–30 ms	6 sessions, 4- to 6-wk intervals	59 (59/0)	IV–V (breakdown NR)	Face	57.5% with terminal hair had success, 53.8% for intermediate hair	Pain, erythema, perifollicular edema, blistering
Yeung et al. [23] 2010	Controlled prospective (NB)	Wavelength: 1064 nm Energy settings: 22–30 J/cm^2 Pulse duration: 10 ms	1 session, interval NA	12 (12/0)	III–IV (breakdown NR)	Axilla	100% or >75% in 27.3% of pts treated with PSF + 36.4% of pts treated with DCD, respectively	Transient post-inflammatory hyperpigmentation

DCD dynamic cooling device, *F* female, *FST* Fitzpatrick skin type, *M* male, *NA* not applicable, *NB* not blinded, *Nd:YAG* neodymium-doped yttrium aluminum garnet, *NR* not reported, *PSF* pneumatic skin flattening, *pt(s)* patient(s), *RCT* randomized controlled trial, *wk* week

safety and efficacy as a typical longer-pulse laser. A fluence of either 21 or 36 J/cm^2 was used with a 0.65-ms pulse duration for four monthly treatments. At 4 months after the final treatment, a 76% reduction was reported in high-fluence patients and a 72% reduction for patients treated with the lower fluence. No skin scarring was reporting with this cheaper, portable method of the Nd:YAG laser [18].

Fournier [19] tested the safety and efficacy of a high-energy Nd:YAG laser with the use of pneumatic skin flattening (PSF) to block transmission of pain signals by applying pressure before each laser pulse. A 1064 nm Nd:YAG laser was used with a fluence of 36–44 J/cm^2 in 28 patients with FST IV–VI. The hair count reduction by 12 weeks was 79% in both the PSF and the control group. No burns or hyperpigmentation were reported, but remarkable pain reduction was noted in all patients whose treatment included PSF [19].

Tanzi and Alster [20] tested a long-pulsed 1064-nm Nd:YAG in 36 FST I–VI patients using pulse durations ranging from 10 to 30 ms and fluences ranging from 30 to 60 J/cm^2, with higher pulse durations and lower fluences used in more pigmented skin types. Patients received three treatments at 4- to 6-week intervals. The results indicated a peak hair reduction approximately 1 month after the series of treatments, with 58–62% reduction on facial treatment sites and 66–69% reduction on non-facial sites. By 6 months, these numbers reduced to 41–46 and 48–53% for facial and non-facial sites, respectively. Only 1% of patients experienced temporary hyperpigmentation; no fibrosis or scarring were reported in any skin type [20].

Women ($n = 25$) with FST IV–VI completed a study using a long-pulsed 1064 nm Nd:YAG with fluence 10 J/cm^2. Patients received three consecutive treatments delivered at 1-month intervals. A reduction in hair growth after each treatment was noted and persisted for 1 year after treatment ended. The axilla showed the highest hair reduction scores, with approximately 80% reduction persisting in axillary treatment sites at 1-year follow-up. Pigment changes occurred in 5% of patients treated on exposed facial or leg areas and lasted an average of 4 weeks, with no long-term complications reported [21].

Indian women ($n = 59$) with skin phototypes IV and V were treated with the long-pulsed, 1064-nm Nd:YAG in a study by Mittal et al. [22]. Treatment parameters included 10-mm spot size, fluence of 30–50 J/cm^2, and pulse duration 15–30 ms, and six consecutive treatment sessions were administered at 4- to 6-week intervals. Treatment was effective for both terminal and intermediate hair; 6 weeks after the sixth and final treatment, 57.5% of those treated for terminal hair and 53.8% of those treated for intermediate hair achieved marked results. In total, 20% of the subjects had no significant reduction of hair, all of whom had intermediate hair, thereby indicating that multiple laser sessions increase effectiveness in dark-skinned individuals, particularly in terminal hair [22].

Yeung et al. [23] investigated the effectiveness of the 1064-nm Nd:YAG in conjunction with PSF for axillary hair removal in 12 Chinese women with FST III and IV. Patients received one treatment with the Nd:YAG laser coupled with PSF on the right axilla and one treatment with the Nd:YAG laser with a dynamic cooling device (DCD) on the left axilla (18-mm-diameter spot size, 10-ms pulse duration, fluence 22–30 J/cm^2). Of 12 patients, eight rated treatments using PSF as less painful, three rated DCD as less painful, and one rated them equivalent in terms of pain. At 36 weeks' follow-up, hair growth was nonexistent or $<$25% in 27.3% of the participants on the PSF side and in 36.4% on the DCD side, although the difference between the two groups was not statistically significant. Adverse effects were limited to purpura, edema, and pinpoint bleeding [23].

These results are summarized in Table 2.

3.2 Diode Laser

Barolet et al. [24] performed a randomized, controlled, bilaterally paired within-patient double-blind study to assess the safety and efficacy of an 810-nm diode laser using a high repetition rate of 5 Hz and a lower fluence of 15 J/cm^2, which should reduce associated adverse effects at the expense of lowering efficacy. Low fluence with repetitive millisecond pulses using multiple passes to achieve heat stacking in the hair bulb represents a new approach. This study intended to show a low fluence with a high repetition rate could yield hair reduction comparable to that with high fluence, single-pass devices. Patients ($n = 17$) with FST II–V were treated four times at 1-month intervals, and hair growth was recorded for 10 months. A mean hair reduction of 48.15% from baseline was found 6 months post-treatment. Only one patient with FST II showed transient pigment changes, and no scarring or long-term effects were seen in any patients [24].

In a multi-center prospective study of 368 patients with FST III–V, Royo et al. [25] evaluated the efficacy of an 810-nm diode laser with low fluences, ranging from 5 to 10 J/cm^2, and pulse durations of 10–20 ms. Of the patients included in the study, 211 were FST IV and 55 were FST V; they were treated with five sessions at 2-month intervals. At 6-month follow-up, 102 of the total 368 patients achieved 25–49% hair reduction, 219 patients achieved 50–74% hair reduction, and 18 achieved 75–100% reduction. While no adverse effects persisted at 6 months, nine cases of first-degree burns, three cases of second-degree burns, two cases of hyperpigmentation, and 11 cases of

Table 3 Diode laser for epilation in patients with Fitzpatrick skin type IV–VI: treatment protocols, results, and adverse effects

Study	Study type	Treatment	Sessions and intervals	Pts (*n*); sex (F/M)	Skin type	Anatomic location	% mean hair reduction	Adverse effects
Barolet [24] 2012	Randomized, controlled, bilaterally paired within-pt (DB)	Wavelength: 810 nm Energy settings: 15 J/cm^2 Pulse duration: 15 ms	4 sessions, 4-wk intervals	17 (12/5)	4 IV, 2 V	Upper back (M), posterior thigh (F)	48.15%	Transient pigment changes
Royo et al. [25] 2011	Multi-centered, prospective clinical trial (NB)	Wavelength: 810 nm Energy settings: 5–10 J/cm^2 Pulse duration: 10–20 ms	5 sessions, 8-wk intervals	368 (337/31)	211 IV, 55 V	Axilla, bikini, abdomen, thorax, pubis	102 achieved 25–49%, 219 achieved 50–74%, 18 achieved 75–100%	First-degree burns, Second-degree burns, hyperpigmentation, hypopigmentation
Wheeland [26] 2007	Prospective clinical trial (NB)	Wavelength: 810 nm Energy settings: 22 J/cm^2, 17.5 J/cm^2, 13 J/cm^2 Pulse duration: 600 ms, 450 ms, 300 ms	1 session, interval NA	121 (102/19)	16 IV, 12 V, 30 VI	Neck, arm, leg, axilla	NR	Blistering reported at 24 h
Hussain et al. [27] 2008	Prospective controlled trial (NB)	Wavelength: 940 nm Energy settings: group A: 50 J/cm^2; group B: 44 J/cm^2 Pulse duration: group A: 60 ms; group B: 80 ms	1 session, interval NA	30 (30/0)	18 IV, 12 V	Legs	At 8 mo: group A 54%, group B 60%	Transient folliculitis, crusting and blisters
Greppi [28] 2001	Prospective (NB)	Wavelength: 810 nm Energy settings: 10 J/cm^2 Pulse duration: 30 ms	7–10 sessions, 4- to 6-wk intervals	8 (0/8)	5 V, 3 VI	Beard area	75–90%	Blistering with subsequent transient crusting and hypopigmentation, hyperpigmentation
Adrian and Shay [29] 2000	Prospective (NB)	Wavelength: 800 nm Energy settings: 15–25 J/cm^2 for FST V, 15–20 J/cm^2 for FST VI at 30 ms PD 20–35 J/cm^2 for FST V, 20–30 J/cm^2 for FST VI at 100 ms PD Pulse duration: 30–100 ms	NR, NR	NR	V–VI	Face, neck, axilla	NR	Transient acute crusting at 24 h
Campos et al. [30] 2000	Prospective (B)	Wavelength: 800 nm Energy settings: 20–30 J/cm^2 for FST II–IV, 10–20 J/cm^2 for FST V–VI Pulse duration: 5–20 ms	Mean 2.7 (range 1–4), "When hair started to grow back"	38: 11 with IV–VI (21/17)	4 IV, 5 V, 2 VI	Axilla, arm, back, buttock, bikini, face, shoulder	59% of pts showed spare regrowth at 4-mo follow-up	Transient pigmentation changes

B blinded, *DB* double-blinded, *F* female, *FST* Fitzpatrick skin type, *M* male, *mo* month, *NA* not applicable, *NB* not blinded, *NR* not reported, *PD* pulse duration, *pt(s)* patient(s), *wk* week

hypopigmentation were reported throughout the duration of the study [25].

Wheeland [26] tested the safety, efficacy, and ease of use of a battery-powered, hand-held portable diode laser with 810 nm wavelength and three settings: high (fluence 22 J/cm^2, pulse duration 600 ms), medium (fluence 17.5 J/cm^2, pulse duration 450 ms), and low (fluence 13 J/cm^2, pulse duration 300 ms). Patients with FST V–VI are contraindicated users of this product and thus were placed in a 'non-treatment group' to determine the worst case of adverse effects. At 24 h after one pulse was administered at the highest fluence, one of 12 patients with FST V and 10 of 30 with FST VI had a blister, indicating the device is unsafe for the contraindicated FST V–VI users. However, 16 patients with FST IV were included in the treatment group, and no specific side effects were reported for this group [26].

Hussain et al. [27] evaluated a 940-nm diode laser on 30 female Asian patients with FST IV–V on bilateral legs, with treatment group A receiving one 50 J/cm^2, 60-ms pulse duration treatment and group B receiving a 44 J/cm^2, 80-ms pulse duration treatment. At 3 months after treatment, group A averaged a 70% hair reduction and group B averaged a 78% reduction. By 8 months, group A showed 54% persistent reduction and group B showed 60%. Only three patients displayed adverse effects, including folliculitis, crusting, or blisters, and all were transient. No residual scarring or pigmentation changes persisted at 8 months. The results of this study indicate that a higher wavelength reduces hair regrowth with no long-term effects in dark-skinned patients, and that a higher pulse duration may decrease thermal damage to epidermal melanosomes [27].

Greppi [28] used an 810-nm pulsed diode laser in eight patients with FST V–VI. All patients received the same energy settings (fluence of 10 J/cm^2, pulse duration 30 ms) and averaged seven to ten treatment sessions every 4–6 weeks. After the first session, patients experienced 10–25% hair reduction; after all sessions were completed, hair reduction averaged 75–90% depending on the number of treatments. Two patients experienced blistering, crustiness, and hypopigmentation that resolved within 2 months. Other adverse effects included three patients with hyperpigmentation, which cleared by 4 months. Another noteworthy finding in this experiment was that four patients who had concurrent pseudofolliculitis barbae experienced complete resolution of the condition by the end of treatment [28].

Adrian and Shay [29] used an 800-nm diode laser in patients with FST V–VI. Patients with FST V were treated with pulse duration 30 ms and fluences from 15 to 25 J/cm^2, whereas patients with FST VI received 30-ms pulse duration with fluences of 15–20 J/cm^2. At 100 ms pulse duration, fluences of 20–35 and 20–30 J/cm^2 were used in FST V and VI, respectively. Adverse effects included crusting 24 h after treatment in one FST IV patient, which repaired within 1 week. The 100-ms pulse duration allowed for inclusion of darkly pigmented individuals in the study and resulted in minimal complications [29].

Campos et al. [30] studied the effects of the 800-nm diode laser in 50 patients with FST II–VI. Patients with FST II–IV received a fluence of 20–30 J/cm^2, and those with FST V–VI were treated with 10–20 J/cm^2. Subjects underwent one to four treatments, averaging 2.7 sessions; evaluation was performed at least 4 months after the last treatment. At long-term follow-up, 59% of patients showed sparse regrowth, with the highest fluence showing the most efficacious results. In total, 11 patients showed transient pigmentation changes: eight displayed hyperpigmentation and three displayed hypopigmentation. The darkly pigmented individuals in the study had a higher incidence of these adverse effects, but all cleared in an average of 3 months [30].

These results are summarized in Table 3.

3.3 Alexandrite Laser

In a retrospective study with 2359 Turkish FST II–V patients, Kutlubay [31] investigated the efficacy of multiple treatments using the 755-nm alexandrite laser on reducing hair regrowth. The pulse duration ranged from 10 to 40 ms and fluences ranged from 15 to 24 J/cm^2. All patients underwent at least three sessions, 4–6 weeks apart. The results indicate that increased efficacy is directly correlated with increased fluence. Overall, the mean hair reduction was 80.6%; FST II patients had a mean 86% hair reduction with a mean fluence of 21 J/cm^2, FST III patients had a mean 82% hair reduction with a mean fluence of 19 J/cm^2, FST IV patients had a mean hair reduction of 75% with a mean fluence of 18 J/cm^2, and FST V patients had a mean 61% hair reduction with a mean fluence of 17 J/cm^2. Only 2.2% of patients reported any adverse effects, including transient hyper- and hypopigmentation and folliculitis. All cleared by 6-month follow-up but were found to be more common in darker skin types (40 of the 52 patients with adverse effects were FST IV–V) [31].

Aldraibi et al. [11] studied a 3-ms alexandrite laser in 31 FST IV–VI patients. Each patient received one treatment: one group was treated with an 18-mm spot size, and the other was treated with a 15-mm spot size; fluence ranged from 8 to 32 J/cm^2. At 1-week post-treatment, hyperpigmentation was noted in 48.4% of subjects; however, by 6 months, only one patient with FST VI still displayed mild hyperpigmentation. Also at 1 week, eight sites showed crusting, seven of which proceeded to hypopigmentation. The mean hair reduction was 36% at 6 months; by skin

Table 4 Alexandrite laser for epilation in patients with Fitzpatrick skin type IV–VI: treatment protocols, results, and adverse effects

Study	Study type	Treatment	Sessions and intervals	Pts (*n*); sex (F/M)	Skin type	Anatomic location	% mean hair reduction	Adverse effects
Kutlubay [31] 2009	Retrospective (NB)	Wavelength: 755 nm Energy settings: 15–24 J/cm^2 Pulse duration: 10–40 ms	3 sessions, 4- to 6-wk intervals	2359 (2095/264)	405 IV, 83 V	Axilla, bikini	80.6%	Transient hyperpigmentation, transient hypopigmentation, folliculitis
Aldraibi et al. [11] 2007	Prospective (NB)	Wavelength: 755 nm Energy settings: 8–32 J/cm^2 Pulse duration: 3 ms	1 session, interval NA	31 (NR)	12 IV, 15 V, 10 VI	NR	36% at 6 mo	Transient hyperpigmentation, crusting, hypopigmentation
Lu et al. [12] 2001	Prospective (NB)	Wavelength: 755 nm Energy settings: low fluence: 15–20 J/cm^2, high fluence: 21–25 J/cm^2 Pulse duration: 20 ms	3–7 sessions, 4- to 16-wk intervals	146 (117/29)	134 IV, 4 V	Wide range of regions, axilla and legs the most common	After 2 txs: low fluence: 58–62%, high fluence: 66–67% After 5 txs: high fluence near 90% at 17 mo follow-up	Transient hypopigmentation and hyperpigmentation
Garcia et al. [32] 2000	Prospective (NB)	Wavelength: 755 nm Energy settings: 13–24 J/cm^2 Pulse duration: 40 ms	3 sessions, 3- to 6-wk intervals	150 (132/18)	80 IV, 68 V, 2 VI	Wide range of regions, facial the most common	40% after at least 3 sessions	Blistering, folliculitis, transient pigmentation changes, excoriations

F female, *M* male, *mo* month, *NA* not applicable, *NB* not blinded, *NR* not reported, *pt(s)* patient(s), *tx* treatment, *wk* week

type, the mean hair reductions were 29, 33.6, and 48.6% in FST IV, V, and VI, respectively [11].

Lu et al. [12] used a 755-nm long-pulse alexandrite laser with pulse duration 20 ms in 146 FST III–V Asian patients. Two treatment groups were selected: the low-energy group received fluences of 15–20 J/cm^2 and the high-energy group received fluences of 21–25 J/cm^2. All patients underwent three to seven treatments on an average of 8-week intervals. After two treatments, the low-energy group displayed hair reduction of 58–62% and the high-energy group displayed hair reduction of 66–67%, which increased to 86–91% after multiple sessions. At an average of 17-month follow-up, mean reduction for the high-energy group was 90%. However, within the high-energy group, 1.5% of patients developed transient hypopigmentation and 3% developed transient hyperpigmentation [12].

A prospective study by Garcia et al. [32] in 150 FST IV–VI patients using a 755-nm long-pulsed alexandrite laser with a 40-ms pulse duration revealed that this laser may prove beneficial in epilation. Throughout the study, fluences ranged from 13 to 24 J/cm^2 (average 18 J/cm^2). Patients received an average of three sessions at 3- to 6-week intervals. The results of this study indicated a direct correlation between efficacy and fluence. After at least three sessions, a mean 40% hair reduction was observed, and only 2.7% of patients reported adverse effects, including blistering, folliculitis, transient hyper- and hypopigmentation, and excoriations. The incidence of adverse effects was higher in FST VI patients, leading the authors to conclude that they may be relatively contraindicated users for this laser system [32].

These results are summarized in Table 4.

3.4 Ruby Laser

Elman et al. [33] studied 16 FST IV patients under treatment with a long-pulse 694-nm ruby laser. Two were selected to compare long and short pulses; they each received two test spots, one with a 1-ms pulse duration and one with a 20-ms pulse duration at fluences ranging from 15 to 21 J/cm^2. All 16 patients received one treatment with a 20-ms pulse duration and were followed weekly for 3 months. The results of the comparison between short and long pulses indicated that long pulse should certainly be favored; the sites that received a 1-ms pulse duration showed immediate erythema, with eschar forming 24 h after treatment and hypopigmentation requiring several months to resolve. Treatment areas tested with a long pulse (20 ms) showed negligible adverse skin reactions. In terms of efficacy, the authors claimed that hair reduction was approximately equivalent to that of 3000 patients previously treated with this system at their clinic, who averaged 70–80% hair reduction with 6–12 treatments [33].

Table 5 Ruby laser for epilation in patients with Fitzpatrick skin type IV–VI: treatment protocols, results, and adverse effects

Study	Study type	Treatment	Sessions and intervals	Pts (*n*); sex (F/M)	Skin type	Anatomic location	% mean hair reduction	Adverse effects
Elman et al. [33] 2000	Prospective (NB)	Wavelength: 694 nm Energy settings: 15–21 J/cm^2 Pulse duration: 1 ms or 20 ms	1 session, interval NA	16 (NR)	IV (all 16)	Leg	NR	1 ms pulse duration: immediate erythema with subsequent eschar formation, 20 ms: mild erythema and transient hyperpigmentation
Liew et al. [34] 1999	Retrospective (NB)	Wavelength: 694 nm Energy settings: 13–16 J/cm^2 Pulse duration: 50 ms	Median 1 session (range 1–6), interval NA	138 (NR)	9 IV, 24 V	Upper lip, chin, cheek, ear, abdomen, arm, leg, back	FST V achieved 41%, FST I–IV achieved 58% at 18-wk follow-up	Blistering, pigment changes

F female, *FST* Fitzpatrick skin type, *M* male, *NA* not applicable, *NB* not blinded, *NR* not reported, *pt(s)* patient(s), *wk* week

In a retrospective analysis, Liew et al. [34] studied the long-pulse ruby on 138 FST I–V patients. A 694-nm ruby laser with 50-ms pulse duration and fluences ranging from 13 to 16 J/cm^2 was used to compare results in FST V patients with those in FST I–IV patients. In total, 24 patients with FST V were included in the study and received an average fluence of 13.1 J/cm^2. Patients with FST V had a mean hair reduction of 41%, whereas those with FST I–IV had a mean reduction of 58% at 17–18 weeks' follow-up. In total, 8% of FST V patients and 0% of FST I–IV patients experienced blistering. Hypopigmentation was seen in 14% of FST V patients and 2% of FST I–IV patients at 12 J/cm^2, and hyperpigmentation was seen in 12% of FST V patients and 0% of FST I–IV patients at 8–15 J/cm^2. While the results indicate this system is effective for patients with FST V, the incidence of side effects was noticeably higher in this population than in those with FST I–IV. FST V patients should first be treated with a test spot to identify potential adverse effects from this laser [34].

These results are summarized in Table 5.

3.5 Intense Pulsed Light

Trelles et al. [35] studied the axillae of ten FST III–V subjects treated using an IPL system four times at 1-week intervals in a simulated home-use trial. This device emits a fluence of 10 J/cm^2 and uses pulse durations of 25 ms. No cut-off filter was specified by the authors. After three treatments, mean hair reduction was 72%, which increased to a 92% overall reduction 2 weeks after the fourth treatment. At 6 months' follow-up, mean hair reduction was 87%. Patients with dark skin types experienced more perifollicular edema, reactive erythema, and symptoms of discomfort, such as itching and burning, than their lighter-skinned counterparts. No burns or pigmentation changes were observed [35].

Mohanan et al. [36] studied the efficacy of an IPL system on 12 Indian patients with FST III–V. Patients were treated at fluences of 10–12 J/cm^2 in a multiple pulse mode averaging 0.25 Hz, and treatment sessions were conducted three to six times at 4-week intervals. No cut-off filter was specified by the authors. In total, 66% of patients reported excellent results, indicating 76–100% hair reduction, and no adverse effects other than transient mild erythema were seen. This excellent response was achieved in an average of 2.9 sessions [36].

A new IPL device was investigated by Feng et al. [37] in 18 female Chinese patients with FST II–V. Patients were treated four times at 4- to 6-week intervals on the axilla or upper lip. The fluences ranged from 14 to 22 J/cm^2, and 695/755-nm filters with a triple pulse were used on the axillae and 640/695-nm filters with a double pulse were

Table 6 Intense pulse light for epilation in patients with Fitzpatrick skin type IV–VI: treatment protocols, results, and adverse effects

Study	Study type	Treatment	Sessions and intervals	Pts (n); sex (F/M)	Skin type	Anatomic location	% mean hair reduction	Adverse effects
Trelles et al. [35] 2014	Prospective, controlled trial (NB)	Wavelength: NR Energy settings: 10 J/cm^2 Pulse duration: 25 ms	4 sessions, 1-wk interval	10 (10/0)	3 IV, 3 V	Axilla	87% at 6-mo follow-up	Perifollicular edema, reactive erythema
Mohanan et al. [36] 2012	Prospective (NB)	Wavelength: NR Energy settings: 10–12 J/cm^2 Pulse duration: NR	3–6 sessions, 4-wk intervals	12 (10/0)	5 IV, 1 V	Chin, upper lip, cheek, neck	76–100% reduction achieved in 66% of pts	Transient mild erythema
Feng et al. [37] 2009	Prospective (NB)	Wavelength: 695/755 nm filter for axilla; 640/695 nm filter for upper lip Energy settings: 14–22 J/cm^2 Pulse duration: 50–80 ms	4 session, 4- to 6-wk intervals	18 (18/0)	13 IV, 2 V	Axilla, upper lip	83.8%	Mild transient erythema, perifollicular edema
El Bedewi [38] 2004	Prospective (NB)	Wavelength: 615 nm filter Energy settings: 25–40 J/cm^2 Pulse duration: 50–80 ms	3–5 sessions, 6-wk intervals	210 (207/3)	86 IV, 21 V	Face, extremities, axilla, bikini, back, chest	70% for FST IV–V at 6 mo	Leukotrichia, facial scarring in one pt

F female, *FST* Fitzpatrick skin type, *M* male, *mo* month, *NB* not blinded, *NR* not reported, *pt(s)* patient(s), *wk* week

used on the upper lips. Overall hair reductions were 49.9, 58.6, 79.3, and 83.8% after one, two, three, and four sessions, respectively. The upper lip tended to show a better clinical response than the axilla after two treatments, but this reversed after four treatments. However, these differences were not statistically significant. The side effects were limited to mild transient erythema and perifollicular edema, and no scarring or pigmentation changes were observed [37].

El Bedewi [38] tested a fluorescent IPL source on 210 Egyptian patients with FST II–V. All patients received between three and five treatments at 6-week intervals and were followed-up at 6 months after the final session. Treatment parameters included fluences ranging from 25 to 40 J/cm^2 and pulse durations of 50–80 ms; the cut-off filter used was at 615 nm with a double pulse. With FST V, fluence was adjusted to a 25 J/cm^2 fluence and pulse duration of 50 ms. Mean hair reductions at 6 months were 80, 70, and 70% for FST III, IV, and V, respectively. Failure to achieve 100% reduction was attributed to the presence of vellus hair, which responds poorly to IPL. No post-inflammatory pigmentation changes, scarring, or burns were reported. Only one patient with FST IV displayed leukotrichia and facial scarring, but this patient had previously undergone repeated electrolysis therapy [38].

These results are summarized in Table 6.

3.6 Comparative Studies

3.6.1 Long-Pulsed Nd:YAG Laser Versus Intense Pulsed Light

In a within-patient, right-left, assessor-blinded comparison, Ismail [39] compared Nd:YAG laser with IPL therapy on the axillae of 39 women with FST IV–VI. A long-pulse Nd:YAG laser (1064 nm, 50–60 J/cm^2, 30–40-ms pulse duration) and an IPL system (610–1000 nm, 22–32 J/cm^2, 25–45 ms pulse duration) were studied. Subjects underwent five treatment sessions at 4- to 6-week intervals, and right and left sides were randomly assigned to either laser or IPL. At 6 months, the IPL sites showed a 54.4% decrease and the laser sites showed a 79.4% decrease in hair count. No post-inflammatory pigmentation changes, scarring, or burns were reported on either side. This study concluded that, in terms of efficacy, the long-pulse Nd:YAG was significantly superior to IPL for dark-skinned patients [39].

Goh [40] compared response to a single treatment in 11 patients with FST IV–VI using long-pulsed Nd:YAG laser (1064 nm, 35–42 J/cm^2, 20–25-ms pulse duration) and an IPL system (600 nm filter, 12–14 J/cm^2, 5–40-ms pulse duration). One side of the patient's body was treated with the laser, the other half with IPL. The results showed that

Table 7 Comparative studies for epilation in patients with Fitzpatrick skin type IV–VI: treatment protocols, results, and adverse effects

Study, study type	Study design	Wavelength (nm)	Energy settings (J/cm^2)	Pulse duration (ms)	Sessions and intervals	Pts (*n*), sex (F/M)	Skin type	Anatomic location	% mean hair reduction	Adverse effects	
										Rate	Listed
Ismail [39] 2012 (RCT [AB])	Nd:YAG	1064	50–60	30–40	5 sessions, 4- to 6-wk intervals	39 (39/0)	IV–VI (breakdown NR)	Axilla	79.4%	NR	
	IPL	610–1000 filter	22–32	25–45					54.4%	NR	
Goh [40] 2003 (split-body RCT [NB])	Nd:YAG	1064	35–42	20–25	1 session, interval NA	11 (NR)	3 IV, 2 V, 5 VI	Upper lip, chin, jaw	<20% in 73% of sites	0%	
	IPL	600 filter	12–14	5–40					<20% in 64% of sites (at 6-mo follow-up)	45%	Post-inflammatory pigmentation changes, blistering
Bouzari et al. [41] 2004 (retrospective [NB])	Nd:YAG	1064	40–55	25–32	Mean 5.5, 4-wk intervals	75 (74/1)	25 IV, 3 V	Chin, upper lip, peri-auricular, neck	42.4%	45%	Pain, pigment changes, blister, erosion, folliculitis
	Alexandrite	755	15–25	10–20	Mean 5.2, 4-wk intervals				65.6%	40%	
	Diode	800	25–40	10–30	Mean 2.6, 4-wk intervals				46.9%	46%	
Galadari [42] 2003 (RCT [NB])	Nd:YAG	1064	30–120	9.5	3 or 6 sessions, interval NR	100 (100/0)	IV–VI (breakdown NR)	Facial area	3 tx: 25% 6 tx: 35%	Least	Redness, superficial burns, scarring, pigmentation changes
	Alexandrite	755	20–40	40					3 tx: 30% 6 tx: 40%	Most	
	Diode	800	20–40	40					3 tx: 25% 6 tx: 40%		
Puri [43] 2015 (RCT [NB])	Nd:YAG	1064	NR	NR	8 sessions, 4-wk intervals	30 (30/0)	III–V	Chin	90%	Middle	Pain, erythema, blistering, post-inflammatory pigmentation
	Diode	810	NR	NR					92%	Most	
	IPL	NR	NR	NR					70%	Least	
Chan et al. [44] 2001 (split-body RCT [blinding NR])	Diode Nd:YAG	800 1064	NR	NR	1 session, interval NA	15 (15/0)	IV–V (breakdown NR)	Axilla, legs	NR	NR	Erythema, folliculitis, perifollicular edema, transient hypopigmentation

AB assessor blinded, *F* female, *IPL* intense pulsed light, *M* male, *mo* month, *NA* not applicable, *NB* not blinded, *Nd:YAG* neodymium-doped yttrium aluminum garnet, *NR* not reported, *pt(s)* patient(s), *RCT* randomized controlled trial, *tx* treatment, *wk* week

64% of IPL sites and 82% of laser sites indicated slowing of hair growth. After 6 weeks, 64% of IPL sites and 73% of laser sites evidenced a hair reduction <20%. The side effects are of note, as 45% of IPL-treated sites but no laser-treated sites experienced pigmentation changes. Importantly, significance was not mentioned. These authors concluded that the longer wavelength of the Nd:YAG laser system accounted for protection against thermal damage and increased efficacy over the IPL treatment [40].

3.6.2 Long-Pulsed Nd:YAG Laser Versus Long-Pulsed Alexandrite Laser Versus Long-Pulsed Diode Laser

Bouzari et al. [41] compared a long-pulsed Nd:YAG (1064 nm, 40–550 J/cm^2, 25–32-ms pulse duration), long-pulsed alexandrite (755 nm, 15–25 J/cm^2, 10–20-ms pulse duration), and long-pulsed diode (800 nm, 25–40 J/cm^2, 10–30-ms pulse duration) lasers in a retrospective study of 75 patients with FST I–V over 18 months. Mean hair reduction for the Nd:YAG, alexandrite, and diode lasers were 42.4, 65.6, and 46.9%, respectively. The number of treatment sessions to reach these numbers were 5.5, 5.2, and 2.6 for the Nd:YAG, alexandrite, and diode, respectively, indicating significantly fewer sessions for the diode. When accounting for number of visits in determining efficacy, there was no significant difference between diode and alexandrite, and the Nd:YAG was found to be the least efficacious. The overall occurrence of side effects did not significantly vary across the three types of lasers used. This study concluded that efficacy of the 755-nm alexandrite and 800-nm diode were equal and both greater than that of the 1064-nm Nd:YAG. However, the number of treatments was a confounding factor and may have skewed the results [41].

3.6.3 Nd:YAG Laser Versus Alexandrite Laser Versus Diode Laser

In a comparison investigation, Galadari [42] compared Nd:YAG laser (1064 nm, 30–120 J/cm^2 fluence, 9.5-ms pulse duration), alexandrite laser (755 nm, 20–40 J/cm^2 fluence, 40-ms pulse duration), and diode laser (800 nm, 20–40 J/cm^2 fluence, 40-ms pulse duration). Female patients ($n = 100$) with FST IV–VI were treated on the upper lip and face. At 12-month follow-up after three treatments, hair reduction was 25, 30, and 25% for Nd:YAG, alexandrite, and diode, respectively. At 12-month follow-up after six treatments, hair reduction was 35, 40, and 40% for Nd:YAG, alexandrite, and diode, respectively. The Nd:YAG showed the smallest percentage for all side effects, including redness, superficial burn, scarring, and pigmentation changes, whereas the alexandrite showed the highest percentage for all side effects, though statistical significance was not mentioned. This study concluded that all three laser systems provided comparable results in terms of efficacy, but the Nd:YAG was considered the least damaging in terms of adverse effects [42].

3.6.4 Nd:YAG Laser Versus Diode Laser Versus Intense Pulsed Light

In an RCT, Puri [43] compared the efficacy and safety profiles of the Nd:YAG laser, diode laser, and IPL in 30 Indian women with hirsutism (skin types III–V). Eight treatment sessions were performed at monthly intervals and yielded the following percentages of hair reduction after treatment cessation: 90% in the Nd:YAG group, 92% in the diode laser group, and 70% in the IPL group. Side effects, including post-inflammatory hyperpigmentation, blistering, and erythema, were comparable in all three groups, but pain was maximized in subjects undergoing treatment with the Nd:YAG laser and minimized in patients receiving IPL treatment. Overall, the authors concluded that, although the diode laser induced slightly more adverse effects than the Nd:YAG laser, the diode laser was most efficacious for individuals with darker skin, followed by the Nd:YAG laser and then IPL. Since IPL only targets fine hairs, it is not suitable for dark-skinned patients [43].

3.6.5 Diode Laser Versus Long-Pulsed Nd:YAG Laser

Chan et al. [40] compared the efficacy and safety of an 800-nm diode laser and a 1064-nm Nd:YAG laser in 15 female Chinese patients with FST IV–V; each received one treatment with one type of laser on one side of the body and the other type on the opposite side. Eight patients received Nd:YAG laser to one side first, followed immediately by diode laser to the other side, whereas the other seven patients received the same treatments with the same parameters but in the opposite order. By the final follow-up at 36 weeks, both devices achieved a significant degree of regrowth. On objective evaluation, five patients developed adverse effects such as erythema, folliculitis, and perifollicular edema, all of which resolved by week 2. One patient developed hypopigmentation on both treatment sides, which resolved by week 36. This study concluded that multiple treatment sessions and long pulse widths yielded more efficacious results but did not show any significant differences in efficacy for these two laser systems [44].

These results are summarized in Table 7.

4 Discussion

Our review of the efficacy and safety of laser and IPL hair removal in FST IV–VI included a total of 32 papers, of which eight were RCTs, nine were controlled trials (with a

total of six RCTs), four were retrospective analyses, and the remaining were prospective analyses. These papers discussed the treatment of at least 4429 patients using Nd:YAG laser (nine papers, 566 patients), diode laser (seven papers, at least 503 patients; one did not mention the number of patients), alexandrite laser (four papers, 2686 patients), ruby laser (two papers, 154 patients), and IPL (four papers, 250 patients) in addition to comparative studies of these devices (six papers, 270 patients). Of the studies mentioning a specific FST classification, at least 2047 patients had FST IV–VI, including 1233 with FST IV, 532 with FST V, and 69 with FST IV. Regarding technical specifications, the range of applied settings was Nd:YAG 10–75 J/cm^2, pulse duration 0.65–50 ms; diode laser 5–50 J/cm^2, pulse duration 5–600 ms; alexandrite laser 8–32 J/cm^2, pulse duration 3–40 ms; ruby laser 13–21 J/cm^2, pulse duration 1–50 ms; and IPL 10–40 J/cm^2, pulse duration 5–80 ms. Treatments were performed between one and ten times, with intervals from 1 to 16 weeks in various anatomic locations, including both facial and non-facial regions. Long-term efficacy was assessed at 18 weeks up to 17 months after treatment. All data collected from the 32 studies included in this review are presented in Tables 2, 3, 4, 5, 6 and 7.

The Nd:YAG laser has the highest wavelength of all devices included in this review. This variable should theoretically minimize the absorption of light in epidermal melanin and thus maximize efficacy and minimize adverse effects in patients with dark skin. The percent mean hair reduction reported from studies of the Nd:YAG laser in this review range from 41 to 100%. The studies reporting the greatest efficacy were those that focused treatment on the axilla. In studies that treated other anatomic sites such as the face, multiple treatment sessions appeared to improve efficacy. No permanent adverse effects were noted with the Nd:YAG. Transient adverse effects reported were limited to erythema, superficial crusts, burns, pigmentation changes, and pain with treatment. The pain was minimized significantly in one study with the use of PSF and in multiple studies with the use of various cooling techniques [15–23].

The diode laser, with a wavelength significantly lower than that of the Nd:YAG, yielded mean hair reductions ranging from 25 to 100% [24–30]. One study used a particular diode laser with a higher wavelength than the rest, and the authors attribute improved clinical efficacy to this variable [27]. This improvement could also be attributed to the use of higher fluences, which is only possible with higher wavelengths. Similar to results seen with the Nd:YAG, multiple treatment sessions set at intervals that allowed time for hair regrowth appeared to improve efficacy in multiple anatomic sites such as the face, back, abdomen, legs, and axilla. Similar to the Nd:YAG, no permanent adverse effects were reported. One study reported numerous second-degree burns, which could be attributed to thermal damage caused by the lower wavelength allowing for increased epidermal light absorption [25].

A 36–90% mean hair reduction was reported with the use of the alexandrite laser, with a wavelength and accompanying energy settings even lower than those of the diode. Again, some of the most impressive results came from a study that treated the axilla, and others showed that increased treatment sessions significantly improved long-term results. Adverse effects were all transient and limited to pigmentation changes, crust formation, blistering, folliculitis, and excoriation [11, 12, 31, 32].

Only two studies used a ruby laser, which utilizes the lowest wavelength of all the lasers included in this review. However, the energy settings for the ruby laser are very similar to those used with the alexandrite. These studies showed a range of percent mean hair reduction of 41–58%. One study used only one treatment session, and the other reported a median of one treatment session, thus making it impossible to draw conclusions about improved efficacy with increased treatments. However, it is possible to conclude that this laser can be effective and safe, as long-term results were significant and adverse effects were both transient and limited to those seen with all aforementioned devices [33, 34].

IPL, with a polychromatic spectrum of light emitted, yielded a percent mean hair reduction ranging from 70 to 100% in the four studies included in this review. As with many of the lasers, IPL appeared to display improved efficacy with increasing treatment sessions. Furthermore, the studies on IPL reported a lower incidence of pigmentation changes, blistering, and burning. Only one patient reported facial scarring, but this was attributed to a history of previous repeated electrolysis treatments [35–38].

The six comparative studies included in this review did not indicate any clear pattern of superiority of one laser or light device over another in terms of efficacy or safety [39–44]. In three studies, the Nd:YAG provided superior clinical results as compared with IPL, but only one of the three discussed statistical significance [39]. In the study by Puri [43], the diode demonstrated superior clinical results over IPL and Nd:YAG. In one study, the alexandrite and diode provided improved efficacy over the Nd:YAG [42] and in another [41] the alexandrite was significantly superior to both the Nd:YAG and the diode. In terms of efficacy, alexandrite seems to be the most effective. Adverse effects varied between the studies. This may be attributed to non-uniform treatment protocols, including energy settings, devices used, number of treatment sessions, and anatomic locations. One observation of note is that while the independent studies of IPL systems rarely

reported major adverse effects and showed significant efficacy of their respective devices, one of two comparative studies of Nd:YAG lasers versus IPL systems concluded that IPL was less effective than the Nd:YAG and was associated with pigmentation changes and blistering [40].

While the published literature for laser and light hair reduction on dark-skinned patients is limited, the available articles suggest this technology can be safe and efficacious if used within the appropriate treatment parameters for this particular patient population. The results of this review indicate that certain anatomic regions, such as the axilla, as well as multiple treatment sessions at intervals that allow for hair regrowth provide improved clinical results. The use of higher wavelengths along with higher energy settings, as can be seen with the Nd:YAG, allowed for some of the most significant results while minimizing adverse effects. IPL also yielded some of the most impressive results and even minimized the mild transient adverse effects associated with all laser devices, including the Nd:YAG. All of the devices included in this review, with the specified treatment parameters, appear to be both safe and efficacious for use in patients with dark skin, whereas some may be associated with slightly higher rates of hair reduction or adverse effects than others.

4.1 Limitations

One of the greatest limiting factors in comparing the safety and efficacy of different laser and light systems is that every study uses a unique treatment protocol. In addition to using different fluences, wavelengths, and pulse durations, protocols differed in terms of number of treatments, length of time between treatment sessions, methodology used to assess hair reduction, means of measuring patient satisfaction, and means of collecting evidence of adverse effects. Moreover, different laser and IPL devices produced by different manufacturers were used, further decreasing our ability to properly compare the results across studies.

It should also be noted that the FST classification system is based on subjective human assessment and patient-self reporting and thus may not be a reliable measurement for comparison across studies. More objective tools for measuring tanning response and melanin content in an individual have been developed, including a color analyzer to compare tanning capacity based on sun-exposed versus unexposed skin, and a device to measure absorption of broadband ultraviolet B (UVB) after exposure [45, 46].

4.2 Future Directions

While none of the devices in this review reported permanent adverse effects, the transient pigmentation changes, blistering, and crust formation that were seen with nearly every device is still of great concern for patients with FST IV–VI and should be addressed in future studies. The results of this review suggest that more treatment sessions yield an increase in sustained long-term hair reduction. Perhaps by increasing treatment sessions, lower fluences could be used in an attempt to reduce thermal damage while maintaining clinical efficacy, allowing patients with dark skin to achieve desired results without experiencing unwanted adverse effects.

Furthermore, one critical study format that was missing was the prospective comparative study across all types of lasers and IPL devices used in FST IV–VI patients employing a completely unified treatment protocol for all parameters, including number of treatment sessions, interval between sessions, anatomic location of treatment, skin type, and energy settings. This would seem to be the optimal trial format for yielding comparable results for the safety and efficacy of laser and light hair reduction devices in FST IV–VI patients.

5 Conclusion

Safe and effective hair reduction for patients with FST IV–VI is achievable under proper treatment protocols and energy settings. The Nd:YAG, diode, alexandrite, and ruby lasers, as well as IPL devices, have all been studied and shown to be efficacious for this particular subset of patients and were not found to yield permanent adverse effects. The longer wavelength of the Nd:YAG serves as a protective factor against thermal damage to the epidermal melanin and allows for the use of higher fluences to provide improved clinical results. Even with lower wavelengths and fluences, the diode, alexandrite, and ruby lasers may also be safely used in these patients. IPL systems were also observed to provide significant hair reduction and were often associated with the lowest incidence of thermal damage. However, treatment protocols, energy settings, and anatomic locations varied widely in the existing literature, and more prospective, blinded RCTs with a large number of FST IV–VI patients are necessary to fully exploit the differences in efficacy and safety between lasers and IPL devices for patients with dark complexions.

Compliance with Ethical Standards

Conflict of interest RAF, MP, AEE, ASA, and KN have no conflicts of interest.

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