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REVIEW ARTICLE

Treatment of keloid scars using light-, laser- and energy-based devices: a contemporary review of the literature

E. Forbat[1] · **F. R. Ali**[2] · **F. Al-Niaimi**[2]

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Abstract Keloid scars are common and have a predilection for young, ethnic skin often with a family history. Keloids can be painful and pruritic and cause significant emotional distress when particularly visible or prominent. In this article, we review the evidence underlying the use of laser- and energy-based devices for treatment of keloid scars, either as monotherapy or in conjunction with other therapies such as corticosteroids, surgery and silicone gel in the treatment of keloid scars.

What's already known about this topic? • Keloid scars have a higher predilection for younger, ethnic skin.
• Keloid scars can be caused by a multitude of mechanisms, including injury, acne, surgical trauma, piercings and burns.
• Existing treatments for keloid scars include corticosteroid injections, silicone sheeting, cryotherapy, surgical excision, 5-fluorouracil and interferon alfa-2b injections, radiotherapy.

What does this study add? • We have comprehensively reviewed and summarised contemporary literature relating to the use of light-, laser- and energy-based devices for treatment of keloid scars and quantified the evidence according to the strength of recommendation taxonomy criteria.
• Although initial findings are promising for multiple subcategories of lasers, lights and fractional radiofrequency, current evidence comprises multiple small studies and with few randomised trials
• The use of lasers in keloids is a relatively new concept, as either monotherapy or an adjunct to medical therapies. Future use of laser-assisted delivery to treat keloid scars has potential.

✉ F. Al-Niaimi
firas55@hotmail.com

[1] Chelsea and Westminster Hospital, 369 Fulham Rd, London SW10 9NH, UK

[2] Dermatological Surgery & Laser Unit, St John's Institute of Dermatology,, St Thomas' Hospital, Westminster Bridge Road, London SE1 7EH, UK

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Introduction

Keloid scars are common with a predilection to younger patients and higher Fitzpatrick skin types, particularly patients of African, Asian or Hispanic origin with an associated family history [1]. They present as raised protuberant nodules or plaques, often asymptomatic but may occasionally be pruritic or painful. Frequently, they cause significant distress to the patients, particularly if they are located on visible areas. Keloids can be caused by a multitude of mechanisms including injury, acne vulgaris, surgical trauma, piercings and burns. The pathogenesis of keloid formation is still not completely understood; however, theories include overproduction of type 1 procollagen in fibroblasts from keloid wounds with raised levels of transforming growth factor and platelet-derived growth factor [2]. Treatments of keloid scarring include topical and injected corticosteroids, silicone-based dressings, cryotherapy, surgical excision, 5-fluorouracil [3] and interferon alfa-2b injections [4]. In recent years, the use of laser- and energy-based devices for treatment of multiple dermatological conditions has become more widespread, with treatment of keloids proving no exception. We have systematically reviewed contemporary evidence supporting the use of light-, laser- and energy-based devices in the treatment of keloid scarring. We performed a systematic literature review using the Pubmed, Medline and Embase databases, employing the search terms 'keloid' and 'laser'. Only articles written in the English language were evaluated. We also scrutinised citation lists from retrieved articles. Lasers can be subcategorized into ablative and non-ablative lasers which can be further subdivided into vascular and non-vascular strata.

Ablative lasers

The most commonly used ablative lasers are the erbium-doped yttrium aluminium garnet (Er: YAG) and carbon dioxide (CO_2) lasers. Henderson et al. first reported the use of Argon and CO_2 lasers to treat keloids in 1984 [5].To date, there are no published randomised controlled trials (RCTs) on the effectiveness of CO_2 laser or Er:YAG lasers to treat keloid scars. We have identified ten studies reviewing the efficacy and safety of CO_2 laser in the treatment of keloid scars (Table 1). Overall, 140 patients were included within the ten studies [6–15], which include retrospective reviews, prospective uncontrolled single studies and case reports with the largest sample size including 30 patients [15].

Ang and Tay carried out the most recent review in 2013, in which they compared the use of CO_2 ablation to treat earlobe keloid scars to alternative treatment methods. A total of 16 patients were included within the study, eight of whom were treated with CO_2 ablation, six with cold-steel surgery, one with combination treatment and one with triamcinolone (40 mg/ml) alone. The authors found that CO_2 ablation and surgery had equally effective outcomes with regards to reducing earlobe keloid size based on the notes of physician assessment, whereas the patient treated with steroid injection only had a partial response. Of note, every patient treated with CO_2 ablation or surgery had recurrence within 18 weeks of treatment completion [6].

Another study found that the combination of CO_2 ablation with interferon alfa-2b injections given to all 30 patients with either trunk or auricular keloids led to no recurrence in 66% of the patients at 3 years post treatment, with no recurrence found in the auricular area [15].

Only one clinical study specifically reviewing the efficacy of Er:YAG in keloid scars has been published. Combination treatment of Er:YAG laser and twice-daily topical betamethasone under occlusion was carried out until scar flattening or no further improvement of the scar in 70 keloids (found in a total of 23 patients). This study found a median improvement of 50%. Of particular note, recurrences occurred in 22% of the treated lesions [16].

To date, there are no studies reviewing the efficacy of fractional ablative lasers in keloid scars.

Non-ablative vascular laser devices: vascular (PDL and Nd:YAG)

Non-ablative vascular lasers include the potassium titanyl phosphate (KTP), pulsed dye (PDL) and neodymium-doped yttrium garnet (Nd:YAG) lasers. There are no studies using KTP lasers for keloid scars.

The use of PDL lasers in keloid scars has been widely studied, with seven studies [18–24] conducted between 2000 and 2016, including a comparative randomised split-scar trial [18] and a prospective paired comparison RCT (Table 1) [20].

PDL monotherapy has shown to be effective in treating keloid or hypertrophic sternotomy scars. One study (n = 19) evaluated if the pulse width of a 595-nm flash lamp-pumped PDL held a bearing on outcome and found that the 0.45-ms width was superior to 40-ms width in reducing scar size [20]. Nouri et al. published a study on short- versus long-pulse therapy in scars and found the short pulse to also be more beneficial [37]. The hypothesis is that often, in scars (including keloids), the vessels are of small diameter; hence, according to the theory of photothermolysis, the short pulse width will confine heat within the vessels and thus produce a better outcome.

The largest study reported to date is a retrospective case series of 99 mainly Caucasian patients (85%) with keloid refractory to intralesional triamcinolone (ILT), treated with either PDL alone or rotational PDL combined with ILT. The study reviewed patient notes over a 5-year period and concluded monotherapy with PDL required 12–14 sessions for moderate to excellent outcomes versus only 4–5 sessions with combination treatment [19].

A single-blinded trial reviewed the outcome of a combination of ILT, 5-fluorouracil (5-FU) and PDL for keloid or hypertrophic scars. Sixty-nine patients were selected, of whom 60 completed the trial, and they were randomly distributed into three treatment groups. Group 1 was treated with ILT (10 mg/ml) weekly for 8 weeks, group 2 with ILT 0.1 ml of 40 mg/ml in combination with 5-FU (0.9 ml of 50 mg/ml) weekly for 8 weeks and group 3 was treated as per group 2 but lesions also had 585-nm flash lamp PDL treatment at weeks 1, 4 and 8. The trial demonstrated that all groups showed acceptable improvement but there was evidence of statistically more improvement in groups 2 and 3 ($p < 0.05$). Group 3 (with additional PDL treatment) was found to have subjectively better results than group 2, according to patients, and a higher percentage of blinded observer outcomes (70% in group 3 versus 40% in group 2) [21]. This indicates a more favourable outcome following combination therapy.

In 1984, Abergel et al. conducted an in vitro and subsequent clinical trial which demonstrated Nd:YAG laser to suppress collagen production and clinically flatten keloids post laser treatment (n = 8) with sustained improvement seen at 3-year follow-up [27]. Two more recent studies have been carried out reviewing the use of 1064-nm Nd:YAG laser to treat keloid and hypertrophic scars in 2013 and 2014. The first study demonstrated improvement in keloid scars with Nd:YAG laser, and the second found that anterior chest keloid scars did not respond as well as the hypertrophic scars to Nd:YAG treatment, with recurrence of keloid scarring being the issue [25, 26] highlighting the molecular differences between hypertrophic and keloid scars.

Table 1 Summary of studies using laser and energy based devices to treat keloid scar

Study	Details	Aim	Patient number	Dose	Findings	SORT Criteria
CO_2 laser						
Ang and Tay [6]	Retrospective review of earlobe keloids	To compare treatment methods of keloid scars	n = 16; mean age = 20 years	eight patients with CO_2 ablation versus – six cold-steel surgery – one patient with combined treatments – one 40 mg/ml intralesional TAC CO_2 laser settings: 0.15-mm spot size, superpulsed, continuous mode Model: lasering slim evolution E30 TM	Both methods equally effective at debulking earlobe keloids; steroid injection only partial response; all patients treated with CO_2 ablation/cold-steel surgery had recurrence 2–18 weeks post procedure.	B
Martin and Collawn [7]	Treatment of refractory keloid scars with triple treatment therapy including CO_2 laser, PDL and triamcinolone acetonide injection	A case study	n = 1; 30-year-old Caucasian	Combination of CO_2 fractional laser (10,600 nm), cynergy PDL (585 nm) and triamcinolone acetide injection (40 mg/ml) monthly for 7 sessions Laser settings: PDL:585 nm, 10 J/cm^2, 2 ms,7 mm CO_2 laser: 300–350 nm,500–600 ms	Improvement in the keloid scar after five sessions with flattening and reduced pigmentation; SE: hypopigmentation (improved keloid appearance)	C
Nicoletti et al. [8]	Review of effect of pulsed CO_2 laser on moderate keloids	Is pulsed CO_2 laser effective	n = 50; mean age 40 years; 40 females and 10 males	High-energy pulsed CO_2 laser for four treatment sessions Laser settings: treatments 1 and 2: 3-mm spot, super pulse mode 5–8-Hz energy and 200–225 microsecond power Treatments 3 and 4: super pulse mode 30 Hz and 300-μs power	CO_2 laser is safe and effective with minimal side effects	B
Tenna et al. [9]	CO_2 laser combined with cyanoacrylate glue to treat earlobe keloids	To assess effectiveness of combination therapy	n = 2 (7 keloids)	CO_2 laser with application of cyanoacrylate glue 5 days post treatment every 5 days for 3 months	Good results without significant SE. Authors hypothesised glue creates rigid membrane to decrease skin tension and favour scar outcome	C
Scrimali et al. [10]	Comparing CO_2 laser versus radiotherapy in the treatment of keloid scars	To compare effectiveness between the treatment	n = 4; age 15–28 years	All six keloids surgically excised first then post suture removal treated monthly with CO2 laser with BD same plast gel for 6 months. Laser setting: 8 SX of index and 40% coverage	CO_2 laser post surgical excision of keloid scars has better outcome than radiotherapy, without the side effect risk of carcinogenesis; no recurrence at 1 year, no SE of hypo- or hyperpigmentation.	C
Garg, Sao and Khopkar [11]	CO_2 laser ablation post intralesional steroids of keloid scars	Prospective single-center uncontrolled open study	n = 28	Keloids treated with CO_2 laser followed by intralesional steroids 3–4 weeks for 6 months Follow up: 6 months post steroids Laser settings: continuous, repetitive and super-pulse mode.	At 6-month follow-up, – of the 13 patients who attended for regular intralesional steroids, only 2 patients had recurrence of keloid scars. – of the patients who had irregular treatment with steroid, seven showed recurrence – significant effect of post laser regular versus irregular steroids in the development of recurrence – synergistic effect of CO_2 laser combined with steroids.	B
Scrimali et al. [12]	Superpulsed CO_2 laser to treat hypertrophic and keloid scars	A personal experience	n = 8; 12 keloid scars in total	Patients treated monthly with CO_2 laser in combination with same plast gel BD; 12 treatments per scar; follow up 1 year; laser	SE blistering; no recurrence at 1 year; authors deduced that the later the scar was	C

Table 1 (continued)

Study	Details	Aim	Patient number	Dose	Findings	SORT Criteria
				settings: 8 SX of index and 40% coverage spot diameter of 300 μm; each scar treated 12 times; follow-up at 1 year	treated, the more treatment sessions were required	
Morosolli et al. [13]	Treatment of earlobe keloid with CO_2 laser	A case report	$n = 1$	Surgical excision followed by CO_2 laser; laser settings: 0.8-mm focus, power density 2.5 W/cm in continuous mode; follow-up at 6 months	Very good outcome with functional intact hole to insert earring	C
Driscoll [14]	CO_2 laser to treat keloids	A personal account	Number not declared	Keloids excised with CO_2 laser on super pulse mode (no more detail given), then wound is left to heal by secondary intention with monthly steroid injections thereafter (20-40 mg/mL triamcinolone)	This surgeon declared excellent outcome from personal experience	C
Conejo-Mir, Corbi and Linares [15]	CO_2 laser ablation and interferon alfa-2b injections reduce recurrence of keloids		$n = 30$; size range 1–3-cm diameter; area: trunk or auricular	Ablation of keloid followed by injection of 3 million IU interferon alfa-2b three times weekly; laser settings: ultra pulse CO_2 laser	Sixty-six percent did not recur at 3-year follow-up (no recurrence in auricular area)	C
Er:YAG						
Cavalie et al. [16]	Treatment of keloids with laser-assisted topical steroid	A retrospective study	$n = 23$; 70 keloids; mean follow-up 8 months	Erbium fractionated laser combined with topical high-dose corticosteroid cream to treat keloid-resistant scars using 2940-nm ablative erb laser and topical betamethasone BD under occlusion	Median percent improvement found to be 50% and recurrence in 22% (8 lesions)	B
Cheng, Nowak and Koch [17]	Blended CO_2 and erbium: YAG laser on pre-auricular and earlobe keloid fibroblast secretions of growth factors	Laboratory-based wound healing		Human keloid-producing fibroblasts explanted from operative specimens and treated with er:YAG and CO_2 laser; laser settings: 1.7 J/pulse of Er:YAG laser energy; CO_2 delivered at duty cycle of 25, 50 or 100%	Transforming growth factor beta 1 (TGF-beta 1) known to be a vital role in wound healing; post laser treated specimens had reduced production of TGF-beta1	C
Non ablative vascular lasers						
Pulsed dye laser: PDL laser						
Al-Mohamady,Ibrahim and Muhammad [18]	PDL versus microsecond Nd:YAG laser to treat hypertrophic and keloid scars	A comparative randomised split-scar trial	$n = 20$	Half of each scar randomised to 595-nm PDL and 1064-nm Nd:YAG.; six passes per patient at monthly intervals. Follow-up 1 month post last session using VSS scores; laser settings: PDL fluence of 7–9 J/cm^2, pulse duration of 1.5 ms, spot size 10 mm; Nd:YAG fluence of 30–35 J/cm2, pulse duration of 20 ms, spot size 14 mm	At 1-month follow-up, VSS analysis of both treatment arms showed significant improvements ($p < 0.001$) with average improvement in VSS score 55.14 and 65.4% for PDL and Nd:YAG, respectively; no significant difference found between treatment groups	B
Stephanides et al. [19]	Treatment of refractory keloids with PDL alone and with rotational PDL and intralesional triamcinolone (ILT)	A retrospective case series	$n = 99$ (58 female, 41 male, 85% Caucasian); follow-up at 6 months post last treatment	Researchers reviewed notes of patients between 2005 and 2010 *Raised* erythematous symptomatic keloid not responsive to ILT offered repeated rotational treatment of three PDL followed by one ILT (10 mg or 40 mg/dl)	From patient notes was found that the average PDL treatments need to achieve moderate to excellent rating between 12 and 14 sessions (found in 76% of patient cohort). Average number of ILT for the same as above was four to five sessions. Thirty-three out of ninety-nine responded	B

Table 1 (continued)

Study	Details	Aim	Patient number	Dose	Findings	SORT Criteria
				Flat ILT resistant keloids treated with PDL alone six to eight times weekly PDL laser settings: 4–15 J/cm^2, 7-mm spot, 1.5 ms pulse duration, 595-nm wavelength	to the questionnaire and reported a 70% improvement in the redness and thickness of the keloids.; SE: transient erythema, cutaneous atrophy and discomfort	
Manuskiatti, Wanitphakdeedecha and Fitzpatrick [20]	595-nm flash lamp-pumped PDL to treat keloid and hypertrophic sternotomy scars	To review the effect of the pulse width on PDL in treating keloid scars	n = 19	Both segments of sternotomy scars randomly treated four times weekly for three treatments; laser settings: 595-nm PDL with pulse width of 0.45 and 40 ms; follow-up: 0, 4, 8 and 24 weeks	Authors found pulse width of 0.45 ms which is better than 40 ms in decreasing scar size	B
Asilian,Darougheh and Shariati [21]	Combination of triamcinolone, 5-fluorouracil (5-FU) and PDL to treat keloid and hypertrophic scars	Single-blinded clinical trial	n = 69; 60 completed the study; follow-up 8 and 12 weeks	Random division into three groups 1. ILT (10 mg/ml) weekly for 8 weeks 2. ILT 0.1 ml of 40 mg/ml and 5-FU (− 0.9 ml of 50 mg/ml) weekly for 8 weeks 3. As per group 2 but lesions also had 585-nm flash lamp PDL at weeks 1, 4 and 8 Laser settings 5–7.5 J/cm2	All groups showed acceptable improvement, but there was evidence of statistically more improvement in groups 2 and 3 ($p < 0.5$); group 2 found to be comparable with group 3, but group 3 (with PDL) was found to have subjectively better results and a higher percentage of blinded observer outcomes (70% in group 3 versus 40% in group 2)	B
Bellew,Weiss and Weiss [22]	Comparison of intense pulsed light (IPL) to 595-nm-long pulsed PDL for treatment of hypertrophic surgical scars	A pilot study	n = 15 (number of scars); 10 breast reduction scars and 5 abdominoplasty scars	Two treatments two times monthly whether to half of the abdominoplasty scar or one of each breast scars	Mean improvement in scars similar between treatments; however, IPL was thought to be more painful but also had lower post treatment purpura	B
Manuskiatti and Fitzpatrick [23]	Comparison of ILT,5-FU and 585-nm flash-pumped PDL to treat keloid and hypertrophic sternotomy scars	A prospective, paired comparison RCT	n = 10	Five segments of the scar were randomly treated with four different treatments 1. PDL 2. ILT 3. 5-FU 4. ILT 5-FU 5. No treatment: control segment 6. Laser settings: 585-nm PDL (5 J/cm^2)	Statistically significant clinical improvement in all treated segments—with no significant differences between treatments given and outcome. Authors found intralesional treatment had faster results than PDL. Interestingly, scar induration improved best with intralesional treatment and scar texture with PDL. SE only seen with ILT: hypopigmentation, telangiectasia and skin atrophy in 50%	B
Connell and Harland [24]	Treatment of recalcitrant keloid scars with PDL and ILT	A pilot study	n = 10	Patient treated with combination of PDL and ILT	3/10 no benefit; 7/10 showed improvement with flattening improved by 60%, erythema 40% and pruritus/pain 75%	B
Nd:YAG						
Rossi et al. [25]	300-μs 1064-nm Nd:YG laser to treat keloid scars	A retrospective study	n = 44; Fitzpatrick 1-VI	Three treatment groups: 1. Control-whole keloid treated with intralesional triamcinolone 10 mg/cm^3 (n = 16) 2. Laser-1064 nm Nd:YAG laser fixed pulse 300 microsecond for total of 2000 pulses (n = 14) 3. Combination of above: n = 14	Combination and laser groups had clinical reduction in thickness and erythema of keloids in comparison to control group. SE overall: mild transient erythema. No SE of post inflammatory hyper- or hypopigmentation	B
Koike et al. [26]						B

Table 1 (continued)

Study	Details	Aim	Patient number	Dose	Findings	SORT Criteria
	Nd:YAG laser to treat keloids and hypertrophic scars		n = 102; Japanese patients (23 men and79 female); 38 = hypertrophic scars; 64 = keloid; follow-up + 1 and 6 months post last session	Treated three to four times weekly for 52 weeks with long-pulsed 1064-nm Nd:YAG laser (contact mode)	Evaluated using Japan scar workshop score. Significant reduction in score found 1 year post treatment ($p < 0.05$). 8.8% of anterior chest keloids did not respond. At 6 months post treatment, 4% of hypertophic abdominal scars recurred, 52.9% of anterior chest keloids, 35.7% of upper arm keloids, and 25% of scapula keloids. Authors postulated that hypertophic scars responded better than keloid and keloid recurrence are more likely if there is any remaining redness or induration post treatment	
Abergel et al. [27]	Nd:YAG laser to treat keloids	An in vitro study and clinical trial	n = 8; follow-up 3 years	Nd:YAG laser treatment of keloid scars; laser settings: Nd:YAG 1064 nm, energy 60 J/cm^2 repeated at one to two weekly intervals	ND:YAG found to suppress collagen production in vitro, within the clinical trial flattening and improvement of keloids seen at 3 years	B
Non-ablative non-vascular lasers						
Q-switched lasers						
Cho et al. [28]	Efficacy and safety of 1064-nm Q-switched Nd:YAG laser with low fluence for keloids and hypertrophic scars		n = 12 (Korean patients); mean age 23.8 years; follow up 3 months post final treatment	1064-n Q-switched Nd:YAG laser with low fluence at five to six passes one to two times weekly; laser settings: 8–2.2 J/cm^2, 7-mm spot size	At 3-month follow-up pigmentation, vascularity, pliability and height improved post treatment, and there was a significant reduction in the hospital burn scar assessment score 8.6–5.9 ($p < 0.0001$); SE: mild prickling and erythema-both transient	B
Bowes et al. [29]	Treatment of pigmented hypertrophic scars with 585-nm pulsed dye laser and 532-nm frequency-doubled Nd:YG laser in Q-switched and variable pulse modes	A comparative study	n = 6	Scar divided into four equal 2-cm segments 1. 585-nm FLPDL 2. 532-nm Q-switched frequency-doubled Nd:YAG laser 3. 532-nm Q-switched frequency-doubled Nd:YAG laser: variable pulse mode 4. control Average of 3.3 treatments per segment at 4–6-week intervals; follow up 22 weeks	Outcome used Vancouver General Hospital (VGH) burn scar scale. No SE noted. 532-nm Q-switched Nd:YAG laser and 585-nm FLDPL both showed similar improvements in pigmented hypertrophic scars. Eighty-three percent of patients subjectively chose segment treated with 532-nm Q-switched Nd:YAG laser as the best.	C
Fractional non ablative lasers						
Maria et al. [30]	Topical delivery of triamcinolone via skin pretreated with ablative radiofrequency: a new method in hypertrophic scar treatment	A prospective study	n = 4 hypertrophic scars	Laser settings: 3 passes followed by triamcinolone acetonide (0.1 ml per lesion)	SE: mild burning sensation, erythema and oedema up to 2 days post procedure and mild atrophy up to months post procedure. Complete resolution in 75% cases (nose, mandibular area) and large improvement in the remaining (knee scar)	C
Verhaeghe et al. [31]	Nonablative fractional laser (NAFL) for hypertrophic scars	A RCT for efficacy of 1540-nm NAFL	n = 18	Four monthly NAFL treatments (half scar treated, half control)	Results used physician global assessment and found no statistical difference except for one patient. Mild SE only	B

Table 1 (continued)

Study	Details	Aim	Patient number	Dose	Findings	SORT Criteria
Lin et al. [32]	Efficacy of fractional photothermolysis on scar remodelling	A RCT	$n = 20$	Non-ablative fractional resurfacing randomised to either high density or low density on one half of the scar versus no treatment on the other half; Treatment two times weekly for a total of four treatments; follow-up 1 and 3 months	Eighty-five percent of patients subjectively thought improvement in the treated side. Scars improved by 3-month FU versus 1 month. Low-density treatment arm rated higher outcome than high density ($p = 0.001$), and three from the high density group felt that scars were worse post treatment. Lower density group less SE and as effective as high density group	A
Tierney et al. [33]	Treatment of surgical scars with non-ablative fractional laser versus PDL	A RCT split-scar study	$n = 12$ (15 scars)	Fifteen scars (post Mohs) treated with four treatments at two-week intervals. Half of the scar treated with 1500-nm NAFL and the other half with 595 nm PDL	Better outcome in half-treated with NAFL 75.6% improvement versus 53.9% in PDL ($p < 0.001$)	A
Niwa et al. [34]	Fractional photothermolysis to treat hypertrophic scars	Evaluate efficacy of 1550-nm erb-doped fibre laser	$n = 8$	Four weekly treatments of eight to ten passes of 1550-nm erbium-doped fibre laser; laser settings: 35–50 mJ, treatment levels 6–8	Evaluated by independent physician with a mean grade of 2.4 (moderate improvement)	B
Laser-assisted skin healing (LASH) 1210-nm diode laser						
Capon et al. [35]	Scar prevention using LASH in plastic surgery	A pilot study	$n = 30$; mean age = 41.4 years; Fitzpatrick I–IV; follow-up 10 days and 3 and 12 months	Eight centimetres of surgical excision treated with laser immediately post closure, the other 8 cm untreated; 22 treated with high dose (0–130 J/cm), 8 with low dose (< 80 J/cm)	Improvement found with high-dose laser compared with control side at 12 months (patient and surgeon) with an associated reduction in scar height (profilometry used) of 38.1% ($p = 0.027$). Of note, three patients with SE of superficial burns with high dose. Low doses showed no significant difference between treated side and control. No SE	B
Lithium triborate (LBO) laser						
Cassuto,Scrimali and Sirago [36]	Hypertophic and keloid scars treated with combination of LBO (532 nm) laser and silicone gel sheeting		$n = 37$ (48 scars); hypertrophic ($n = 34$); keloid ($n = 14$); mean age = 34; Fitzpatrick II–IV	LBO laser plus adjunct of silicone sheet to scars; laser settings: spot size 10 × 10 mm, 607 J/cm^2, pulse duration 2–3 ms	Authors deduced excellent resolution of scars as per VSS when LBO laser (532 nm) used in conjunction with silicone gel sheet	B

Koike et al. treated 102 Japanese patients with hypertrophic and keloid scars (n = 38 and n = 64 respectively) with 1064-nm microsecond Nd:YAG laser 3–4 times weekly for 52 weeks, using a spot size of 5 mm and 65–75 J/cm^2 with 0.25-ms exposure and 2-Hz repetition rate. The results were evaluated using the Japan scar workshop score. A significant reduction in the score was found 1 year post treatment ($p < 0.05$). Recurrence, as with all previous methods, was observed at 6 months following treatment in 4% of hypertrophic abdominal scars, 52.9% of anterior chest keloids, 35.7% of upper arm keloids and 25% of scapula keloids. Authors postulated that hypertrophic scars responded better than keloid and keloid recurrence is more likely if any remaining redness or induration persisted following treatment [26].

Non-ablative non-vascular: Q-switched and fractional non-ablative

There have been several RCTs investigating the effects of fractional, non-ablative lasers [31–33] upon hypertrophic and surgical scars, but no studies have looked at keloid scarring specifically, and only smaller comparative or case series with regards to Q-switched laser and keloids have been carried out [28, 29].

Cho et al. reviewed the efficacy and safety of 1064-nm Q-switched Nd:YAG laser (low fluence) 5–6 passes at 1–2 weekly intervals in 12 Korean patients. At 3-month follow up, a significant improvement was found with regard to pigmentation, vascularity, pliability and height of the scar, with a 2.7-fold reduction in hospital burn scar assessment score ($p < 0.001$) in keloid and hypertrophic scarring [28].

Laser-assisted drug delivery

Lasers are increasingly being used to act synergistically with topical drugs, with a hypothesised mechanism of laser pre-treatment facilitating passage of topically applied drugs across the relatively impenetrable stratum corneum; consequently, lower drug doses or concentrations may provide similar therapeutic efficacy as the higher doses without laser pre-treatment, with less risk of adverse events [38]. It is thought that both ablative (fractional and non-fractional) lasers can have this effect. Fractional photothermolysis works by creating microscopic treatment zones (MTZs), thus enabling drug penetration whilst concomitantly enabling neocollagenesis via the preserved skin around the MTZs. Laser-assisted drug delivery has been used successfully for a variety of indications, including actinic keratoses, Bowen's disease, vitiligo, vaccination and local anaesthetic application [38].

Cavalie et al. carried out a retrospective study using Er:YAG-fractionated laser combined with twice-daily topical betamethasone to treat refractory keloids until the scar had flattened or no further changes were found. They found that nine treatment sessions were required to produce a 50% reduction in the scar profile. Of note, keloid scarring recurred in 22% of the cohort 8 months post treatment [16].

Another prospective case series (n = 15), of mainly hypertrophic burn scars and some acne keloids scars, carried out three to five treatment sessions, at 2–3 monthly intervals, of fractional ablative laser in conjunction with topical triamcinolone (10-20 mg/ml) given immediately post laser. The assessment was evaluated by three blinded observers comparing baseline scar to the scar at 6 months post treatment and found a 2.73/4.0 average improvement [39].

Ethnic skin and laser

Pigmented skin types present particular challenges with regards to laser treatment. Higher Fitzpatrick skin types are associated with more melanin and greater fibroblast responses than fair skin [40] and hence higher risk of not only keloid scar formation but also reactive changes to lasers such as discoloration (notably hyperpigmentation), which remains a daily challenge to a dermatologist. Robust evidence on the treatment of keloid scars with lasers in ethnic skin is lacking.

Discussion

Conventional, longer-standing treatment options for keloid scars include topical and injected corticosteroids, silicone-based dressings, cryotherapy, surgical excision, 5-fluorouracil and interferon alfa-2b injections [4], each of which are often limited by poor outcome or recurrence. CO_2 laser and PDL are the most widely used devices trialled for treatment of keloid scars.

Evidence belying the use of ablative lasers (Er:YAG and CO_2) is encouraging but premised upon small studies with no RCTS, with the pervasive problem of keloid recurrence yet to be reckoned with [6].

The mechanism underlying laser treatment and improvement in keloid scarring has been analysed at a histological level. A laboratory-based study treated human keloid producing fibroblasts with a combination of CO_2 and Er:YAG lasers. The levels of transformation growth factor beta 1 (TGF-β1), known for its role in wound healing, were reduced following treatment, implicating the role of TGF-β1 in the pathogenesis of keloid scarring following ablative laser therapy, similar to fractional lasers [17].

Non-ablative laser techniques, most notably PDL, have yielded encouraging outcomes, particularly when combined with corticosteroid injections, as discussed previously [19].

A comparative, randomised, split-scar trial compared 595-nm PDL with long-pulsed 1064-nm Nd:YAG laser in the treatment of hypertrophic and keloid scars after six laser sessions per patient at monthly intervals. One-month follow-up demonstrated the Vancouver scar scale (VSS) scores to be significantly reduced in both treatment arms ($p < 0.001$) with a higher (but non-significant) improvement in the Nd:YAG versus PDL groups (65.4 versus 55.14%, respectively) [18]. Of note, many practitioners do not use Nd:YAG devices for scars owing to the narrow therapeutic window and higher risk of bulk heating causing subsequent worsening of the scar.

As discussed earlier, it is apparent that the pulse width of a 595-nm flash lamp-pumped PDL has an important effect on outcome, with the 0.45-ms width being found to be superior to 40-ms width in reducing scar size [20].

With respect to monotherapy, there is evidence of benefit of treating keloid scars with CO_2 [10, 13], Er YAG [17], PDL [18, 20], Nd:YAG [25–27] and Q-switched lasers [28, 29]; however, the evidence presented is from small studies with a paucity of RCTs. To date, there are no studies reviewing the use of fractional non-ablative laser or KTP laser in keloid scarring, with current inferences derived from studies of hypertrophic scarring [31, 32, 34, 41, 42].

Combination laser therapy to treat keloid scarring is much more widely researched. Often, different laser subsets are combined with intralesional steroid injections [7, 11, 19, 21, 24]; however, there is also evidence for laser therapy in combination with other laser modalities [7, 17, 29], cyanoacrylate glue [9], interferon alfa 2b injections [15], topical corticosteroids [16] and 5-fluorouracil [21, 23]. Combination therapy was found to be far more efficient in terms of treatment sessions required [19]. Whilst promising, the aforementioned studies are small and larger RCTs are required.

Koike et al. highlighted the pertinent fact that keloid recurrence is more likely if any remaining redness or induration persisted following treatment [26].

Of interest, Niwa et al. demonstrated that 1550-nm erbium-doped fractional photothermolysis in hypertrophic scars ($n = 8$) appeared to induce moderate improvement [34] but research specific to keloid scarring is still lacking.

Recurrence rate and follow-up

Whilst a multitude of energy-based devices show promise in treating keloid scars, recurrence of lesions remains an issue [43]. Recurrence of keloids following CO_2 laser treatment may present from as short as 2 weeks post treatment [6] and up to 3 years post treatment [11, 15], and Er:YAG has demonstrated a 22% recurrence at 8-month follow up [16]. Nd:YAG showed variable recurrence percentages at 6 months post treatment dependent on the anatomical site of the keloid, with one study reporting recurrence in 52.9% anterior chest keloids, 35.7% upper arm keloids and 25% scapula keloids [26], suggesting that not only treatment modality and mechanism but also anatomical site of keloid determines the likelihood of recurrence. A shortcoming of the majority of the studies is the failure or inability to undertake follow-up beyond 12 months, hampering our capacity to draw inferences about the long-term consequences of treatment.

Future considerations

Whilst the presented data are promising, larger RCTs for each modality of therapy with longer follow-up duration would further enhance our understanding of the role of light-, laser- and energy-based devices in treatment of keloid scars. All of the evidence has been labelled according to the strength of recommendation taxonomy (SORT) criteria to enable clinicians to rate the quality of the evidence presented [44]. In order for a study to be classified as SORT level A, it must meet strict criteria; for example, either be a Cochrane review or show consistent findings from two or more good-quality RCTs. From our entire search, there were only two SORT A studies and the remaining were of SORT B/C criteria. Thus, this demonstrates the need for more robust studies in order to enable clinicians to guide their decision on the treatment of keloids based on high-quality evidence. Some of the reported studies conflate hypertrophic and keloid scars; studies using a stringently defined cohort of exclusively keloid scars would be instructive. In addition to combination therapies, neoteric approaches such as laser-assisted drug delivery and LASH may show future promise. Increased adoption of these nascent techniques and future comparative studies will lead to a more comprehensive understanding of the role of these devices in the treatment of keloid scars.

Compliance with ethical standards

Conflicts of interest The authors declare that they have no conflicts of interest.

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