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ORIGINAL RESEARCH REPORT

Laser and energy-based devices' complications in dermatology

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ABSTRACT

Laser dermatology is an ever-expanding part of the specialty used extensively for both aesthetic and medical conditions. Advances in laser technology have led to an expansion in the number of devices available, with as a consequence an increase in the total number of complications. Fortunately, the current technology has improved greatly which adds to the safety profile of such devices; nevertheless, thorough knowledge of laser complications and how to avoid them is paramount for any practitioner who uses such technology.

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Introduction

Laser procedures have become increasingly popular in the aesthetic and dermatology sector. In the majority of cases, the treatments are associated with mild transient side effects and fortunately long-term complications are uncommon. In addition to accurate patient selection, a thorough understanding of laser physics and light–tissue interaction is essential in minimizing the risk of complications. This article explains the possible complications that may arise from laser treatments in dermatologic practice involving the skin only (ocular hazards are not discussed). Measures to avoid such complications as well as some recommendations to manage those will be discussed. Table 1 summarizes the common complications per treatment modality.

Expected side effects

Depending on the type of laser and procedure performed, temporary and transient side effects are extremely common and in some procedures is an expected desired clinical endpoint. These will be discussed here briefly, but strictly speaking these do not fall under the category of "complications."

Erythema, for example, is almost always present as a result of heat scattering following any laser procedure and tends to fade within 24 h. This is often accompanied by edema which similarly usually fades within 24 h, except when it involves the periorbital areas where it tends to last a bit longer (1). In symptomatic cases, the use of ice packs and a short course of oral and/or topical corticosteroids can help. Erythema and edema can also occur following the use of high-intensity focused ultrasound.

Purpura is common and expected with the use of pulsed dye laser (PDL), particularly with the use of shorter pulse widths less than six milliseconds, and generally tends to fade in 7–10 days (2). Care should be taken if this occurs in individuals with darker skin types as well as in the lower legs due to the possible risk of post-inflammatory hyperpigmentation (PIH) once the bruising settles. This can be avoided by using longer pulse widths, lower fluences, adequate cooling, and the use of sunblock and bleaching agents (3).

Perifollicular erythema and edema is a desired endpoint in laser hair removal (LHR) and generally tends to fade in few hours. Pain may be experienced in LHR (and many other laser procedures) and this can be minimized by the use of local anesthetics where appropriate, cooling methods, and the use of longer pulse widths where appropriate to the clinical setting.

Crusting and oozing as a result of ablative procedures are expected and though the duration may vary slightly depending on the intensity and method of treatment, it is expected to last 3–5 days in the fractional mode and 7–10 days in the fully traditional ablative mode (4).

Complications

Complications that may arise from laser treatments are best defined as undesired events that occur as a result of laser treatments without intention. These can be divided into minor, intermediate, and major complications.

Minor complications

Acne/milia

These minor complications are generally easy to treat and tend to occur most commonly following ablative and non-ablative laser procedures (5). They are most likely to be due to disruption of pilosebaceous units by photothermolysis resulting in inflammation and follicular occlusion (6). Individuals with a history of acne are particularly prone to this and acne often tends to flare up following non-ablative fractional laser therapy and the use of the 1450-nm diode laser (Smoothbeam). Milia often result due to occlusion of eccrine ducts and follicles secondary to the use of occlusive ointments in the aftercare

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Table 1. Laser complications per treatment modality.

Laser procedure	Complications	Management
Laser hair removal	Hyperpigmentation Hypopigmentation Crusting/blistering Folliculitis Scarring Paradoxical hypertrichosis Acne	• Sun protection • Lightening creams • Narrowband UVB/excimer laser/fractional lasers • Petrolatum-based ointments • Anti-septic treatment • Avoidance of "picking" of the crust • Antiseptic treatment and in some cases oral antibiotics • Corticosteroid injections and PDL for hypertrophic scars • Fractional ablative or non-ablative treatment for atrophic scars • Adequate fluences with cooling. Adequate pre- and post-treatment cooling in particular to the adjacent areas • Topical and systemic standard acne therapy
Tattoo removal	Blistering Hyperpigmentation Hypopigmentation Scarring Darkening of cosmetic tattoos Infections Allergic reactions Immediate pigment darkening following previous gold therapy treatment (Chrysiasis)	• As above • Reduce subsequent fluences with less overlap • As above • As above • As above • Treatment subsequently with 1064-nm Nd:YAG and/or fractional ablative therapy • Prompt systemic antibacterial and antiviral agents • Topical antibiotics (care of contact dermatitis particularly following ablative procedures) • Systemic antihistamines and corticosteroids • Fractional ablative laser tattoo removal • Difficult to treat but switch to 1064-nm • Nd:YAG • Fractional ablative laser pigment removal
Laser treatment for vascular lesions	Bruising Hyperpigmentation Hypopigmentation Scarring Indentation	• Longer pulse widths and lower fluences (with PDL) • Short-term use of topical corticosteroids in intense purpura (particularly to avoid PIH in higher skin types) • As above • As above • As above • Filler injections or autologous fat transfer
Ablative and non-ablative procedures	Infection Hyperpigmentation Hypopigmentation Scarring Milia/acne Prolonged erythema Contact dermatitis Line of demarcation	• As above • As above • As above • As above • Switch to light-based topical treatments and standard acne therapy • Milia extraction may be performed • Sun protection • Vitamin C serum • PDL/IPL • Limit the use of topical agents to non-irritating • Avoidance of "alcohol-containing" products • "feathering" the edges with lower fluences and density

period of resurfacing procedures (7). In general switching to light cream-based emollients and the passage of time is all that is required, although occasionally manual extraction may be needed.

The development of acne has been reported to occur following LHR on the face and although the exact mechanism for this is unknown it is likely that follicular occlusion and thermal effects play a role (8). Treatment is with topical and systemic antibiotics.

Purpura

Purpura is a common expected outcome in many cases with the use of PDL and in some conditions, such as port-wine stains, is an expected clinical endpoint (9). Purpura can also occur with the use of 532-nm Nd:YAG Q-switched laser when treating pigmented lesions, particularly with higher settings and similar to PDL this fades within 3–5 days. It is worth mentioning here that purpura is not an expected outcome in the use of long-pulsed 1064-nm Nd:YAG and its occurrence may result in subsequent scarring.

A rare complication of LHR, however, is the development of purpura, often in the lower legs which represents the rupture of small cutaneous vessels as a result of gravity and higher hydrostatic pressures (10). Termination of LHR is not required in most cases and leg elevation and the use of compression stockings would suffice.

Urticaria

Short-term wheals typical of urticaria can occur rarely following laser procedures and represent mostly a form of

physical urticaria. A rare variant of cold-induced urticaria can occur as a result of the cooling used during the procedure (11). Treatment is generally symptomatic and with a short course of antihistamines.

Intermediate complications

Hyperpigmentation

PIH is a relatively common complication of laser therapy and is often observed in individuals with higher skin types, those with a tan or severely photodamaged, although idiosyncratic cases can occur in any skin type (12). Common causes for this complication include the use of high fluences, inadequate cooling, and treatment in tanned individuals (often associated with a degree of crusting in the latter group due to increased epidermal absorption of the laser radiation). In some cases, PIH can occur with sublethal fluences, a phenomenon sometimes seen when treating lentigines with the subsequent appearance of a halo around the faded lentigo. The mechanism involves primarily an increase in melanin dispersion from active epidermal and follicular melanocytes as a result of the inflammation and in some occasions secondary to the damage of the basement membrane leading to uptake of the melanin by melanophages (sometimes referred to as dermal type of PIH) (13,14). It is worth noting that in higher skin types PIH can be caused by the use of excessive cryogen cooling or following marked purpura.

PIH after purpura in vascular treatments has a component of hemosiderin deposition, and, particularly in the lower legs, this can be very difficult to treat and may take several months to resolve (10).

PIH generally tends to improve over time and its management involve the use of vigorous sun protection and in some occasions the use of lightening creams of which hydroquinone is the most effective. In some cases of intense purpura, a short course of topical corticosteroids after laser therapy can reduce the risk of PIH later.

Hypopigmentation

Fortunately, hypopigmentation as a result of laser therapy is far less common than PIH. Though this complication may be transient, in some cases it can be permanent and notoriously difficult to treat (15). The mechanism involves either complete destruction of both epidermal and follicular melanocytes as a result of excessive thermal damage, or the suppression of melanogenesis by melanocytes as result of the inflammatory process triggered by the laser injury (16). Immunohistochemical studies have shown a normal number of melanocytes and it is possible that a reduced tyrosinase activity, an enzyme which is heat sensitive, is responsible for this phenomenon (17). Distinction between the two possible mechanisms is not possible, however in the latter gradual spontaneous recovery may be possible. Temporary hypopigmentation is relatively common following the use of Q-switched lasers, possibly due to targeting the melanosomes in the melanocytes as a result of damage from shock waves, the physical effects of thermal expansion, and extreme temperature gradients (18).

"Relative" hypopigmentation often occurs following the treatment of solar lentigines or benign epidermal pigmented lesions which following the mild crusting or peeling phase can appear relatively hypopigmented compared with the surrounding skin.

In some cases, the use of narrow band UVB phototherapy or excimer laser may help through the stimulation of melanocytes (19). Recently there are some published reports on the use of fractional laser technology with good results (20).

Delayed hypopigmentation typically seen in some cases after full ablative resurfacing is fortunately less common nowadays due to the increasing use of the fractional methods. In addition to the aforementioned mechanisms involved some authors speculate that the hypopigmented appearance of the skin is the result of opacification of newly formed collagen bundles in the dermis leading to alteration of light reflection (21).

Crusting/blistering

Crusting and vesiculation both imply epidermal injury. In crusting often suprabasal necrosis of the epidermis occurs with subsequent sloughing off of the necrotic tissue (22). Although the mechanisms involved are similar with vesiculation; the latter can also occur as a result of cleavage at the dermoepidermal junction as a result of thermal injury and often involves full epidermal separation from the dermis due to damage of the basement membrane. In the majority of cases these complications occur as a result of high fluences, cooling failure, pulse stacking, high repetition rate, treatment in tanned individuals, or inadequate removal of make-up (14). In some cases debris accumulated at the handpiece can lead to focal areas of overheating of the epidermis leading to crusting.

Crusting is however sometimes an expected consequence of treatment (with correct fluence), such as the case with Q-switched lasers for pigmented lesions, 1450-nm diode laser (Smoothbeam) for sebaceous gland hyperplasia and other benign pigmented lesions, and with 1927-nm thulium in the treatment for pigmented lesions in which modest peeling or desquamation occurs.

Vesiculation can also occur in laser tattoo treatments and in particular when the ink density is high, pulse stacking, pulse overlap, and the use of excessive fluences (23). Large unilocular bullae tend to occur at distal extremities such as the wrist and ankle. Bullae or vesicles occurring in the setting of non-ablative fractional lasers are often the result of "bulk heating" and subsequent treatments should be performed with lower densities (23,24). Intact bullae should either be left and a non-adherent dressing applied, or drained carefully with the use of a sterile needle with good antiseptic cover later.

The management of crusting involves the regular use of a petrolatum-based ointment with the area kept clean (occasionally with the use of antiseptic agents). It is vital that the formed scabs are not picked or removed as this can result in hypopigmentation, scarring, or infection.

Signs of acute epidermal injury with impeding crusting or vesiculation include whitening or graying of the treated area which should be promptly treated with vigorous cooling and the use of lubricating ointments regularly. It is worth

mentioning that some cutaneous infections can present with vesicles or blisters and this should be excluded.

Line of demarcation

This complication represents a color step-off between the treated and non-treated area and typically occurs in ablative and to a lesser degree non-ablative rejuvenation procedures. This may not necessarily be due to high fluences and tend to occur more among higher skin types and individuals with actinic bronzing (4). Measures to minimize this include confining treatments to cosmetic subunits and "feathering" the edges of the treated areas using lower fluences and densities and in skilled hands the use of high repetition mode in a "painting" fashion can also be applied.

Paradoxical hypertrichosis

This complication is a relatively uncommon phenomenon in LHR and tends to be of particular problem in individuals with skin types III–V and in particular on the face. Although the physical consequences of this are minor, it generally tends to cause a lot of distress among its sufferers. The exact mechanism for this "stimulated hair" is unknown though hormonal influences could play a role, and exclusion of an underlying endocrine disorder in females is recommended. The condition is defined as "an increase in the color, density, and coarseness of hair following LHR."

The condition can be divided into two separate entities; namely one involving the treated area and another involving the surrounding adjacent areas. In the former this is often due to insufficient fluences leading to photobiostimulation of the hair follicles through synchronization of dormant hair follicles into terminal anagen hair growth instead of stem cell damage (25). In such cases the use of higher fluences or double passes (with adequate care and cooling) may be required. It is also noteworthy that in finer hairs the target for laser (follicular melanin) is reduced and therefore ideally shorter wavelengths and pulse widths are required, or shorter treatment intervals may be applied (26). This is often performed by experienced laser practitioners with thorough knowledge of this treatment and potential side effects.

In the second scenario in which stimulated hairs appear in the adjacent areas of the treated sites the mechanism here involves diffusion of heat to the surrounding areas at low levels that lead to stimulation in the mitochondria leading to biostimulation of hair follicles (12). In such cases adequate pre- and post-treatment cooling of the adjacent surrounding areas is required.

Prolonged post-laser resurfacing erythema

The exact timing for the erythema to be defined as "prolonged" is unclear; however, this term defines the presence of prolonged erythema following a laser procedure (most commonly ablative and non- ablative rejuvenation) beyond the expected duration for such an intervention. Some laser experts define this as four days for non-ablative fractional ablation and four weeks for ablative procedures (15). There is however no general consensus on this. In some cases this prolonged erythema may progress to scarring or PIH. The risk of prolonged erythema is present in particular among patients with "plethoric" skin or rosacea (27).

Treatment is with vigorous sun protection as well as the use of some topical treatments such as vitamin C serum. Other measures to avoid aggravation of erythema are avoidance of caffeine, exercise, alcohol, and spicy food intake. In some cases, particularly when pruritus is present, a short course of topical corticosteroids can be used. The differential here would include a rare *Candida* infection, or in the presence of "dermatitis," an irritant or allergic contact dermatitis to the topical products used during the aftercare.

In many cases, treatment with light-emitting diodes, IPL, or PDL in non-bruising settings can further help ameliorate this complication (28).

Major complications

Scarring

Scarring is the most feared laser complication by both practitioners and patients, and represents the most serious cutaneous complication of laser therapy. Scarring results from irreversible injury to the collagen and adnexal structures leading to the inability of the stem cells to repopulate the damaged cells. In some patients there is an inherent susceptibility for scar formation. Risk factors include the use of excessive fluences, inadequate cooling (in particular due to "bulk heating" with the use of deeper penetrating wavelengths such as 1064-nm Nd:YAG), post infection, pulse stacking particularly at purpuric settings, high repetition rate, or crusting/blistering if not managed promptly (29). Scarring can also occur, due to irreversible collateral thermal damage, with the use of long-pulsed millisecond lasers in the treatment of tattoos where the chromophore (exogenous ink) is very small. Therefore, procedures such as LHR should avoid treating hairs overlying tattoos.

Prevention of incipient scar formation is vital and it is therefore imperative to treat as early and as often as possible with an early sign of induration or intense dusky persistent erythema with early textural change. Treatment of established hypertrophic scars is with the use of corticosteroid injections, silicone gel sheets, 5-fluorouracil or 5-FU injections, and PDL. Early treatment with PDL in the event of an incipient scar formation (prolonged erythema for example) can in some cases avert such a complication (30). A novel approach is to deliver the treatment through fractional ablative channels as a mode of laser-assisted drug delivery.

Atrophic scarring as a complication of laser therapy is more challenging to treat although both ablative and non-ablative fractional treatments as well as dermal fillers can be used with some success (31).

Indentations

This is a relatively uncommon complication from laser therapy and is almost always a result of excessive fluence use (32). Indentations that occur following epidermal damage (crusting,

blistering, erosions, etc.) are often the result of associated marked collagen damage and shrinkage often as a result of high fluence or inadequate cooling of the skin. While isolated collagen damage and shrinkage can certainly occur with the inadequate use of deep penetrating lasers that generate "bulk heating" such as 1064-nm Nd:YAG (particularly on the face leaving a "grooving" type of indentation), subcutaneous indentation may occur as a result of isolated subcutaneous fat injury with fat necrosis or a panniculitis-like inflammation. Cold panniculitis can also occur. Such complications were often observed with the use of cryolipolysis (in the case of too much fat localized in an area that was not blended with the surrounding fat) or monopolar radiofrequency devices when high energy was used in a single pass (33). The use of devices with "vacuum suction" may also result in such injuries.

In some occasions shallow indentations may spontaneously recover over time, however deeper indentations tend to be permanent and though difficult to treat, filler injections or autologous fat transfer can in some cases offer a remarkable cosmetic improvement (34).

Infections

Cutaneous infections as a result of laser treatment can pose a particular problem due to the risk of scarring that may ensue. The risk of infection increases with any disruption of the epidermal barrier such as crusting and blistering. The risk is the highest among ablative laser procedures.

Infections can be divided into bacterial, viral, and yeast infections. Bacterial infections are commonly caused by *Staphylococcus aureus* and are a particular risk with ablative procedures due to the degree of oozing, crusting, and epidermal barrier disruption. Pain is a particular useful diagnostic sign together with evidence of superficial crusting or focal areas of patchy erythema with erosions. The risk appears to be higher 48 h after ablative procedures and should be treated promptly with oral antibiotics and appropriate topical antiseptic agents. Cultures should be obtained prior to commencement of antibiotic therapy. In high-risk cases such as immunocompromised patients pre-treatment with oral antibiotics might reduce this risk (23). The use of topical antibiotics post laser resurfacing can lead to an increased risk of contact dermatitis and the clinician should be aware of this. In fractional ablative laser procedures, infections may present slightly differently due to (often) the deeper localization of the infection and hence may present with subtle redness and edema or when sudden deterioration in the healing process occurs.

Viral infections are almost always due to reactivation of herpes simplex infections (HSV) and are a risk in both ablative and non-ablative procedures, particularly with procedures performed around the mouth (5). The appearance of painful crusting or vesicles following such procedures should alert the practitioner to the possibility of this diagnosis. In cases where there is no reepithelialization yet this can present superficial erosions associated with a burning and tingling sensation. The differential between herpetic and bacterial infections can be difficult at this stage and microbiological investigations may be required. Empirical antiviral treatment should start promptly as disseminated HSV infections are likely to delay reepithelialization and lead to scar formation. It is generally agreed now that prophylactic treatment is given to almost all ablative procedures and in high-risk cases of non-ablative treatments.

Yeast infections, most commonly with *Candida* species, are rare and present often with erythema and pruritus, particularly following ablative procedures (35). Treatment is with systemic and/or topical antiyeast agents.

Sensory nerve injury

Temporary and prolonged sensory nerve injury lasting for months has been reported following the use of radiofrequency, cryolipolysis, and high-intensity focused ultrasound (reference 36). This can cause pain and distress to patients and may be difficult to treat. In some cases of nerve injury associated or subsequent to edema, a short course of topical or oral corticosteroids can be used (reference 36). Prevention remains the best strategy and knowledge of facial anatomy with danger zones such as the temporal and marginal mandibular branches of the facial nerve is essential.

Conclusion

The use of laser and light devices has increased greatly over the years, with as a result a rise in complications from the use of these devices. Fortunately, most devices available to us are generally safe and serious complications are rare among trained and experienced professionals. Lack of thorough knowledge of laser physics and poor training coupled with improper patient selection are unfortunately all too common nowadays. Therefore, in the author's opinion a sound knowledge of laser physics coupled with a thorough knowledge of laser complications and how to avoid them should hopefully lead to an overall decline in such incidents.

Learning points

1. Laser complications are common due to the increase in the use of this technology in dermatology
2. Complications can be divided into minor, intermediate, and major.
3. The majority of laser complications are related to thermal effects.
4. Pigmentary changes are common in dark skinned or tanned individuals
5. Paradoxical hypertrichosis is an increasingly recognized complication of laser hair removal
6. Scarring is the most severe complication of laser therapy and the highest risk is with the use of ablative systems.

Declaration of interest

The author reports no conflicts of interest. The author alone is responsible for the content and writing of the paper.

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