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# Posttraumatic Laser Treatment of Soft Tissue Injury

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## KEY POINTS

- Lasers are a relatively safe and noninvasive modality in the management of posttraumatic facial scarring when used appropriately.
- Lasers exert their therapeutic effects through volumetric heating, selective photothermolysis, or frank ablation.
- Combining several lasers with or without surgical scar revision may continually improve the texture and appearance of facial scars.
- The literature regarding ideal dosimetry is mixed, and more randomized controlled trials and split scar studies may provide greater insight into the ideal management strategy based on scar type.

## INTRODUCTION

Posttraumatic soft tissue injuries can result in complex, disfiguring, and often permanent scars, which may defy optimal restoration despite aggressive wound care, pharmacologic therapy, hyperbaric O<sub>2</sub>, mechanical dermabrasion, and conventional surgery (scar revision). Whereas clean, straight lacerations may heal as well as a postoperative surgical incision, blast injuries, and penetrating and blunt trauma may result in crushed tissue, jagged wounds, and/or frank soft tissue loss leading to suboptimal closure, tension, and poor wound healing. Posttraumatic soft tissue injuries require thorough irrigation to reduce microbial burden, removal of debris to decrease risk of traumatic tattooing, proper selection of appropriate suture material, and meticulous skin closure without undue tension.<sup>1,2</sup> Several adjunctive measures after primary surgical management are known to reduce scar formation and improve appearance, including posttreatment dressings, silicone sheeting, isotretinoin, and dermabrasion. Although classic dermabrasion improves surface texture, contour, and, hence, the overall appearance of traumatic wounds, skin may bleed excessively during treatment, shear forces may disrupt the wound closure, and depth control is operator dependent, requiring skill and experience.<sup>3</sup> Laser devices have revolutionized skin care and are used to treat fine rhytides, correct acne scars, manage dyschromia, eliminate vascular birthmarks, remove tattoos, and manage both surgical and posttraumatic injuries.<sup>4-6</sup> Lasers alter tissue based on the propagation of light through tissue, and subsequent absorption of photons with conversion to heat, photochemical interactions (photodynamic therapy), or generation of stress transients (photoacoustic waves). Clinicians have the ability to control the specific laser-tissue interaction by selecting dosimetry (pulse duration, energy density) and wavelength. Light propagates through tissue and is absorbed and scattered differentially depending on wavelength and, ultimately, this distribution of light dictates the tissue effect.<sup>7</sup> In the region of light distribution, if sufficient photons are absorbed, heat is generated, which may lead to a number of effects, including (1) bulk volumetric heating with elevation of temperature (nonablative therapies), (2) selective photothermolysis,<sup>5</sup> (3) water vaporization (CO<sub>2</sub> or Erb:YAG resurfacing), (4) tissue

pyrolysis, and (5) generation of photoacoustic transients (adiabatic heating causing stress waves as in laser lithotripsy). Photochemical modification (photodynamic therapy) and nonlinear multiphoton events, including plasma formation (keratorefractive eye surgery), also may occur, but generally have at present limited roles in the management of scars and soft tissue injury. In skin, the most widely used laser devices alter the skin via volumetric heating (nonablative techniques), selective photothermolysis (targeting of pigments such as hemoglobin or melanin), or frank ablation. Volumetric heating, such as that seen with the 1450-nm diode targets water resulting in localized heating in the upper dermis and subsequent tissue remodeling. Alternatively, lasers using selective photothermolysis, such as the pulsed-dye lasers (PDL) or Q-switched (QS) lasers work through selective chromophore targeting such as hemoglobin or exogenous pigments (ie, carbon particles), respectively, and are useful for treating cutaneous vascular malformations and tattoos.

The focus of the current review is on PDL, and ablative and nonablative resurfacing. Through the ablation process, heat generation incites inflammation and vascular permeability by inducing a pattern of thermal injury in the dermis, which stimulates complex tissue remodeling processes.<sup>8</sup> These treatments can be dramatic, with ablative resurfacing resulting in epidermal and superficial dermal vaporization, allowing later neocollagenesis and skin tightening. The unwanted side effects of ablative laser resurfacing (chiefly prolonged erythema and complete deepithelialization, but also third-degree burns) has been addressed through the development of alternative approaches, including nonablative and fractional laser devices.<sup>2,8,9</sup> Advances in fractional photothermolysis have revived the interest in both ablative and nonablative lasers in both treatment and prevention of posttraumatic scars by controlling the spatial extent of thermal injury in the upper dermis induced by the laser in both axial (in the direction of light propagation) and radial (lateral) directions. Because specifying dosimetry is the first step toward optimized therapy, controlling the spatial extent of laser-induced tissue modification has become equally as important.

Suffice it to say that many laser devices can be used to treat posttraumatic skin injuries, both acute and chronic, and there is much confusion with respect to developing a rational strategy for use. Herein we review lasers used for the management of posttraumatic facial scars and provide a flow chart (Fig. 1) to aid clinicians in optimizing therapy.

## **GENERAL TREATMENT CONSIDERATIONS**

Posttraumatic skin injuries are challenging to manage, because patients may seek care either immediately after injury or even months later. Those seen acutely for example, after suture removal, may be amenable to laser treatments that may mitigate the acute inflammatory process and reduce scar formation. Patients who seek expert care long after the acute phases of wound healing may have erythematous, hypertrophic, or atrophic scars with discrete step offs, or in the case of the face, contractures compromising eyelid, nasal airway, or oral commissure function. The narrow laceration oriented along relaxed skin tension lines (RSTL) without contracture may heal well in a patient without keloid predisposition, and is generally well-suited for laser resurfacing, or no treatment at all. The challenge often lies in managing posttraumatic facial scars that were initially

contaminated and insufficiently cleansed, have crushed or missing tissue, irregular wound edges, or were approximated under tension. These injuries may require classic scar revision surgery before or after laser resurfacing, because laser technology for the skin focuses primarily on optimizing surface texture, dermal remodeling, and pigmentation.

During initial scar evaluation, a thorough history should be obtained with particular attention to time course, history of keloids, immunodeficiency, connective tissue disorder, and previous trial of dermabrasion or laser resurfacing. The clinician should determine whether there is a personal or family history of vitiligo, and a recent or remote history of the use of isotretinoin (Accutane) or skin lightening agents such as hydroquinone, which may ultimately change the time course with which treatment may be initiated.<sup>1</sup> A detailed discussion with the patient should focus on expectations and goals, and explain that multiple procedures may be needed, or that recovery times will vary with specific devices. Before treatment, the clinician should consider the types of topical agents used to promote wound healing, whether administration of prophylactic antibiotics is necessary, whether pretreatment with hydroquinone (for patients with Fitzpatrick type III or higher), analgesia, or antivirals are indicated.<sup>6</sup>

## **Scar Assessment**

Several methods for assessing scars have been developed both from a patient and clinician perspective. The Vancouver Scar Scale is the most widely validated clinician survey used to assess scar pigmentation, pliability, vascularity and height.<sup>10</sup> Additionally, the Patient and Observer Scar Assessment Scale allows for an observer determination, and goes one step further to assess patient perceptions of scar pain, pruritus, color, stiffness, thickness and irregularity. Proper evaluation before treatment requires detailed and consistent photography under appropriate lighting conditions. These assessments allow for consistent pretreatment and post-treatment assessment, and provide a useful tool for outcomes analysis as an adjunct to photodocumentation.

## **SCAR CLASSIFICATION**

The characteristics of the posttraumatic scar in conjunction with patient preferences ultimately dictates the type of laser device and number of treatments required. Hypertrophic scars may benefit from multimodality therapy, such as laser resurfacing combined with intralesional steroids,<sup>11</sup> whereas combination resurfacing with multiple lasers may be needed to treat specific regions of a heterogeneous scar.

## **Hypertrophic Scars and Keloids**

Within the first month of closure, hypertrophic scars may develop along the boundaries of the laceration and are characterized by pink or erythematous, raised, and firm areas within the scar boundary.<sup>12</sup> Closure under tensile deformation creates areas that are prone to slow healing, promoting unrestrained collagen proliferation,<sup>3</sup> increasing the propensity for an imbalance of stromal matrix collagen degradation and collagen biosynthesis in the setting of fibroblast proliferation.<sup>13</sup> Adjunct therapies for treating hypertrophic scarring include intralesional steroid and/or 5-fluorouracil injections, compression therapy, and

radiation, among others.<sup>14,15</sup> Several lasers have shown efficacy in reducing keloids and hypertrophic scar burden, which are discussed elsewhere in this article.

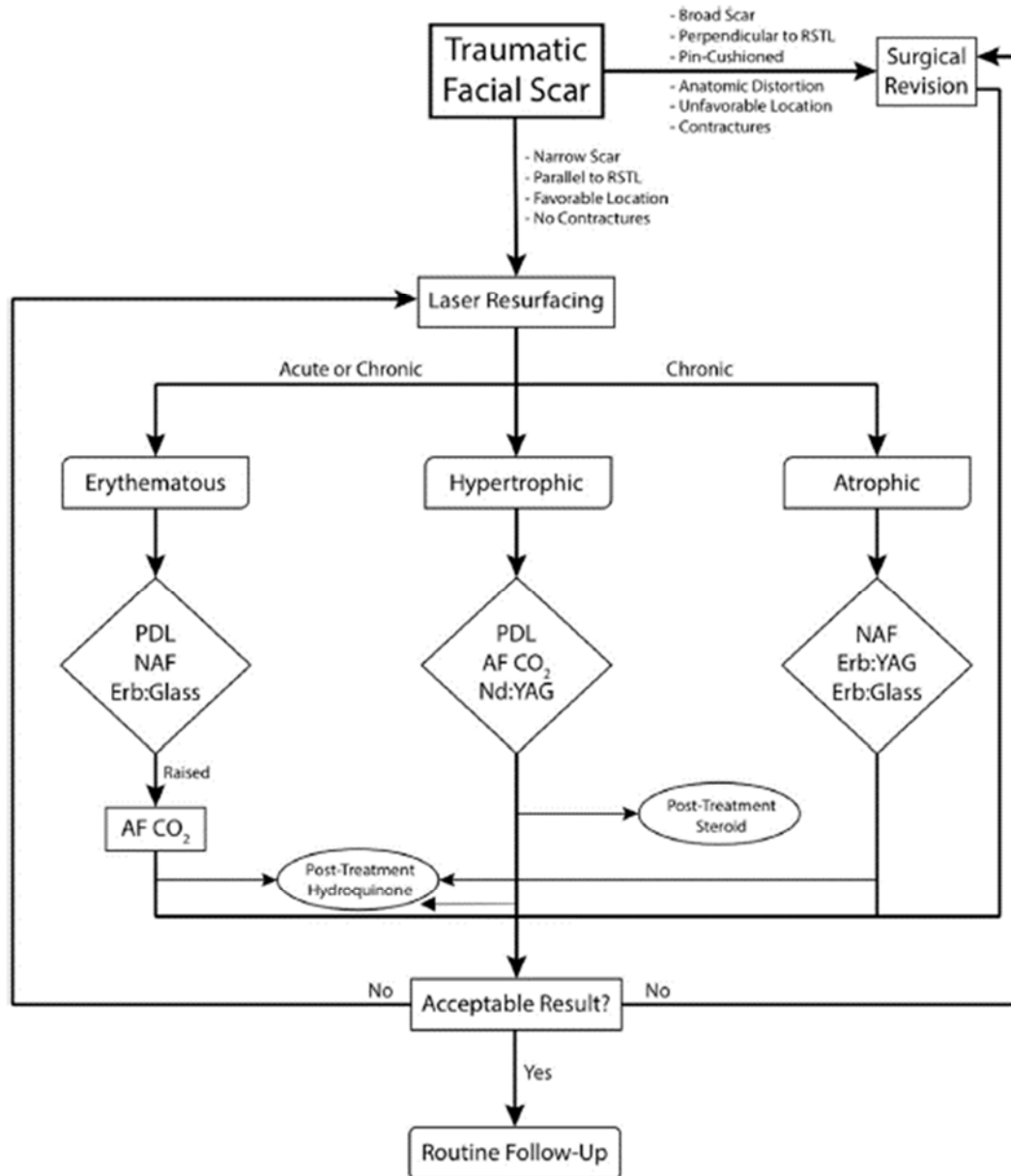
Keloids represent a unique process of continued fibroblast proliferation outside of the area of the scar that can continue to mature and grow. In addition to genetic or ethnic predisposition, wound closure under tension also predisposes the scar to keloid formation. In contrast with hypertrophic scars that may be pruritic or painful, keloids are generally asymptomatic.

### **Atrophic Scars**

Whereas hypertrophic scars are the result of matrix imbalance and fibroblast proliferation, atrophic scars generally result from traumatic collagen loss.<sup>16</sup> Atrophic depressions in the dermis form as the inflammatory reaction results in collagen destruction, atrophy, dermal fibrosis, and scar contraction.<sup>17</sup> Before laser resurfacing, methods for treating scars were aimed at improving atrophic contour and included punch excision, hyaluronic acid fillers, and autologous fat transplant.<sup>17,18</sup> Although these have had variable success, laser resurfacing allows for the benefit of reproducible vaporization, neocollagenesis, and blending and contouring the scar with adjacent normal skin. Lasers have the added benefit of use at any time during the development of the scar given the lack of mechanical trauma to the skin.

### **Timing of Treatment**

Precise control of dosimetry and, hence, tissue effect, has generated enthusiasm for using lasers earlier to treat posttraumatic injuries with the focus on altering the skin's inflammatory physiologic milieu during wound healing, and early application has shown promise in mitigating the development of scars and improved wound healing.<sup>9</sup> Classical wound care management dictates that early laser treatment would result in soft tissue destabilization and, therefore, should not started before 1 year after complete scar maturation, after which time spontaneous resolution has been given ample opportunity, although dermabrasion is often performed as early as 8 weeks.<sup>4</sup> Over the past 15 years, the interval between injury and laser treatment has become shorter, such that resurfacing, PDL treatment, and nonablative therapy is initiated within the first 6 to 8 weeks, and even as early as the day of suture removal (personal communication with the late R. Fitzpatrick, MD, Encinitas, CA, 2004). Fractional and PDL have shown significant promise,<sup>4</sup> with the putative mechanisms being an alteration of the inflammatory cascade or reduction in local blood flow to the scar, respectively.<sup>3</sup> Fractional irradiation using Erb:Glass (nonablative), Erb:YAG,<sup>19-21</sup> CO<sub>2</sub>,<sup>22</sup> and 810-nm diode lasers<sup>23</sup> has been performed as early as 10 days after surgical repair.<sup>24</sup> Although no specific protocol is currently established with respect to treatment initiation or laser type, energy density, or spot size, PDL at the time of suture removal and fractional therapy within 2 to 4 weeks are frequently used in the management of posttraumatic scars, and has proven successful in our experience.



**Fig. 1.** Suggested algorithm for treating traumatic facial scars. Indications for surgical scar revision are outlined, and can be followed with laser resurfacing to achieve the desired outcome. Otherwise, resurfacing can commence based on scar characteristics. If acceptable clinical outcome is achieved, patients are followed. Otherwise, laser therapy continued or option for surgical revision provided. AF, ablative fractional; NAF, nonablative fractional; PDL, pulsed-dye laser; RSTL, relaxed skin tension lines.

### Treatment Algorithm

Approaching the posttraumatic facial scar requires a thorough analysis of the scar's features, orientation, pattern, and relationship to surrounding tissue to determine both the type and extent of treatment. Our treatment algorithm (see Fig. 1) seeks to achieve a balance between repeated surgical revision and laser therapy. Do note, however, that the

flow chart is fairly dynamic and going from relatively conservative approaches (ie, laser) to aggressive (surgery) is common. It is difficult to predict the response to laser treatment, but inasmuch as they are low morbidity treatments, laser therapy can be repeated multiple times. Failure of laser therapy to meet patient expectation would be a potential indication for surgical scar revision, which can always be optimized with more laser treatments. One may start with lasers first, particularly in regions of the face where surgical scar revision may have significant risk or if a patient is reluctant to proceed. In our practices, where we have access to a broad range of laser devices, treatment is always initiated first, except in cases where it is clinically obvious that scar revision is the first step. After the initial consultation, the surgeon must consider whether to initiate laser treatment first, or to begin with scar revision and appropriately time laser therapy. This decision should consider several scar characteristics, such as broadness, pliability, relationship to anatomically sensitive areas (ie, oral commissure, nasal ala, and medial and lateral canthi), presence or absence of scar contractures, and orientation along RSTL. A scar that is broad, thickened, and causing anatomic distortion of the oral philtrum may be unfavorable for initial laser therapy, and should undergo surgical scar revision, such as a Z-plasty, to assist in reorientation and reduce retraction of the upper lip. Laser therapy may commence soon after suture removal. In contrast, a patient with an acute, linear, and hyperemic scar parallel to cheek RSTL has a favorable scar amenable to early initiation of laser therapy soon after consultation.

When the decision to proceed with laser is made, the surgeon must consider the variety of options available and the effect desired. The descriptions of the lasers and suggested dosimetry are discussed elsewhere in this review. As an example, if a cheek scar on a 6-month-old is erythematous and raised, it is reasonable to begin combined treatment with PDL using an energy density of 7.5 to 8.0 J/cm<sup>2</sup>, 6-ms pulse duration, with cryogen spray cooling. The hypertrophic component may then be addressed with ablative fractional Erb:YAG with a 250- $\mu$ m ablation zone for 2 passes with postprocedure application of topical corticosteroids, performed every 3 to 5 weeks. If the scar continues to be raised, ablative fractional CO<sub>2</sub> laser can be used at 12.5 to 20 mJ based on thickness. Conversely, a hypertrophic facial scar would benefit from PDL combined with early ablative fractional CO<sub>2</sub>, followed by the administration of topical corticosteroids. Advocates for the use of topical corticosteroid immediately after fractional laser treatment cite improved penetration of the agent in the setting of microthermal injury zones. Likewise, much research has been focused on the delivery of these agents through these microchannels into the dermis. Last, tissue loss and necrosis can result in burdensome and unsightly atrophic facial scarring. Treatment of these scars may start with an Erbium-doped laser or nonablative fractional therapy such as 1550-nm diode Erb:Glass (Fraxel re:Store, Solta, Hayward, CA) using 8 mJ/cm<sup>2</sup> with a density of 100 MTZ/cm<sup>2</sup>. In these 3 scenarios, posttreatment hydroquinone can be applied to prevent hyperpigmentation, particularly in patients with darker skin phototypes.

After either laser treatment(s) or surgical scar revision(s), the patient and surgeon must discuss whether improvements to the scar have been attained and what is realistically achievable. If after several laser treatments, a hypertrophic scar remains thickened, surgical revision may be considered. Similarly, if after surgical revision, there remains a significant erythematous area, repeat PDL treatment can be initiated. So long as the scar remains unacceptable to the patient and surgeon, a combination of treatments

can continue until the surgeon and patient are in agreement regarding the realistic result; otherwise, routine follow-up is suggested. The different laser types and dosimetry are discussed elsewhere in this article.

## **LASER SELECTION**

The selection of a laser for scar treatment is paramount in guiding treatment and predicting overall outcome, especially in the management of scars in their early healing phase. The appropriate wavelength is chosen based on desired effect, that is, volumetric heating (generally water) and ablation with CO<sub>2</sub> (10,600 nm), Erb:YAG (2940 nm), and Erb:glass (1550 nm), or targeting chromophores such as hemoglobin with potassium-titanyl-phosphate (532 nm) or PDL (595 nm). The scar type, that is, hypertrophic or atrophic, is a crucial consideration in determining the appropriate skin penetration depth required. For example, although PDL may be effective in modulating superficial scar progression by decreasing blood flow to tissue, its use for thicker or deeper scars is debatable.<sup>25</sup> Ablative lasers may be used for large, hypertrophic, or contracted scars, and nonablative lasers for atrophic and flat or mature scars.<sup>4</sup> The specific laser types and their applications are outlined elsewhere in this article and in our recommended treatment algorithm (see Fig. 1).

### **Ablative, Nonfractional**

The initial enthusiasm over laser use for aesthetic surgery began with the development of CO<sub>2</sub> lasers to perform “laser skin resurfacing.” CO<sub>2</sub> laser ablation removed the stratum corneum and papillary dermis to treat fine facial rhytides and scars. This process achieved similar outcomes and results to dermabrasion, albeit with notable differences including hemostasis and precise control over the depth of tissue removal. Unlike dermabrasion (or chemical peels), which require substantial skill, training, and experience, the degree of tissue removal by laser is purely governed by dosimetry; hence, this technology was rapidly adopted and widely used. Most ablative resurfacing relies primarily on water as the absorption target chromophore, with removal of the epidermis, and in part the papillary and upper reticular dermis. Collateral heating of deeper tissue layers results in modest tissue injury triggering reparative processes which include neocollagenesis.<sup>6</sup> Efficacy is a consequence of both tissue removal (with reepithelization from the preserved adnexa [hair follicles, glands, etc]) and thermal injury.

### **Carbon dioxide, 10,600 nm**

The CO<sub>2</sub> laser was the first device used for laser skin resurfacing.<sup>26</sup> These lasers are still used to correct facial rhytides and atrophic scars, as well as elevated scars requiring contouring.<sup>3</sup> Light from this laser is absorbed within the most superficial 20 to 30 μm of the skin with a collateral axial thermal damage zone of up to 1 mm.<sup>27</sup> Heat generated during the ablation of tissue triggers neocollagenesis. Each subsequent pass of this laser removes additional tissue. Several studies showed efficacy of pulsed high-energy ablative CO<sub>2</sub> lasers for the treatment of atrophic acne scarring<sup>18,28</sup>; however, its use in posttraumatic scars has largely been replaced by fractional CO<sub>2</sub>, Erb:YAG, and PDL,



which are discussed elsewhere in this article. The superior result of this laser is directionally proportional to axial (into the plane of light propagation) tissue damage, and comes at the risk of hyperpigmentation, hypopigmentation, prolonged postoperative erythema, risk of infection, and scarring.<sup>27,29</sup> The dosimetry used for CO<sub>2</sub> laser skin resurfacing is broad, and can be used in a fractional form pulsed at 2 ms with an energy density of 40 J/cm<sup>2</sup> for traumatic tattooing,<sup>30</sup> or pulsed at 200 ms at an energy of 102 mJ/pulse for posttraumatic facial scars<sup>31</sup>

### **Erb:YAG, 2940 nm**

The side effect profile (chiefly prolonged erythema lasting months) of full facial resurfacing using CO<sub>2</sub> lasers led engineers to develop Erb:YAG ablative lasers. The Erb:YAG emitting at a wavelength of 2940 nm is absorbed by tissue water by a factor of 12 to 18 times higher as compared with the CO<sub>2</sub> laser. The depth of penetration is much more superficial, depending on the energy density applied, as compared with the CO<sub>2</sub> laser.<sup>32</sup> The consequence of this decreased skin penetration depth is decreased focal damage axially,<sup>26</sup> less collagen regeneration, and reduced postoperative erythema. The Erb:YAG laser is useful for depressed or atrophic scars, although it is considered by some to be less efficacious than CO<sub>2</sub> lasers for cosmetic applications. Energy density selection is variable with 4 J/cm<sup>2</sup> indicated for delicate tissue areas and superficial lesions, or higher (12–15 J/cm<sup>2</sup>) with multiple passes indicated for complex scars.<sup>16,32</sup> The depth of penetration can also range up to 200 μm, with 50 μm sequential coagulation for atrophic scars<sup>28</sup> or no coagulation for hypertrophic scars. The Erb:YAG laser can be used in patients with Fitzpatrick skin phototypes III or higher.<sup>33</sup> Pulsed Erb:YAG has value in treating several types of scars,<sup>34</sup> and fractional Erb:YAG lasers may result in improvement of color, stiffness, thickness, irregularity, and overall patient satisfaction as compared with fully ablative Erb:YAG resurfacing.<sup>35</sup>

### **Pulsed-dye Laser, 595 nm**

The PDL targets hemoglobin as its chromophore and relies on selective photothermolysis for efficacy, because 595-nm light is highly absorbed by hemoglobin and poorly absorbed by water and other dermal matrix proteins.<sup>3,5,36,37</sup> Primarily used to treat vascular lesions (ie, the port wine stain), the PDL has value in treating the hyperemic components of posttraumatic scars,<sup>38</sup> hypertrophic scars, and keloids,<sup>12</sup> and may lead to improvement in skin color, texture, and pliability while reducing dyspigmentation, scar bulk, and vascularity. PDLs are increasingly being used to treat early, immature scars to prevent hypertrophy in the remodeling phase,<sup>39</sup> potentially obviating the need for surgical scar revision for posttraumatic scarring.<sup>40,41</sup> Literature regarding dosimetry is adjustable, and varies from 4.0 to 8.0 J/cm<sup>2</sup> based on spot size, with short pulse durations of 0.45 to 3.0 ms with treatments repeated every 3 weeks to 2 months depending on surgeon and patient preference and expectations.<sup>4,38</sup>

Combining PDL with adjunct therapy has also shown promise in small studies.<sup>36,38</sup> Depth of penetration for the PDL is about 1 to 2 mm and can be combined with corticosteroids for keloid management.<sup>36</sup> Combination PDL followed by fractional Erb:glass or 1450-nm diode has been found valuable in small studies evaluating

posttraumatic scars.<sup>38,42</sup> Here the hyperproliferative vascular component is treated with PDL, and a fractional laser is used to induce dermal remodeling to recreate a more uniform skin appearance.

Keloids present a unique challenge given their location in areas under tension, thickness, and resistance to intralesional steroid injections. Systematic reviews suggest that PDL treatment significantly improves Vancouver Scar Scale scores in patients with keloids with respect to scar pigmentation.<sup>12</sup> It is equivocal whether scar thickness or erythema decreases, although the PDL has demonstrated some promising results. Outcomes have proven superior in patients with lighter skin phototypes and adverse events are minimized when lower energy densities (eg, 4 J/cm<sup>2</sup>) are used. Keloids have been treated by PDL using energy densities of 3.5 to 9.0 J/cm<sup>2</sup> with a pulse duration of 0.45 to 1.5 ms, every 4 to 8 weeks for 2 to 12 treatments, used in conjunction with intralesional triamcinolone, 5-fluorouracil, or erbium lasers.<sup>12</sup>

### **Fractional Ablation**

Fractional skin resurfacing involves the selective ablation of specific regions of tissue using microlaser spots distributed with a user-defined density across the skin surface. Fractional laser devices intersperse healthy tissue between ablation sites and these pristine regions remain as potent nutrient reservoirs and as a source for keratinocytes to repopulate ablated tissue.<sup>6,8</sup> This process, collectively referred to as “focal destruction with islands of spared tissue,” results in collagen remodeling and elastic tissue formation, which leads to more rapid wound healing, less downtime, and reduced postoperative erythema.<sup>11</sup> These devices (chiefly CO<sub>2</sub> and Erb:YAG) can be used to debulk fibrotic scars and, in each microspot, incite new collagen formation.<sup>43</sup> They are valuable to treat posttraumatic<sup>44,45</sup> and postsurgical facial scarring,<sup>46–48</sup> hypertrophic facial scarring,<sup>35</sup> and posttraumatic extremity scarring.<sup>49</sup> Innumerable fractional ablation devices have been developed and differ in terms of which specific laser used, and parameters that govern microlaser spot size and density.

### **Nonablative, Nonfractional**

By selectively heating the dermis while sparing the epidermis from thermal injury, nonablative laser devices possess a lower side effect profile with respect to erythema, infection, and risk of herpetic reactivation. Accordingly, outcomes are modest<sup>1,28</sup> when compared with ablative modalities. Several nonablative lasers have been developed including 1319-nm pulsed energy (Sciton, Palo Alto, CA) for rhytides and acne pulsed at 5 to 200 ms for 30 J/cm<sup>2</sup>, 1.320-nm Nd:YAG (Cool-Touch CT3Plus, Alma Harmony XL, Syneron, Roseville, CA) pulsed at 450-ms for the same purposes,<sup>17,50</sup> and 1450-nm diode for posttraumatic facial scars.<sup>51</sup> For atrophic and hypertrophic scarring alike, the 1450-nm diode has been safely used with an energy density of 12 J/cm<sup>2</sup> with a 6-mm spot size, and combined with PDL.<sup>42,52</sup> These devices have been used primarily for the treatment of postacne scarring and facial rejuvenation; however, small nonrandomized trials have shown some benefit for posttraumatic scars.<sup>53</sup>

## **Nonablative, Fractional**

Nonablative fractional lasers can be used to safely treat darker skinned (Fitzpatrick III and above) individuals and may have value for posttraumatic scar resurfacing.<sup>26</sup> Originally developed for use in rejuvenation procedures, they have largely been replaced by ablative fractional lasers because the effects are modest. The fractionated nonablative Erb:Glass laser 1550-nm (Solta Fraxel re:store) may improve the texture and appearance of posttraumatic scars. This can be combined with PDL treatments,<sup>38</sup> using an energy density of 6 J/cm<sup>2</sup>, spot size of 6 mm, and 3 a ms-pulse duration for the PDL, and energy density of 8 mJ/cm<sup>2</sup> and density of 100 MTZ/cm<sup>2</sup> for the fractional laser at 3-week intervals. This efficacy may be enhanced with greater energy densities, but requires further investigation.<sup>24</sup> Additionally, when combined with traditional CO<sub>2</sub> laser, fractional Erb:glass results in significant reduction in Vancouver Scar Scale scores, with more improvement in scar pliability and pigmentation.<sup>37</sup>

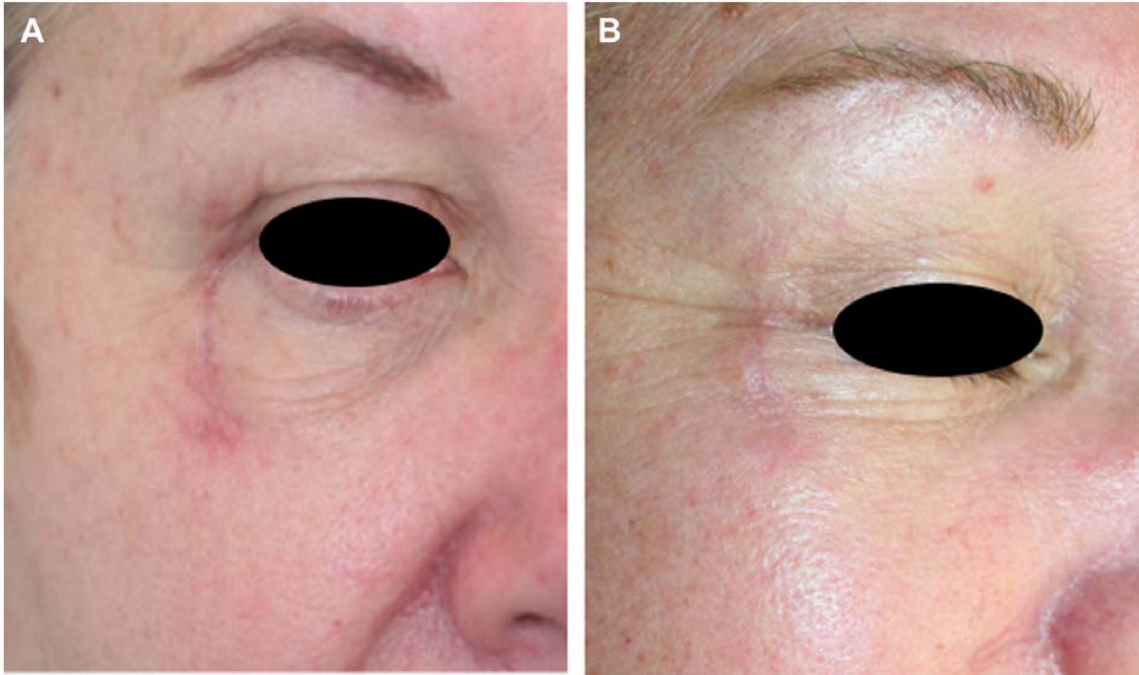
## **TRAUMATIC TATTOO**

Traumatic tattoos are the result of pigmented deposition from lodged foreign debris in the dermis owing to abrasions, explosive forces, “road rash,” and inadequate wound irrigation before closure.<sup>3,54</sup> Optimal treatment requires the use of a QS laser. These devices release high energy in extremely short pulse durations, on the order of nanoseconds or picoseconds, leading to high temperature gradients and induced acoustic waves within the particle. The pigmented particles fragment and eventually undergo macrophage-mediated phagocytosis. Currently, QS ruby, QS Nd:YAG, and QS alexandrite are used for traumatic tattoo removal, although fractional CO<sub>2</sub> has shown some benefit.<sup>30</sup> QS ruby initiated at energy densities of 3 to 4 J/cm<sup>2</sup> repeated at 6-week intervals can very effectively reduce pigment from traumatic tattoos.

## **Clinical Examples**

In our practice, we have had excellent results with combination treatment laser therapy to treat specific components of posttraumatic scars as per our algorithm. The patient in Fig. 2 had sustained blunt force trauma lateral to the right eye, resulting in atrophic surrounding skin and a raised and erythematous scar perpendicular to the RSTL. She opted for laser resurfacing alone, and underwent combination PDL at 7.5 to 8 J/cm<sup>2</sup>, 6-m pulse duration for the hyperemic portion and fractional Erb:YAG, at 150 to 200 mm depth to treat the hypertrophic portions. After 5 treatments, the scar was noted to be smoother, with a dramatic reduction in erythema and hypertrophy. The patient self-reported improvement based on a 50% improvement in her overall Patient and Observer Scar Assessment Scale score, with a reduction in pain and itching, and improvement in color, stiffness, thickness, and overall appearance. Similarly, our patient in Fig. 3 had right facial skin necrosis, resulting in significant skin fibrosis, retraction, and atrophy along the right cheek with erythema inferior to the right orbital rim. She was initially managed conservatively with local wound care as the wound began to declare. She eventually underwent combined PDL and Fraxel Dual (Solta) using energies of 45 to 70 mJ deposited at a depth of 1176 to 1359 mm, over 10 treatments, over 2 years. She

underwent surgical scar revision with excision of the inferior hypertrophic scar followed but continued combination laser treatment resulting in near-total resolution of the superior hyperemia and overall reduction in the atrophy and evening of the scar with respect to her native skin. Last, our patient in Fig. 4 demonstrates the dramatic effects of surgical scar revision and tincture of time. She was injured in a dog mauling, which resulted in a straight left cheek laceration that extended on the left lateral nasal sidewall and was closed primarily in the operating room. She subsequently underwent 2 major surgical scar revisions over 4 years, resulting in dramatic improvement in overall scar characteristics, resolution of hypertrophy and erythema, and thinning of the scar overall.



**Fig. 2.** A 57-year-old female patient with a traumatic scar lateral to the right lateral canthus with vertical extension at (A) 2 weeks posttrauma and (B) 6 month after 5 treatments of pulsed-dye and Erb:YAG laser. There was significant reduction in scar erythema and thickness.



**Fig. 3.** A 17-year-old girl with full-thickness skin necrosis secondary to embolization of vascular arteriovenous malformation. (A, B) The lesion extends from her malar eminence inferiorly toward the mandibular body. (C, D) Significant improvement at 18 months in overall erythema and atrophic scarring after multiple treatments with a pulsed-dye laser using an energy density of  $8 \text{ J/cm}^2$ , 10-ms pulse duration, and fractional 1550 erbium/1927 thulium treatment (Fraxel Dual) using an energy of 45 mJ deposited at a depth of 1176 mm for the middle cheek, and 70 mJ at 1359 depth for the upper and lateral cheek. (E, F) Continued improvement at 30 months after surgical scar revision of lower broad scar and continued 1550 erbium/1927 thulium.



**Fig. 4.** A 3-year-old girl with left facial trauma secondary to dog bite injury after multiple surgical scar revisions. (A) Laceration extending from left nasal sidewall to malar eminence 14 days after closure. (B) Follow-up at 19 months shows improvement in hypertrophic scar over the nasal sidewall after surgical scar revision 2 months previously. (C) Follow-up at 22 months showing continued improvement in scar erythema and texture. (D) Followup at 4 years after second scar revision.

## POSTTREATMENT COMPLICATIONS

As mentioned, laser treatments for scars are generally well-tolerated, but complications can occur. Immediate posttreatment erythema is considered a normal part of the dermal remodeling process; however, it may persist. Generally, erythema persisting for 4 days is common for nonablative treatment, and 1 month for ablative. In 12.5% of patients treated with ablative lasers,<sup>6</sup> erythema can persist for up to 6 months. Pinpoint bleeding is also worse with fractionated CO<sub>2</sub> compared with Erb:YAG given the increase in zone of coagulation with the former.<sup>4</sup> Significant thermal damage can also result in hypertrophic scarring and skin weeping, and although these complications can be mitigated with compresses, analgesia, and steroids, they can increase patient downtime. Local skin irritation can also result in significant dermatitis, bacterial or fungal superinfection, or viral reactivation; therefore, judicious follow-up and discussion of prophylactic antimicrobial and antiviral therapy is warranted. Posttreatment scarring can also result from conventional ablative lasers, and is also seen with patients receiving ablative fractional therapy.<sup>9</sup> The most feared complication is postinflammatory hyperpigmentation, which is more common in patients with darker Fitzpatrick skin phototypes. This hyperpigmentation can be managed through rigorous patient and laser selection, as well as preprocedural bleaching agents, such as compounded tretinoin, hydrocortisone, or hydroquinone<sup>3</sup> and strict sun avoidance after the laser procedure for a minimum of 3 months.

## SUMMARY

Although initially applied to the treatment of postacne scarring and deep facial rhytides, laser technology has undergone a dramatic shift in clinical application and is an effective method for reducing the appearance and thickness of posttraumatic facial scars. Laser resurfacing for facial scars offers the facial plastic surgeon a variety of options for reducing the appearance of posttraumatic atrophy, hypertrophy, and dyspigmentation. This technology has equipped the clinician to intervene early with a modality that mediates the inflammatory effects of tissue healing soon after traumatic laceration, while offering an adjunct therapy to surgical scar revision. The surgeon must paint a realistic picture of what is attainable before delving into a goal-directed laser selection based on scar characteristics, patient skin type, risk of posttreatment complications, and consideration of patient downtime. Although the results of these treatments are promising, ideal dosimetry remains an ongoing challenge as the literature emphasizes experience-based rather than evidence-based practice; large-scale, randomized, controlled trials and split-scar studies are lacking, especially with combination modalities. Nevertheless, the variety of lasers, variable time with which to initiate therapy, and countless combinations offer the clinician a stocked armamentarium from which treatment algorithms may be tailored and designed.

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