Acne scarring: A review and current treatment modalities

Albert E. Rivera, DO
Kirksville, Missouri

Acne is a prevalent condition in society and often results in secondary damage in the form of scarring. Of course, prevention is the optimal method to avoid having to correct the physically or emotionally troublesome scars. However, even with the best efforts, scars will certainly arise. This article attempts to give a broad overview of multiple management options, whether medically, surgically, or procedurally based. The hope is that a general knowledge of the current available alternatives will be of value to the physician when confronted with the difficult task of developing a treatment plan for acne-scarred individuals, even in challenging cases. (J Am Acad Dermatol 2008;59:659-76.)

ACNE

Acne is caused and characterized by multiple factors, including: *Propionibacterium acnes* activity; increased sebum production; androgenic stimulation; follicular hypercornification; lymphocyte, macrophage, and neutrophil inflammatory response; and cytokine activation. Multiple surveys and studies have attempted to determine the prevalence of acne within various groups. None of these are without shortcoming but all have done well with targeted, representative groups. A good review, too extensive to be included in this work, containing tables (consisting of 15 general population or schoolchildren-based cross-sectional surveys along with 3 separate case-control studies) and discussions of several of these publications has been compiled and published by a group of Australian authors.[1]

In 1978, the most comprehensive study to date, HANES-1,[2] established the prevalence of acne vulgaris within 20,749 US citizens aged 1 to 74 years (excluding those hospitalized for another dermatologic condition and those with the disease in remission) to be 68 per 1000 for both sexes, 70.4 per 1000 for men and boys and 65.8 per 1000 for women and girls. Cystic acne was present in 1.9 per 1000 for both sexes, 3.3 per 1000 in men and boys and 0.6 per 1000 in women and girls. The common complication of acne scarring was found in 1.7 per 1000 for both sexes, 2.0 per 1000 in men and boys and 1.3 per 1000 in women and girls. Approximately 80% of girls and 90% of boys develop acne in their adolescent years. The peak incidence for girls is age 14 to 17 years and age 16 to 19 years for boys and men. Furthermore, of individuals aged 11 to 30 years, 80% have some degree of active acne.

Abbreviations used:

Er:YAG:	erbium:yttrium-aluminum-garnet
FDA:	Food and Drug Administration
HA:	hyaluronic acid
IPL:	intense pulsed light (not listed)
Nd:YAG:	neodymium:yttrium-aluminum-garnet
PDL:	pulsed dye laser
TCA:	trichloroacetic acid

More recently, a community-based study, using the Leeds grading technique for acne[3] and including 749 patients, all older than 25 years (range 25-58 years, mean age 39.5 years), was used to determine overall acne prevalence as 58% of women and 40% of men. "Clinical" (>0.75 on the Leeds scale) acne was present in 3% of men and 12% of women. The prevalence of clinical acne decreased significantly only after age 45 years. Their definition of scarring was noted in 14% of the women and 11% of the men in the study.[4] However, even in the two examples above, statistics are often inaccurate because most estimations are based on patients who seek treatment, physician diagnoses, hospital records, compensation claims, medication purchases, or various exclusion or inclusion criteria, rather than a full cross-population sample.[5]

From the Department of Dermatology, Northeast Regional Medical Center.
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Please see the Appendix for a listing of the manufacturers of brand name drugs mentioned in this article.
Reprint requests: Albert E. Rivera, DO, Department of Dermatology, Northeast Regional Medical Center, 700 W Jefferson St, Kirksville, MO 63501. E-mail: bo_rivera@yahoo.com.
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Even though this condition is widespread, patients do not always present to physicians for prompt diagnosis and treatment. Of those with acne, only approximately 16% seek appropriate medical treatment: 74% wait greater than 1 year before seeking evaluation, 12% wait 6 to 12 months, 6% wait 3 to 6 months, and only 7% waited less than 3 months to be seen.[6] This is attributed to multiple factors that could include financial limitations, physician access, and patient delay, among others. The delay in treatment, though, increases the probability of secondary sequelae such as scarring. Educational efforts should be undertaken to inform the public and physicians as to the importance of preventative measures and urgency of early management. A good review of such treatments, including topical or systemic medication and lasers, was authored fairly recently.[7]

BACKGROUND

It has been written that "there is no single disease which causes more psychic trauma, more maladjustment between parent and children, more general insecurity and feelings of inferiority and greater sums of psychic suffering than does acne vulgaris."[8] So too, and possibly more so through its permanence, is the effect of the resulting damage in the form of a physical scar. "Scar," as a noun, is defined as "the fibrous tissue that replaces normal tissue destroyed by injury or disease" by the American Heritage Stedman's Medical Dictionary.[9]

An impressive study involving the histology, pathology, and immunology of acne scarring found that "the cellular infiltrate was large and active with a greater nonspecific response (few memory T cells) in early lesions of NS [not prone to develop scarring] patients, which subsided in resolution. In contrast, a predominately specific immune response was present in S [prone to develop scarring] patients, which was initially smaller and ineffective, but was increased and activated in resolving lesions. Such excessive inflammation in healing tissue is conducive to scarring. . .."[10]

Collagen and other tissue damage from the inflammation of acne leads to permanent skin texture changes and fibrosis. Scars normally proceed through the specific phases of the wound-healing cascade: inflammation, granulation, and remodeling. However, even normal scars never reach the same level of strength as original skin, only about 80% at best.[11] Dermal damage is more long lasting and results in an increase or decrease of tissue and often worsens in appearance with age as a result of normal skin changes. In contrast, damage limited to the epidermis or papillary dermis can heal without scar formation.[12] Epidermal damage results in more transient erythema or pigmentary changes and not true scars as defined above.

In one study of 185 patients (101 female and 84 male with various quantity, morphology, and severity of acne of the face, chest, or back), it was found that facial scarring affected 95% of both sexes to some degree. The truncal region of male patients showed significantly more total, hypertrophic, and keloidal scarring than the same region of female patients. The correlation with scar formation was related to those acne lesions with a time delay of up to 3 years between initial onset and sufficient treatment regardless of sex or location.[13]

A very touching and enlightening article by Koo[14] discussed psychosocial effects primarily in regard to acne but it also applies to scars. They may both lead to emotional debilitation, embarrassment, poor self-esteem, social isolation, preoccupation, low confidence, altered social interactions, body image alterations, identity difficulties, anger, frustration, confusion, unemployment, lowered academic performance, exacerbation of psychiatric disease, anxiety, or depression. Although these effects are difficult to quantify in patient terms, health care effect, or social expense, the scarring that results from tissue damage and inflammation is a significant issue that requires attention and will be expanded. Now the focus will turn to the scars themselves; initially, the scar types are covered and then several of the treatment options currently available are discussed.

ACNE SCARS

The two causes of acne scar formation can be broadly categorized as either a result of increased tissue formation or, the more common cause, loss or damage of tissue. Two examples of excess tissue presence are hypertrophic scars and keloids. Hypertrophic scars are confined within the margins of the original injury. These scars are most prevalent within the first couple of months postinjury, and then, in contrast to keloids, tend to normally mature with occasional spontaneous regression. However, some do also worsen. These scars are most often less bothersome and treatment may or may not be needed based on severity. Keloids are a human-specific phenomenon that is characterized by disproportionate creation and deposition of collagen with an excess outside of the original injury margins. They are commonly found on the chest, back, shoulders, and ears. These lesions are very persistent and are found almost equally among male and female patients, less commonly in the very young or old. There are familial and genetic influences with both autosomal dominant and recessive traits. Clinically, there may be pain, itching, burning, or limited range of

motion. Surgery is sometimes done for debulking and multiple modality treatment is recommended because of the high recurrence with surgery alone; aggressive scars have a regrowth of 50% to 100%.

Histologically, normal-appearing dermis demonstrates relaxed, randomly aligned collagen. Both hypertrophic scars and keloids demonstrate thicker, more abundant collagen that is stretched and aligned in the same plane as the epidermis. More specifically, hypertrophic scars have islands of dermal collagen fibers, small vasculature, and fibroblasts throughout.[15] Suggested pathophysiology includes transforming growth factor-beta-I, platelet-derived growth factor, matrix metalloproteinases, interleukin-I-alpha, fibroblasts themselves, altered microvascular regeneration, histamine, carboxypeptidase A, prostaglandin D2, and tryptase.[16] Keloids, on the other hand, reveal regions of reticular dermal acellular nodelike structures and are more acellular as a whole compared with hypertrophic scars.

Both keloids and hypertrophic scars have an incidence 5 to 15 times higher in African Americans and 3 to 5 times higher in Asians compared with Caucasians.[17] It is estimated that they affect both the African American and Hispanic populations between 4.5% to 16%.[18] As briefly noted above, both are treated either singly or in combination with multiple therapies such as excision, abrasion, laser treatment and medication, among others. As an outside reference, Alster and West[19] authored an excellent, thorough review on hypertrophic and keloid scars along with atrophic scars.

The other cause of scars, loss or damage of tissue, is demonstrated by the 3 primary acne scars as described by Jacob et al[20]: icepick, rolling, and boxcar. The icepick scars are usually smaller in diameter (<2 mm) and deep with tracts to the dermis or subcutaneous tissue possible. Although the orifice is smaller and steep-sided, there may be a wide base that could evolve into a depressed, boxcar scar. Commonly these are seen on the cheeks. Treatment is frequently done by punch excision with closure by small suture along relaxed skin tension lines. Nonabsorbable suture is preferred because of the predisposition of the skin to scar and the inflammatory response seen with absorbables.[21] Depressed or boxcar scars are described as shallow (<0.5 mm) or deep (>0.5 mm) and are often 1.5 to 4 mm in diameter. They have sharply defined edges with steep, almost vertical walls. Shallow scar treatment can be with resurfacing or possibly punch elevation whereas deep scar treatment is most often done by punch excision, elevation, or other modality. Soft rolling scars can be circular or linear, are often greater than 4 mm in diameter, and have gently sloped edges that merge with normal-appearing skin. There may be dermal or subdermal tethering, so treatment is commonly by subcision, which will be discussed later. An additional, sometimes categorized class, atrophic scars, exhibit a slightly wrinkled texture and may be somewhat pigmented because of the underlying vasculature. Treatment is most often with abrasion, excision, or augmentation but occasionally with creams or peels that have generally poor results.

Objective evaluation of the scars is a necessity for discussion, treatment, and research. There are grading devices that focus on 3-dimensional grid-based mapping of lesions and molded skin replicas for comparison examination.[22] However, these are not as applicable in practical, daily use by the average physician. There are grading scales for acne scars that are more practical for day-to-day implementation. In 1999, the ECLA (echelle d'evaluation clinique des lesions d'acne)[23] was introduced, followed by the ECCA (echelle d'evaluation clinique des cicatrices d'acne)[24] in 2006. Using this scale, the qualitative aspects of scars define the type of scar, which is then associated with a quantitative score (0-4) determined semiquantitatively and multiplied by a weighting factor (15-50) of clinical severity, leading to possible totals of 0 to 540. It was found to have good interinvestigator reliability although it did not focus on icepick, rolling, or boxcar specifically but rather variations of atrophic and hypertrophic. Goodman and Baron[25] described a quantitative grading system based on counting (1-10, 11-20, >20) of scar type (atrophic, macular, boxcar, hypertrophic, keloidal) and severity (mild, moderate, severe). Points are assigned to each respective category and totaled within the range of a minimum of 0 to a maximum of 84. This was found to be reasonably accurate and reproducible with good interinvestigator reliability. The same physicians also outlined a qualitative (rather than quantitative) grading system[26] that is simpler for quick, daily use. It distinguished 4 grades for level of disease: (1) macular, (2) mild, (3) moderate, and (4) severe. Subdivisions of macular disease are erythematous, hyperpigmented, or hypopigmented and those of mild to severe disease are atrophic and hypertrophic. Further specification includes the number of cosmetic units involved: A for focal or one lesion and B for discrete or 2 to 3 lesions. As the reader can appreciate, these systems and variation therein can become quite confusing. In the literature, there is one attempt at creating a comprehensive classification system based on several other systems.[27] However, the lack of a true consensus scale hinders standardization of diagnosis and treatment of acne scarring.

Table I. Medical management

Retinoids
Topical/injectable steroids
Silicone dressing
Various other topical or injectable substances

Some lesions are called "scars" but are not truly so by definition but, rather, are changes in skin color. A first is postinflammatory erythema. The resolving acne site's initial presentation may be pink or red but usually improves. Persistent redness can be addressed with laser or other therapy. Postinflammatory hyperpigmentation is a very commonly seen variant. It is a black or brown residual discoloration in the location of previous acne or other inflammatory reaction. These lesions are more common in those with darker skin or those who tan. Fading may occur but quite frequently takes a prolonged time period, sometimes up to a year. Chemical peels, lasers, or bleaching agents are usually the first-line therapies. Hypopigmentation is a loss of pigment in the area of the lesion. It can range from lightening to total whitening of the skin. Often these areas do not regain the level of previous pigmentation and only late if so. Multiple treatments can be considered for all of these pigmentary lesions after the acne is adequately addressed. Included are hydroquinone, tretinoin, cortisone, azelaic acid, camouflage, combination creams (primary choice is retinoid plus hydroquinone), superficial chemical peels, microdermabrasion, laser therapy, or ultraviolet A/B sunscreens.[28] The one agreed-on facet is that the most effective treatment for both the true scars and pigmentary changes is to prevent and control the acne lesions themselves to limit inflammation and other sequelae.

ACNE SCAR TREATMENT

Treatment of the true scars resulting from acne must reflect several considerations by the physician. Cost of treatment, severity of lesions, physician goals, patient expectations, side-effect profiles, psychological or emotional effect to the patient, and prevention measures should all play a role. The ultimate goal of any intervention is for improvement, not for a total cure or perfection. Single treatment, multiple treatments, or combination therapy may be required. An excellent review and discussion by Goodman[29] on postacne scarring treatments was recently published as an update to a similar previous study by Goodman and Baron.[30] Another in-depth article by Tsau et al[31] examined the procedural techniques available. Studies to evaluate these methods are often difficult because of sample sizes, lack of controls, objective grading scales, follow-up, or sponsorship/funding bias. The following sections, although not totally comprehensive, will attempt to cover a majority of the medical, procedural, and surgical options. It is less often that acne lesions lead to hypertrophic scars or keloids, however, it is a possibility and certainly is a side effect consideration with treatments for other types of scars, so will therefore be included in these discussions. There will be an attempt to mention basic information or pertinent advantages or disadvantages for each of the options from review of literature that is as fairly contemporary as possible.

MEDICAL MANAGEMENT

There are numerous medical options available for treatment of acne scars. Hypertrophic scars, keloids, and pigmentary changes are the usual focus of medical management whereas the other types require other forms of intervention. Only a few of the more commonly used or proven selections will be mentioned here (Table I). Of course, if desired, more information can be researched for such topicals or injectables as vitamin A, vitamin E, vitamin C, zinc, colchicine, hyaluronidase, cyclosporine, honey, onion extract, 5-fluorouracil, bleomycin, retinoids, verapamil, pepsin, hydrochloric acid, formalin, and almost unlimited others. Retinoids, specifically, have supporting sparse reports of treatment to keloids, hypertrophic scars, and very superficial scars.[32] The benefit is attributed to an increase in elasticity with dermal collagen deposition and alignment.[33]

One of the more popular choices for medical therapy, again, mostly for hypertrophic scars and keloids, is the use of the generically termed "steroids." These are substances that are based on 4 fused carbon rings that derive from the cholesterol molecule. The glucocorticoids (eg, triamcinolone, hydrocortisone, methylprednisone, and dexamethasone), in the corticosteroid family, have immunomodulatory and anti-inflammatory properties. They reduce the expression of cytokines, cellular adhesion molecules, and other enzymes related to the inflammatory process.[34] The exact mechanism is unknown but it is thought to related directly to the anti-inflammatory properties, reduction of collagen, glycosaminoglycans, and fibroblasts, along with overall lesion growth retardation. Used as a topical, both with and without occlusion, there is a wide range of clinical response. Steroids used in high doses, typically intravenously, may lead to multiple systemic side effects but these are highly unlikely in the topical doses used in scar treatment. However, cutaneous use does include side effects that might include telangiectases, bruising, atrophy, pain, or pigmentary change. The other route, some say the

first-line treatment, commonly used for hypertrophic scar and keloid treatment is intralesional injection because surgery is often debatable for these lesions. Often, multiple injections spaced one or several months apart are required to determine the final result and prevent excess atrophy. If a permanent filler for augmentation is used and there is overcorrection, atrophy of the area may be a desired effect to balance the contours. Other side effects of injected steroids include intolerance, necrosis, allergy, bruising, hyperpigmentation or hypopigmentation, injection pain, and telangiectases.

Another treatment modality used that focuses on hypertrophic scars and, although less effective, keloids is silicone dressing. There is variable support to the silicone itself, with results more likely attributable to occlusion or hydration. Pressure was also one supported mechanism along with other rationales that include temperature, increased oxygen tension, electrostatic properties, or immunologic effects. There are conflicting reports as to its efficacy. One study noted improved pruritus, pain, and pliability but found no improvement in pigmentation, average elevation, or minimum elevation of scars.[35] A separate review of effects, efficacy, and safety determined that "although the mechanism of action of silicone elastomer sheeting has not been completely elucidated...it appears to be an effective means of treating and preventing hypertrophic and keloid scars and can be used with little risk of serious adverse effects." The included commentary pointed out that "they work clinically and are safe and quite frankly should be part of all hypertrophic scar and keloid therapy."[36] Rarely, side effects include pruritus, contact dermatitis, maceration, skin breakdown, xerosis, and odors.

SURGICAL MANAGEMENT

Surgical management is an essential tool in the armamentarium against acne scarring. The icepick, boxcar, and rolling scars are frequently addressed by surgery (Table II). Punch or elliptical excision to the subcutaneous level is preferred for icepick scars. A scar "requiring a punch larger than 3.5 mm is repaired by elliptical excision or punch elevation because these larger defects lend to 'dog ear' formation on the face."[19] The goal is to trade a larger, deeper scar for a smaller, linear closure that will hopefully be less noticeable and possibly fade with time. Rarely, a skin graft may be required rather than primary closure. This usually only applies if a sinus tract or wide-based lesion is unroofed. A second alternative, punch elevation, is a method of treatment for depressed boxcar scars. The biopsy tool should match the inner diameter of the lesion and the base should appear normal because it will be elevated to the skin surface. After the punch is done and the base elevated, it is sutured flush with the normal-appearing skin and allowed to heal in place. Finally, the surgical choice for rolling or depressed scars (definitely not for icepick or atrophic scars or infected areas) is "subcision." This was first described by Orentreich and Orentreich[37] in 1995 as an original word created from "subcutaneous incisionless." A tri-bevel needle is probed under the lesion through the needle's puncture so it is not a true incision. This movement results in the releasing of papillary skin from the binding connections of the deeper tissues and creates controlled trauma that leads to wound healing and associated additional connective tissue formation in the treated location. It may be necessary to perform variable depths of sweeping, fanning, or lancing to disrupt the fibrous connections and multiple attempts or sessions may be required. Although uncommon, there is the potential for bruising, hypertrophy, cysts from pilosebaceous unit disruption, infection, additional scar, or worsening of the scar.

Table II. Surgical management

Punch excision
Elliptical excision
Punch elevation
Skin graft
"Subcision"
Debulking

Intervention for hypertrophic scars or keloids must be done with care because the patient is known to have a propensity for that type of response. There is argument regarding the appropriateness of surgery with both types of scars but more so with keloids. If undertaken, some say that the incision must be within the lesion boundaries to prevent further extension. In addition, steroids are commonly administered locally. Therefore, the goal would be more to reduce overall size or debulk rather than completely excise.

Secondary, refining procedures may also be used in the areas if desired or needed. It was found in a study of 21 patients (10 male, 11 female; age 17-59 years, mean age 35.52 years; Fitzpatrick skin I-III) that there was good improvement, as rated by both independent assessors and patients, when laser resurfacing was done after punch excision of scars.[38] The noted advantage was that punch excision eliminates the deeper components and allows for only superficial laser treatment with fewer passes. So, if surgery is done, laser resurfacing may also be a

Table III. Procedural management

Cryosurgery
Electrodessication
Radiation treatment
Chemical peels
Microdermabrasion
Dermabrasion

consideration because the chance of unwanted side effects could be reduced. Medical, additional surgical, or other procedural interventions are also available after any surgical management and may be appropriate.

PROCEDURAL MANAGEMENT

Procedures will be addressed distinct from surgeries for the purposes of this article. Initially, several procedural options will be covered within this section (Table III). Then following, although they are technically also procedures, there will be dedicated discussions of augmentation and light, laser, and energy treatments because these topics require more review than some of the others as a result of the diversity within those categories.

Two simple procedural treatment options include cryosurgery and electrodessication. Cryosurgery involves the use of liquid nitrogen spray, or historically solid carbon dioxide, locally. Its use is primarily for hypertrophic scars and keloids, although it is fairly ineffective for the latter. The mechanism is through direct physical damage by thrombosis, cell damage, or other changes. Side effects include possible atrophy or hypopigmentation, which is quite often long lasting or permanent. Electrodessication involves the use of electrical probes or elements that heat the tissues to destruction and coagulation. This is a rarely used technique typically indicated for shaping or reducing the sharp edges of boxcar scars. If used, this is not isolated treatment but usually with adjunctive therapies as well. There are multiple obvious side effects that may arise, most importantly the creation of new scar.

Radiation is another possible intervention also focused on hypertrophic scars and keloids that is available to the physician. Its use is derived from the destruction of fibroblast vasculature, decrease of fibroblast activity, and local cellular apoptosis. It has been found that the regrowth of keloids is proportional to the total dose of irradiation given and that 900 cGy is the minimal effective dose recommended. Initiation of treatment, size of the largest fraction given, fractionation of doses, duration of treatment, or location of lesion are less important.[39] This modality is used more as an adjunct to prevent a recurrence rather than a stand-alone treatment. A Japanese study of 38 keloids (ear, neck, and upper lip) treated with surgical excision and postoperative irradiation on average day 4.0 ± 4.9, with follow-up at a mean of 4.4 ± 2.5 years, showed significant improvement of pigmentation, pliability, height, vascularity, and hardness. Recurrence rate was 21.2% overall with none observed in the craniofacial area. Thus, it was concluded that surgical excision plus electron beam radiation started within a few days is beneficial in both controlling scar quality and preventing recurrence.[40] A controversial risk-to-benefit ratio is sometimes cited as a deterrent to selection of radiation. These risks include hyperpigmentation or hypopigmentation, prolonged erythema, telangiectases, atrophy, and questionable increase in malignancies.

Topically, chemical peels are another prospect for addressing the scarring left from acne lesions. These can be from superficial to deep effect and, unless the very deep peels are used, are generally considered for milder acne scarring and certainly not icepick or keloid scars. Usually multiple treatments are necessary for efficacy, although some secondary benefit is seen with acne lesions in earlier sessions. The expected result is a mild blister and/or desquamation with normal skin regeneration.

Light or superficial peels include alpha hydroxy acid (glycolic, lactic, citric) or beta hydroxy acid (salicylic), Jessner's solution, modified Jessner's solution, resorcinol, and low-strength (concentration $< 10\%$) trichloroacetic acid (TCA). Beta hydroxy acids inhibit the arachidonic pathway and, therefore, decrease inflammation and may be better for sensitive skin. They do not require neutralization and are contraindicated in pregnancy or breast-feeding.[41] If resorcinol is used, awareness of pigmentary changes or direct toxicity must be kept in mind. A Jessner's solution contains salicylic acid, resorcinol, lactic acid, and ethanol. Its primary risk is of hyperpigmentation and to a lesser degree the toxicity of resorcinol. That solution becomes "modified" with the addition of hydroquinone and kojic acid to lower the risk of hyperpigmentation. TCA causes epidermal coagulative necrosis and protein precipitation along with dermal collagen necrosis and regeneration. This mechanism may lead to scarring or pigmentary changes but not as frequently when used at lower concentrations.

The medium-depth peels are primarily considered to be the 10% to 40% TCA solutions. The risks just mentioned increase as the concentration increases. However, used with caution, they may be very beneficial. A study introducing the CROSS (chemical reconstruction of skin scars) method

described the focal application of TCA at high concentrations directly to scars. After 3 to 6 treatments, 90% of patients showed good (50%-70%) improvement by blinded physician assessment. Within the 65% TCA group, 82% were satisfied with results compared with 94% satisfaction in the 100% TCA group. They found the technique to be safe, with the 100% TCA treatments of atrophic scars more effective than the 65% TCA treatments.[42]

The peels considered to be deep are often phenol (carbolic acid) or croton oil based. These can certainly be more effective but carry an even greater potential for side effects including acne, milia, dermatitis, pigmentary alteration, secondary infection, atrophy, or scarring. Both the positive and negative results of the peel are based on the concentration, duration, skin type, prior medical or surgical intervention, location, sun exposure preprocedure and postprocedure, concomitant medications, and other factors. One specific fact of great physician and patient importance is that phenol requires full cardiopulmonary monitoring and intravenous hydration because of direct cardiotoxicity that leads to decreased myocardial contraction and electrical activity.[43]

Two other management options that use a direct mechanical means of skin removal are microdermabrasion and the more invasive dermabrasion. Microdermabrasion is a usually painless, superficial treatment with more texture benefit than permanent surface change. There are variable results seen and multiple sessions are frequently required. The most improvement is achieved with fine wrinkles and postinflammatory hyperpigmentation, although superficial acne scars may benefit from deeper, more aggressive settings. Most often, aluminum oxide crystals used with a pressurized application and vacuum removal system or, sometimes, crystal-free diamond-tipped abrasive devices, are chosen. Occasionally, sodium chloride, sodium bicarbonate, or magnesium oxide crystals are used. Although cheaper, these crystal alternatives are not as abrasive and are less efficacious.[44] Side effects typically include temporary striping of the treatment area, bruising, burning or stinging sensation, photosensitivity, and occasional pain. There is no wounding expected with the force, suction, and speed determining the ultimate depth attained. If using isotretinoin, it is common to wait up to 6 months after the last application to minimize probability of side effects.

Arguably one of the most effective but operator-dependent therapies is dermabrasion. Its benefits include removal of the skin surface and refined contouring of scars. The sharp edges of some acne scars cast a shadow that emphasizes the lesions; contouring reduces these contrasts, lessening their visible impact. Essential removal of superficial scars can be achieved along with a reduction of deeper scars. In addition, it may be used as an adjunct to the surgical procedures as previously mentioned.

Dermabrasion is accomplished by use of a high-speed brush, diamond cylinder, fraise, or manual silicone carbide sandpaper. Superficial treatment eliminates the epidermis and deep treatment removes the epidermis and partial dermis. Once complete, re-epithelialization by migration of cells to the healing surface stems from the adnexal structures including hair follicles, sebaceous glands, and sweat ducts. Thus, neck, chest, and back are not ideally suited for treatment because of paucity of adnexal structures.[45] In addition, in similar fashion, burns and hypertrophic scars, or more commonly keloids, have a poor response because of their lack of adnexa.[46] Meticulous wound care should be emphasized throughout the entire postoperative course. After healing is complete, improvements may continue to be seen for months. If active, inflammatory acne lesions are present these must be controlled with corticosteroids, antibiotics, or retinoids first. If infection or a history of significant scarring is encountered, then treatment should be postponed or avoided. Many practitioners advocate testing for HIV, hepatitis, or other blood-borne diseases prior. Others suggest prophylactic treatment with antibiotics and antivirals.

The aggressiveness of this procedure correlates with its side-effect profile. Included are prolonged erythema and healing time, eczema, milia, bacterial or viral infection, hypertrophic or keloidal scarring, unroofing of unapparent wide-based scars, telangiectases, sun-sensitivity, treatment demarcation lines, and prolonged or permanent hyperpigmentation or hypopigmentation.[47] As always, pigmentary concerns are greater for darker-skinned individuals. Hyperpigmentation typically slowly resolves during several months but initiation of pigmentary return in hypopigmentation begins at approximately 4 to 6 weeks, if at all, with full results at up to 1 year. The procedure is painful so at least local anesthesia or regional blocks plus anxiolytics and anti-inflammatories are used, but often light or occasionally general sedation are chosen.

TISSUE AUGMENTATION

Augmentation is a further alternative for management of acne scarring. This topic includes numerous variations and compositions of filler substances. Those to be addressed may or may not be available in the United States and the list is certainly not comprehensive or detailed for each product mentioned. In addition, some products, such as

Table IV. Tissue augmentation

Xenografts	Autografts	Homografts
Zyderm (bovine)	Autologen (not available)	Dermalogen (not available)
Zyderm II (bovine)	Isolagen (United Kingdom and Australia)	Alloderm
Zyplast (bovine)	Autologous fat	Cymetra
Resoplast (bovine)		Fascian
Endoplast-50 (bovine)		Cosmoderm
Evolence (porcine)		Cosmoplast

Autologen and Dermalogen, are mentioned for historical interest. However, there is an excellent, comprehensive, in-depth review of multiple filling agents published several years ago by Klein[48]; a recent review of non-Food and Drug Administration (FDA)-approved fillers by Ellis and Segall[49]; and a very complete, easy-to-use dermal filler product comparison chart in a separate publication.[50] These alternatives may be xenografts (from a different species), autografts (obtained from the patient), homografts (same-species derived), or synthetics.

An ideal filler material would be physiologic (incorporates into the body's tissues), simple to place (injection), permanent (no degradation), and risk free (no complications or side effects).[51] Potential superficial skin products may include collagen or hyaluronic acid and deep skin products include fat, synthetics, silicone, implants, and permanents. Although close, none available meet all of these criteria completely. Most of these are applicable to depressed scars such as the atrophic rolling variant or sometimes others. Potential side effects may include pain, pigmentary changes, bruising, infection, allergic reaction, hypertrophic scarring or keloids, possible granulomas, bleeding, migration of product, ulceration, tissue death, significant distortion, or technical error on placement. If a permanent substance is chosen and is placed too deep, too shallow, or overcorrected, or if there is a persistent defect, minor surgical removal, excision, electrodessication, or steroid treatment could be required.

The first FDA-approved fillers were collagen based. The reconstituted bovine class of collagen has been available since the late 1970s to early 1980s. However, there are various other derivations. Collagen functions as a physical augmentation medium and a stimulus for scar base formation by connective tissue encapsulation. The placement should focus on mature scars rather than those that are newly created because static, noninflamed scars or those with no ongoing disease demonstrate longer efficacy.[52] Its use is very technique sensitive, which also affects the quality and duration of the treatments. Placement should be superficially in the dermis and not in the subcutaneous tissue. There is fairly rapid degradation so maintenance sessions are necessary. Usually there is a benefit at 3 to greater than 6 months with some accounts of up to several years. Common to all of these products could be discomfort, inflammation, bruising, allergy, erythema, discoloration, and correction defects. Hypertrophic scars, keloids, and icepick scars are not indicated for treatment with this method. In addition, those with autoimmune disease should avoid its use because of the higher risk of sensitization or allergy. Double allergy tests over 4 to 6 weeks are even required for those with normal immune systems because of a delayed hypersensitivity in approximately 3% of the population (2% will sensitize after the first skin test exposure).[53] The following paragraphs go into further depth for a few collagen products and briefly mention multiple others (Tables IV and V).

The first injectable filler approved by the FDA was Zyderm. The other similar products are Zyderm II and Zyplast. These collagen products are derived from a closed US bovine herd. Even though this helps to ensure quality, purity, and safety, its immunologic basis is not effected, therefore, skin tests are still required.[44] Type I collagen represents 95% to 99% and type III collagen represents 1% to 5% of the product contained in prefilled syringes. Zyderm I was approved in 1981. It is a 25% suspension (3.5% by weight) of collagen in saline and lidocaine solution. It is usually for shallow scars, so is placed in the papillary dermis. Overcorrection is initially required because of water loss after placement. Two to 3 months of result are typically expected. Zyderm II gained approval in 1983. It is a 50% suspension (6.5% by weight) of collagen. Larger scars are more often addressed with this variant. Overcorrection is again recommended and 4 to 6 months of effect can be expected. Zyplast, approved in 1985, is a 35-mg/mL solution of collagen cross-linked with 0.0075% glutaraldehyde to slow reabsorption. Injection into the mid dermis allows for contouring and larger scar treatment. Overcorrection is not required and its duration of effect may be up to 1 year.

ArteFill or Artecoll are 20-volume percent suspensions of 30 to 50 μm—diameter microspheres of polymethyl-methacrylate (also known as Plexiglas or

Lucite) in atelocollagen (3.5% collagen solution), saline, and lidocaine.[54] ArteFill (US) is the same composition as Artecoll (Europe and Canada) but the spheres are somewhat smaller and more symmetrical. Polymethyl-methacrylate is used in bone cements for joint replacements, cataracts surgeries, dental procedures, and neurosurgical applications. The polymethyl-methacrylate is permanently deposited and encapsulated with fibrous tissue after injection while the remaining collagen is gradually resorbed.[55] Both serve physical augmentation and scar stimulus functions. As noted above, skin testing is required because it is from a bovine source. There may be initial inflammation, erythema, bruising, and discomfort from the injection of these products. A 2006 article reporting 4- to 5-year outcomes with ArteFill used as a filler for wrinkle lines evaluated its safety and length of effect. Of the 128 patients who received the product (of 251 total patients in the initial study), a subgroup of 69 were reassessed. There were 6 adverse events noted within 5 patients treated with 272 injections. Four (1.5%) were mild (lumpiness) and two (0.7%) were severe (nodular, minimal to noninflammatory reactions in the nasolabial folds bilaterally). These severe events were treated with intralesional steroid injections and were resolving as the article was being published. In addition, somewhat surprisingly, it was noted in the other patients that the results actually appeared better at 5 years than at 3 months to 1 year. It was concluded that ArteFill was relatively free from side effects and was an efficacious material that demonstrated good long-term persistence and safety.[56]

An initial harvest of the patient's skin was required to produce Autologen (a product no longer available). Injectable product (1 mL) was obtained from 2 sq in of tissue. The autologous human collagen fibers were sterilized and then provided as an injectable 4% or 6% suspension. Several injections were required and overcorrection had to be achieved because there was approximately 20% to 30% volume loss after injection from fluid reabsorption.[57] Dermalogen, also unavailable, was similar to Autologen but it was allogenic, sterilized, primarily intact collagen fibers obtained from tissue-banked skin. It was screened for viral, bacterial, fungal, and prion presence. In addition, skin tests were not required before use. Several injections of the 3.5% solution were required over time and overcorrection should have been done with each administration. A duration of benefit around 3 to 6 months was regularly achieved.[58]

Introduced in 1992, Alloderm is an allogenic human collagen acellular graft derived from tissue-banked skin. It must be implanted by incision rather

Table V. Tissue augmentation

	Synthetics						
PMMA	**Silicone**	**Hyaluronic acid**	**Polylactic acid**	**Polyacrylamides**	**Polyoxyethylene/ polyoxypropylene polymer**	**Epsilon-aminocaproic acid (plus porcine gelatin, patient plasma)**	**Calcium hydroxyapatite**
ArteFill (plus bovine collagen)	Adatosil	Hylaform	Newfill	Outline	Profill	Fibrel	Radiesse
Artecoll (plus bovine collagen)	Silikon 1000	Hylaform Plus	Sculptra	Evolution			
	Biopolimero	Restylane		Bio-Alacamid			
	Silskin	Restylane Fine Lines		Agriform			
	Polydimethylsiloxane gel	Perlane		Aquamid			
		Captique					
		Juvederm					
		Dermalive (plus 40% acrylate)					
		Dermadeep (plus 40% acrylate)					
		Teosyl					
		Reviderm Intra (plus dextran)					

PMMA, Polymethyl-methacrylate.

than injected so only a limited number of acne scars may benefit from its use. There is no skin testing required and there is possible longer benefit as a result of the method of placement. Cymetra is a micronized, injectable from of Alloderm. It is allogenic acellular human collagen obtained from screened, standardized US skin and tissue banks. It is a dried product that requires resuspension before use. Again, no skin testing is necessary before injection but multiple injections over time and overcorrection are both advised.[59]

Isolagen, available in the United Kingdom and Australia, is an autologous isolation of fibroblasts obtained by a punch biopsy specimen from the patient. The tissue is sent to a laboratory where the company cultures the fibroblasts and then places them in an injectable suspension. That product is returned to the clinician for use within 1 day of receipt. There are few side effects because it is autologous, however, the company does still suggest skin testing for this product. This is another substance that loses volume initially so more than one injection with overcorrection is usually standard.

An available bovine collagen in 3.5% or 6.5% solution is Resoplast. Because of its derivation, a skin test is required before use. Endoplast-50 consists of solubilized elastin peptides in bovine collagen. Fascian was introduced in 1998 as allogenic human cadaver collagen from fascia lata or gastrocnemius fascia. There are 5 particle sizes: 0.1, 0.25, 0.5, 1.0, and 2.0 mm. Neocollagenesis from the ingrowth of fibroblasts occurs after injection of the product.[60] Cosmoderm was created in 2003 as a human-derived collagen produced under laboratory conditions with extensive safety testing. On completion, it is mixed into a solution of lidocaine for injection. No skin testing is required and 3 to 7 months of benefit can be expected. Cosmoplast is yet another laboratory-created human-derived collagen. It is also put into a lidocaine solution for use and does not require skin tests. This product, however, is cross-linked with glutaraldehyde to resist degradation and hopefully prolong effect.[61] A newer, porcine-derived product is Evolence. It contains ribose moieties that are cross-linked to the collagen. No skin testing is necessary and refrigeration of the injectable is not needed. There may be up to 1 year of effect after placement.[62]

Autologous fat is another alternative for augmentation, first noted in 1893, to improve acne scars. These cells are obtained from the patient's own body so must be harvested by liposuction or other methods. Injection is into the subcutaneous area, although some suggest dermal application is acceptable as well. It is good for contour defects but overcorrection must be done because a percentage of the injected material is initially or permanently nonviable. The reabsorption rate varies by location, amount injected, technique, or other factors. Variable reports of 6 to 18 months' duration may be seen. One study of autologous fat transplantation included 43 patients (24 women, 19 men; age 22-69 years, mean 34.5 years), 23 specifically with acne scars, with 3- to 48-month (mean 26 months) follow-up to evaluate graft survival. It found that the greatest resorption was in areas of fibrotic acne scars and 65% remained at 3 months, 50% at 6 months, 40% at 9 months, and 30% at 12 months. The authors suggested that this was possibly because of decreased vascularity and, thus, viability.[63] It has also been reported that including adipose-derived stem cells with the injected fat improves results. At 6 months, fat with the stem cells weighed 2.5 times more than the fat-only group and demonstrated a greater volume. In addition, the stem cell—free grafts appeared more fibrous at 6 months as compared with the adipocytes rich—appearing grafts.[64] This finding may improve long-term results or lead to other valuable research. The benefit is direct augmentation from the adipocytes if they are vascularized and can function normally or, some propose, from their contribution to fibrosis and physical enhancement of the area. As stated, several sessions are required and bruising, erythema, or mild inflammation may occur with a report of unilateral blindness as a result of intravascular injection even noted. Excess fat may be frozen for later use and there are no immunologic concerns because it comes from the patient.

"Silicone," a term consisting of polymers in the family of the element silicon, most commonly polydimethylsiloxane (silicon, oxygen, methane), is a permanent injectable. It is safe, nonmutagenic, noncarcinogenic, and nonteratogenic despite scattered case reports of adverse events. The mechanism of action is from physical filling of connective tissue defects and possible production of fibrotic collagen that encapsulates the injected material (a foreign body) preventing migration. Final results could take months while the collagen is deposited and remodels. In addition, it is not altered, metabolized, or destroyed by the human body. Considering all of these facts, undercorrection is often prudent initially. Side effects, including injection pain, mild inflammation, edema, hyperpigmentation or hypopigmentation, and poor placement, are possible but can be reduced with meticulous detail. Silicone is not a growth media for bacteria or other organisms and no true allergies have been reported, so skin tests are not required before use.

With any mention of silicone, there will always be those concerned with safety and who argue against its use. There has been controversy about the safety profile but a meta-analysis based on 7 studies performed in 1996 by Hochberg and Perlmutter[65] did not reveal any significant relationship between silicone (specifically associated with augmentation mammaplasty) and the development of connective tissue diseases, including systemic sclerosis. Another study that reviewed 524 patients receiving 422.5 mL of silicone through 4756 treatments over 20 years only discovered 4 symptom reports or adverse events. One was "signs and symptoms of infection," another developed 1- × 1.5-mm papules 1 cm remote from the injection site without evidence of silicone on histopathology (reported as "hyperkeratosis"), a third had "erythema," and the final was a symptom of "doughnutting" that required shave excision, resulting in localized infection.[66] In fact, Barnett and Barnett[67] discussed silicone use in relation to acne scarring and provided examples of 5 patients with follow-up up to 30 years posttreatment that demonstrated its efficacy along with its safety and permanence.

There are several silicone products that are available, with the usual difference based on viscosity. The original silicone was 350-centistoke viscosity. Adatosil 5000 is medical-grade silicone of 5000-centistoke viscosity and Silikon 1000 is of 1000-centistoke viscosity. Polydimethylsiloxane gel is a silicone oil with viscosities from 350 to 5000 centistokes and another is Silskin. One that is slightly different from these is Bioplastique. It consists of solid silicone particles (100-400 and 600 μm) suspended in polyvinylpyrrolidone gel. There is gradual replacement of the gel with fibrous tissue and native collagen.

Another valuable injectable filler material for acne scars is hyaluronic acid. This substance is a highly hydrophilic, natural, linear polysaccharide (alternating residues of d-glucuronic acid and n-acetyl-d-glucosamine) component of connective tissue in all mammals so is not tissue or species specific.[68] Hyaluronic acids do not require the initial overcorrection as collagen does because there is less water loss after injection. In addition, it displays isovolemic degradation in which molecules of HA degrade allowing those remaining to absorb more water. Thus, the total volume of gel remains stable. The injectable concentration steadily decreases through reabsorption while the relative volume is essentially unchanged.[69] The duration of effect for acne scars is roughly a year or more. Side effects potentially include erythema, edema, bruising, inflammation, delayed reactions, infection, pain, milia or acne, and rare reports of necrosis (most likely technique related).[70] There is very low true allergic potential so skin testing is not required although some physicians prefer to do so.

Developed in the 1980s, Hylaform and Hylaform Plus are hyaluronic acid products derived from rooster comb and cross-linked with divinyl sulfone. Hylaform Plus has larger particle sizes. A series of injections into the dermis are required and there are few adverse events, side effects, or allergies.[71] Restylane (with Restylane Fine Lines and Perlane), approved in 2003, is a hyaluronic acid (HA) derived from production by *Streptococcus equi*. All are 20 mg/mL of HA but differ in the particle size and viscosity. Restylane Fine Lines has 200,000 gel particles/mL with the smallest particles, in comparison with Restylane, which has 100,000 gel particles/mL. Perlane has the largest particles and has a concentration of 8 to 10,000 gel particles/mL. Restylane Fine Lines is the least viscous and Perlane is the most viscous and is for deeper injection.[72] Captique was introduced in 2004 and is derived from bacterial sources. It is for dermal injection as well. The family of Juvederm products was FDA approved in 2006. They are all derived from *S equi* and cross-linked with 1,4-butane-diol-diglycidyl ether. Inflammation, erythema, papules, pustules, flushing, and swelling have all been reported but less so than with other hyaluronic acids.[73] Dermalive is a 60% hyaluronic acid plus 40% acrylate suspension of 45 to 65 μm, irregularly shaped hydroxyethyl methacrylate and ethyl methacrylate particles. Injections are to be done every 3 months to desired effect with approximately 40% retention of each treatment. No skin testing is required prior. Dermadeep is the same composition as Dermalive but the acrylate crystals are larger, 80 to 110 μm. Teosyl contains hyaluronic acid microspheres at 15- to 25-mg/mL concentration.

Polyacrylamides compose yet another form of injectable augmentation products and, once again, several products exist. Outline is composed of absorbable hydrophilic polyacrylamide gel particles that are positively charged, thus attracting negatively charged glycosaminoglycans already in the skin such as hyaluronic acid. Similarly, Evolution, positively charged polyvinyl microspheres in hydrophilic gel, also attracts the negatively charged molecules. Bio-Alcamid is a polyalkylimide gel that is 96% water and 4% synthetic polymer that stimulates a fibrous response after injection. Agriform is a 5% water and 95% hydrophilic polyacrylamide gel combination, in contrast to Aquamid, a 97.5% water and 2.5% hydrophilic polyacrylamide gel mixture.

The polylactic acids are a more recent addition to the treatment options available for injection to scars.

Table VI. Laser, light, and energy

Ablative lasers	Nonablative lasers	Light and energy
Carbon-dioxide	532-nm KTP	Intense pulsed light
Er:YAG	510/585-nm Pulsed dye	Radiofrequency
Fractionated (also nonablative)	1064/1320-nm Nd:YAG	Plasma
	1450-nm Diode	
	1540 Er:glass	

Er, Erbium; *KTP*, potassium-titanylphosphate; *Nd*, neodymium; *YAG*, yttrium-aluminum-garnet.

Previously, these materials were used in suture materials and other treatments. NewFill, the primary brand for Europe, was available in 1999, as freeze-dried polylactic acid available for reconstitution with water. Poly-L-lactic acid was rebranded in the United States in 2000 as Sculptra.[74] A frequent use, other than scars, is in lipoatrophy because of HIV. It is thought to stimulate neocollagenesis over 3 to 6 months and is for long-term augmentation. Side effects are possibly worsened by excess injection material, inadequate duration between injections, or multiple single-session injections. No skin tests are necessary with the use of polylactic acids.

Other substances are constantly being created or tried for use in augmentation of scars. It is impossible to include each one and address them with the attention they deserve. Only 4 other products will be briefly mentioned. However, others exist that can be researched at the reader's option (eg, Gore-Tex or SoftFoam that are typically reserved for facial implantation but can used for acne scarring reconstruction). Radiesse contains 25 to 45 μm—diameter calcium hydroxyapatite microspheres in polysaccharide (carboxymethylcellulose) aqueous gel. It is categorized as "semi-permanent" with earlier claimed durations of 2 to 5 years, but more recent estimates of a year to 16 months. There is little inflammation or side-effect profile and no allergy testing is required. Reviderm Intra consists of 40- to 60-μm Sephadex (dextran) beads suspended in bacterial-derived hyaluronic acid. It stimulates inflammation and neocollagenesis. ProFill is a polyoxyethylene and polyoxypropylene polymer forming an injectable gel that must be refrigerated as a liquid until used. Skin testing is not necessary. Fibrel is patient plasma that is mixed with porcine gelatin plus epsilon-aminocaproic acid and lidocaine. It serves as a physical filler and a media for neocollagenesis. This product requires a patient blood draw and may be more painful on injection or lead to a local inflammatory response.

Light, laser, and energy therapy

The concept of selective photothermolysis bases treatment on the wavelengths of various chromophores, notably water, hemoglobin, and melanin. In 1983, Anderson and Parrish[75] authored a study outlining selective photothermolysis. They noted that "selectively brief pulses of selectively absorbed optical radiation can cause selective damage to pigmented structures, cells, and organelles in vivo. Precise aiming is unnecessary in this unique form of radiation injury because inherent optical and thermal properties provide target selectivity." Two key concepts are, first, "in choosing the laser wavelength for selective photothermolysis is to maximize selective optical absorption in the desired targets" and, next, that "the transition from specific to nonspecific thermal damage occurs as the laser exposure duration (pulse width) equals and then exceeds the thermal relaxation time."[75] This established principle is used in all of the following laser or wavelength-based treatments. Again, this is not an all-inclusive discussion and does not cover the nuances of variation between different companies' products or all of the positives and negatives of a particular device, because that can be researched elsewhere if desired. However, each of the ablative or nonablative methods discussed (Table VI) includes key points with an attempt to include at least one fairly recent reference to its use.

The first category will include those methods of ablative skin resurfacing: carbon-dioxide laser, erbium:yttrium-aluminum-garnet (Er:YAG) laser, and fractionated lasers. The carbon-dioxide laser has a wavelength of 10,600 nm as its target chromophore is extracellular and intracellular water. This treatment is more aggressive and deeper than a chemical peel but remains at a specific depth of 20 to 30 μm with thermal damage of 50 to 150 μm. It is usually bloodless but still achieves total ablation of the epidermis and a portion of the dermis. In addition to the destructive nature, there may also be stimulation of collagen by the procedure. The usefulness is primarily for hypertrophic scars, boxcar scars (preferably shallow), and, less effectively, keloids. There are some who achieve fairly quick results, visible as soon as 2 weeks, but improvement because of the wound-healing phases continues for at least 18 months. Walia and Alster[76] studied 60 patients (50 women, 10 men; age 18-53 years, mean age 38 years; Fitzpatrick I-V) after treatment with the carbon-dioxide laser. The average improvement was 69% at 1 month, 67% at 6 months (the decrease was attributed to resolution of edema with the temporary revisualization of some lesions), 73% at 12 months, and 75% at 18 months. Neocollagenesis and

remodeling were persistent up to the 18-month period of observation. It is not usually necessary to repeat the procedure but the visible recovery time is prolonged, often 1 to 3 months or more. Other side effects could be protracted visible healing, prolonged erythema, eczema, hyperpigmentation or hypopigmentation, milia, acne, cysts, infection, telangiectases, or additional scarring.

The Er:YAG laser is a more gentle ablative therapy than the carbon-dioxide laser. Its targeted chromophore is also water but there is 16 times more energy absorption. There is more superficial penetration, which leads to less collateral damage and more rapid healing but that also makes it less efficacious for dermal remodeling and collagen stimulation. Again, this may be of benefit for hypertrophic scars, rarely keloids, and shallower boxcar scars. There are available short-, variable-, and dual-pulsed modes. Each of these was evaluated in a study of 158 patients (70 male, 88 female; age 18-46 years, average age 26.4 years; Fitzpatrick III-V) with icepick, rolling, and shallow or deep boxcar scars. In all, 83 were treated with short-pulsed Er:YAG, 35 were treated with variable-pulsed Er:YAG, and 40 were treated with dual-mode Er:YAG. All 3 modes resulted in good to excellent results for icepick and shallow boxcar scars. Rolling scars achieved good to excellent results only with dual-mode treatment. The best result for deep boxcar scars was rated as good and was also after treatment with the dual-mode laser. The authors reasoned that the rolling and deep boxcar scars required "a long-pulse duration for a thermal effect" for successful treatment.[77] Potential side effects again may include delayed healing, erythema, milia, acne, edema, hyperpigmentation or hypopigmentation, infection, or scarring but equal or less so than with the carbon-dioxide laser. A comparison study of postoperative healing and short- and long-term side effects was done between the carbon-dioxide laser and the Er:YAG laser. This retrospective review was of 50 consecutive patients (49 female, 1 male; mean age 51 years; Fitzpatrick I-V) treated with single pass carbon-dioxide resurfacing and 50 consecutive patients (47 female, 3 male; mean age 47 years; Fitzpatrick I-V) treated with multiple pass, long-pulsed Er:YAG resurfacing. The average time to reepithelialization, postoperative erythema, hyperpigmentation, acne, milia, superficial bacterial infection, and patient satisfaction were all similar. There were no occurrences of hypopigmentation or scarring. The conclusion was that these two procedures were of comparable postoperative period and complication profile.[78]

A newer concept, fractional photothermolysis, introduced and discussed in 2004,[79] may be a very important development for use in the improvement of acne scarring. Fractional photothermolysis ablates tissue and stimulates collagen remodeling and neocollagenesis in a columnar fashion leaving surrounding rings of viable tissue, sparing the noninvolved, intertreatment epidermal and dermal regions. As its value and potential are being realized, there are new fractionated devices being developed and tested constantly. One study used a 1550-nm erbium-doped fractional laser to create microscopic thermal zones as described above on facial skin with mild to moderate atrophic acne scars. In all, 53 patients (39 women, 14 men; age 19-78 years, mean age 39.6 years; Fitzpatrick I-V) were treated with several sessions. Blinded assessments of photographs revealed 91% to have 25% to 50% improvement after a single treatment whereas 87% of patients undergoing 3 treatments had 51% to 75% improvement. Age, sex, and skin type did not alter the outcome. At the 6-month follow-up, the results were maintained.[80] Chiu and Kridel[81] note that energy levels of 25 to 40 mJ are chosen for deeper skin lesions that include scars such as those from acne. It is discussed that those authors' most impressive results have included those with deep acne scarring and they summarize that fractional technology "represents a particularly useful modality for difficult-to-treat conditions, such as melasma and acne scarring."[81] There are similar side-effect concerns as other ablatives but there tend to be less problems overall because of the selective sparing of skin rather than total ablation.[82] There is still the possibility for transient erythema or edema, dryness, scabbing, milia or acne, hyperpigmentation or hypopigmentation, prolonged healing, or infection. As with other aggressive or ablative procedures, isotretinoin is often stopped 6 to 12 months before treatment and the retinoids, glycolics, or other acids are stopped 2 weeks prior. Fractionated technology may be one of the groundbreaking developments for the treatment of acne scarring and future studies using this mechanism should be eagerly anticipated and studied.

The second category consists of the nonablative therapies, which include multiple wavelength lasers, pulsed light, and other forms of energy delivery. Because these modalities are less aggressive as a whole, they are more useful for atrophic, rolling, or possibly hypertrophic scars rather than icepick, boxcar, or keloid scars. The morphology of the scar seems to be more predictive of results than the extent or amount. In addition, these therapies are more often used with darker skin types because ablative management tends to have a higher risk of pigmentary alterations.[83] In general, there is selective thermal stimulation of dermal collagen to increase local

proliferation while the epidermis is spared, although cooling is often required to ensure superficial protection.

The first to mention is the 532-nm KTP laser, which is safe and effective for improvement of acne[84] (more so than scar treatment), thus aiding in prevention of acne sequelae such as scarring. The optimal nonablative laser to use for hypertrophic scars or keloids is the 585-nm pulsed dye laser (PDL). Best results and least side effects are obtained on Fitzpatrick skin types I or II because of less competition with melanin.[16] This laser focuses on erythema and vascularity so incidental scar improvement is possibly because of decreasing vascularity (the scars are hyperemic because of angiogenesis) and its associated secondary effects in the local field or other cellular alterations, specifically regarding collagen. Improvement after use can be seen up to a year later. One study of 15 patients with erythematous, hypertrophic scars treated with 510- or 585-nm PDL with the objective of observing pigmentation and/or erythema improvement found incidental improvement in scar texture and elevation. It was suggested that this was most likely a result of the above explanation, which leads to decreased perfusion and nutrition with resultant anoxia, cell death, and enzymatic changes.[85] However, the discussion after that article does not completely concur, noting some shortcomings of the article, such as the improvement seen in younger scars that would potentially improve as part of the natural maturation process. The author of that discussion performed her own study, using optical profilometry, to evaluate the 585-nm PDL when used for previous argon laser—treated port wine stains. It was found that there was improvement of hypertrophic and atrophic scar regions as exhibited by flattening and reappearance of skin markings, respectively. The article went on to reason that part of the improvement could possibly be attributed to eradication of enlarged blood vessels trapped within the sclerotic collagen.[86] So, to this author, it does seem plausible that, within scars, both the laser's primary effect on vasculature and the proposed, secondary effect on collagen (because of the nutrition changes and/or heat generation) both have benefit.

The 1064-nm neodymium:YAG (Nd:YAG) laser demonstrates low pigment effect with higher vascular effect causing hemostasis and resultant infarctions within vessels. It could have effect similar to those just discussed for PDLs used on hypertrophic scars or keloids. One small observational study using short-pulsed 1064-nm Nd:YAG lasers showed improvement in 100% of subjects' scars. Nine patients completed the study of 10 initially enrolled (7 male, 3 female; 15-48 years, mean age 32 years; Fitzpatrick I-V; mild to severe scarring). There were 8 total treatments, each given 2 weeks apart. Physician assessment was performed 1 to 2 months after the final treatment and graded as 29.36% average improvement. Self-assessment revealed 8 of 9 patients thought improvement was 10% to 50%, whereas one patient noted that they were less than 10% better. However, all reported that they were satisfied with the results and would undergo the same treatment again.[87] Recent studies have evaluated the effectiveness for atrophic scars as well. For example, 12 subjects (age 18-36 years, average age 27.6 years; Fitzpatrick II-V) with mild to moderate atrophic acne were treated with the 1064-nm Nd:YAG laser every 4 to 6 weeks over 8 months to total 5 sessions. Patients reported continual improvement on satisfaction surveys through the treatments. On completion, the mean satisfaction score was 8.6 of 10, with one patient reporting a grade of 6. Photographs evaluated by independent dermatologists revealed mild to moderate improvement for all patients (with one patient being graded by one physician only as no improvement). Histology revealed a statistically significant increase in dermal collagen.[88]

A minimal melanin absorption spectrum and deep papillary and midreticular dermal treatment is achieved with the 1320-nm Nd:YAG laser. For 12 patients (10 female, 2 male; 35-59 years, mean age 50 years; Fitzpatrick I-III) with mixed scars, photographs and nontreating physician and patient clinical evaluations at baseline and at 6 months after the last treatment were performed using the 10-point scale of Jacob et al.[20] The acne scars were rated as more severe by the subjects than by the physicians at all intervals. Those with a predominance of atrophic scars, defined as greater than 90% of scars present, improved the most with mixed scars next. The trend was not found to be statistically significant. Physicians noted improvement in 100% of the subjects whereas only 67% of subjects believed they had seen improvement themselves. None of those involved reported a worsening of appearance or complications.[89]

Another laser variant is the 1450-nm diode. One small study evaluating its effectiveness, primarily as an acne treatment, showed improvement in acne scarring in 83% (of 6 who initially presented with scarring, 5 improved; 9 of 11 finished the study proper) of subjects. A split-face bilaterally paired treatment design was used with one half of the face receiving a single pass that was double-stacked and the other a double pass of single pulses. Mean acne scar improvement on a scale of 0 to 3 was ranked as a 1 and there was no difference between the two treatment protocols.[90] Even if only an acne treatment,

this may carry importance as a measure for scar prevention. Further evaluation will be needed to evaluate this laser specifically for scar treatment.

Efficient absorption is seen by water but minimally by melanin when using the 1540 Er:glass laser. The primary depth is within the papillary dermis where collagen tightening and neocollagenesis are achieved. A review of several articles noted progressive improvement and long-term benefit after treatment with this modality.[91] It states that outcomes are often gradual with increased dermal collagen seen in approximately 6 months after 4 successive treatments and continued improvement occurs several months after the session. The following included commentary on the study points out that typical responders show 20% to 30% improvement. Although less than some other interventions, this may be an acceptable goal for some patients.

The next few therapies are not true lasers by definition but are more reliant on different energy forms to achieve their effect. The first is intense pulsed light (IPL). These machines emit a wide range of wavelengths from their source that can be precisely narrowed using wavelength filters. Other parameters such as pulse length, pulse delay, and joules can be adjusted also. All of these options, in combination, allow for tailoring therapy to a defined goal. One study done by Goldberg,[92] focusing on rhytides, examined 5 women (age 40-55 years and Fitzpatrick I-II). Punch biopsy specimens before intervention and 6 months after treatment with 4 IPL sessions were examined by an independent dermatopathologist. These biopsy specimens revealed an increase in superficial papillary dermal fibrosis and evidence of increased numbers of fibroblasts throughout the dermis. Both of these findings prove beneficial for superficial acne scarring and the rhytides studied. In comparison with atrophic or depressed scar benefit, some studies note the efficacy of IPL for reducing hypertrophic scars. One evaluated hypertrophic scars of 6 to 8 weeks' duration on 20 patients (all female; 10 breast reduction, 10 abdominoplasty) after treatment with either 595-nm PDL or IPL. Two treatments with each device were performed 2 months apart for designated halves of the same scar of each patient. Single, nontreating physician assessment of the results was then done. Both sides were found to be significantly improved with the difference in effectiveness not statistically significant. The mean scar improvement for IPL was 45% after the first treatment and 65% after the second. The authors attribute this to targeted treatment of the vascular proliferation within the scars. They conclude "IPL offers a therapeutic alternative to the gold standard PDL [for the treatment of hypertrophic scars] since it minimizes the development of posttreatment purpura, although the tradeoff is greater discomfort."[93] The discussion of effect on vasculature is similar to that already covered above for the PDL. Of course, it would be necessary to corroborate these findings to facial scars to determine the benefit in that setting.

Radiofrequency devices are another possible option for improving scars through stimulation of remodeling. A monopolar device uses a single contact location for the area of origin of the electric current. That current then diminishes as it flows to a remote grounding pad. A bipolar device has two local electrodes so there is not a path of current through the body.[94] Physicians are able to treat variable skin types because this is electric energy use and not a chromophore-based intervention. It leads to tissue tightening and skin appearance improvement through dermal collagen denaturation with subsequent neocollagenesis and remodeling without the ablation and invasion of other treatments. One study investigating the use of nonablative radiofrequency for the treatment of moderate to severe acne (scar preventative treatment) noted, as an incidental result, that there was qualitative improvement in underlying scarring.[95] Still, large studies that evaluate treatment of acne scarring with this technology need to be performed.

A newer form of energy treatment used in skin remodeling is plasma. Plasma pulses are created by passing ultrahigh radiofrequency energy through inert nitrogen gas, leading to stripping of electrons and formation of the ionized gas. The energy is then directed to the patient's skin surface by the handpiece. No specific chromophore is targeted but the energy causes dermal collagen denaturation and stimulates neocollagenesis with minimal side effects. A short discussion of the technology involved can be reviewed if wished.[96] A presentation at the American Society for Laser Medicine and Surgery meeting included 11 patients (1 male, 10 female; Fitzpatrick I-II; 4 with fine-line wrinkles, 8 with acne scarring, one patient had both wrinkles and scarring) treated with the plasma device. Acne scarring showed a 34% reduction in depth at 10 days, 26% at 3 months, 23% at 6 months, and no significant change in findings between 6 months and 2 years. There was no itchiness, weeping, exudates, lumpiness, pain, scarring, or hyperpigmentation or hypopigmentation recorded. The greatest reepithelialization time was 5 days and the most persistent erythema resolved by day 6. This article, although limited, concluded that plasma resurfacing was an effective long-term option with minimal side-effect profile.[97]

Conclusion

Scarring is an unfortunate complication of acne vulgaris in the general population. To adequately manage this occurrence, one should understand the underlying cause so that attempts at prevention can be effectively implemented. However, if pre-emptive intervention is not effective or the patient presents after the lesions are already established, then knowledge of proper treatment options is essential. There are multiple options that can be tailored to each individual's needs, tolerance, and goals along with the physician's assessments, skills, and expectations. Medical, surgical, and procedural options are all historically proven and often modified methods to consider. More contemporary options include fillers and laser or energy-derived therapies that are constantly being introduced and currently being tested. Whatever the choice, it should be clearly understood by both physician and patient that, at present, improvement of acne scarring, rather than total cure, is the probability.

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Appendix. Manufacturers of brand name drugs mentioned in this article*

Product	Company	Location
Zyderm	Allergan/Inamed	Irvine, CA
Zyderm II	Allergan/Inamed	Irvine, CA
Zyplast	Allergan/Inamed	Irvine, CA
Resoplast	Rofil Medical Intl	Breda, North Brabant, The Netherlands
Endoplast-50	Laboratories Filorgra	Paris, France
Evolence	ColBar LifeScience, Ltd	Herzliya, Israel
Isologen	Isologen, Inc	Exton, Pa
Alloderm	Lifecell Corporation	Branchburg, NJ
Cymetra	Lifecell Corporation	Branchburg, NJ
Fascian	Fascia Biosystems, LLC	Beverly Hills, CA
Cosmoderm	Allergan/Inamed	Irvine, CA
Cosmoplast	Allergan/Inamed	Irvine, CA
Artefill	Artes Medical	San Diego, CA
Artecoll	Rofil Medical Intl	Breda, North Brabant, The Netherlands
Profill	Laboratories Filorga	Paris, France
Fibrel	Mentor	Santa Barbara, CA
Adatosil	Bausch & Lomb Surgical	Rochester, NY
Silskin	RJ Development	Chester, MO
Silikon 1000	Alcon Laboratories, Inc	Fort Worth, TX
Bioplastique	Uroplasty BV	Geleen, The Netherlands
Hylaform	Genzyme	Cambridge, MA
Hylaform Plus	Genzyme	Cambridge, MA
Restylane	Medicis	Scottsdale, AZ
Restylane Fine Lines	Medicis	Scottsdale, AZ
Perlane	Medicis	Scottsdale, AZ
Captique	Genzyme	Cambridge, MA
Juvederm	Allergan/Inamed	Irvine, CA
Dermalive	Dermatech	Paris, France
Dermadeep	Dermatech	Paris, France
Teosyl	Teoxane SA	Geneva, Switzerland
Reviderm Intra	Rofil Medical Intl/Philoderm	Breda, North Brabant, The Netherlands
Newfill	Dermik/Aventis	Bridgewater, NJ
Sculptra	Dermik/Aventis	Bridgewater, NJ
Gore-Tex	WL Gore & Assoc Medical	Flagstaff, AZ
SoftFoam	Johnson & Johnson Medical	Langhorne, PA
Radiesse	BioForm Medical	San Mateo, CA
Outline	ProCytech SA	Bordeaux, France
Evolution	ProCytech SA	Bordeaux, France
Bio-Alcamid	Polymekon	Brindisi, Italy
Agriform	Bioform	Moscow, Russia
Aquamid	Ferrosan A/S	Soeborg, Denmark

*Listed in order of mention in article.