

REVIEW

The Use of Chemical Reconstruction of Skin Scars (CROSS) Method With Trichloroacetic Acid (TCA) for Atrophic Scars: A Comprehensive Review on Application Techniques, Adjunct Therapies, and Complications

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BACKGROUND: Atrophic scars have a significant psychosocial and functional impact on quality of life. Chemical reconstruction of skin scars (CROSS) using trichloroacetic acid (TCA) has emerged as an effective procedure for targeted treatment of atrophic scars, yet application methods and efficacy vary across scar types and patient populations. **OBJECTIVE:** To evaluate the methodology, indications, efficacy, and safety profile of the TCA CROSS technique in atrophic scarring and to compare TCA CROSS outcomes to other therapeutic modalities and assesses its adjunctive use. **METHODS:** A PubMed literature search was performed for clinical studies evaluating TCA application in scar management; inclusion criteria focused on studies using the CROSS technique published after 2002. Two reviewers independently screened 133 results: 34 publications (20 clinical trials, 4 comparative/cohort studies, 4 case series, 2 case reports, and 4 expert opinions) met eligibility criteria. **RESULTS:** In total, 937 patients (predominantly female, aged 4–65 years, Fitzpatrick skin types I–V) were included. TCA CROSS was primarily used for ice pick and boxcar acne scars, but it was also used for varicella and leishmaniasis scars. Application techniques varied, with fine-gauge needles and paintbrushes enabling more precise delivery. Multiple sessions yielded greater improvement, and higher TCA concentrations increased the risk of complications. Patient satisfaction was generally high, with improvement rates of 50% to 80%. The most common adverse events were transient postinflammatory pigmentary changes. **CONCLUSION:** TCA CROSS is a safe, effective option for treating atrophic scars. Methodical application and multimodality approaches optimize patient outcomes; further research should address technique standardization and efficacy across diverse skin types. **KEYWORDS:** Trichloroacetic acid, TCA, CROSS, atrophic, scar, cosmetic dermatology, adjunct therapy

Atrophic scarring can be a sequela of multiple different dermatologic conditions, most commonly acne vulgaris, and can cause significant impacts on quality of life.¹ The pathogenesis of atrophic scarring is driven by dysregulated wound healing, persistent inflammation, and aberrant fibroblast activity, leading to flawed collagen synthesis and tissue contraction.² This pathogenic process results in dermal depressions from insufficient collagen deposition.² Atrophic scars can be categorized based on their appearance through the Jacob et al³ classification system for atrophic acne scars. There are 3 types of atrophic acne scars: ice pick, rolling, and boxcar scars. Atrophic scars are associated with substantial psychosocial distress, diminished quality of life, and functional impairment, necessitating effective and individualized treatment strategies.^{4,5}

The therapeutic landscape for atrophic scarring has evolved considerably, with evidence supporting the efficacy of ablative and nonablative fractional laser, microneedling, platelet-rich plasma (PRP), dermal fillers, subcision, and chemical peels, either as monotherapies or in combination.⁵ Among these modalities, the trichloroacetic acid (TCA) chemical reconstruction of

skin scars (CROSS) technique has emerged as an effective treatment option for ice pick and boxcar scars. TCA CROSS causes focal chemical injury to the dermal tissue at the base and walls of scars, which stimulates new collagen synthesis and dermal remodeling through fibroblast activation.⁶ This subsequently results in gradual elevation of the scar base, reducing scar depth with improvement in texture and appearance over multiple sessions.

In recent years, the TCA CROSS technique has been used to treat nonacne atrophic scarring such as varicella and leishmaniasis atrophic scars.^{6–10} Furthermore, TCA CROSS can be combined with other treatment modalities for patients who often have a spectrum of different atrophic scars. Since the comprehensive review by Chung et al,¹¹ additional studies have provided new insights into this technique, such as optimal application instruments, comparative efficacy of different TCA concentrations, and outcomes in a larger population of Fitzpatrick skin types (FST). The objective of this review is to update the current literature about the methodology, indications, efficacy, and safety profile of TCA CROSS in atrophic scars. Moreover, this review aims to compare the outcomes of TCA

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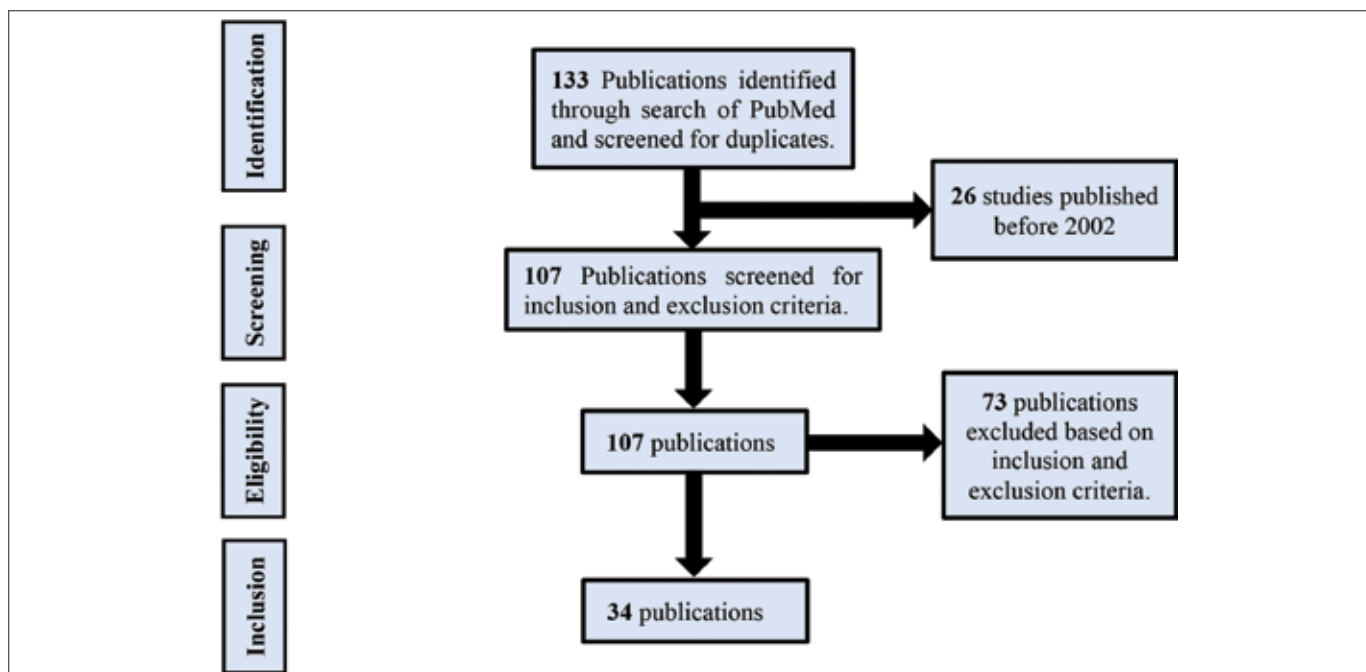


FIGURE 1. PRISMA flow diagram

CROSS to other treatment modalities or as an adjunct for atrophic scarring.

METHODS

A systematic literature search was conducted using the PubMed database to identify studies evaluating the use of TCA in the management of scars, with a particular focus on acne scars. The search strategy employed the following terms: ("scar" OR "acne") AND "trichloroacetic acid." The search retrieved 133 results that were subsequently restricted to 107 publications by limiting the time frame to studies published after 2002, the year in which the CROSS technique was first described. Two independent reviewers (S.S. and H.H.) screened each article for eligibility criteria. Publications were excluded if they were animal studies or review articles, not written in English, lacked available full text, or represented duplication publications or if they did not utilize the CROSS methodology. Procedural pearls and opinion pieces from experts were included. After reviewing for exclusion criteria, 34 publications (20 clinical trials, 4 comparative/cohort studies, 4 case series, 2 case reports, 4 expert opinions) were included in this review (Figure 1).

RESULTS

Patient demographics. A total of 937 patients were included in the selected 34 publications (Table 1), and most were female.

The age range for patients was 4 to 65 years. The most common FST range was IV to V. Nine publications included FST II,^{8,9,12-18} and 2 publications included FST I.^{15,19}

Clinical indications. The types of scars evaluated in these publications were predominantly atrophic acne scars (ice pick, rolling, and boxcar). Fourteen publications specifically mentioned evaluating ice pick acne scars.^{13,14,16,19-29} In addition to atrophic acne scars, the CROSS method was employed in varicella^{6,7,9} and leishmaniasis scars^{8,10} as well as enlarged pores.³⁰

Techniques. Types of applicators. There were several types of applicators used (Figure 2). Sharpened wooden applicators, toothpicks, and cotton-wrapped applicators were commonly used. However, this reportedly led to longer treatment times as the wooden applicator or toothpick required repeated dipping into TCA. Whang et al³⁰ proposed the use of either a 30-, 31-, or 33-gauge needle and syringe for acne scars or enlarged pores, eliminating the need to repeatedly dip back into TCA solution. Cho et al³¹ suggested bending the needle on a syringe, which increases the resistance of flow and, therefore, slows the flow rate of TCA from the needle, allowing for more precise application. More recently, Rullan²⁹ commented on the use of a cosmetic paint brush for TCA CROSS, a technique that was also implemented by



FIGURE 2. Various applicators for trichloroacetic acid chemical reconstruction of skin scars

Sun and Lim.¹⁹ Use of a cosmetic paintbrush allows for painting TCA on the raised borders of boxcar and polymorphic scars, which would not normally be possible with a toothpick or wooden applicator. Currently, there are no studies comparing these different applicators, and selection of a preferred applicator is provider dependent.

Concentration of TCA. There were varying concentrations of TCA used, ranging from 50% to

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TABLE 1. Summative table of included articles

FIRST AUTHOR	STUDY DESIGN	NUMBER OF PARTICIPANTS (SEX)	FITZPATRICK SKIN TYPE	AGE RANGE (YEARS)	INDICATION	CHEMICAL AGENT	APPLICATOR	FREQUENCY
Fabbrocini ⁶	Single-arm clinical trial	5 (3F, 2M)	III	30–40	Atrophic acne scars, varicella scars	50% TCA	Wooden applicator	3 treatments, every 4 weeks
Agarwal ⁷	Single-arm clinical trial	13 (8F, 5M)	III–V	10–45	Atrophic varicella scarring	100% TCA	Toothpick	4 treatments, every 2 weeks
Nilfrouzshadeh ⁸	2-arm randomized clinical trial	92 (74F, 18M)	II–IV	18–41	Leishmaniasis atrophic scar	50% TCA	Cotton tip applicator	5 treatments, every 4 weeks
Barikbain ⁹	Single-arm clinical trial	100 (86F, 14M)	II–IV	9–45	Atrophic facial varicella scars	70% TCA	Cotton-wrapped sharpened wooden applicator	6 treatments, every 3 weeks
Irajli ¹⁰	Case series	6 (4F, 2M)	N/A	4–34	Leishmaniasis scar	50% TCA	Cotton-tipped applicator	Maximum of 3 treatments every 2 weeks
Leheta ¹²	Two-arm randomized clinical trial	30 (14F, 16M, 3 dropped out)	II–IV	19–36	Atrophic acne scarring	100% TCA	Sharpened wooden applicator	4 treatments, every 4 weeks
Weber ¹³	Case report	1 (F)	II	28	Ice pick and boxcar acne scars	80% TCA	Sharpened applicator	2 treatments, every 1 month
Ahmed ¹⁴	2-arm randomized clinical trial	28 (20F, 8M, 14 in each group)	II–IV	19–36	Ice pick acne scars	100% TCA	Toothpick	4 treatments every 3 weeks
Dalpizzol ¹⁵	Nonrandomized, single-blinded, self-controlled clinical trial	15 (12F, 3M)	I–IV	18–52	Atrophic acne scarring	90% TCA	Wooden toothpick	4 treatments, every 21 days
Bahl ¹⁶	Retrospective analysis	25 (14F, 11M)	II–V	21–41	Ice pick acne scars or boxcar scars	80% or 100% TCA	31-gauge needle	1–7 treatments, repeated every 4–6 weeks
Horovitz ¹⁷	Case series	6 (2M, 4F)	II–IV	18–32	Atrophic acne scars	85% TCA	30-gauge needle	N/A
Soysal ¹⁸	Split-face randomized clinical trial	28 (18F, 10M)	II–IV	16–65	Atrophic acne scars	70% and 100% TCA	Wooden toothpick	3 session total, every 3 weeks
Sun ¹⁹	Cohort study	37 (15M, 22F)	I–VI	19–52	Boxcar, ice pick acne scars	90% TCA	Element Games detail brush	3 treatments, every 7–9 weeks
Yug ²⁰	Case series	3 (2F, 1M)	III	27–32	Ice pick acne scars	95% TCA	Sharpened wooden applicator	6 treatments, every 6 weeks
Kim ²¹	2-arm randomized clinical trial	20 (6F, 14M, 2 dropped out)	IV–V	22–37	Rolling and ice pick acne scars	100% TCA	Sharpened wooden applicator	2 treatments, every 12 weeks
Bhardwaj ²²	Single-arm clinical trial	12 (10F, 2M, 2 dropped out)	IV–V	14–42	Predominantly ice pick acne scars	100% TCA	Toothpick	4 treatments, every 2 weeks
Khunger ²³	Single-arm clinical trial	30 (20F, 10M)	IV–V	17–42	Ice pick acne scars	100% TCA	Toothpick	4 treatments, every 2 weeks
Vishwanath ²⁴	Case series	3	N/A	N/A	Ice pick acne scars	100% TCA	Blunt insulin needle tip	N/A

TABLE 1 CONTINUED. Summative table of included articles

FIRST AUTHOR	STUDY DESIGN	NUMBER OF PARTICIPANTS (SEX)	FITZPATRICK SKIN TYPE	AGE RANGE (YEARS)	INDICATION	CHEMICAL AGENT	APPLICATOR	FREQUENCY
Kamei ²⁵	2-arm randomized clinical trial	20 (15F, 5M)	III–IV	20–60	Ice pick, rolling, and boxcar scars	50% TCA	Sharpened wooden applicator	3 treatments total, every 3 weeks
Mitra ²⁶	Pearl	N/A	N/A	N/A	Ice pick acne scars	N/A	27-gauge tuberculin needle	N/A
Veenstra ²⁷	Case report	1 (M)	V	46	Ice pick and boxcar scars	100% TCA	30-gauge needle	N/A
Ghassemi ²⁸	Randomized split-face clinical trial	45	N/A	N/A	Ice pick and atrophic acne scars	100% TCA	N/A	N/A
Rullan ²⁹	Opinion	N/A	N/A	N/A	Ice pick acne scars	TCA	Fine paintbrush	N/A
Whang ³⁰	Opinion	N/A	N/A	N/A	Acne scars, enlarged pores	100% TCA	1-mL syringe with a 30- or 31-gauge needle for acne scars, 33-gauge needle for enlarged pores	N/A
Cho ³¹	Opinion	N/A	N/A	N/A	N/A	N/A	31-gauge bent needle on 1-mL syringe	N/A
Dac Thuy ³²	Nonrandomized, single-blinded, self-controlled clinical trial	31 (19F, 12M)	N/A	12–42	Atrophic acne scars	50% and 80% TCA	Wooden toothpick	4 treatments total, every month
Lee ³³	Retrospective cohort study	65 (55F, 10M)	IV–V	25–45	Atrophic acne scars	100% TCA (33) vs 65% TCA (32)	Sharpened wooden applicator	3–6 treatments, every 1–3 months
Ramadan ³⁴	2-arm randomized clinical trial	20 (14F, 6M)	III–IV	20–52	Rolling acne scars	100% TCA	Sharpened wooden applicator	1–3 treatments, every 1–4 months
Kaur ³⁵	Single-arm clinical trial	10 (10F, 0M)	IV–V	20–35	Atrophic acne scarring	50% TCA	Toothpick	3 treatments, every 4 weeks
Nofal ³⁶	3-arm randomized clinical trial	45 (31F, 14M, 15 in each group)	III–V	19–40	Atrophic acne scarring	100% TCA	Cotton-tipped wooden applicator	3 treatments, every 2 weeks
Agarwal ³⁷	Single-arm clinical trial	53 (20F, 33M)	IV–V	19–29	Atrophic acne scarring	70% TCA	Toothpick	4 treatments, every 2 weeks
Mumtaz ³⁸	2-arm randomized clinical trial	92; 46 in each group	III–V	10–45	Atrophic varicella scarring	100% TCA	Toothpick	4 treatments, every 2 weeks
Roy ³⁹	Prospective comparative study	66 (35M, 31F, 6 dropped out)	IV–V	16–41	Atrophic acne scars	65% TCA	Wooden toothpick	3 treatments, every 2 weeks
Kang ⁴⁰	Single-arm clinical trial	35 (8F, 2M, 25 dropped out)	IV–V	22–37	Atrophic acne scars	100% TCA	29-gauge needle on 1-cc insulin syringe	2 treatments, every 2–3 months

F: female; M: male; N/A: not applicable; TCA: trichloroacetic acid

TABLE 2. Summative table of pre-, post-, and adjunct therapies with patient and physician assessments

FIRST AUTHOR	PRETREATMENT	POSTTREATMENT	ADJUNCT THERAPY	PHYSICIAN ASSESSMENT	PATIENT SATISFACTION	FINDINGS	COMPLICATIONS
Fabbrocini ⁶	N/A	Emollients for 7 days and photoprotection	N/A	Physician-assessed improvement in depth and appearance of scars	Patient satisfaction with treatment increased with each session	N/A	N/A
Agarwal ⁷	Sun avoidance and sunscreen	HQ 2% QHS and sun avoidance	N/A	>75% → 69% 25%–75% → 31% 1%–25% → 0% No change → 0%	All patients reported satisfaction with the treatment provided	N/A	Transient erythema: 100% (faded over 3–8 weeks)
Nilforouzhadeh ⁸	Acetone for defatting	Sunscreen twice daily and HQ QHS	Compared to 1-time CO ₂ laser treatment (10,600 nm, 3-mm spot size, fluence 5 J/cm ² , 1–3 passes)	(1=nonhealing, 2=1%–19% improvement, 3=20%–39% improvement, 4=40%–59% improvement, 5=60%–79% improvement, 6=80%–100% improvement) TCA: 20% (no cure/1), 30% (2); 15% (3); 12% (4); 12% (5); 8% (6) CO ₂ : 38% (no cure/1), 10% (2); 15% (3); 15% (4); 12% (5); 8% (6)	N/A	There was significant difference post-treatment but no difference between the two methods.	Hyperpigmentation observed in 11 patients in TCA group vs 8 patients in CO ₂ group Resistant erythema in 3 patients in CO ₂ group
Barikbini ⁹	N/A	Sun protection	N/A	>75% → 41% 25%–75% → 42% 1%–25% → 12% No change → 5% Worsening → 0%	Highly satisfied → 20% Moderately satisfied → 59% No change → 18% Dissatisfied → 3%	N/A	Mild erythema (17%), transient PIH (15%), transient PIHO (2%)
Irajli ¹⁰	N/A	Neutralized with water and covered with vaseline	CO ₂ laser 1st pass: pulse duration=50 ms, power=3 watt; 2nd pass: pulsed mode (pulse duration=0.6–0.9 ms, fluence 500 mJ/pulse)	N/A	N/A	None of the cases in the laser alone group responded completely. However, all lesions in the CO ₂ laser and TCA group showed good or excellent response	No adverse effects noted
Leheta ¹²	Topical retinoid and HQ 4% for 2 weeks until 2 days before treatment	Antibiotic cream until focal crust formation	Compared against PCI	>75% → 0% 50%–74% → 66.7% 25%–49% → 25% <25% → 8.3% Ice pick: Better with CROSS Rolling: Better with PCI	70% patients reported subjective improvement (range, 50%–80%)	No statistically significant difference was found between the groups regarding overall scar severity improvement (P=0.98)	Burning pain (100%), posttreatment erythema (100%), transient PIH (50%)
Weber ¹³	N/A	N/A	N/A	N/A	After first treatment was satisfied, after second treatment developed atrophy	N/A	Atrophy

TABLE 2 CONTINUED. Summative table of pre-, post-, and adjunct therapies with patient and physician assessments

FIRST AUTHOR	PRETREATMENT	POSTTREATMENT	ADJUNCT THERAPY	PHYSICIAN ASSESSMENT	PATIENT SATISFACTION	FINDINGS	COMPLICATIONS
Ahmed ¹⁴	HQ 2%–4% QAM, tretinoin cream QHS, and sunscreen for 2 weeks	Panthenol cream BID for 2 weeks and sunscreen QAM	Compared against CO ₂ laser; 99 Hz, 0.12-mm spot size, 1.0-ms pulse width and power of 0.9 watts	TCA >70% → 0% 51%–70% → 21% 30%–50% → 50% <30% → 29%	TCA Well: 64.2% Fair: 28.5% Poor: 7.3% CO ₂ Well: 86% Fair: 14.3% Poor: 0%	Significant dramatic reduction in the severity of the ice pick scars after the treatment in CO ₂ group vs those in TCA group Patients showed statistically significant difference in satisfaction in CO ₂ group vs those in TCA group	TCA Transient PIH: 64.2% Infection: 42.8% Itching: 7.1% CO ₂ No complications: 35.7% Transient PIH: 14.2% Infection: 14.2%
Dalpizzol ¹⁵	Sunscreen SPF 30 daily, 3× Adapalene 0.3% starting 15 days before	Sunscreen SPF 30 daily, 3×	Compared against 88% phenol	ECCA grading scale: TCA → 91.0±72.0 Phenol → 90.0±68.3 Significant differences (P<0.001) were found when mean values were compared from pre- and post-treatment assessments	Post-treatment assessment was 3.3 (±3.3) and was significantly lower (P<0.05) when compared to pretreatment assessment, which was 6.7 (±5.4) This demonstrated a significant improvement in the quality of life after treatment	No statistically significant differences were found between TCA and phenol sides	Persistent erythema: 42.85% Hypochromia: 14.3% Scar enlargement: 14.3%
Bahl ¹⁶	HQ or topical retinol and sunscreen at least 4 weeks prior Lidocaine 4% prior to procedure	N/A	Fractionated nonablative laser post-TCA (Lux 1540, 2 Hz, 15-ms pulse duration, 3 passes)	After 3 sessions, the average improvement score was 2.07 with 66.7% of mild and 20% of moderate improvement. After 5 sessions, the average improvement score was 2.78, with 45% of mild, 33% of moderate, and 22% of significant improvement. After 6 sessions, all patients achieved moderate-to-significant improvement with the average score of 3.4	All patients reported satisfaction with treatment after their last session; 24% (6/25 patients) were very satisfied and 76% (19/25) were satisfied	N/A	Crusting, swelling, and redness No patient had PIH or PIHO 1 patient developed a hypertrophic scar
Horovitz ¹⁷	N/A	N/A	N/A	Scar volume decreased from 2.71 mm ³ to 1.96 mm ³ after treatment. 26.3% decrease in the volume of the scars after one treatment.	N/A	N/A	Transient PIH in two patients

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TABLE 2 CONTINUED. Summative table of pre-, post-, and adjunct therapies with patient and physician assessments

FIRST AUTHOR	PRETREATMENT	POSTTREATMENT	ADJUNCT THERAPY	PHYSICIAN ASSESSMENT	PATIENT SATISFACTION	FINDINGS	COMPLICATIONS
Soysal ¹⁸	SPF50 daily	SPF50 daily	N/A	Goodman-Baron Scale 70% TCA → 2.85±0.77 (P<0.001) 100% TCA → 2.64±1.00 (P<0.001)	70% TCA → 3.07±0.99 100% TCA → 2.78±1.12	No statistically significant difference was found between groups in terms of patient or investigator scores	Burning sensation and crusting postprocedure
Sun ¹⁹	Cleaned with acetone SPF 50+ BID, 3 weeks before treatment	White paraffin moisturizer 3 times per day for 6 days, doxycycline 50 mg daily for 7 days, SPF 50+ BID up to Day 5 postprocedure; valacyclovir 500 mg BID for 5 days if history of HSV; HQ 5% for FST IV-VI	N/A	Patients with FST III–VI had a higher percentage of excellent outcomes (13 patients; 59%) than patients with the lighter FST of I–II (9 patients; 41%).	N/A	N/A	PIE in one participant (FST IV) and PIH in one participant (FST VI)
Yug ²⁰	N/A	Polysporin ointment until crusting stopped	N/A	Physician assessed improvement in depth and appearance of scars	High satisfaction rate at 100%	N/A	None
Kim ²¹	N/A	Topical mupirocin ointment for 3–4 days postprocedure	Compared to 1,550-nm Er:Glass fractional laser (split face), 3 treatments, every 6 weeks 30–32 ml, 300–350 spots/cm ²	Improvement was rated using a quartile scale (0: no improvement; 1: 1%–25% improvement; 2: 26%–50% improvement; 3: 51%–75% improvement; 4: >75% improvement) 100% TCA Overall → 2.44 Rolling → 2.31 Ice pick → 2.57 1,550-nm fractional laser Overall → 2.51 Rolling → 2.88 Ice pick → 2.14	100% TCA Overall → 2.43 Rolling → 2.29 Ice pick → 2.57 1,550-nm fractional laser Overall → 2.78 Rolling → 2.85 Ice pick → 2.71	No statistically significant differences in mean grades between laser and CROSS sites For rolling scar type, physician and patient improvement rates were significantly higher with laser than CROSS method. However, for ice pick scar type, there were no statistically significant differences between treatment sides	Erythema, downtime, pain Side treated with laser had grades of pain that were significantly higher. However, downtime and erythema were significantly longer in CROSS side
Bhardwaj ²²	Sunscreen 4% HQ QAM and tretinoin 0.025% every night every 2 weeks	Sunscreen until crusts detach, resume tretinoin 0.025% 1 week after treatment	N/A	>70% → 80% 50%–70% → 20% 30%–50% → 0% <30% → 0%	The feedback from patients correlated with investigator results	N/A	Transient PIHO (1 case)

TABLE 2 CONTINUED. Summative table of pre-, post-, and adjunct therapies with patient and physician assessments

FIRST AUTHOR	PRETREATMENT	POSTTREATMENT	ADJUNCT THERAPY	PHYSICIAN ASSESSMENT	PATIENT SATISFACTION	FINDINGS	COMPLICATIONS
Khungel ²³	Sunscreen 4% HQ QAM and tretinoin 0.025% every night every 2 weeks	Tretinoin 0.025% after crust detached; cases at risk for PIH: sunscreen with HQ for at least 3–6 months; others: Sunscreen only	N/A	>70% → 73.3% 51%–70% → 20% 31%–50% → 6.7% <30% → 0%	The feedback from patients correlated with investigator results	N/A	Transient PIH: 6.7% Transient PHO: 3.3%
Vishwanath ²⁴	N/A	N/A	N/A	N/A	N/A	Magnified images showed more precise deposition of the drug into the depth of the scar and less onto surrounding skin	N/A
Kamel ²⁵	Broad spectrum sunscreen 2 weeks before 2.5% lidocaine applied before procedure; cleaned with alcohol and iodine	Topical antibiotic applied 3× daily for 3 days; sunscreen	Subcision and intradermal PRP vs subcision, PRP, and TCA	Goodmand-Baron Scale Subcision+PRP Baseline: 7.90±2.05 Final: 2.45±1.70 (P<0.001) Subcision+PRP+TCA Baseline: 7.70±2.20 Final: 2.30±1.75 (P<0.001)	Patients' satisfaction was reported as excellent (>70% improvement) by 60% of patients and good (50%–70% improvement) by 40% No significant difference between both treated sides regarding improvement	No statistically significant difference between the 2 treated sides before, during, or after treatment regarding the quantitative global grade scoring system	Transient erythema and edema in all patients; bruising in 5 patients; transient PIH in 2 patients that resolved with HQ
Mitra ²⁶	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Veenstra ²⁷	N/A	N/A	N/A	N/A	N/A	N/A	Persistent erythema and increased atrophy
Ghassemi ²⁸	N/A	N/A	Saline injection and/or 0.5% topical timolol	Generalized Estimated Equations method TCA + saline injection 6.37±3.71 TCA + timolol 2.20±1.89 TCA + saline + timolol 5±3.45	In the saline + TCA group, the patients were more satisfied with the TCA treatment, which was the control therapy, but in the TCA+timolol group the patients were more satisfied with the new treatment compared to the control (TCA)	Average number of scars was not significantly different between the treatment area and the control area. TCA as control and TCA in combination with other methods as intervention are significantly effective in reducing acne scars There was no significant difference in patients' satisfaction with the 2 studied treatments in the group of patients who received saline + TCA + timolol	PIH in 29 patients

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TABLE 2 CONTINUED. Summative table of pre-, post-, and adjunct therapies with patient and physician assessments

FIRST AUTHOR	PRETREATMENT	POSTTREATMENT	ADJUNCT THERAPY	PHYSICIAN ASSESSMENT	PATIENT SATISFACTION	FINDINGS	COMPLICATIONS
Rullan ²⁹	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Whang ³⁰	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Cho ³¹	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Dac Thuy ²²	SPF30 daily	Petroleum jelly 3 times per day	N/A	50% TCA Pre-treatment: 30±9.49 Post-treatment: 21.77±8.52 80% TCA Pre-treatment: 28.55±8.96 Post-treatment: 17.90±7.16	N/A	Post-treatment differences between 50% and 80% TCA were statistically insignificant; however, post-treatment effect was more pronounced in those treated with 80%	All patients experienced transient PIH and PIE
Lee ³³	N/A	Antibiotic ointment until crust formation, starting 1 to 2 weeks post-treatment hydrobase topical containing 0.05% tretinoin and 5% HQ in some patients, minimum of 4 weeks	N/A	65% TCA: >70% → 36% 50%–70% → 46% 30%–50% → 9% <30% → 9% 100% TCA: >70% → 59% 50%–70% → 34% 30%–50% → 6% <30% → 0%	65% TCA >70% → 49% 50%–70% → 33% <50% → 18%	Higher treatment frequency of CROSS on acne scars improved its therapeutic effect Application of a higher TCA concentration was more effective in the treatment of atrophic acne scars	Mild erythema, transient PIH, mild pustular eruption (4 patients cleared in 1 week with oral antibiotics)
Ramadan ³⁴	N/A	Antibiotic cream until focal crust formation on the CROSS side; sunscreen for 1 month after treatment	Compared against subcision	Mean decrease in size of scars: TCA: 0.0865±0.090 cm ² (P<0.001) Subcision: 0.386±0.391 cm ² (P<0.001)	Improvement was statistically significant according to subjective patient assessment (68%)	A statistically significant difference between subcision and 100% TCA CROSS in terms of decrease in scar depth was observed, with decreasing more on the subcision side (P=0.001). Pigmentary alternation from baseline was more on the 100% TCA CROSS side (50%) than on the subcision side (10%).	Residual erythema, PIH, and PIHO
Kaur ³⁵	Sunscreen SPF>30 QAM HQ 2% and Tretinoin 0.025% QHS for two weeks	Antibiotic cream BID Sunscreen SPF>30 QAM Azelaic acid 20% QD after 10 days	Subcision with 18-gauge needle after TCA	>70% → 60% 51–70% → 30% 30–50% → 10% <30% → 0%	All patients were satisfied with results except for one.	Subcision combined with TCA CROSS is a simple, safe, and cost-effective procedure.	Transient PIH: 30% (last 15–20 days postprocedure)

TABLE 2 CONTINUED. Summative table of pre-, post-, and adjunct therapies with patient and physician assessments

FIRST AUTHOR	PRETREATMENT	POSTTREATMENT	ADJUNCT THERAPY	PHYSICIAN ASSESSMENT	PATIENT SATISFACTION	FINDINGS	COMPLICATIONS
Nofaj ³⁶	N/A	Antibiotic cream Sunscreen	Compared against intradermal PRP versus microneedling with topical PRP	Intradermal PRP >75% → 20% 50%–74% → 26.7% 25%–49% → 20% <25% → 33.3% TCA >75% → 0% 50%–74% → 26.7% 25%–49% → 33.3% <25% → 40% Microneedling with topical PRP >75% → 13.3% 50%–74% → 46.7% 25%–49% → 13.3% <25% → 26.7%	Intradermal PRP >75% → 20% 50%–74% → 46.7% 25%–49% → 33.3% <25% → 0% TCA >75% → 40% 50%–74% → 20% 25%–49% → 40% <25% → 0% Microneedling with Topical PRP >75% → 33.3% 50%–74% → 33.3% 25%–49% → 33.3% <25% → 0%	No statistically significant difference in the degree of improvement and therapeutic response between the 3 groups	Mild pain: 100% Transient PIH: 26.7% (treated with HQ 2%)
Agarwal ³⁷	N/A	Sunscreen every day HQ 2% QHS after crust shedding Topical desonide for PIH	N/A	>75% → 22.6% 50%–74% → 43.4% 25%–49% → 18.9% <25% → 15.1%	>75% → 11.3% 50%–74% → 54.7% 25%–49% → 34% <25% → 0% 81.1% were either satisfied (n=30, 56.6%) or very satisfied (n=13, 24.5%). 18.9% were dissatisfied because treatment was not up to their expectations or development of PIH	N/A	PIH (18%) Scar enlargement (17%)
Mumtaz ²⁸	N/A	Sunscreen	Compared against intradermal PRP	Goodman-Baron Scale PRP 12 weeks, 14.15±3.05 24 weeks, 7.09±1.46 (P<0.001) TCA 12 weeks, 17.57±4.51 24 weeks, 10.09±3.58 (P<0.001)	N/A	No significant difference in scar score at 4 and 8 weeks, with significant difference at 12 and 24 weeks Intradermal PRP was superior to 50% TCA	N/A

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TABLE 2 CONTINUED. Summative table of pre-, post-, and adjunct therapies with patient and physician assessments

FIRST AUTHOR	PRETREATMENT	POSTTREATMENT	ADJUNCT THERAPY	PHYSICIAN ASSESSMENT	PATIENT SATISFACTION	FINDINGS	COMPLICATIONS
Roy ³⁹	Degreased with acetone prior to procedure	Moisturizer and sunscreen with SPF50+	Compared against glycolic acid 50% peel	Goodman-Baron Scale Glycolic acid No grade change: 65.52% Grade 1 change: 20.68% Grade 2 change: 6.89% Grade 3 change: 6.89% Grade 4 change: 0.00% TCA No grade change: 32.36% Grade 1 change: 248.38% Grade 2 change: 3.22% Grade 3 change: 6.45% Grade 4 change: 9.68%	Glycolic acid Unsatisfactory: 34.48% Fair: 41.38% Good: 20.69% Excellent: 3.45% TCA Unsatisfactory: 6.45% Fair: 25.81% Good: 58.06% Excellent: 9.68%	Patients who received TCA CROSS had statistically significantly better visual results than those who received glycolic acid	7 patients developed hypersensitivity reactions 11 patients reported photosensitivity 38 patients developed burning sensation
Kang ⁴⁰	N/A	N/A	Combined with 1,550-nm Er:Glass, 3–4 treatments, every 4 weeks; 350–800 spots/cm ² , pulse energy 25 mJ Subcision performed simultaneously with dot peeling	The mean scar severity score decreased to 3.4, 8±14.2 as compared to 80.0±31.7 before the treatment.	The mean patients' subjective scores were recorded as 2±0.7, which represented significant improvement (51%–75%)	N/A	No significant complications

BID: twice daily; CO₂: carbon dioxide; CROSS: chemical reconstruction of skin scars; ECCCAFST: Fitzpatrick skin type; HQ: hydroquinone; HSV: herpes simplex virus; PLE: postinflammatory erythema; PIH: postinflammatory hyperpigmentation; PHO: postinflammatory hypopigmentation; PCI: percutaneous collagen induction; PRP: platelet-rich plasma; QAM: every morning; QHS: every evening before bedtime; QD: every day; SPF: sun protection factor; TCA: trichloroacetic acid

100%. The most used TCA concentration was 100%. Several studies investigated the differences in TCA CROSS concentration and patient outcomes.^{16,18,32} While there was no significant difference in efficacy between lower and higher concentrations of TCA, there were more complications in higher TCA concentrations.^{18,32}

Method of application. The CROSS technique involves pinpoint application of a high concentration acid to an atrophic scar using an applicator. The clinical endpoint is white frosting of each scar, which usually occurs within seconds of application (**Figure 3** and **Figure 4**). This results in a controlled injury, prompting the skin to heal and rebuild through neocollagenesis.

Multiple methods of application have been previously described (**Figure 2**). The proceduralist may stretch the skin surrounding the atrophic scar and use an applicator to touch the base of the scar.^{6–10,13–15,18,20–23,25,32–39}

A needle attached to a syringe can be used to form microdroplets of acid, which subsequently fills the atrophic scar.^{16,17,24,26,27,30,31,40} Controlled application of TCA in atrophic scars is recommended, as spillage outside of the scar can result in worsening of the scar or other adverse events. Kang et al⁴⁰ performed the CROSS technique in a different way by using a 29-gauge needle with a syringe to prick atrophic scars, facilitating deeper penetration of 100% TCA.

Pre-care instructions. Various topical agents were reportedly used either together or separately in the weeks leading up to TCA application. Sunscreen, both SPF 30 or SPF 50+, was typically combined with hydroquinone (HQ) or a topical retinoid (tretinoin or adapalene). Some publications reported using HQ and/or topical retinoids at least 2 to 4 weeks prior.^{12,14–16,22,23,35}

On the day of the procedure, several authors reported using topical lidocaine for anesthesia prior to procedure. Before the procedure, acetone or alcohol were used frequently to degrease the patient's skin. There were no reports of patients needing oral prophylaxis with antibiotics or antivirals prior to CROSS procedure.

Post-care instructions. Most publications reported using general wound care through petrolatum-based ointments and moisturizers or emollients. Topical antibiotics such as mupirocin, polysporin, or other antibiotic creams were used for a few days after TCA CROSS



FIGURE 3. (A) Before chemical reconstruction of skin scars (CROSS) method; (B) clinical endpoint of CROSS method with frosted appearance; (C) 3 days postprocedure with 80% trichloroacetic acid

until focal crust formation. As with the precare instructions, some patients were advised to use sunscreen for photoprotection or HQ and/or retinoids to mitigate postinflammatory hyperpigmentation (PIH).

Other adjunctive medications for mitigating PIH included topical desonide and 20% azelaic acid daily. Sun and Lim¹⁹ were the only ones to report using oral doxycycline and oral valacyclovir. They reported using doxycycline 50 mg daily for 7 days postprocedure and valacyclovir 500 mg twice daily for 5 days, but only if the patient reported a history of herpes simplex virus infection.

Number and frequency of treatments. Across the included studies, 4 treatment sessions was the most common number of treatments for most studies; 3 treatment sessions were also typically seen. The number of treatments increased based on the severity and chronicity of the target scar type. For instance, 5 treatments were reported by Nilforoushzadeh et al⁸ when treating leishmaniasis scars with 50% TCA. Barikbin et al⁹ reported using 6 treatments for atrophic facial varicella scars with 70% TCA.

Regarding frequency of treatment, a 2- to 4-week interval between treatments was most common. However, some studies personalized their treatment intervals based on the healing and PIH risk of their patients.

Adjunct and compared therapies. *Laser therapy.* Fractional laser techniques were either

used as adjunct therapies or as comparators to TCA CROSS in several studies.^{8,10,14,16,21,40}

Kim et al²¹ and Kang et al⁴⁰ both employed a 1,550-nm Erbium glass (Er:Glass) fractional photothermolysis device for management of atrophic acne scars. Kim et al²¹ conducted a split-face randomized trial directly comparing Er:Glass fractional laser with TCA CROSS, finding no statistically significant difference in mean scar improvement between the 2 modalities. However, both physician and patient assessments indicated significantly greater improvement for rolling scars with the fractional laser than with TCA CROSS, whereas no significant difference was observed for ice pick scars.

In contrast, Kang et al⁴⁰ implemented the 1,550 nanometer Er:Glass fractional laser as an adjunct to dot peeling and subcision, reporting marked reductions in scar severity scores. The authors concluded that a multimodal therapeutic strategy for scar treatment is needed to address solitary atrophic acne scars, improve skin texture, and treat broad depressed boxcar or rolling scars. Bahl et al¹⁶ also used nonablative fractional laser therapy in combination with TCA CROSS to treat ice pick and boxcar acne scars. After 3 to 6 sessions, all patients achieved moderate-to-significant improvement in their scarring. All patients were either satisfied (76%) or very satisfied (24%) after their last treatment.

Ahmed et al¹⁴ compared carbon dioxide (CO₂) ablative therapy to 100% TCA CROSS in ice pick acne scars. Both groups (CO₂ and TCA CROSS) had 4 treatments every 3 weeks with 3 months of follow-up. The authors reported a significant reduction in the severity of scar appearance in the CO₂ group compared to the TCA group. Patients were also significantly more satisfied in the CO₂ group with no major complications. Nilforoushzadeh et al⁸ also compared 1-time CO₂ ablative therapy against focal 50% TCA peeling for leishmaniasis scars. They reported significant improvement post-treatment in both groups, but there was no significant difference between the 2 methods. While there were more cases of hyperpigmentation in the TCA group, there was more resistant erythema in the CO₂ group. Iraj et al¹⁰ used CO₂ ablative therapy as an adjunct therapy to focal peeling with 50% TCA for leishmaniasis scars. They compared TCA and CO₂ ablative therapy to laser therapy alone and found that none of the cases in the laser monotherapy group responded completely. All leishmaniasis lesions in the TCA and CO₂ laser group showed either good or excellent response.¹⁰

Subcision. Subcision is a minor surgical procedure in which a needle, cannula, or specialized blade is inserted under the surface of the skin to directly disrupt fibrous septae that anchor the scar to deeper structures, allowing the overlying skin to elevate. Kang et al⁴⁰ implemented this technique alongside

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FIGURE 4. (A) Immediately postprocedure with combination trichloroacetic acid (TCA) chemical reconstruction of skin scars (CROSS) and nonablative Fraxel laser; (B) Day 1 postprocedure with crust and flaking skin; (C) Day 3 postprocedure with improvement in erythema and crusting

dot peeling and laser with significant improvement in acne scars. Kaur and Kalsy³⁵ also used subcision as an adjunct to TCA dot peeling but did not use laser in their sample. Based on their assessments, 6 patients had an excellent response, 3 had a good response, and 1 had a fair response. Transient PIH occurred in 3 patients, while there were no “significant complications” reported by Kang et al.⁴⁰

Ramadan et al³⁴ compared subcision against 100% TCA for rolling acne scars and found a statistically significant improvement in the average size of scars for both TCA and subcision groups. However, there was a more significant reduction on the subcision side, suggesting that other modalities may be more suitable for rolling scars (eg, subcision or ablative laser) than TCA CROSS. Moreover, there was more pigmentary alteration from baseline on the TCA side compared to the subcision side.

Platelet-rich plasma. Platelet-rich plasma (PRP) is a blood product with a high concentration of platelets and growth factors, such as platelet-derived growth factor, transforming growth factor beta, and epidermal growth factor, that are critical for tissue regeneration and wound healing. Intradermal injection of PRP into atrophic acne scars can promote collagen synthesis and remodel the extracellular matrix.⁴¹ Mumtaz et al³⁸ compared intradermal PRP against 50% TCA in patients with atrophic acne scarring. After 12 and

24 weeks of therapy, they reported a significant difference in scar scores for both intradermal PRP and TCA; however, intradermal PRP was significantly superior with a greater reduction in scar scores when compared to 50% TCA.

Nofal et al³⁶ compared intradermal PRP to 100% TCA and microneedling with topical PRP. Each group had 3 treatment sessions with 2-week intervals. By the end of the study period, each group demonstrated significant improvement in scar severity.³⁶ There was also no significant difference in the degree of improvement between groups. Kamel et al²⁵ used intradermal PRP but as an adjunct therapy to 50% TCA CROSS along with subcision. The authors used a global scarring grading system and compared subcision with PRP to subcision with PRP and TCA CROSS. Both groups demonstrated significant improvement in their scar severity, and patients’ satisfaction was reported as excellent by 60% of patients and good by 40%.²⁵ There was no statistically significant difference between the 2 treated sides. The authors reported that while the CROSS technique is beneficial for ice pick acne scars, combining TCA CROSS with PRP and subcision may provide added improvement to skin texture and/or other scars.

Microneedling. Percutaneous collagen induction (PCI), or microneedling, is a minimally invasive procedure that uses fine needles to create controlled micro-injuries in the skin. These controlled injuries stimulate the wound

healing cascade, leading to increased production of collagen and elastin and remodeling of the extracellular matrix. Leheta et al¹² compared PCI against TCA CROSS in 30 participants with atrophic acne scars. All the participants had an objective improvement in their acne scars, and the authors reported statistically significant improvement when using CROSS technique for ice pick scars and PCI for rolling scars. There was no statistically significant difference between either group regarding overall scar severity improvement. However, post-treatment erythema and overall downtime was longer in participants who received TCA than those who received PCI.

Acid peels. While the CROSS technique has been extensively studied using TCA, it has also been studied in other chemical agents such as phenol.¹⁵ Phenol is used for deep chemical peels and penetrates into the mid-reticular dermis. It is used to treat deep wrinkles and scars but has a higher risk of complications, most notably cardiac arrhythmias. Dalpizzol et al¹⁵ used phenol with the CROSS technique and compared this to 90% TCA. Post-treatment assessment scores were significantly lower compared to pretreatment assessment among physicians and patients. While there was no significant difference between TCA and phenol sides, treatment discomfort was significantly higher with phenol, while complications such as hypochromia and scar enlargement were only reported on the TCA side.¹⁵

Glycolic acid is another chemical agent used for superficial peels, and its effects are limited to the epidermis and superficial papillary dermis. Glycolic acid peels are effective in improving skin texture, hyperpigmentation, mild photodamage, and acne, but they are less effective for deep wrinkles or scars, although improvement with 70% glycolic acid peel has been reported for acne scars.⁴² Roy et al³⁹ investigated 50% glycolic acid peel against 65% TCA CROSS for atrophic acne scars. Patients who received TCA CROSS had statistically significant improvement in visual results than those who received glycolic acid peel. However, adverse events were more prevalent in the TCA CROSS group compared to the glycolic acid group.

Timolol. Timolol is a beta-adrenergic receptor blocker that has been shown to improve and accelerate healing.⁴³ Ghassemi et al²⁸ used topical timolol as an adjunct therapy to TCA CROSS to reduce scar complications and accelerate the wound healing process. In addition to timolol, they also performed normal saline injections as an adjunct therapy, which has been shown to stimulate fibroblasts, collagen production, and rearrangement of the extracellular matrix.⁴⁴ This results in accelerated healing of atrophic scars caused by acne. Forty-five participants with atrophic acne scars were randomly divided into 3 groups of 15 people. The new treatment was performed on 1 side of their face, and the other side was considered the control (TCA alone). Group 1 received TCA and normal saline, Group 2 received TCA and timolol, and Group 3 received TCA, normal saline, and timolol.

Through intragroup comparisons and evaluation of the efficacy of the new treatment, there was no significant effect on the number of scars in the participants when compared to the control group. However, patients who had received timolol (TCA and timolol; or TCA, normal saline, and timolol) experienced a significantly shorter period of postprocedure hyperpigmentation compared to patients who received saline and TCA. The results of the study showed that PIH after TCA CROSS may be significantly reduced if paired with topical timolol and/or saline.²⁸

Clinical efficacy. Acne scars. Variable methods were used for physician assessment of scar improvement, with a quantile grading scale being the most common (**Table 2**). In studies using the quantile grading scale, 60% to 100% of patients experienced a >25% to 30% improvement in their atrophic acne scarring with participants in Nofal et al³⁶ experiencing the least amount of

improvement.^{7,12,14,19,22,23,33,35,37} For the other 9 studies, 66% to 100% of patients experienced a >50% improvement in their atrophic acne scarring. Yug et al²⁰ and Fabbrocini et al⁶ did not use a specific assessment scale but did report an improvement in appearance and depth of scars. Horovitz et al¹⁷ measured scar volume deficit with a validated high-resolution 3-dimensional imaging system and found a 26.3% decrease in the volume of the scars after just 1 treatment.

The Échelle d'Évaluation Clinique des Cicatrices d'Acne (ECCA) grading scale associates each kind of acne scar with a quantitative score and a weighting factor.⁴⁵ Dalpizzol et al¹⁵ used this grading scale to assess their participants' atrophic acne scar improvement and reported significant improvement from pre- (130.7±73.7) and post-treatment (91.0±72.0) with TCA CROSS. Other studies used a global acne grading system, the Goodman-Baron scale, to determine acne scar improvement.^{18,25,38,39} The Goodman-Baron scale evaluates the degree of scarring after acne has resolved, with higher numbers for numerous lesions and severe atrophic or hypertrophic scars.⁴⁶ Each author group that used this scale demonstrated a significant improvement in atrophic acne scarring for their participants by the end of the treatment protocol.^{25,38,39}

Patient satisfaction with TCA CROSS for acne scars was rated generally high across multiple studies and clinical trials. Studies typically used a quantile scale to assess patient satisfaction, and most patients reported subjective improvement in their appearance.^{9,12,14,16,25,33,34,36,37,39} Satisfaction rates commonly ranged from moderate to high, usually 50% to 80% improvement. Patient-reported outcomes consistently reflected favorable perceptions about TCA CROSS efficacy, especially when treatment was repeated for several sessions and tailored to scar type and skin phototype.

Kim et al²¹ and Leheta et al¹² were the only groups to stratify improvement based on scar type. Kim et al²¹ concluded that 1,550-nm fractional laser had significantly higher improvement rates of rolling scars compared to TCA CROSS. However, there was no statistically significant difference in ice pick scar improvement when compared to this laser therapy and TCA CROSS.²¹ For Leheta et al,¹² their physicians reported TCA CROSS performed better than PCI for ice pick scars but that PCI performed better than TCA CROSS for rolling scars. However, there was no statistically significant difference between the groups (TCA CROSS vs PCI) regarding overall scar severity improvement.

Based on the results of our comprehensive review, TCA CROSS appears more suitable for ice pick scars rather than rolling scars, but this conclusion is limited by the few publications that stratified improvement based on scar type. Generally, acne scarring improves as the total number of treatment sessions increases.

While Lee et al³³ suggested that higher TCA concentrations yield a higher therapeutic effect, other authors found no significant differences with TCA concentrations; instead, higher TCA concentrations come with more risk of complications, such as erythema, PIH, or postinflammatory hypopigmentation (PIHO). While the frequency between treatment remains ambiguous, the authors suggest that TCA be applied every 4 to 6 weeks to mitigate possible complications. Furthermore, we suggest an extension to 6 to 9 weeks for higher TCA concentrations (≥80%) or in patients with darker FSTs (IV–VI).

Varicella scars. Three publications investigated the use of TCA CROSS in atrophic varicella scars through clinical trials.^{6,7,9} Barikbin et al⁹ used 70% TCA, and 83% of patients had >25% improvement in their varicella scars. Agarwal et al,⁷ however, used 100% TCA, and 100% of patients had >25% improvement. Although their sample size was small (n=5), Fabbrocini et al⁶ reported improvement in scar appearance and depth with 50% TCA.

Leishmaniasis scars. Through a 2-arm randomized clinical trial, Nilforoushadeh et al⁸ used 50% TCA CROSS to treat atrophic leishmaniasis scars. They reported that 57% of their participants experienced >20% improvement in their atrophic leishmaniasis scars. These results were also statistically insignificant when compared to 1-time carbon dioxide (CO₂) ablative laser therapy. Iraj et al¹⁰ also investigated TCA CROSS in the treatment of leishmaniasis scars but used CO₂ ablative laser therapy as an adjunct in a small case series. They found that all lesions in the CO₂ and TCA group showed good or excellent response.¹⁰

Complications. TCA CROSS is generally a well-tolerated procedure with few serious adverse effects. Of the publications that were included in our study, patients with FST I through VI were all evaluated. PIH was the most frequent adverse event, with incidence rates varying from mild, transient cases (weeks) to more prolonged episodes (months). Several studies reported rates of PIH ranging from 6.7% to over 60%.¹⁴ The current literature suggests that PIH from TCA CROSS

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is a transient adverse event and can also be treated with hydroquinone and tretinoin to expedite resolution. Every patient, regardless of FST, should be counseled on this possible adverse event, and proceduralists should be informed about possible treatments to help expedite PIH resolution.

Postinflammatory erythema (PIE) and PIHO were the more common adverse events after PIH. While most cases of PIE were transient, some studies reported PIE that was more persistent.^{15,34} PIHO was less common than PIE, and only transient cases that were documented.^{9,22,23,34} Mild crusting was nearly universal after procedure, but it generally resolves without significant sequelae. Burning sensation and pain were infrequently reported; some authors used topical lidocaine before the procedure.^{16,25} Finally, infection was uncommon and reported in only 1 study.¹⁴

One significant adverse event that was documented from TCA CROSS was scar enlargement or worsening atrophy.^{13,15,27,37} Three of these 4 publications used a sharpened wooden applicator or toothpick.^{13,15,37} This could have resulted in poorly controlled application of TCA, with spillage onto perilesional skin and subsequent worsened atrophy. Veenstra et al²⁷ used an electronic micropipette device to perform TCA CROSS; however, they presumed this resulted in less precise application of TCA, resulting in worsening scar atrophy for 1 of their patients. Based on the current literature, proceduralists recommend using a fine-gauge needle or a fine paintbrush for controlled application of TCA.^{15,18,19,26,28}

Not every study included in our review stratified complication by FST. Therefore, the proceduralist performing TCA CROSS should counsel their patients on each of the previously mentioned complications regardless of the patient's FST. Future directions for research should focus on assessing complication rates based on patient FSTs.

DISCUSSION

TCA CROSS is well-tolerated in patients with atrophic acne scars with minimal complications. Specifically, TCA CROSS is best used for ice pick scars, followed by boxcar scars, then rolling scars. While TCA CROSS demonstrated improvement in patients with atrophic scars from varicella and leishmaniasis, additional research through clinical trials is warranted to determine its efficacy in this population. Regarding FST, types I through V were the most studied, and this technique appears

relatively safe in this patient population. Only 1 participant with FST VI was included in our review, and they subsequently developed PIH. Additional research is needed about the efficacy and safety profile of TCA CROSS in patients with FST VI.

Multiple treatment sessions increase the overall success rate of TCA CROSS. While higher TCA concentrations can also increase success rate, the risk of complications (eg, PIH, PIE, and PIHO) is higher. Regarding method of application, fine-gauge needles with syringes offer more precise control compared to toothpicks or other wooden applicators. A fine paintbrush can also be used to apply TCA at the base and sides of an atrophic scar. Complications such as PIH, PIE, and PIHO are generally transient and topical agents such as hydroquinone and tretinoin can be used to prevent and/or hasten resolution of these adverse effects.

CONCLUSION

While TCA CROSS is a useful tool, it is important to recognize that no one treatment may be most suitable for a patient. Instead, the authors recommend a multimodality approach to address each patient's unique scar concerns and provide synergistic therapeutic effects on different scar types, which commonly co-occur in the same individual. Therefore, when approaching scar treatment, combination therapy should always be considered. The published literature continues to have several limitations, such as small sample sizes, inconsistent follow-up between patients, differing TCA concentrations and frequency of application, and variations in assessment scores. Future research in randomized controlled trials should focus on defining the optimal application frequency, concentration, and number of sessions. These studies should also aim to include participants with a broad spectrum of FST and stratify analysis by patient demographics, including skin type and scar classification.

ETHICS STATEMENT

Consent for the publication of all patient photographs and medical information was provided by the authors at the time of article submission to the journal, stating that all patients gave consent for their photographs and medical information to be published in print and online with the understanding that this information may be publicly available.

AUTHOR CONTRIBUTIONS

Both authors contributed substantially to the

conception, design, acquisition of data, analysis and interpretation of the data included in this manuscript. They were both involved in draft production and revision of intellectual content.

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