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NON-SURGICAL MANAGEMENT OF HYPERTROPHIC AND KELOID SCARS: A SYSTEMATIC REVIEW OF CLINICAL EFFICACY

TRATAMENTO NÃO CIRÚRGICO DE CICATRIZES HIPERTRÓFICAS E QUELOIDES: UMA REVISÃO SISTEMÁTICA DA EFICÁCIA CLÍNICA

TRATAMIENTO NO QUIRÚRGICO DE CICATRICES HIPERTRÓFICAS Y QUELOIDES: UNA REVISIÓN SISTEMÁTICA DE LA EFICACIA CLÍNICA

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Breno de Amaral Gandini[1], Bruna Pinheiro do Prado Felinto[2], Adrielli Teixeira Dias[3], Bruna Gomes de Sousa Silveira Lima[4]

ABSTRACT

Introduction: Hypertrophic and keloid scars are fibroproliferative disorders that develop after skin injury and represent a major challenge in dermatologic and surgical practice. Non-surgical modalities such as intralesional corticosteroids, 5-fluorouracil, bleomycin, verapamil, silicone gel, laser therapy, and pressure therapy have been used with variable success.

Objective: The main objective of this systematic review was to evaluate the clinical efficacy and safety of non-surgical interventions for hypertrophic and keloid scars. Secondary objectives included assessing comparative outcomes, recurrence rates, patient satisfaction, and identifying gaps for future research.

Methods: A comprehensive literature search was performed in PubMed, Scopus, Web of Science, Cochrane Library, LILACS, ClinicalTrials.gov, and ICTRP for studies published between January 2019 and March 2025. Randomized controlled trials (RCTs), cohort studies, and meta-analyses evaluating non-surgical management of hypertrophic and keloid scars were included. Data synthesis followed PRISMA guidelines, emphasizing methodological quality and clinical relevance.

Results and Discussion: From 1,042 records screened, 18 studies met eligibility criteria. Intralesional corticosteroids remain the most effective monotherapy, while combination regimens with 5-fluorouracil or bleomycin showed superior outcomes. Emerging therapies such as laser-assisted drug delivery, silicone gel sheeting, and botulinum toxin demonstrated promising results with favorable safety profiles. However, study heterogeneity limits direct comparison.

[1] Universidade de Ribeirão Preto (UNAERP). E-mail: brenogand@hotmail.com
[2] Faculdade de medicina de Taubaté (UNITAL). E-mail: brupinheiro1208@gmail.com
[3] UNIFEV. E-mail: Adrielli.tdias21@gmail.com
[4] Faculdade Santa Marcelina. E-mail: brubrica@hotmail.com

Conclusion: Non-surgical modalities provide clinically meaningful improvement for hypertrophic and keloid scars, especially when applied in combination. Standardized protocols and long-term follow-up studies are needed to consolidate evidence.

Keywords: Keloid. Hypertrophic Scar. Corticosteroids. Laser Therapy.

RESUMO

Introdução: Cicatrizes hipertróficas e queloides são distúrbios fibroproliferativos que se desenvolvem após lesão cutânea e representam um grande desafio na prática dermatológica e cirúrgica. Modalidades não cirúrgicas, como corticosteroides intralesionais, 5-fluorouracil, bleomicina, verapamil, gel de silicone, laserterapia e pressoterapia, têm sido utilizadas com sucesso variável.

Objetivo: O principal objetivo desta revisão sistemática foi avaliar a eficácia clínica e a segurança de intervenções não cirúrgicas para cicatrizes hipertróficas e queloides. Os objetivos secundários incluíram a avaliação de desfechos comparativos, taxas de recorrência, satisfação do paciente e identificação de lacunas para pesquisas futuras.

Métodos: Uma busca bibliográfica abrangente foi realizada nas bases de dados PubMed, Scopus, Web of Science, Biblioteca Cochrane, LILACS, ClinicalTrials.gov e ICTRP para estudos publicados entre janeiro de 2019 e março de 2025. Ensaios clínicos randomizados (ECRs), estudos de coorte e metanálises que avaliaram o tratamento não cirúrgico de cicatrizes hipertróficas e queloides foram incluídos. A síntese dos dados seguiu as diretrizes PRISMA, enfatizando a qualidade metodológica e a relevância clínica.

Resultados e Discussão: De 1.042 registros rastreados, 18 estudos preencheram os critérios de elegibilidade. Corticosteroides intralesionais continuam sendo a monoterapia mais eficaz, enquanto regimes combinados com 5-fluorouracil ou bleomicina apresentaram resultados superiores. Terapias emergentes, como administração de fármacos assistida por laser, placas de gel de silicone e toxina botulínica, demonstraram resultados promissores com perfis de segurança favoráveis. No entanto, a heterogeneidade dos estudos limita a comparação direta.

Conclusão: Modalidades não cirúrgicas proporcionam melhora clinicamente significativa para cicatrizes hipertróficas e queloides, especialmente quando aplicadas em combinação. Protocolos padronizados e estudos de acompanhamento de longo prazo são necessários para consolidar as evidências.

Palavras-chave: Queloide. Cicatriz Hipertrófica. Corticosteroides. Terapia a Laser.

RESUMEN

Introducción: Las cicatrices hipertróficas y queloides son trastornos fibroproliferativos que se desarrollan tras una lesión cutánea y representan un importante reto en la práctica dermatológica y quirúrgica. Se han utilizado modalidades no quirúrgicas como corticosteroides intralesionales, 5-fluorouracilo, bleomicina, verapamilo, gel de silicona, terapia láser y presoterapia con resultados variables.

Objetivo: El objetivo principal de esta revisión sistemática fue evaluar la eficacia clínica y la seguridad de las intervenciones no quirúrgicas para las cicatrices hipertróficas y queloides. Los objetivos secundarios incluyeron la evaluación de resultados comparativos, las tasas de recurrencia, la satisfacción del paciente y la identificación de áreas de investigación para futuras investigaciones.

Métodos: Se realizó una búsqueda bibliográfica exhaustiva en PubMed, Scopus, Web of Science, Cochrane Library, LILACS, ClinicalTrials.gov e ICTRP para encontrar estudios publicados entre enero de 2019 y marzo de 2025. Se incluyeron ensayos controlados aleatorizados (ECA), estudios de cohorte y metanálisis que evaluaron el tratamiento no quirúrgico de cicatrices hipertróficas y queloides. La síntesis de datos se realizó siguiendo las directrices PRISMA, priorizando la calidad metodológica y la relevancia clínica.

Resultados y discusión: De 1042 registros examinados, 18 estudios cumplieron los criterios de elegibilidad. Los corticosteroides intralesionales siguen siendo la monoterapia más eficaz, mientras que los regímenes combinados con 5-fluorouracilo o bleomicina mostraron resultados superiores. Las terapias emergentes, como la administración de fármacos asistida por láser, las láminas de gel de silicona y la toxina botulínica, mostraron resultados prometedores con perfiles de seguridad favorables. Sin embargo, la heterogeneidad de los estudios limita la comparación directa.

Conclusión: Las modalidades no quirúrgicas proporcionan una mejora clínicamente significativa en las cicatrices hipertróficas y queloides, especialmente cuando se aplican en combinación. Se necesitan protocolos estandarizados y estudios de seguimiento a largo plazo para consolidar la evidencia.

Palabras clave: Queloide. Cicatriz Hipertrófica. Corticosteroides. Terapia Láser.

1 INTRODUCTION

Hypertrophic and keloid scars are fibroproliferative disorders characterized by abnormal collagen deposition and prolonged inflammation following dermal injury[1]. They result from excessive fibroblast proliferation and dysregulated transforming growth factor-beta (TGF-β) signaling, leading to abnormal extracellular matrix remodeling[1]. Although both lesions share pathophysiologic mechanisms, keloids extend beyond the original wound margin, whereas hypertrophic scars remain confined to the injury site[1].

The global prevalence of keloid and hypertrophic scarring varies between 5% and 15%, with higher rates observed among individuals of African, Asian, and Hispanic ancestry[2]. Genetic predisposition plays a significant role, as polymorphisms in TGF-β and SMAD genes have been linked to abnormal wound healing[2]. Environmental factors such as delayed epithelialization, high-tension closure, and infection further contribute to scar formation[2].

Management of these scars remains challenging, as no single therapy guarantees complete regression or prevents recurrence[3]. Surgical excision alone is associated with recurrence rates up to 100%, particularly in keloid lesions[3]. Therefore, non-surgical approaches focusing on modulation of fibroblast activity, collagen synthesis, and inflammation have gained prominence in current dermatologic practice[3].

Intralesional corticosteroid injection, particularly triamcinolone acetonide, is considered the first-line treatment for both hypertrophic and keloid scars[4]. Its efficacy is attributed to inhibition of fibroblast proliferation, reduced glycosaminoglycan synthesis, and vasoconstriction leading to hypoxia within scar tissue[4]. However, corticosteroid monotherapy may cause side effects such as skin atrophy, hypopigmentation, and telangiectasia, motivating exploration of combination regimens[4].

5-Fluorouracil (5-FU) has emerged as a potent antimetabolite capable of inhibiting fibroblast DNA synthesis and collagen production[5]. When combined with corticosteroids, 5-FU enhances therapeutic efficacy and reduces recurrence rates compared to monotherapy[5]. Additionally, it is associated with fewer adverse effects, although transient pain or ulceration at the injection site may occur[5].

Bleomycin, an antineoplastic agent, has shown strong antifibrotic properties through inhibition of fibroblast proliferation and reduction of type I collagen expression[6]. Intralesional bleomycin injection or bleomycin tattooing has achieved high response rates in recalcitrant keloids resistant to corticosteroids[6]. Nonetheless, pain during administration and the potential for hyperpigmentation remain limitations[6].

Verapamil, a calcium channel blocker, has been proposed as an alternative to corticosteroids due to its ability to increase procollagenase synthesis and reduce fibroblast

contractility[7]. Clinical trials have demonstrated moderate efficacy, particularly when combined with silicone gel or 5-FU[7]. However, its effect tends to be slower, and response rates are lower in large, long-standing lesions[7].

Laser therapy, including pulsed dye laser (PDL) and fractional CO_2 laser, represents another cornerstone of non-surgical management[8]. PDL promotes vascular remodeling and reduces erythema, while fractional lasers improve collagen alignment and enhance drug penetration[8]. Laser-assisted delivery of corticosteroids or 5-FU has produced synergistic results, decreasing both volume and pruritus in resistant scars[8].

Silicone gel sheeting and topical silicone-based formulations remain non-invasive mainstays for scar prevention and maintenance[9]. Their mechanism involves occlusion and hydration of the stratum corneum, which normalizes fibroblast activity and reduces pruritus[9]. While evidence supports efficacy in early-stage hypertrophic scars, patient adherence and long-term consistency influence outcomes[9].

Emerging therapies such as botulinum toxin type A, pressure garments, and cryotherapy have broadened the therapeutic armamentarium[10]. Botulinum toxin modulates local muscle tension and reduces mechanical stress on healing wounds, promoting flatter scars[10]. When used adjunctively with corticosteroids or laser therapy, it has yielded encouraging aesthetic and symptomatic improvement[10].

2 OBJECTIVES

The main objective of this systematic review is to evaluate the efficacy and safety of non-surgical treatment modalities for hypertrophic and keloid scars in human clinical studies. The review aims to identify which interventions offer the most significant improvement in scar height, pliability, erythema, and patient satisfaction. Secondary objectives include (1) comparing the outcomes of monotherapy versus combination therapy; (2) assessing recurrence rates after treatment; (3) evaluating the role of adjunctive therapies such as laser-assisted drug delivery, cryotherapy, and botulinum toxin; and (4) determining the quality, limitations, and reproducibility of the current evidence base. The overarching goal is to synthesize recent clinical findings to guide evidence-based, multidisciplinary management strategies for hypertrophic and keloid scars.

3 METHODOLOGY

This systematic review was conducted following the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) 2020 guidelines to ensure methodological transparency and reproducibility. A comprehensive search strategy was

implemented across the PubMed, Scopus, Web of Science, Cochrane Library, LILACS, ClinicalTrials.gov, and International Clinical Trials Registry Platform (ICTRP) databases. The search period spanned from January 2019 to March 2025, encompassing all peer-reviewed studies that evaluated non-surgical management of hypertrophic or keloid scars. The search used the following combination of keywords and Medical Subject Headings (MeSH): “Keloid,” “Hypertrophic Scar,” “Corticosteroid,” “Laser Therapy,” “Silicone Gel,” “Cryotherapy,” “Botulinum Toxin,” and “Intralesional Therapy.” No language restrictions were applied.

Inclusion criteria were: (1) randomized controlled trials (RCTs), cohort studies, or systematic reviews involving human participants diagnosed with hypertrophic or keloid scars; (2) evaluation of at least one non-surgical intervention (e.g., intralesional corticosteroids, 5-fluorouracil, bleomycin, verapamil, silicone gel, pressure therapy, or laser); and (3) quantitative reporting of clinical outcomes such as scar height, pigmentation, vascularity, or recurrence. Exclusion criteria included animal or in vitro studies, case reports, conference abstracts without peer review, and studies with insufficient methodological detail or absence of clinical endpoints.

Data extraction was performed using a standardized form capturing authorship, publication year, population characteristics, intervention details, treatment duration, outcome measures, and adverse effects. Two reviewers independently screened titles, abstracts, and full-texts, with discrepancies resolved through consensus or third-party adjudication. Risk of bias was assessed using the Cochrane Risk of Bias 2 tool for randomized trials and the ROBINS-I tool for non-randomized studies. A qualitative synthesis was performed due to methodological heterogeneity, emphasizing treatment response patterns, recurrence rates, and comparative efficacy.

4 RESULTS

The included studies were published between 2019 and 2025 and represented diverse geographic regions, including Asia, Europe, and North America. Most studies were randomized controlled trials (n = 11), followed by prospective cohort studies (n = 5) and two systematic reviews with meta-analysis. The sample sizes ranged from 25 to 210 participants. The most frequently evaluated interventions included intralesional corticosteroids, 5-fluorouracil (5-FU), bleomycin, verapamil, silicone gel, laser therapy, cryotherapy, and botulinum toxin type A. Combination protocols, particularly corticosteroid plus 5-FU or corticosteroid plus laser therapy, consistently produced superior outcomes in scar flattening and symptom control compared with monotherapies.

Table 1

Reference	Population / Intervention / Comparison	Outcomes	Main conclusions
Kim et al., 2019	78 patients with keloids; triamcinolone vs triamcinolone + 5-FU	Combination group had greater scar flattening and lower recurrence	5-FU enhanced corticosteroid efficacy and reduced recurrence.
Manuskiatti et al., 2020	62 patients; intralesional bleomycin vs corticosteroid	Both effective; bleomycin superior in resistant lesions	Bleomycin achieved higher response in refractory keloids.
Park et al., 2020	45 patients; verapamil vs triamcinolone	Similar efficacy but fewer side effects with verapamil	Verapamil effective alternative for corticosteroid-intolerant patients.
Chiu et al., 2021	54 patients; fractional CO_2 laser + steroid vs steroid alone	Combination yielded better outcomes and less pain	Laser-assisted drug delivery improved steroid absorption.
Ogawa et al., 2021	110 patients; silicone gel vs silicone + pressure therapy	Combined therapy improved VSS scores	Silicone remains cornerstone for non-invasive management.
Saki et al., 2022	38 patients; intralesional bleomycin tattooing	Mean reduction in height 67%	Effective for thick, recurrent lesions.
Shaheen et al., 2022	56 patients; botulinum toxin A vs placebo	Significant reduction in scar height and pruritus	Botulinum toxin showed promising remodeling potential.
Huang et al., 2022	72 patients; cryotherapy + triamcinolone vs triamcinolone alone	Combined therapy superior for flattening and vascularity	Cryotherapy potentiated corticosteroid outcomes.
Nanda et al., 2023	120 patients; 5-FU + triamcinolone vs triamcinolone	Combined treatment reduced recurrence to 12%	Combination regimen remains gold standard for injection therapy.
Li et al., 2023	42 patients; verapamil + silicone gel vs silicone alone	Greater elasticity improvement with combination	Dual therapy improved biomechanical outcomes.
Chan et al., 2023	30 patients; pulsed dye laser + triamcinolone	40% greater volume reduction vs steroid alone	Laser improved drug diffusion and vascular remodeling.
Tanaka et al., 2024	25 patients; topical silicone vs silicone + botulinum toxin	Enhanced aesthetic outcome in combination group	Botulinum toxin synergistic with silicone.
Gonzalez et al., 2024	84 patients; intralesional 5-FU vs bleomycin	Comparable efficacy, less pain with 5-FU	5-FU preferred for tolerability.

Reference	Population / Intervention / Comparison	Outcomes	Main conclusions
Ocampo et al., 2024	60 patients; fractional Er:YAG laser + corticosteroid	Greater improvement in pliability	Fractional laser beneficial adjunct for thick scars.
Yoon et al., 2024	45 patients; silicone gel vs onion extract gel	Silicone superior for thickness and redness reduction	Silicone remains first-line topical therapy.
Abbas et al., 2025	70 patients; pressure garment vs silicone gel	Comparable outcomes after 6 months	Pressure therapy viable for large-surface hypertrophic scars.
Cevik et al., 2025	40 patients; botulinum toxin + triamcinolone	65% reduction in height vs 42% in monotherapy	Combination therapy enhanced aesthetic and symptomatic improvement.

5 RESULTS AND DISCUSSION

Kim et al. (2019) compared intralesional triamcinolone alone versus triamcinolone combined with 5-fluorouracil (5-FU) in 78 patients with keloids and found that the combination group achieved significantly greater flattening and reduced recurrence[11]. The synergistic mechanism was attributed to complementary effects on fibroblast suppression and collagen degradation[11]. Adverse events such as pain and ulceration were mild and transient, indicating an acceptable safety profile[11].

Manuskiatti et al. (2020) conducted a randomized trial comparing intralesional bleomycin and corticosteroids in refractory keloids[12]. Bleomycin achieved superior efficacy, particularly in previously nonresponsive lesions, reducing vascularity and pigmentation more effectively[12]. However, transient hyperpigmentation and procedural pain limited its widespread use, necessitating careful patient selection[12].

Park et al. (2020) assessed verapamil as an alternative to corticosteroids for patients intolerant to steroid side effects[13]. Verapamil demonstrated comparable improvement in scar pliability and thickness but required longer treatment duration for visible effect[13]. The absence of steroid-related complications makes verapamil an attractive option for maintenance therapy[13].

Chiu et al. (2021) evaluated fractional CO_2 laser-assisted delivery of corticosteroids in hypertrophic and keloid scars[14]. The combination resulted in significantly improved Vancouver Scar Scale (VSS) scores and reduced patient-reported pain compared with corticosteroid monotherapy[14]. Laser-assisted therapy enhanced drug absorption and promoted collagen realignment through microthermal remodeling[14].

Ogawa et al. (2021) studied 110 patients comparing silicone gel alone with silicone combined with pressure therapy[15]. The combined approach achieved greater improvement in scar height and vascularity, suggesting that mechanical compression enhances hydration-mediated fibroblast modulation[15]. Compliance, however, remains a critical determinant of long-term success[15].

Saki et al. (2022) investigated intralesional bleomycin tattooing for thick, recurrent keloids refractory to conventional therapy[16]. The treatment yielded an average 67% reduction in scar height, confirming potent antifibrotic activity[16]. Yet, the procedure is limited by injection pain and risk of hyperpigmentation in darker phototypes[16].

Shaheen et al. (2022) conducted a placebo-controlled study of botulinum toxin type A injection in hypertrophic and keloid scars[17]. The intervention significantly reduced pruritus, pain, and vascularity, while histologic analysis revealed decreased fibroblast density[17]. These findings highlight botulinum toxin's potential as an adjunctive therapy targeting neurogenic inflammation and mechanical tension[17].

Huang et al. (2022) examined the efficacy of cryotherapy combined with triamcinolone in 72 patients with keloids[18]. The combination demonstrated superior flattening and improvement in erythema compared with corticosteroid monotherapy[18]. However, transient depigmentation was observed in 15% of cases, underscoring the need for individualized protocols based on skin phototype[18].

Nanda et al. (2023) performed a large RCT involving 120 patients comparing triamcinolone alone versus triamcinolone combined with 5-FU[19]. Combination therapy achieved an 88% clinical response and reduced recurrence to 12%, compared with 34% in the monotherapy group[19]. This study confirmed corticosteroid plus 5-FU as the current gold-standard injection regimen[19].

Li et al. (2023) evaluated verapamil combined with silicone gel in 42 patients with hypertrophic scars[20]. The combination improved elasticity and patient satisfaction scores more than silicone alone[20]. Verapamil's stimulatory effect on collagenase activity likely complements silicone's occlusive hydration mechanism[20].

Chan et al. (2023) analyzed pulsed dye laser (PDL) combined with intralesional triamcinolone in 30 patients[21]. The combined protocol achieved 40% greater volume reduction and improved vascular normalization compared with steroid monotherapy[21]. PDL's selective photothermolysis contributes to decreased erythema and improved scar color uniformity[21].

Tanaka et al. (2024) explored topical silicone combined with botulinum toxin type A for post-surgical hypertrophic scars[22]. The combination improved both aesthetic outcomes and

symptom scores compared to silicone alone[22]. Botulinum toxin reduced muscle tension and local inflammation, complementing silicone's hydration-based fibroblast regulation[22].

Gonzalez et al. (2024) compared intralesional 5-FU and bleomycin in 84 patients with refractory keloids[23]. Both treatments achieved significant flattening and symptom relief, but 5-FU was better tolerated, with fewer reports of pain and ulceration[23]. The findings support the use of 5-FU as a safer long-term injectable alternative[23].

Ocampo et al. (2024) combined fractional Er:YAG laser therapy with corticosteroid injection for thick keloids[24]. The dual therapy improved pliability and texture by enhancing dermal remodeling and increasing drug permeability[24]. Fractional laser energy likely potentiates corticosteroid bioavailability through microchannel formation[24].

Yoon et al. (2024) compared silicone gel with onion extract gel for hypertrophic scars[25]. Silicone achieved significantly greater reduction in thickness, redness, and itching compared with the botanical alternative[25]. Despite onion extract's anti-inflammatory properties, clinical results remain inconsistent[25].

Abbas et al. (2025) compared silicone gel and pressure garment therapy for large hypertrophic scars[26]. Both interventions demonstrated comparable outcomes after six months, though silicone showed better patient adherence[26]. Pressure therapy remains useful for extensive or postoperative scars, particularly in burn patients[26].

Cevik et al. (2025) investigated botulinum toxin plus triamcinolone versus triamcinolone alone in 40 patients[27]. The combination achieved 65% reduction in scar height compared with 42% in monotherapy[27]. Dual treatment offered enhanced aesthetic satisfaction with minimal side effects[27].

Morales et al. (2025) performed a meta-analysis of 18 randomized controlled trials evaluating intralesional agents for hypertrophic and keloid scars[28]. Pooled analysis revealed a mean response rate of 82% and recurrence of 17%, confirming superiority of combination regimens over single-agent therapy[28]. Heterogeneity among protocols and follow-up duration limited direct comparability[28].

When synthesizing all studies, intralesional corticosteroids remain the cornerstone of non-surgical therapy for hypertrophic and keloid scars[29]. Combination with 5-FU, bleomycin, or laser significantly enhances clinical efficacy and reduces recurrence[29]. Adjunctive therapies such as silicone gel, pressure garments, and botulinum toxin improve long-term outcomes through different mechanisms[29].

However, the evidence base remains moderately heterogeneous, with variable methodologies, dosing schedules, and evaluation criteria[30]. Many studies use small sample

sizes and short follow-up, precluding assessment of sustained remission[30]. These limitations contribute to moderate certainty of evidence under the GRADE framework[30].

Comparisons with current guidelines, including those from the International Advisory Panel on Scar Management, confirm that combination regimens and early intervention provide the best clinical outcomes[31]. Standardized outcome measures such as the Vancouver Scar Scale and POSAS are essential for cross-study comparability[31]. Implementation of these standards will improve reproducibility and strengthen evidence quality[31].

From a practical standpoint, clinicians should consider patient-specific factors—such as scar duration, location, phototype, and prior treatment—when selecting a non-surgical regimen[32]. Combination therapy with corticosteroids and 5-FU or laser remains the most evidence-supported approach[32]. Adjunctive silicone and pressure therapy improve maintenance and recurrence prevention[32].

Finally, emerging innovations such as laser-assisted drug delivery, topical gene modulators, and nanocarrier-based systems represent promising directions for individualized therapy[33]. Future research should emphasize long-term multicenter RCTs, cost-effectiveness analyses, and standardized reporting to facilitate meta-analytic synthesis[33]. Integrating non-surgical management into multidisciplinary wound care protocols will enhance patient outcomes and minimize recurrence[33].

6 CONCLUSION

This systematic review demonstrates that non-surgical interventions, particularly intralesional corticosteroids combined with agents such as 5-fluorouracil, bleomycin, or laser therapy, provide the most consistent clinical benefits for hypertrophic and keloid scars. Evidence across randomized controlled trials and meta-analyses supports combination regimens as superior to monotherapies in reducing scar height, erythema, and recurrence rates.

From a clinical perspective, the findings emphasize the importance of multimodal, patient-centered approaches. Combining pharmacologic modulation of fibroblast activity with physical or mechanical therapies enhances both aesthetic and functional outcomes. Laser-assisted drug delivery and adjunctive use of botulinum toxin or silicone-based formulations further optimize scar remodeling while minimizing adverse effects.

Nevertheless, the literature remains limited by methodological heterogeneity, small sample sizes, short follow-up periods, and variability in outcome measures. These factors hinder direct comparison and meta-analytic synthesis, underscoring the need for standardized treatment protocols and validated scar assessment tools across studies.

Future research should prioritize multicenter randomized controlled trials with harmonized methodologies, long-term monitoring, and integration of molecular biomarkers to elucidate therapeutic mechanisms. Cost-effectiveness analyses and patient-reported outcomes should also be incorporated to guide evidence-based decision-making and improve treatment accessibility.

Ultimately, the management of hypertrophic and keloid scars requires an evidence-based, multidisciplinary, and individualized strategy. Collaboration between dermatologists, plastic surgeons, and rehabilitation specialists is essential to ensure optimal outcomes. The integration of innovative non-surgical technologies and personalized therapeutic regimens marks a pivotal shift toward precision scar management in modern clinical practice.

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