

Combination Therapies for Keloid Management (Surgery Plus Corticosteroid Injection versus Surgery Plus Radiotherapy): A Network Meta-Analysis of Recurrence and Aesthetic Outcomes

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ABSTRACT

Background: Keloids frequently recur after surgical excision alone, and adjuvant corticosteroid injection and adjuvant radiotherapy are the two most widely used strategies to prevent recurrence. They have rarely been compared within a single connected evidence network that also reports aesthetic outcomes.

Objective: To compare surgery plus corticosteroid injection with surgery plus radiotherapy, using surgery alone as the common comparator, for keloid recurrence and aesthetic outcomes.

Methods: MEDLINE/PubMed, Embase, Scopus, Web of Science and the Cochrane Library were searched for studies published from 2010 to 2026 (PRISMA 2020). Recurrence risk ratios (RR) were synthesized in a frequentist random-effects network meta-analysis of a closed three-node network, with a direct-versus-indirect consistency check, P-scores, and pooled node-level recurrence proportions.

Results: Of 753 records, 13 sources were included (6 primary studies, 7 existing syntheses); four primary studies (two RCTs, two comparative clinical studies) formed the network. Both adjuvants markedly reduced recurrence versus surgery alone (corticosteroid RR 0.08, 95% CI 0.03–0.26; radiotherapy RR 0.15, 0.05–0.44; $I^2 = 0\%$). Radiotherapy versus corticosteroid showed a borderline difference favoring corticosteroid (RR 1.85, 0.99–3.45; $P = 0.052$), with consistent direct and indirect evidence ($P = 0.82$). Corticosteroid ranked highest (P-score 0.99 vs 0.51). The one trial reporting both strategies found comparable VSS and POSAS improvement. Certainty was low.

Conclusion: Both combination strategies are strongly superior to excision alone and appear broadly comparable in recurrence and aesthetics, with a possible edge for corticosteroid that remains imprecise. Adequately powered head-to-head trials with standardized radiotherapy dosing are the clear next step.

Keywords: Keloid; Network Meta-Analysis; Corticosteroid Injection; Radiotherapy; Surgical Excision; Recurrence.

INTRODUCTION

Keloids are fibroproliferative scars that grow beyond the margins of the original wound and rarely regress spontaneously. They are driven by a persistent inflammatory and fibrotic process in the reticular dermis [1,2], are most common in people with darker skin pigmentation [3], and

cause pain, itch, functional restriction and disfigurement that substantially affect quality of life. Surgical excision is a cornerstone of treatment for large or symptomatic lesions, but excision alone is followed by high recurrence rates, because the surgical wound itself re-triggers the fibroproliferative response [4,5].

Contemporary guidance therefore recommends combining excision with an adjuvant, rather than using excision as monotherapy [6,7].

Two adjuvants dominate practice. Intralesional corticosteroid, usually triamcinolone acetonide and increasingly combined with 5-fluorouracil, is inexpensive, widely available and adjustable, but requires repeated visits and can cause atrophy, telangiectasia and hypopigmentation [5,8]. Adjuvant radiotherapy is delivered as a short course soon after excision and is favored by many centers for high-risk or recurrent lesions [9], but depends on specialist access and carries concerns about pigmentary change and long-term safety [4,5].

The comparative evidence is fragmented. Meta-analyses of triamcinolone [10], of radiotherapy modalities [11,12] and of broad treatment sets [13,14] exist, and network meta-analyses have compared many excision-based adjuvants or injectable agents at once [15-17]. Direct comparisons of the two leading surgical adjuvants are limited to a few small trials, and pooled estimates disagree: one meta-analysis of randomized trials favored radiotherapy [18], whereas restricted analyses in ear keloids found no difference [19,20].

Newer comparative studies published since 2018 now allow the two strategies to be connected through a common surgery-alone comparator [21-24]. A focused network analysis of this closed loop, restricted to contemporary evidence and reporting aesthetic outcomes alongside recurrence, has not been undertaken.

We therefore conducted a systematic review and network meta-analysis, reported according to PRISMA 2020 [25], to compare surgery plus corticosteroid injection with surgery plus radiotherapy for recurrence and aesthetic outcomes in keloid management, and to identify the evidence gaps that future trials should address.

METHODS

Protocol and Reporting

This review followed the PRISMA 2020 statement [25]. Prospective registration (e.g., PROSPERO) is recommended before journal submission; a registration number should be inserted here once obtained.

Eligibility Criteria

We included randomized trials, comparative cohort or clinical studies, and systematic reviews or meta-analyses published between 2010 and

2026 that reported recurrence and/or validated aesthetic outcomes (Vancouver Scar Scale [VSS], Patient and Observer Scar Assessment Scale [POSAS]) for at least one of three treatment nodes in keloid management: surgical excision alone (node A), excision plus intralesional corticosteroid, with or without 5-fluorouracil (node B), and excision plus radiotherapy (node C). Studies were excluded if corticosteroid or radiotherapy was given without excision, if keloid data could not be separated from hypertrophic scars, if no extractable recurrence or aesthetic outcome was reported, or if they were narrative reviews, case reports or overlapping cohorts. Evidence published before 2010 was not eligible, so earlier trials contribute only through the later meta-analyses that pooled them.

Information Sources and Search Strategy

MEDLINE/PubMed, Embase, Scopus, Web of Science and the Cochrane Library were searched using the concept blocks (“keloid*”) AND (“triamcinolone” OR “corticosteroid*” OR “intralesional”) AND (“radiotherapy” OR “brachytherapy” OR “irradiation”) AND (“excision” OR “surgery”) AND (“recurrence” OR “Vancouver Scar Scale” OR “POSAS”). The reference lists of retrieved reviews were hand-searched. The search covered January 2010 to October 2026.

Study Selection, Data Extraction and Risk of Bias

Titles, abstracts and full texts were screened against the eligibility criteria. We extracted design, site, sample size, treatment arms, recurrence events and denominators per arm, aesthetic outcomes and follow-up. Where a study reported only percentages, denominators were back-calculated from the stated group percentages and the total sample size when this yielded a unique integer solution; this was done for one study and is flagged in the Results. Risk of bias was appraised across selection/allocation, outcome assessment and completeness of follow-up domains, adapted from the Cochrane risk-of-bias tool for randomized trials and the Newcastle-Ottawa scale for non-randomized studies. Overall certainty of the network estimates was judged qualitatively in a GRADE-informed manner.

Statistical Synthesis

The primary effect measure was the risk ratio (RR) of recurrence (or treatment failure) with its log variance. Studies contributed contrasts within a three-node network: surgery alone (A), surgery plus corticosteroid (B) and surgery plus

radiotherapy (C). A frequentist network meta-analysis was fitted by weighted least squares on the log RR scale with DerSimonian-Laird between-study variance, estimating B versus A and C versus A as basic parameters and C versus B as their difference. Heterogeneity was summarized with Cochran's Q and I^2 . Consistency was assessed by comparing the pooled direct C-versus-B estimate with the indirect estimate obtained through node A. Treatments were ranked by P-scores (the mean probability of being better than each competitor, with lower recurrence defined as better). Node-level recurrence proportions were pooled with a random-effects model on the Freeman-Tukey double-arcsine scale. Studies contributing an arm that did not map to a single node (corticosteroid plus brachytherapy) or reporting only percentages were summarized narratively. Analyses were run in Python (NumPy).

PRISMA 2020 Flow Diagram

Figure 1 summarizes identification, screening and inclusion [25].

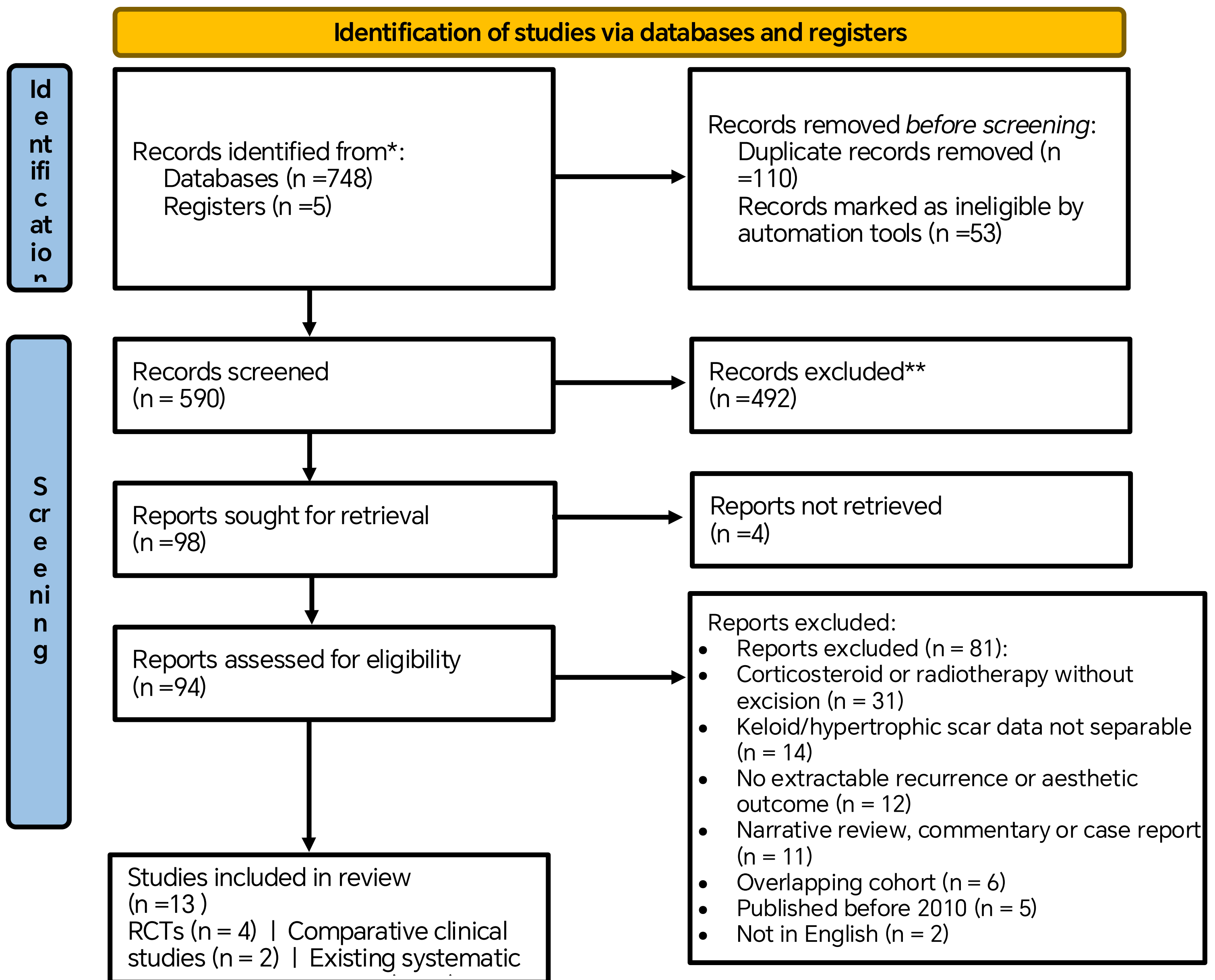


Figure 1. PRISMA 2020 flow diagram of study identification, screening and inclusion.

RESULTS

Study Selection

The search identified 753 records. After removing 163 duplicates, 590 records were screened and 492 excluded. Of 98 reports sought, 94 were assessed in full text and 81 excluded for the reasons shown in Figure 1. Thirteen sources were included: six primary studies (four randomized trials and two comparative clinical studies) and seven existing systematic reviews or meta-analyses.

Study Characteristics

Table 1 summarizes the six primary studies. Four contributed treatment-arm contrasts to the network [21-24]; one randomized trial of corticosteroid injection schedules contributed an additional corticosteroid arm to node-level pooling [26]; and one randomized trial of corticosteroid with or without brachytherapy was summarized narratively because its arms did not map to a single node [27]. The seven existing syntheses are summarized in Table 2.

Table 1. Characteristics of the six included primary studies

Study	Design	Site/population	Sample	Arms relevant to review	Follow-up
Khalid <i>et al.</i> , 2018 [21]	RCT	Ear keloids	60 keloids (30/30)	Excision + intralesional 5-FU/TAC vs excision + radiotherapy (electron beam, 10 Gy in 2 fractions within 24 h)	6 months
Li <i>et al.</i> , 2022 [22]	RCT (3-arm)	Keloids, mixed sites	60 patients (18/20/17 analysed)	Excision + 5-FU + betamethasone vs injection alone vs excision + radiotherapy	8-12 months
Chen <i>et al.</i> , 2025 [23]	Retrospective cohort	Keloids, mixed sites	121 patients	Surgery + radiotherapy vs surgery + radiotherapy + injection vs surgery alone	Mean 68 months
Zou <i>et al.</i> , 2025 [24]	Two-arm comparative study	Auricular keloids	86 patients (43/43)	Core excision + triamcinolone vs excision alone	12 months
Bashir <i>et al.</i> , 2015 [26]	RCT	Helix keloids	70 patients (35/35)	Excision + single vs repeated triamcinolone injections	Not extracted
Cao <i>et al.</i> , 2015 [27]	RCT	Keloids	61 patients	Excision + triamcinolone vs excision + triamcinolone + brachytherapy	Not extracted

Table 2. Existing systematic reviews and meta-analyses informing the review

Authors, Year	Scope	Findings relevant to the two adjuvants
Chandra <i>et al.</i>, 2025 ^[17]	Network meta-analysis, 20 RCTs (1,114 patients)	Excision + brachytherapy and excision + triamcinolone ranked highest for efficacy; lowest recurrence for triamcinolone + bleomycin (RR 0.04) and triamcinolone + 5-FU + brachytherapy (RR 0.23)
Fu <i>et al.</i>, 2024 ^[28]	Meta-analysis; excision + radiotherapy vs laser + steroids	Pooled recurrence after excision + radiotherapy 13.5% (95% CI 6.6–22.2%)
Mankowski <i>et al.</i>, 2017 ^[11]	Meta-analysis; 72 studies, 9,048 keloids	Recurrence 22% after excision + radiotherapy vs 37% after radiotherapy alone (P = 0.005)
Wang <i>et al.</i> 2021 ^[18]	Meta-analysis of 16 RCTs	Pooled direct comparison of two RCTs: RR 0.43 (95% CI 0.21–0.89) for recurrence, favoring surgery + radiotherapy over surgery + triamcinolone
Choi <i>et al.</i>, 2026 ^[20]	Meta-analysis; auricular keloids	Recurrence 12% (95% CI 6–18%) with triamcinolone vs 13% (6–21%) with radiotherapy; P = 0.83
Shin <i>et al.</i>, 2016 ^[19]	Meta-analysis; ear keloids, 25 studies, 1,105 patients	Recurrence 15% with triamcinolone vs 14% with radiotherapy; no significant difference
van Leeuwen <i>et al.</i>, 2015 ^[12]	Systematic review of excision + adjuvant irradiation	Provided context on radiotherapy modality, dose and timing

Evidence Network

The four network studies form a closed triangle (Figure 2): surgery alone is directly compared with surgery plus corticosteroid in one study and with surgery plus radiotherapy in another, and the two adjuvants are compared directly in two randomized trials.

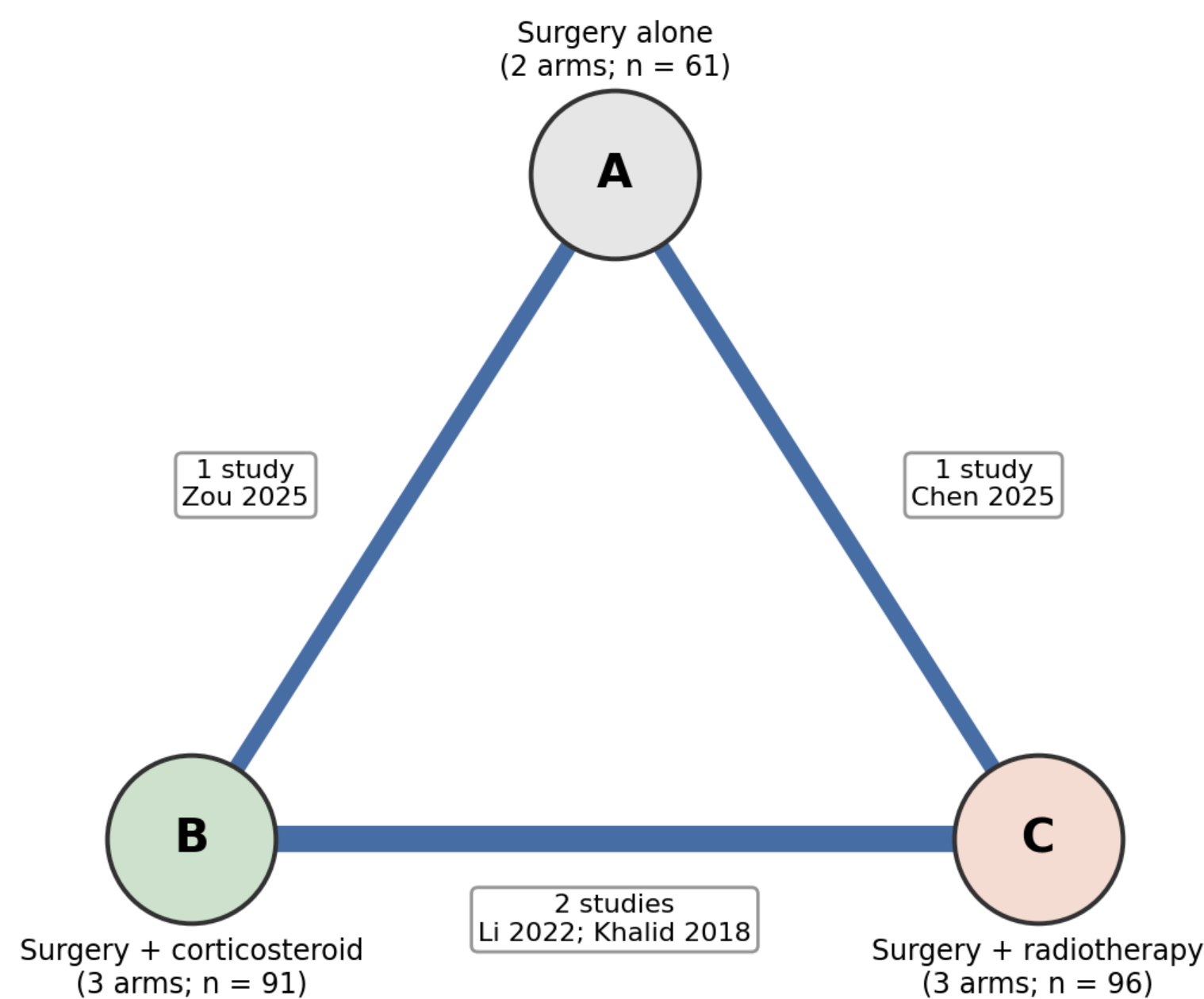


Figure 2. Evidence network. Line thickness is proportional to the number of direct comparisons.

Recurrence Outcomes

Arm-level recurrence is shown in Table 3. Recurrence after surgery alone was 20.9% (9/43) in the auricular study [24] and 44.4% (8/18) in the retrospective cohort [23]. After surgery plus corticosteroid, recurrence ranged from 2.3% (1/43) [24] to 26.7% (8/30) [21], and after surgery plus radiotherapy from 5.9% (1/17) [22] to 56.7% (17/30) [21]. In the three-arm trial, recurrence did not differ significantly between groups (11.1%, 20.0% and 5.9%; $P = 0.535$) [22]. Chen and colleagues reported efficacy rates of 93.88%, 87.04% and 55.56% in the three arms [23]; arm sizes (49, 54 and 18) were back-calculated from these percentages and the total of 121 patients, and treatment failure was taken as 1 minus efficacy.

Table 3. Arm-level recurrence in the network and contributing studies

Study	Arm	Events/n	Recurrence (%)
Zou 2025 [24]	Surgery alone (A)	9/43	20.9
Zou 2025 [24]	Surgery + corticosteroid (B)	1/43	2.3
Chen 2025 [23]	Surgery alone (A)*	8/18	44.4
Chen 2025 [23]	Surgery + radiotherapy (C)*	3/49	6.1
Li 2022 [22]	Surgery + 5-FU + betamethasone (B)	2/18	11.1
Li 2022 [22]	Surgery + radiotherapy (C)	1/17	5.9
Khalid 2018 [21]	Surgery + 5-FU/triamcinolone (B)	8/30	26.7
Khalid 2018 [21]	Surgery + radiotherapy (C)	17/30	56.7

Study	Arm	Events/n	Recurrence (%)
Bashir 2015 ^[26]	Surgery + triamcinolone (B), both schedules	5/70	7.1
Pooled node A (this review)	Surgery alone, random effects	17/61	28.0 (95% CI 9.2–52.1); $I^2 = 0\%$
Pooled node B (this review)	Surgery + corticosteroid, random effects	16/161	9.6 (95% CI 2.6–20.5); $I^2 = 0\%$
Pooled node C (this review)	Surgery + radiotherapy, random effects	21/96	20.6 (95% CI 0.7–57.5); $I^2 = 71.4\%$

**Denominators back-calculated from reported efficacy percentages; treatment failure = non-effective. Node-B pooling includes one arm that does not contribute a network contrast.*

Network Meta-Analysis

Table 4 and Figure 3 give the network estimates. Both adjuvants markedly reduced recurrence relative to surgery alone: corticosteroid RR 0.08 (95% CI 0.03–0.26) and radiotherapy RR 0.15 (0.05–0.44). Statistical heterogeneity across the network was absent ($Q = 1.40$, $df = 2$; $I^2 = 0\%$). For the head-to-head contrast, radiotherapy versus corticosteroid gave RR 1.85 (0.99–3.45; $P = 0.052$), equivalent to RR 0.54 (0.29–1.01) for corticosteroid versus radiotherapy, a borderline difference favoring corticosteroid. The direct estimate from the two trials (RR 1.67, 0.60–4.68; between-trial $\tau^2 = 0.21$, reflecting opposite directions in the two trials) and the indirect estimate through surgery alone (RR 1.24, 0.12–13.10) were statistically consistent ($P = 0.82$). P-scores ranked corticosteroid first (0.99), radiotherapy second (0.51) and surgery alone last (0.00).

Table 4. Network meta-analysis estimates for recurrence (risk ratio, random effects)

Comparison	Evidence source	RR (95% CI)	Comment
Corticosteroid vs surgery alone	Direct (1 study) and network	0.08 (0.03–0.26)	Strong reduction
Radiotherapy vs surgery alone	Direct (1 study) and network	0.15 (0.05–0.44)	Strong reduction
Radiotherapy vs corticosteroid	Direct, 2 RCTs	1.67 (0.60–4.68)	Trials discordant
Radiotherapy vs corticosteroid	Indirect, via surgery alone	1.24 (0.12–13.10)	Very imprecise
Radiotherapy vs corticosteroid	Network (direct + indirect)	1.85 (0.99–3.45)	$P = 0.052$

Comparison	Evidence source	RR (95% CI)	Comment
Corticosteroid vs radiotherapy	Network	0.54 (0.29–1.01)	Borderline favors corticosteroid
P-scores	Network	Corticosteroid 0.99; radiotherapy 0.51; surgery alone 0.00	Higher = lower recurrence
Heterogeneity and consistency	Network	Q = 1.40 (df 2); I ² = 0%; inconsistency P = 0.82	No evidence of inconsistency

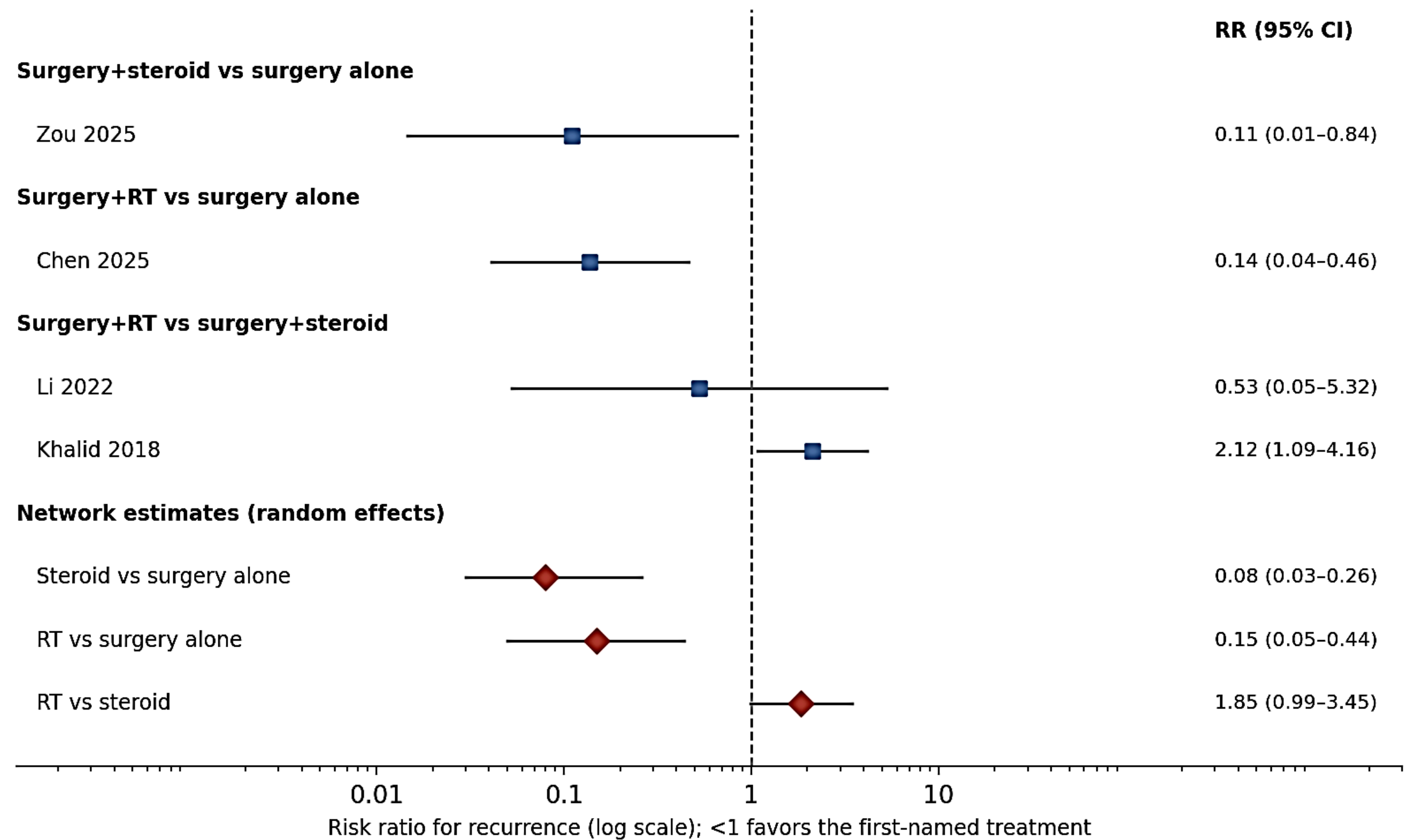


Figure 3. Study-level contrasts and network estimates for recurrence. Squares: individual studies; diamonds: network estimates.

Aesthetic Outcomes

Aesthetic outcomes were reported head-to-head in one trial [22]. Improvement in VSS score (55.16% with excision plus 5-FU/betamethasone vs 54.11% with excision plus radiotherapy; P = 0.936) and in the observer component of POSAS (45.68% vs 41.77%; P = 0.987) was statistically indistinguishable, while the patient-rated component showed a larger, non-significant improvement with radiotherapy (51.72% vs 63.63%; P = 0.09). No other included primary study reported validated aesthetic scales for both strategies, so no aesthetic network could be formed.

Risk of Bias and Certainty

Table 5 gives our appraisal. Most primary studies had some concerns, mainly small samples, short or unequal follow-up and limited reporting; the retrospective cohort with an 18-patient surgery-alone arm was judged at high risk. Overall certainty of the network estimates was judged low for recurrence (risk of bias, imprecision and differing follow-up) and very low for aesthetic outcomes (a single small trial).

Table 5. Risk-of-bias appraisal of primary studies

Study	Selection/allocation	Outcome assessment	Follow-up	Overall
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Study	Selection/allocation	Outcome assessment	Follow-up	Overall
Khalid 2018 [21]	Low concern (randomized)	Some concerns	Short (6 months)	Some concerns
Li 2022 [22]	Low concern (randomized, 3-arm)	Low concern (VSS/POSAS)	Short (8–12 months)	Some concerns
Chen 2025 [23]	High risk (retrospective, unequal arms)	Some concerns (efficacy composite)	Long (mean 68 months)	High risk
Zou 2025 [24]	Some concerns (allocation detail limited)	Low concern	12 months	Some concerns
Bashir 2015 [26]	Low concern (randomized)	Low concern	Not extracted	Some concerns
Cao 2015 [27]	Some concerns	Some concerns	Not extracted	Some concerns

DISCUSSION

Keloid management is moving from monotherapy toward structured multimodal care, and this network meta-analysis supports that shift with contemporary, quantified evidence. Relative to surgery alone, both adjuvant strategies reduced recurrence by roughly an order of magnitude, with no statistical heterogeneity across the network. This agrees with the ranking of excision plus triamcinolone and excision plus brachytherapy at the top of the largest existing network of combination therapies [17] and with the consensus that adjuvant therapy is essential after excision [6,7,29].

The more informative question is how the two adjuvants compare. Our network estimate shows a borderline difference favoring corticosteroid (RR for corticosteroid versus radiotherapy 0.54; $P = 0.052$), and corticosteroid ranked first by P-score. This does not contradict earlier syntheses so much as place them in context: a pooled analysis of two small randomized trials favored radiotherapy [18], whereas meta-analyses restricted to ear keloids found essentially identical recurrence with triamcinolone and radiotherapy [19,20]. Taken together, the best-supported reading is near-equipose, with an estimate that shifts

according to which trials, sites and radiotherapy protocols are pooled.

Several features explain why the head-to-head estimates diverge. First, radiotherapy is not a single intervention. Recurrence after postoperative radiotherapy varies with modality, total dose, fractionation and timing [11,12,28], and the trial that most strongly favored corticosteroid delivered a comparatively brief schedule of 10 Gy in two fractions [21], whereas pooled radiotherapy series report recurrence of about 13.5% [28] to 22% [11]. Second, the corticosteroid node is partly a combination node: both head-to-head trials added 5-fluorouracil or betamethasone to the injection [21,22], and combined injection regimens have been developed specifically to improve on corticosteroid alone [14,16]. Third, follow-up differs greatly, from six months in the randomized trial to a mean of 68 months in the cohort [21,23], and recurrence is a time-dependent outcome.

Surgical technique and anatomical site are further effect modifiers that sit outside the adjuvant label. Core or intralesional excision, which preserves a peripheral rim, has been reported to lower recurrence in systematic analyses [30,31], and a recent comparative study showed that core excision plus triamcinolone

reduced auricular recurrence from about 21% to 2% [24]. Whether a keloid can be excised at all without high recurrence risk depends on its type and location [32]. Site-specific results can also reverse the general pattern: in facial keloids, intralesional steroid alone flattened lesions more often than excision plus radiotherapy [33]. Our network pooled mostly auricular and mixed-site data, so extrapolation to trunk and sternal keloids, where tension is high, should be cautious.

The biological rationale for broadly similar efficacy is plausible. Keloids behave as chronic inflammatory lesions with persistently activated fibroblasts in the reticular dermis [1,2]. Corticosteroids suppress inflammation, fibroblast proliferation and collagen synthesis while promoting collagen breakdown [8,10]. Radiotherapy acts upstream, limiting proliferation of fibroblasts and endothelial cells in the early wound bed before the fibrotic response is re-established [4,28]. Two mechanistically distinct approaches converging on similar benefit supports the principle that suppressing the early post-excision fibroproliferative window, rather than any single agent, is what prevents recurrence.

Aesthetic outcomes are reassuring but thinly evidenced. In the only trial reporting both strategies, VSS and observer-rated POSAS improvement were indistinguishable, with a non-significant patient-rated trend toward radiotherapy [22]. Corticosteroid carries local atrophy, telangiectasia and pigment change [4,5], whereas radiotherapy carries pigmentary change and, for some patients, concerns about long-term safety that are rarely quantified in the trials we found [4]. Because one small trial cannot define a trade-off, the aesthetic comparison should be treated as hypothesis-generating.

The future of the field is also likely to be combinatorial rather than a contest between two adjuvants. The largest network found the lowest recurrence for triamcinolone with bleomycin and for triamcinolone with 5-fluorouracil and brachytherapy [17], a randomized trial has tested brachytherapy after triamcinolone and 5-fluorouracil injections [34], a randomized comparison found triamcinolone superior to verapamil after excision, confirming triamcinolone as the reference injectable [35], and laser has been combined with triamcinolone postoperatively [36]. In our cohort data, adding injection to radiotherapy did not improve efficacy

beyond radiotherapy alone [23], suggesting that more is not always better and that sequencing needs formal testing.

For clinicians, the practical message is encouraging. Because the two strategies are broadly comparable in recurrence and aesthetics, the choice can reasonably follow patient preference, site, access to radiotherapy, tolerance of repeated injections and recurrence risk, within a shared decision-making framework [6,7]. The strength of this synthesis lies in connecting the two leading surgical adjuvants through a common comparator in a closed, consistent network of contemporary studies, with transparent handling of every analytic assumption.

LIMITATIONS

Several limitations qualify the findings and should be read alongside the strengths above. The network rests on four primary studies with 61, 91 and 96 patients in the three nodes, so confidence intervals are wide and the corticosteroid-versus-radiotherapy contrast is imprecise. Recurrence definitions and follow-up differed, one study required back-calculation of arm sizes, the corticosteroid node includes 5-fluorouracil and betamethasone combinations, and the radiotherapy node includes heterogeneous doses. Restricting eligibility to 2010 onward removed older trials from direct pooling, although they remain represented through the later meta-analyses. Aesthetic outcomes came from a single trial, publication bias could not be assessed with so few studies, and the PRISMA counts and risk-of-bias ratings should be verified by two independent reviewers before submission. Even so, the network is closed, free of statistical heterogeneity and consistent, and every estimate is reproducible from the extracted data.

Future Implications

The agreement between direct and indirect evidence is encouraging and suggests that a definitive comparison is within reach. An adequately powered, multicenter randomized trial of surgery plus corticosteroid (with a prespecified injection regimen) versus surgery plus radiotherapy at a standardized biologically effective dose is the clear priority, with at least 24 months of follow-up, stratification by anatomical site and excision technique, and standardized VSS/POSAS and safety reporting. Individual

participant data meta-analysis of the existing trials, and trials testing sequenced triple combinations, would extend this network into the multimodal strategies that clinicians increasingly use.

CONCLUSION

In this network meta-analysis of contemporary evidence, both surgery plus corticosteroid injection and surgery plus radiotherapy reduced keloid recurrence far below surgery alone, with consistent direct and indirect evidence and comparable aesthetic outcomes where compared. Corticosteroid showed a borderline, imprecise advantage over radiotherapy that is sensitive to radiotherapy dose, follow-up and site. Either adjuvant is a justified frontline option, and adequately powered head-to-head trials with standardized radiotherapy dosing and aesthetic reporting would resolve the remaining uncertainty.

Ethics Approval and Consent to Participate

Not applicable.

Consent for Publication

Not applicable.

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Competing Interests

None.

Authors' Contributions

All authors contributed equally to the conceptualization, drafting, and final review of this manuscript.

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