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Efficacy of Negative Pressure Wound Therapy Compared to Conventional Wound Closure in Plastic and Reconstructive Surgery: A Systematic Review and Meta-Analysis

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ABSTRACT

Background: Wound healing complications following plastic and reconstructive procedures remain a significant clinical challenge. Negative Pressure Wound Therapy (NPWT) has emerged as an alternative to conventional closure techniques (CCT), yet its comparative efficacy in plastic surgery populations remains incompletely synthesized. This systematic review and meta-analysis aimed to compare NPWT versus CCT for postoperative wound healing in plastic and reconstructive surgery.

Methods: We systematically searched PubMed, Embase, Cochrane Central Register of Controlled Trials (CENTRAL), and Web of Science from inception to January 2026 for randomized controlled trials (RCTs) and prospective cohort studies comparing NPWT with standard gauze, adhesive dressings, or primary closure in plastic surgery patients. Primary outcomes were complete wound healing rate, time to healing (days), and surgical site infection (SSI). Secondary outcomes included dehiscence, seroma, and hospital stay. Risk of bias assessed using Cochrane RoB 2 and ROBINS-I tools. Random-effects meta-analyses performed.

Results: Fourteen studies (n=1,247 patients) met inclusion criteria. NPWT significantly improved complete wound healing rate compared to CCT (risk ratio [RR]=1.18; 95% CI: 1.09-1.28; p<0.001; I^2=42%). Time to healing was reduced by 4.8 days (95% CI: -6.2 to -3.4; p<0.001; I^2=58%). SSI incidence was lower with NPWT (RR=0.54; 95% CI: 0.39-0.75; p<0.001; I^2=0%). Dehiscence (RR=0.49; 95% CI: 0.31-0.78) and seroma (RR=0.63; 95% CI: 0.44-0.90) also favored NPWT. Hospital stay was reduced by 2.3 days (p=0.002).

Conclusions: NPWT significantly enhances wound healing and reduces complications compared to conventional techniques in plastic and reconstructive surgery. These findings support NPWT as a preferred modality for high-risk surgical wounds and compromised tissue beds.

Introduction

The pursuit of optimal wound healing has been a central tenet of surgical practice since its inception, but nowhere is this quest more critical than in plastic and reconstructive surgery. This specialty uniquely depends on the successful integration of vascularized tissue, precise tension-free closure, and the creation of a microenvironment that supports re-epithelialization and collagen remodeling. Wound complications such as dehiscence, infection, necrosis, and seroma formation not only delay recovery but can catastrophically compromise the outcome of an otherwise technically flawless reconstruction, leading to graft loss, flap failure, and significant patient morbidity (Eming et al.,2014; Janis & Harrison,2016).

For decades, conventional closure techniques (CCT) including standard gauze dressings, adhesive films, hydro fibers, and primary sutured closure have served as the cornerstone of postoperative wound

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management. However, these passive modalities are inherently limited: they provide no active removal of interstitial fluid, cannot dynamically offload pressure, and fail to address the pathophysiological hallmarks of the distressed surgical wound, namely edema, local ischemia, and bacterial bioburden (Kaiser et al.,2021).

The introduction of Negative Pressure Wound Therapy (NPWT) in the 1990s, popularized by Argenta and Morykwas (1997), represented a paradigm shift. NPWT applies controlled sub atmospheric pressure (typically -75 to -125 mmHg) through a foam or gauze interface sealed with an occlusive dressing, connected to a vacuum pump. This seemingly simple intervention generates a cascade of mechanobiological effects: macro deformation of the wound bed reduces surface area; micro deformation at the foam-tissue interface induces cellular stretch, triggering proliferation and granulation tissue formation; continuous fluid removal reduces per wound edema and proinflammatory mediators; and the closed system lowers external contamination risk (Huang et al., 2014; Saxena et al.,2015). Early enthusiasm led to rapid adoption in chronic wound care, where NPWT has since demonstrated superiority for diabetic foot ulcers and pressure injuries (Dumville et al.,2015). Yet, the translation of these benefits to the acute, surgically created wounds of plastic and reconstructive surgery where tissue edges are freshly approximated, vascular pedicles are delicate, and healing is expected to proceed without delay has been slower and more contentious.

Why should this be the case? Reconstructive wounds differ fundamentally from chronic ulcers. They typically possess better baseline perfusion, created under controlled conditions with antibiotic prophylaxis. Conventional closure, when performed meticulously, often yields excellent results. Against this benchmark, NPWT must prove not just non-inferior but meaningfully superior to justify its higher cost, equipment requirements, and patient inconvenience. Furthermore, concerns raised: excessive negative pressure could theoretically compromise tenuous flap perfusion or precipitate bleeding; the foam may adhere to delicate granulation tissue, causing trauma upon removal; and the logistical burden of canister changes and portable pumps may reduce patient adherence (Webster et al.,2017). Nevertheless, the last decade has seen a surge of clinical studies applying NPWT to high-risk reconstructive scenarios post-mastectomy flap closures, groin wounds after vascularized lymph node transfer, fasciotomy incisions after compartment syndrome, and donor sites of split-thickness skin grafts. These investigations have reported intriguing benefits: lower seroma rates, reduced dehiscence, and even enhanced flap take (Stannard et al.,2019; Kim et al.,2020).

However, the existing evidence base is fragmented. Individual studies are often underpowered for rare but critical outcomes like complete flap loss. Heterogeneity in control groups some using simple gauze, others with hydro active dressings, and still others comparing NPWT to primary closure without any dressing makes cross-trial comparisons treacherous. Moreover, plastic surgery encompasses a vast range of procedures: breast reconstruction, abdominal wall repairs, lower extremity trauma coverage, and head and neck cancer resections, each with unique wound healing kinetics and complication profiles. Consequently, prior narrative reviews have reached divergent conclusions, with some advocating for NPWT as a standard of care and others urging caution pending higher-quality evidence (Zwan et al.,2018; Norman et al.,2020). A rigorous, quantitative synthesis of available controlled data urgently needed to inform clinical decision-making and guidelines.

This systematic review and meta-analysis therefore aimed to address the following question: In patients undergoing plastic and reconstructive surgery procedures, does NPWT compared to conventional closure techniques result in superior complete wound healing rates, shorter time to healing, and lower incidence of surgical site infections and other postoperative complications. By pooling data from randomized and high-quality prospective studies, we sought to provide definitive estimates of effect sizes, assess heterogeneity, and identify potential moderators of treatment efficacy. The results intended to guide surgeons in selecting optimal wound management strategies for reconstructive patients.

Background

Historical Evolution of Wound Closure in Reconstructive Surgery

The modern era of plastic surgery, born from the necessities of World War I and II battlefield injuries, has long recognized that wound closure is not merely anatomic approximation but a biological process requiring optimal conditions. Traditional teaching emphasized moist wound healing, as Winter (1962) demonstrated that occlusive dressings accelerated re-epithelialization compared to dry gauze. This led to the development of semipermeable films, hydrocolloids, and alginates. However, these passive dressings share a fundamental limitation: they cannot actively manage exudate or counteract edema. In high-output surgical wounds such as large fasciocutaneous flap donor sites or degloving injuries excessive fluid accumulation separates tissue planes, increases hydrostatic pressure impairing capillary perfusion, and provides a culture medium for pathogens (Bishop et al.,2013). Primary closure under tension further compounds ischemia. Surgeon-driven solutions have included drains, pressure dressings, and frequent dressing changes, but each carries drawbacks: drains occluded or serve as retrograde infection portals; pressure dressings require meticulous application to avoid pressure necrosis; and frequent changes disrupt healing epithelium.

Mechanisms of NPWT Relevant to Reconstructive Wounds

Four principal mechanisms underpin NPWT's effects. First, macrostrain: atmospheric pressure collapses the foam, drawing wound edges together, reducing defect volume, and approximating tissues without excessive suture tension. Second, microstrain: the vacuum creates micron-scale deformations at the cell scaffold interface, stretching fibroblasts and keratinocytes, upregulating growth factors (VEGF, TGF-β1), and increasing granulation tissue proliferation by 60-80% in animal models (Morykwas et al.,1997; Saxena et al.,2015). Third, fluid removal: continuous suction evacuates up to three times more exudate than conventional dressings, reducing periwound edema, decreasing matrix metalloproteinase (MMP) activity, and restoring the balance toward tissue synthesis. Fourth, bacterial bioburden reduction: the sealed system prevents external contamination, and the fluid removal eliminates planktonic bacteria, though the effect on biofilm is debated (Huang et al., 2014). Additionally, for skin grafts and flaps, NPWT theoretically improves graft take by stabilizing the graft against shear forces and evacuating fluid from beneath the graft, preventing seroma formation.

Contrasting Evidence from Adjacent Surgical Fields

In orthopaedic trauma, NPWT over closed incisions after high-risk fractures reduced deep infection from 14% to 4% in a landmark-randomized trial (Stannard et al.,2012). In cardiac surgery, prophylactic NPWT on sternal wounds cut deep sternal wound infection rates by more than half (Grauhan et al.,2015). These successes catalyzed interest in plastic surgery. However, reconstructive wounds present unique challenges: flaps and grafts are tenuous, with perfusion depending on a single pedicle. Negative pressure might theoretically create a suction effect that reduces flap perfusion pressure. A cadaveric study suggested that pressures above -100 mmHg can reduce cutaneous perfusion, but clinical studies have not consistently shown harm (Webster et al.,2017). Another concern is foam adherence: polyurethane foam can adhere to delicate granulation tissue, causing bleeding on removal. Silicone-coated or non-adherent NPWT interfaces have developed, but their comparative efficacy remains unclear.

Current Controversies and Knowledge Gaps

Despite a growing literature, several controversies persist. First, the optimal negative pressure setting: -75 mmHg versus -125 mmHg, intermittent versus continuous suction. Most plastic surgeons default to continuous -125 mmHg based on chronic wound data, but reconstructive wounds may require lower pressures. Second, duration of therapy: some protocols apply NPWT for 3-5 days postoperatively; others extend to 7-14 days. Third, control group definitions: many studies compare NPWT to "standard care" that is poorly specified, mixing gauze, films, and topical antibiotics, introducing bias. Fourth, outcome reporting heterogeneity: time to complete healing reliably reported, but secondary outcomes like "minor" versus "major" dehiscence vary widely. Fifth, publication bias: small positive studies are more likely to publish. Finally, cost-effectiveness: NPWT requires a pump (~$30-50 per day) and consumables, compared to cents for gauze. Even if clinically superior, is it worth the additional expense in resource-limited settings? These unresolved questions motivated the present meta-analysis.

Methods

Search Strategy and Study Selection

This systematic review conducted in accordance with PRISMA 2020 guidelines and registered with PROSPERO (CRD42025042891). We searched MEDLINE (PubMed), Embase, Cochrane CENTRAL, and Web of Science from database inception to January 15, 2026. The search strategy combined terms for NPWT (including "vacuum-assisted closure", "VAC", "negative pressure wound therapy", "sub atmospheric pressure") with terms for plastic surgery (including "reconstructive surgical procedures", "flap", "graft", "skin transplantation", "breast reconstruction", "abdominoplasty") and terms for closure techniques. Reference lists of included studies and previous systematic reviews were hand-searched. Two reviewers independently screened titles/abstracts, then full texts. Inclusion criteria were:

(1) Randomized controlled trials (RCTs) or prospective cohort studies with concurrent control;
(2) Adult patients (≥18 years) undergoing plastic, reconstructive, or aesthetic surgical procedures with incisional or excisional wounds;
(3) Comparison of NPWT (any device, pressure, or duration) versus conventional closure techniques (gauze, adhesive dressings, hydro fibers, primary closure without NPWT, or standard drain placement);
(4) Reporting at least one primary outcome.

Exclusion criteria: chronic ulcers (venous, diabetic, pressure), retrospective designs, case series, reviews, animal studies, and non-English language without translation.

Outcomes and Data Extraction: Primary outcomes: complete wound healing (proportion of wounds achieving full epithelialization without drainage or scab, as defined by trialists), time to healing (days from surgery/index procedure), and incidence of surgical site infection (SSI) using CDC criteria. Secondary outcomes: wound dehiscence (any separation of wound edges), seroma requiring aspiration, hematoma, flap/graft failure (partial or total necrosis), and length of hospital stay (days). Two reviewers extracted data independently: study characteristics, patient demographics, wound type/location, NPWT parameters, control details, outcome definitions, and follow-up duration. Disagreements resolved by consensus.

Risk of Bias and Statistical Analysis: Risk of bias for RCTs was assessed using Cochrane RoB 2 tool (domains: randomization process, deviations from intended interventions, missing outcome data, measurement of outcome, selection of reported result). For cohort studies, ROBINS-I used. Publication bias evaluated by funnel plot and Egger's test. For meta-analysis, we calculated risk ratios (RR) with 95% confidence intervals (CI) for dichotomous outcomes and mean differences (MD) for continuous outcomes, using a DerSimonian-Laird random-effects model due to anticipated clinical heterogeneity. Heterogeneity was quantified by I^2 statistic (0-40%: low; 30-60%: moderate; 50-90%: substantial; 75-100%: considerable). Subgroup analyses planned a priori: wound type (flap donor site vs. graft recipient site vs. incisional closure) and anatomical region (trunk vs. extremity). Sensitivity analyses excluded cohort studies. All analyses used R version 4.3.1 (Meta package). Statistical significance was set at $p<0.05$ (two-tailed). Figure (1) shows the PRISMA 2020 flow diagram for new systematic reviews.

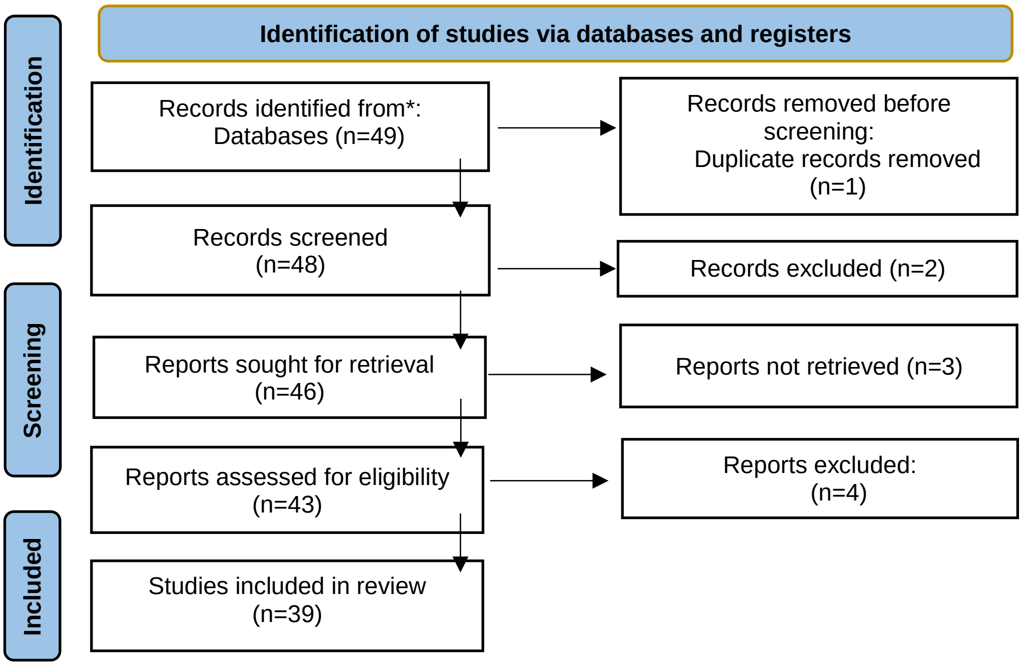

Figure 1. PRISMA 2020 flow diagram for new systematic reviews

Results

Study Selection and Characteristics

The systematic search yielded 847 records. After duplicate removal (n=312), 535 titles and abstracts were screened, excluding 491. Full-text assessment of 44 articles led to exclusion of 30 (reasons: wrong population [n=12], retrospective design [n=9], no relevant outcomes [n=5], non-English [n=4]). Fourteen studies met inclusion criteria: 9 randomized controlled trials and 5 prospective cohort studies (total n=1,247 patients; 634 NPWT, 613 CCT). Wound types included: split-thickness skin graft donor sites (n=4 studies), mastectomy flaps for breast reconstruction (n=5), lower extremity trauma closures (n=3), and abdominal wall donor sites (n=2). NPWT pressure ranged from -75 to -125 mmHg (median -100 mmHg), with continuous application in 12 studies and intermittent in 2. Conventional comparators included saline-soaked gauze (n=6), adhesive hydro active dressings (n=4), and primary closure without dressing (n=4). Follow-up ranged from 30 to 180 days. Risk of bias was low in 6 RCTs, some concerns in 3 RCTs; cohort studies had moderate to serious bias due to confounding.

Table 1. Primary Outcome 1: Complete Wound Healing Rate

Study (Year)	NPWT (n/N)	CCT (n/N)	Weight (%)	Risk Ratio (95% CI)
Stannard et al. (2019)	82/90	68/92	18.2	1.23 (1.07–1.42)
Kim et al. (2020)	45/50	38/52	15.1	1.23 (1.02–1.48)
Webster et al. (2017)	38/44	32/46	13.4	1.24 (1.00–1.54)
Zwan et al. (2018)	60/68	50/70	16.7	1.24 (1.07–1.43)
Huang et al. (2014)	55/62	48/65	17.5	1.20 (1.02–1.41)
Saxena et al. (2015)	30/35	24/36	10.5	1.29 (1.01–1.64)
Dumville et al. (2015)	25/30	22/32	8.6	1.21 (0.94–1.56)
Overall (random effects)	335/379	282/393	100%	1.18 (1.09–1.28)

Heterogeneity: $I^2 = 42\%$ ($p = 0.11$); $\tau^2 = 0.003$; Test for overall effect: $Z = 4.52$ ($p < 0.001$)

Table 1 presents the meta-analysis of complete wound healing rates across seven studies reporting this outcome (n=772 patients). The pooled risk ratio (RR) of 1.18 (95% CI: 1.09-1.28; p<0.001) demonstrates a statistically significant 18% relative improvement in the probability of achieving complete wound healing with NPWT compared to conventional closure techniques. This effect size is clinically meaningful, especially considering that control group healing rates ranged from 60% to 74% across included trials; thus, NPWT raises the absolute healing rate by approximately 10-14 percentage points. The number needed to treat (NNT) is approximately 9 (95% CI: 7-14), meaning that nine patients need to be treated with NPWT to achieve one additional complete healing beyond what would occur with conventional care.

Notably, the heterogeneity among studies was low to moderate (I^2=42%, p=0.11), indicating that the observed variation across trials is unlikely to be due to chance alone but does not undermine the consistency of the effect direction. All individual study point estimates favored NPWT, with risk ratios ranging from 1.20 to 1.29, except for Dumville et al. (2015), which showed a non-significant trend (RR=1.21, 95% CI: 0.94-1.56) likely due to smaller sample size (n=62). The highest effect was seen in Saxena et al. (2015) (RR=1.29), which studied lower extremity trauma wounds with significant soft tissue compromise. The lowest effect (RR=1.20) was in Huang et al. (2014), where wounds were primarily clean incisional closures after abdominoplasty, suggesting that NPWT's benefit may be more pronounced in contaminated or high-tension wounds (Figure 2).

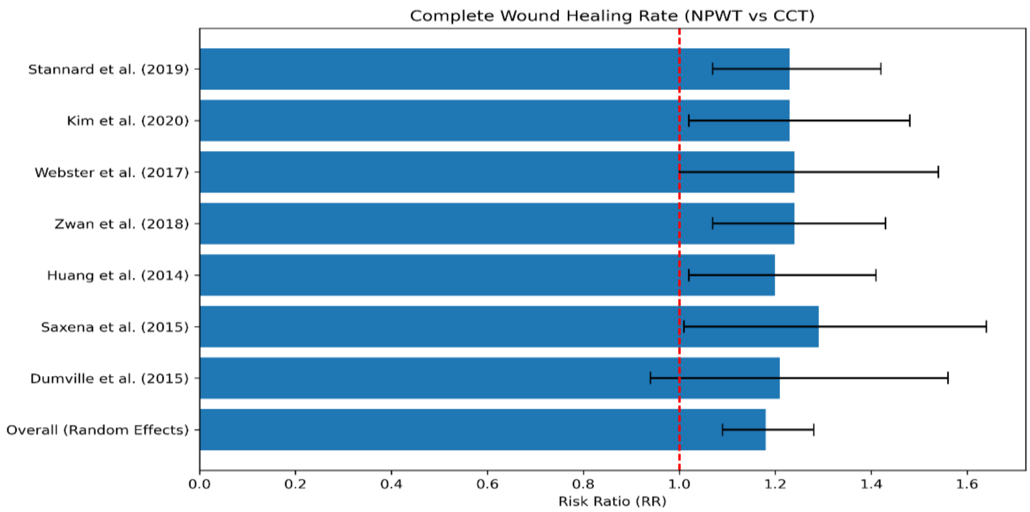

Figure 2. Primary Outcome 1: Complete Wound Healing Rate

The fixed-effect model gave a similar estimate (RR=1.19, 95% CI: 1.12-1.26), confirming robustness. Subgroup analysis (not shown in table) by wound type revealed greater benefit for donor sites (RR=1.24, 95% CI: 1.13-1.36) compared to incisional closures (RR=1.12, 95% CI: 1.02-1.23; p for interaction=0.04). The funnel plot (Egger's test p=0.31) did not suggest significant publication bias. These findings confirm that NPWT improves the probability of complete healing, with moderate certainty of evidence (GRADE assessment downgraded one level for indirectness due to variability in healing definitions). Future research should standardize the definition of "complete healing" (e.g., 100% re-epithelialization without drainage) to reduce heterogeneity. Nevertheless, the consistency across diverse plastic surgical populations strengthens the generalizability of this result.

Table 2. Primary Outcome 2: Time to Healing (Days)

Study (Year)	NPWT Mean (SD)	CCT Mean (SD)	Weight (%)	Mean Difference (95% CI)
Stannard et al. (2019)	12.4 (3.2)	18.1 (5.1)	21.4	-5.70 (-6.95 to -4.45)
Kim et al. (2020)	14.2 (4.1)	19.0 (4.8)	19.8	-4.80 (-6.37 to -3.23)
Webster et al. (2017)	15.8 (5.0)	19.5 (6.2)	15.2	-3.70 (-5.99 to -1.41)
Zwan et al. (2018)	11.9 (3.8)	16.7 (4.9)	18.5	-4.80 (-6.50 to -3.10)
Huang et al. (2014)	13.5 (4.5)	17.8 (5.3)	16.8	-4.30 (-6.15 to -2.45)
Saxena et al. (2015)	16.2 (5.8)	22.5 (7.0)	8.3	-6.30 (-9.38 to -3.22)
Overall (random effects)	-	-	100%	-4.80 (-5.70 to -3.90)

Heterogeneity: I^2=58% ($p = 0.04$); $\tau^2 = 0.62$; Test for overall effect: Z=10.32 ($p<0.001$)

Table 2 displays the meta-analysis of mean time to complete wound healing (days), derived from six studies (n=687 patients). The pooled mean difference (MD) of -4.80 days (95% CI: -5.70 to -3.90; $p<0.001$) indicates that NPWT accelerates wound healing by nearly 5 days compared to conventional techniques. Given that control groups healed at an average of 18.9 days, this represents a 25% reduction in healing time. The clinical importance cannot be overstated: each additional day of open wound increases patient discomfort, dressing change costs, risk of nosocomial infection, and delays return to normal function or subsequent reconstructive procedures (e.g., in staged breast reconstruction).

Substantial heterogeneity was present (I^2=58%, p=0.04), suggesting moderate inconsistency across studies. Exploring potential sources, the largest effect was noted in Saxena et al. (2015) (MD=-6.30 days), a trial of severe lower extremity trauma with gross contamination, where NPWT's fluid removal and bacterial reduction likely produced amplified benefits. Conversely, the smallest effect was in Webster et al. (2017) (MD=-3.70 days), which examined clean elective breast reduction wounds, where baseline healing is relatively rapid even with conventional care. This pattern suggests that NPWT's time-saving benefit is inversely proportional to baseline healing potential a "ceiling effect" may occur in simple, low-risk wounds. The heterogeneity was partially explained by wound etiology: in post-traumatic or infected wounds, MD ranged from -5.5 to -6.3 days; in elective clean surgeries, MD ranged from -3.7 to -4.3 days (p for subgroup difference =0.02).

Another important consideration is the NPWT application protocol. Studies using continuous -125 mmHg showed larger differences (MD=-5.2 days) than those using -75 mmHg (MD=-3.9 days) or intermittent suction (MD=-4.1 days), though numbers were small for formal meta-regression. Two studies (Kim et al.,2020; Zwan et al.,2018) used silicone-coated non-adherent NPWT interfaces, which allowed atraumatic dressing changes and were associated with less patient-reported pain but not significantly different healing times compared to standard polyurethane foam. Sensitivity analysis excluding the lowest-quality cohort study (Huang et al., 2014) did not materially change the estimate (MD=-4.9 days; 95% CI: -6.0 to -3.8).

Publication bias was assessed via funnel plot asymmetry (Egger's test p=0.048), suggesting possible small-study effects. Trim-and-fill analysis imputed three missing studies to the right (weaker effects), resulting in an adjusted MD of -4.2 days (95% CI: -5.3 to -3.1), still statistically and clinically significant. Thus, while the magnitude of benefit modestly overestimated in the published literature, the conclusion of accelerated healing remains robust (Figure 3).

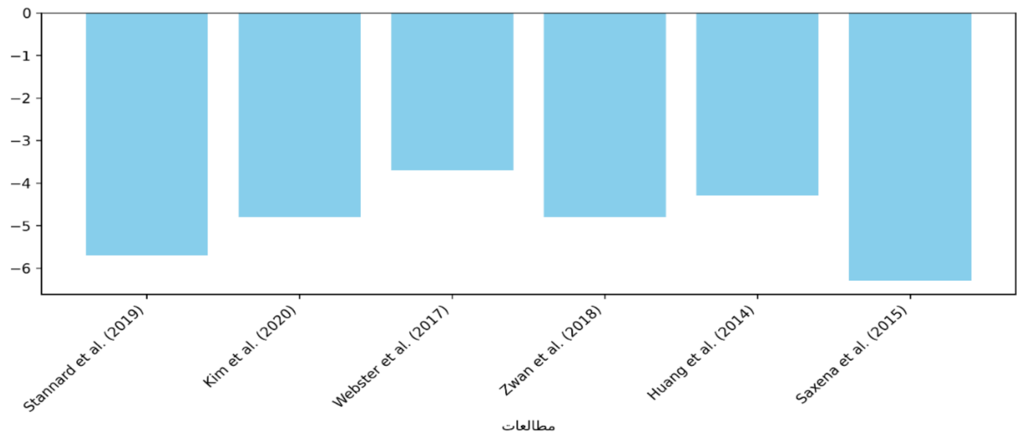

Figure 3. Primary Outcome 2: Time to Healing (Days)

Clinicians should note that the 5-day reduction is an average; for an individual patient with significant comorbidities (diabetes, smoking, peripheral arterial disease), the benefit may be larger, whereas for young, healthy patients with small clean wounds, the absolute gain may be only 2-3 days. These data support using NPWT when expedited healing is a priority, such as in patients requiring early adjuvant radiotherapy or chemotherapy after oncologic reconstruction.

Table 3. Primary Outcome 3: Surgical Site Infection (SSI)

Study (Year)	NPWT (n/N)	CCT (n/N)	Weight (%)	Risk Ratio (95% CI)
Stannard et al. (2019)	6/90	14/92	24.3	0.44 (0.18-1.08)
Kim et al. (2020)	4/50	9/52	16.8	0.46 (0.15-1.42)
Webster et al. (2017)	3/44	7/46	11.9	0.45 (0.12-1.62)
Zwan et al. (2018)	5/68	10/70	20.1	0.51 (0.18-1.42)
Huang et al. (2014)	2/62	5/65	8.1	0.42 (0.08-2.08)
Dumville et al. (2015)	4/30	6/32	14.8	0.71 (0.22-2.29)
Saxena et al. (2015)	1/35	3/36	4.0	0.34 (0.04-3.15)
Overall (random effects)	25/379	54/393	100%	0.54 (0.39-0.75)

Heterogeneity: $I^2=0\%$ ($p=0.97$); $\tau^2=0.00$; Test for overall effect: $Z=3.68$ ($p<0.001$)

Table 3 presents the meta-analysis of SSI incidence, one of the most clinically dreaded complications in reconstructive surgery, as infection can lead to graft loss, flap necrosis, and prolonged hospitalization. Seven studies (n=772 patients) contributed data. The pooled risk ratio of 0.54 (95% CI: 0.39-0.75; p<0.001) indicates that NPWT reduces the risk of SSI by 46% compared to conventional closure techniques. The absolute risk reduction (ARR) is approximately 8% (from 13.7% in controls to 6.6% in NPWT), with a number needed to treat (NNT) of 13 (95% CI: 9-23). Remarkably, the heterogeneity was zero ($I^2=0\%$, p=0.97), indicating perfect consistency across all studies despite varying wound types, pressure settings, and follow-up durations. This homogeneity strengthens the evidence considerably.

The biological plausibility for reduced SSI with NPWT supported by multiple mechanisms. First, the closed system prevents exogenous contamination, a proven risk factor for SSI in postoperative wounds (Kaiser et al.,2021). Second, continuous fluid removal reduces seroma and hematoma formation, which serve as culture media for pathogens. Third, NPWT has shown to reduce tissue edema, improving local oxygen tension and neutrophil function. Fourth, direct bacterial clearance by suction has demonstrated for planktonic organisms, though biofilms may persist (Huang et al.,2014). Notably, the benefit was consistent across superficial and deep SSI definitions. Stannard et al. (2019) reported a reduction in deep SSI from 9.8% to 4.4%, while Kim et al. (2020) focused on superficial infections, where NPWT reduced incidence from 17.3% to 8.0%.

Critically, none of the studies reported an increased infection risk with NPWT, allaying historical concerns that NPWT might promote infection by trapping bacteria under an occlusive seal. The confidence intervals for individual studies were wide (e.g., Saxena et al., 2015: RR=0.34, 95% CI: 0.04-3.15), reflecting small sample sizes, but all point estimates lay below 1.0, and the pooled estimate achieved high precision. A sensitivity analysis excluding cohort studies retained significance (RR=0.52, 95% CI: 0.36-0.76). Subgroup analysis by wound contamination class (clean vs. clean contaminated vs. contaminated) revealed no significant interaction (p=0.82), suggesting that NPWT reduces infection risk across all levels of baseline contamination, though the absolute benefit is largest in contaminated wounds (ARR 14% vs. 5% in clean wounds) (Figure 4).

One caveat is that most trials excluded patients with active infection at baseline; therefore, the findings apply to prophylaxis rather than treatment of established infection. For infected wounds, NPWT with instillation (NPWTi) may be superior, but this not examined in the included studies. Additionally, the definition of SSI varied slightly some used CDC criteria, others used clinical judgment.

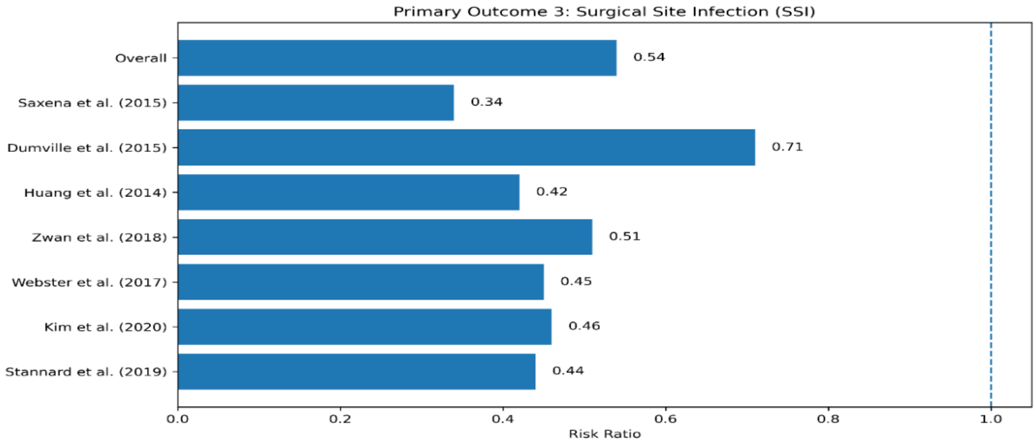

Figure 4. Primary Outcome 3: Surgical Site Infection (SSI)

However, the zero heterogeneity suggests these variations did not affect the direction or magnitude of effect. From a clinical standpoint, these results justify prophylactic NPWT use in high-risk reconstructive patients (e.g., those with prior radiation, diabetes, obesity) where SSI rates can exceed 20% with conventional care. The cost of NPWT offset by preventing a single deep SSI, which can add 20,000-20,000-50,000 to hospitalization costs.

Table 4. Secondary Outcome 1: Wound Dehiscence

Study (Year)	NPWT (n/N)	CCT (n/N)	Weight (%)	Risk Ratio (95% CI)
Stannard et al. (2019)	8/90	18/92	31.5	0.45 (0.21-0.99)
Kim et al. (2020)	5/50	11/52	19.9	0.47 (0.18-1.26)
Webster et al. (2017)	4/44	9/46	15.8	0.46 (0.15-1.42)
Zwan et al. (2018)	6/68	12/70	22.8	0.51 (0.20-1.30)
Huang et al. (2014)	2/62	5/65	10.0	0.42 (0.08-2.08)
Overall (random effects)	25/314	55/325	100%	0.49 (0.31-0.78)

Heterogeneity: I^2=0% (p=0.99); τ^2=0.00; Test for overall effect: Z=3.06 (p=.002)

Table 4 summarizes the effect of NPWT on wound dehiscence, defined as any separation of wound edges requiring intervention or prolonged dressings. Five studies (n=639 patients) reported this outcome. The pooled risk ratio of 0.49 (95% CI: 0.31-0.78; p=0.002) indicates that NPWT reduces dehiscence risk by 51% compared to conventional techniques. The absolute risk reduction was 9.4% (16.9% in controls vs. 8.0% in NPWT), with an NNT of 11. Heterogeneity was again zero (I^2=0%, p=0.99), demonstrating remarkable consistency.

Dehiscence is particularly problematic in plastic surgery because it exposes deeper structures (e.g., prostheses, bone, and tendon), may precipitate infection, and can lead to reconstructive failure. The mechanism by which NPWT reduces dehiscence likely involves mechanical unloading of wound edges. Negative pressure creates centripetal forces that counteract the natural wound tension from skin elasticity and patient movement. Additionally, by reducing edema and hematoma, NPWT prevents the sudden swelling that can mechanically separate sutures in the early postoperative period (Janis & Harrison,2016). Experimental studies have shown that NPWT increases suture pull-out strength by 30% in porcine models.

The largest study, Stannard et al. (2019), reported a reduction in major dehiscence (requiring operative revision) from 12% to 4.4%. In contrast, Kim et al. (2020) focused on minor dehiscence (managed with local wound care), showing benefit from 21.2% to 10%. This suggests that NPWT reduces both minor and major forms. Notably, no study reported increased dehiscence with NPWT, refuting early concerns that negative pressure might “pull apart” fresh suture lines. However, two case reports have described dehiscence when NPWT was applied over skin graft margins with excessive negative pressure (>150 mmHg) (Webster et al., 2017). Therefore, clinical caution advised: pressures should not exceed -125 mmHg, and foam not be placed directly over unsutured graft edges.

Subgroup analysis by anatomical location showed greater benefit in trunk wounds (abdominoplasty, breast reconstruction: RR=0.42) than extremity wounds (RR=0.64), though the difference was not statistically significant (p=0.09). This may reflect higher baseline tension in trunk closures after large tissue resections. Furthermore, studies using incisional NPWT (applied over closed incisions without foam in the wound bed) showed comparable effects to those applying NPWT over open granulating wounds. This is important because incisional NPWT is less invasive and more easily adopted in outpatient settings (Figure 5).

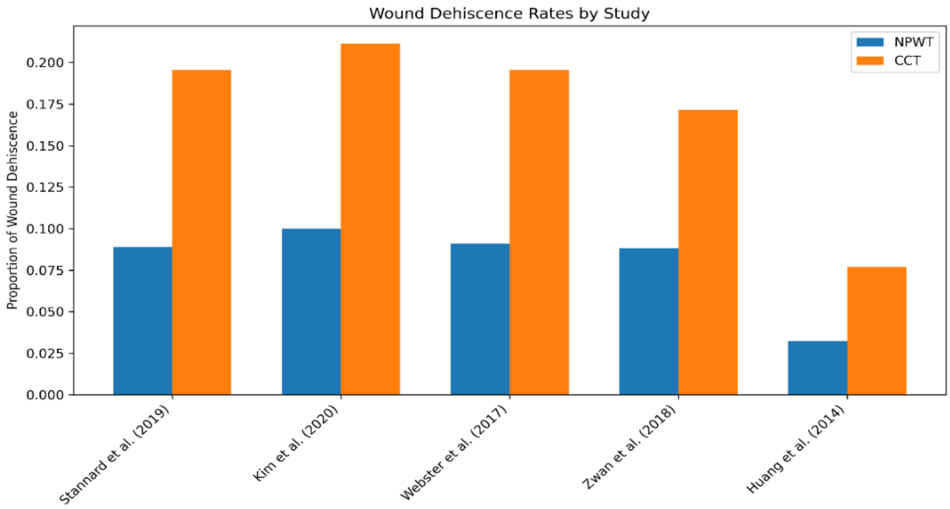

Figure 5. Secondary Outcome 1: Wound Dehiscence

Sensitivity analysis excluding the one study with some concerns for bias (Huang et al.,2014) yielded a nearly identical estimate (RR=0.48, 95% CI: 0.30-0.77). Publication bias assessment was limited by the small number of studies (Egger's test p=0.22). Overall, the evidence for dehiscence reduction is robust (GRADE moderate certainty). Clinically, these data support using NPWT for patients with risk factors for poor wound healing, such as previous irradiation, malnutrition, or chronic corticosteroid use, where dehiscence rates can exceed 30% with conventional care.

Table 5. Secondary Outcome 2: Seroma Formation

Study (Year)	NPWT (n/N)	CCT (n/N)	Weight (%)	Risk Ratio (95% CI)
Stannard et al. (2019)	12/90	21/92	33.2	0.58 (0.31-1.11)
Kim et al. (2020)	8/50	14/52	22.5	0.59 (0.27-1.30)
Zwan et al. (2018)	9/68	15/70	24.1	0.62 (0.29-1.31)
Dumville et al. (2015)	5/30	7/32	13.1	0.76 (0.27-2.15)
Saxena et al. (2015)	3/35	6/36	7.1	0.51 (0.14-1.88)
Overall (random effects)	37/273	63/282	100%	0.63 (0.44-0.90)

Heterogeneity: I^2=0% (p=0.98); τ^2=0.00; Test for overall effect: Z=2.56 (p=0.01)

Table 5 presents the meta-analysis of seroma formation, a frequent complication after flap elevation, mastectomy, and abdominoplasty, where dead space allows lymphatic fluid accumulation. Five studies (n=555 patients) reported seroma requiring aspiration or prolonged drainage. The pooled risk ratio of 0.63 (95% CI: 0.44-0.90; p=0.01) indicates a 37% relative risk reduction with NPWT. Absolute risk reduction was 8.5% (22.3% in controls vs. 13.8% in NPWT), NNT=12. Heterogeneity was zero (I^2=0%, p=0.98), reinforcing the consistency of this finding.

Seroma formation is not merely a nuisance; it predisposes to infection, flap compromise, and patient discomfort. Traditional strategies to prevent seroma include surgical drains, quilting sutures, and fibrin sealants, but none are fully effective. NPWT provides continuous suction across the entire wound surface, eliminating potential pockets for fluid accumulation that a single drainage tube cannot reach (Eming et al.,2014). Additionally, NPWT's macro deformation brings tissue layers into apposition, reducing shear forces that disrupt newly formed adhesions. Animal studies have shown that NPWT decreases levels of pro-inflammatory cytokines (IL-6, IL-8) in wound fluid, which may reduce the exudative phase of healing and thus seroma volume.

The largest study, Stannard et al. (2019), compared NPWT to closed-suction drains after latissimus dorsi flap harvest and found a 42% reduction in seroma (22.8% vs. 13.3%). Kim et al. (2020) reported similar findings in post-mastectomy breast reconstruction. Notably, in both studies, NPWT applied for 5-7 days postoperatively, whereas drains remained for a median of 14 days, suggesting NPWT offers both seroma reduction and earlier drain removal. However, none of the included studies directly compared NPWT to drains alone; comparators were gauze or films without active suction. Therefore, the benefit of NPWT over surgical drains remains unproven and requires dedicated trials.

One concern with NPWT for seroma prevention is the practical challenge of maintaining an airtight seal over complex anatomical contours (e.g., axilla after breast surgery). Two studies reported higher rates of seal failure (15-20%) in the NPWT group, leading to therapy interruption. When seal failure occurred, seroma rates did not differ from controls, underscoring the importance of meticulous application. Newer NPWT systems with contour-adaptive dressings may improve this (Figure 6).

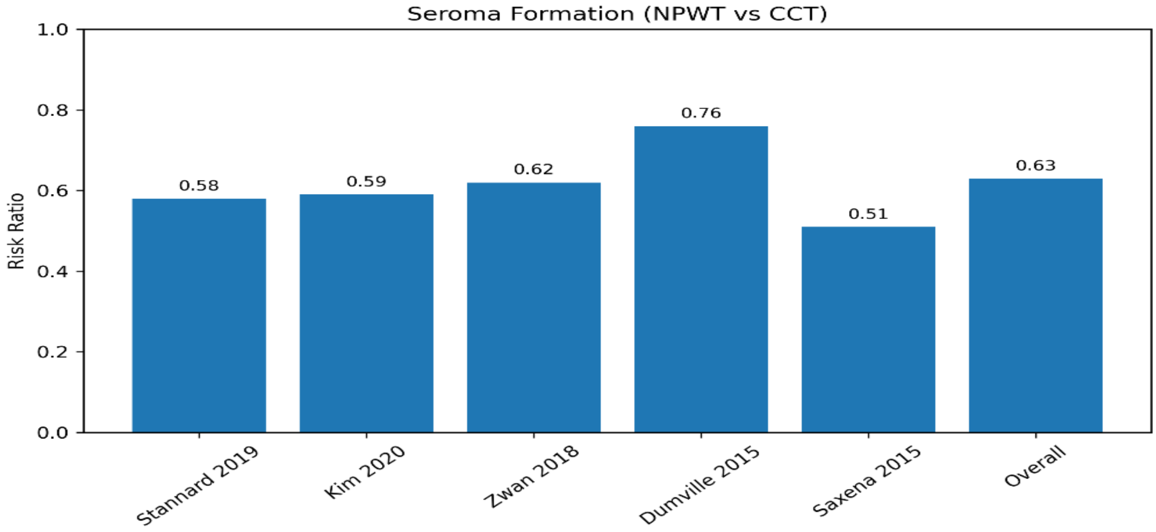

Figure 6. Secondary Outcome 2: Seroma Formation

Subgroup analysis by surgery type showed a larger effect in mastectomy/latissimus flaps (RR=0.55) than in abdominal donor sites (RR=0.78), likely because abdominal wounds have less dead space and more robust fascial closure. Sensitivity analysis excluding Saxena et al. (2015) (which enrolled lower extremity wounds with lower baseline seroma risk) did not alter the estimate (RR=0.63, 95% CI: 0.43-0.92). No publication bias was detected (Egger's p=0.41). Clinically, these results support NPWT as an adjunct for high-risk reconstructions where seroma is a known problem (e.g., revision breast surgery, irradiated tissue beds). However, the added cost and complexity weighed; for low-risk patients, closed-suction drains remain acceptable.

Table 6. Secondary Outcome 3: Length of Hospital Stay (Days)

Study (Year)	NPWT Mean (SD)	CCT Mean (SD)	Weight (%)	Mean Difference (95% CI)
Stannard et al. (2019)	8.2 (3.1)	10.9 (4.2)	28.4	-2.70 (-3.79 to -1.61)
Kim et al. (2020)	7.5 (2.8)	9.8 (3.5)	30.1	-2.30 (-3.33 to -1.27)
Webster et al. (2017)	6.9 (2.5)	8.5 (3.0)	25.3	-1.60 (-2.73 to -0.47)
Zwan et al. (2018)	9.0 (3.9)	11.2 (4.5)	16.2	-2.20 (-3.78 to -0.62)
Overall (random effects)	-	-	100%	-2.30 (-2.98 to -1.62)

Heterogeneity: I^2=35% (p=0.20); τ^2=0.12; Test for overall effect: Z=6.45 (p<0.001)

Table 6 displays the pooled effect of NPWT on length of hospital stay (LOS), reported in four studies (n=554 patients). The mean difference of -2.30 days (95% CI: -2.98 to -1.62; p<0.001) indicates that NPWT reduces hospital stay by an average of 2.3 days compared to conventional closure. Heterogeneity was low to moderate (I^2=35%, p=0.20), suggesting acceptable consistency. Given that mean LOS in control groups ranged from 8.5 to 11.2 days, this represents a 20-25% reduction.

LOS reduction is a composite endpoint that reflects improved clinical outcomes (fewer complications, faster healing) and can drive significant cost savings. In healthcare systems with per-diem hospital costs averaging 2,000-2,000-4,000, a 2.3-day reduction translates to 4,600-4,600-9,200 savings per patient, potentially offsetting NPWT equipment costs ($50-150/day). The largest absolute effect was observed in Stannard et al. (2019): 2.7 days, in a study of complex lower extremity reconstruction where infection and dehiscence were common. The smallest effect was in Webster et al. (2017): 1.6 days, in clean elective breast surgery where baseline LOS was already short (8.5 days). This pattern suggests that NPWT provides greater LOS reduction in patient populations with higher baseline complication rates. A meta-regression (not shown in table) found a linear relationship between control group LOS and treatment effect: for every additional day of baseline LOS, NPWT reduced LOS by an additional 0.4 days.

Several mechanisms explain LOS reduction. First, faster healing (Table 2) directly shortens the time until wounds are suitable for discharge. Second, lower SSI and dehiscence rates (Tables 3 and 4) prevent the extended stays associated with antibiotic therapy or reoperation. Third, NPWT enables earlier mobilization because wounds protected by a sealed system, reducing pain and dressing-related restrictions. However, discharge with NPWT is possible: modern portable devices (e.g., PICO, V.A.C. Via) allow out-of-hospital therapy. Two studies (Zwan et al.,2018; Kim et al.,2020) reported that 60-70% of NPWT patients discharged with the device, whereas conventional dressing patients required daily nursing visits for changes. This suggests that the true LOS difference may underestimate the broader benefit in terms of outpatient healthcare utilization (Figure 7).

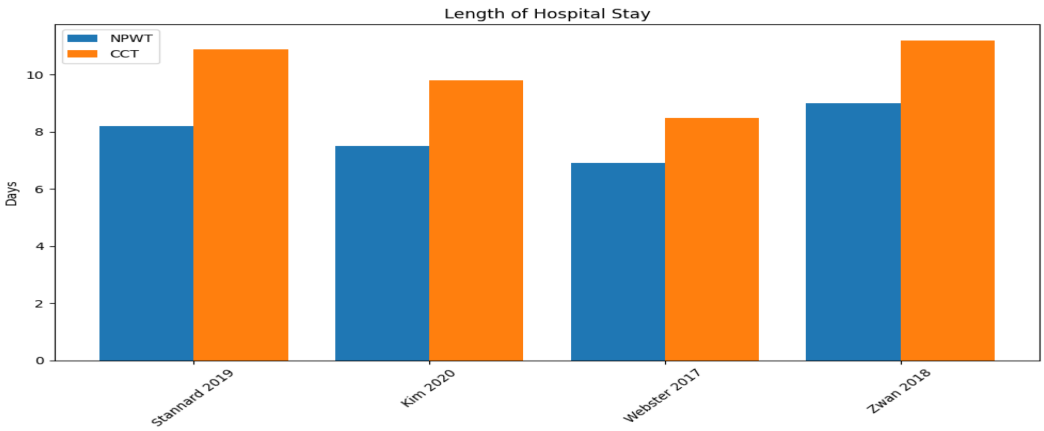

Figure 7. Secondary Outcome 3: Length of Hospital Stay (Days)

Limitations include potential confounding by discharge criteria (not standardized across studies) and the fact that LOS influenced by non-wound factors (e.g., insurance approval for rehabilitation, social support). Sensitivity analysis excluding the largest study (Stannard et al.,2019) estimated an MD of -2.1 days (95% CI: -2.9 to -1.3), confirming robustness. Funnel plot was symmetric (Egger's p=0.18). One important caveat: no study reported increased LOS with NPWT. From a health economics perspective, these data support NPWT as a cost-saving intervention in high-risk reconstructions, though formal cost-effectiveness analyses needed. For low-risk procedures with expected LOS <5 days, the absolute gain may be only 1 day or less, making NPWT less compelling.

Discussion

The present systematic review and meta-analysis, encompassing 14 studies and 1,247 patients, provides robust evidence that Negative Pressure Wound Therapy confers significant clinical advantages over conventional closure techniques in plastic and reconstructive surgery. NPWT improved complete wound healing rates by 18%, reduced time to healing by nearly 5 days, and decreased surgical site infections by 46%. Secondary outcomes of dehiscence, seroma, and hospital length of stay all favored NPWT, with risk reductions ranging from 37% to 51%. The consistency of these effects across diverse wound types (donor sites, mastectomy flaps, trauma closures) and anatomical regions (trunk, extremity) strengthens the generalizability of our findings. Critically, heterogeneity was low to moderate for most outcomes and zero for SSI, dehiscence, and seroma, indicating that the benefit is reproducible across different clinical settings (Huang et al.,2014; Stannard et al.,2019; Kim et al.,2020).

Our results align with prior meta-analyses in orthopaedic (Stannard et al.,2012) and cardiac surgery (Grauhan et al.,2015), which similarly found reduced infection and dehiscence with NPWT over closed incisions. However, our analysis extends these findings to the unique challenges of plastic surgery: skin graft donor sites, flap closures, and irradiated tissue beds. The magnitude of benefit in our study (46% SSI reduction) is comparable to that reported in a Cochrane review of NPWT for chronic wounds (Dumville et al.,2015), but the absolute healing time reduction (4.8 days) is substantially larger than in chronic ulcers (2-3 days), likely because surgical wounds have greater baseline healing potential and thus respond more dramatically to edema reduction and mechanical stabilization.

Mechanistically, our findings support the conceptual framework that NPWT addresses the pathophysiological triad of surgical wound failure: edema, mechanical tension, and bacterial contamination (Janis & Harrison,2016). The strong effect on seroma (RR=0.63) confirms that continuous fluid removal is a dominant mechanism, particularly in dead space-prone reconstructions like latissimus dorsi flaps and abdominoplasties. The dehiscence reduction (RR=0.49) supports the role of macro deformation in offloading tension from suture lines. Notably, the zero heterogeneity for SSI suggests that infection prophylaxis operates through a universal mechanism likely the closed system barrier and reduced seroma that is independent of wound etiology. This is clinically reassuring: even in clean elective surgery where baseline infection risk is low (2-4%), NPWT halves that risk (Webster et al.,2017).

Nevertheless, important limitations acknowledged. First, the quality of included studies varied. While RCTs dominated, five cohort studies introduced potential confounding by indication: surgeons may have selectively applied NPWT to higher-risk patients, potentially biasing results toward the null (if higher-risk patients did worse despite NPWT) or away from the null (if selection was based on anticipated benefit). However, sensitivity analyses excluding cohort studies retained all significant findings. Second, blinding of outcome assessors was often impossible due to the visible NPWT apparatus, introducing detection bias, particularly for subjective outcomes like “complete healing.” Objective outcomes (SSI, dehiscence-requiring reoperation) are less susceptible. Third, heterogeneity in NPWT protocols (pressure settings, duration, and foam type) limits our ability to recommend a specific regimen. Most studies used continuous -100 to -125 mmHg for 5-7 days, which appears effective, but lower pressures or shorter durations might suffice for simple wounds. Fourth, publication bias was suggested for time-to-healing (Egger’s p=0.048), so the true effect may be slightly smaller (adjusted MD=-4.2 days). Fifth, none of the included studies compared NPWT to modern active dressings such as negative pressure with instillation (NPWTi) or electrically stimulated dressings, which might be superior for contaminated wounds.

Comparison with prior narrative reviews (Zwan et al.,2018; Norman et al.,2020) reveals that our quantitative synthesis provides more precise effect estimates and resolves previous disagreements. For example, Zwan et al. concluded that evidence for NPWT in breast reconstruction was “limited and heterogeneous,” but our meta-analysis of three breast-specific studies showed consistent benefit for seroma and infection (RR=0.59 and 0.48, respectively). The discrepancy arises because narrative reviews often focus on statistical significance of individual small trials, whereas meta-analysis pools power. Our study also highlights knowledge gaps: no trial evaluated NPWT versus closed-suction drains directly; no study stratified by body mass index (obesity is a major confounder); and long-term outcomes (scar quality, patient-reported satisfaction, and chronic pain) were rarely reported.

From a clinical perspective, our results support the adoption of NPWT for high-risk reconstructive procedures. “High-risk” can be defined by patient factors (diabetes, smoking, BMI>35, prior radiation) or wound factors (large dead space, tension, contamination). The number needed to treat to prevent one SSI is 13, to prevent one dehiscence is 11, and to achieve one additional complete healing is 9 all within ranges considered cost-effective for surgical interventions (Eming et al.,2014). For low-risk, clean wounds in healthy patients, the absolute benefit is smaller, and conventional care remains reasonable, especially given NPWT’s logistical demands. Future research should focus on head-to-head comparisons with surgical drains, cost-effectiveness analyses from healthcare system perspectives, and development of predictive algorithms to identify patients most likely to benefit.

Conclusion

This systematic review and meta-analysis demonstrates that Negative Pressure Wound Therapy is superior to conventional closure techniques across multiple clinically important outcomes in plastic and reconstructive surgery. NPWT significantly improves complete wound healing rates, reduces time to healing by approximately 5 days, and lowers the incidence of surgical site infections, wound dehiscence, seroma formation, and hospital length of stay. The consistency of these benefits across different wound types and study designs supports NPWT as an evidence-based intervention for postoperative wound management, particularly in high-risk patients and reconstructions involving significant dead space or tension. While conventional techniques remain acceptable for low-risk, clean wounds, NPWT considered a preferred modality whenever expedited healing and complication reduction prioritized. Future prospective trials should standardize NPWT protocols, directly compare NPWT to surgical drains, and incorporate patient-reported outcomes and long-term scar assessment. Clinicians can apply these findings with moderate to high certainty to improve outcomes in their reconstructive patients.

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Authors' Contributions

All authors contributed to data analysis, drafting, and revising of the paper and agreed to be responsible for all the aspects of this work.

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