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Clinical Effectiveness of High-Intensity Laser in Wound Management: A Systematic Review and Meta-Analysis

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ABSTRACT

Chronic wounds remain a major healthcare challenge because of their prolonged healing time, increased risk of infection, extended hospitalization, reduced quality of life, and substantial healthcare costs. High-Intensity Laser Therapy (HILT) has emerged as a promising noninvasive intervention that may enhance wound healing by stimulating tissue regeneration, improving microcirculation, promoting collagen synthesis, and accelerating wound closure. This systematic review and meta-analysis aimed to evaluate the efficacy of HILT compared with conventional wound care, standard medical treatment, or sham laser therapy in improving wound-healing outcomes among patients with chronic and delayed-healing wounds. A systematic literature search was conducted in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines using the PubMed, Scopus, ScienceDirect, and Google Scholar databases up to May 2026. Eligible studies were selected based on predefined inclusion and exclusion criteria. The methodological quality of the included studies was assessed using the Jadad Scale. Five interventional studies met the eligibility criteria and were included in the systematic review. Of these, three studies provided sufficiently homogeneous quantitative data and were included in the meta-analysis. The pooled analysis demonstrated that HILT significantly reduced wound surface area compared with control interventions (mean difference = −3.53; 95% confidence interval: −5.66 to −1.40; p = 0.001), although substantial heterogeneity was observed among the studies (I^2 = 96%). In addition, the included studies consistently reported improvements in wound size reduction, wound appearance, wound-healing scores, and overall clinical outcomes following HILT.

INTRODUCTION

Chronic wounds are wounds that fail to progress through the normal stages of healing within an expected period, commonly persisting beyond four weeks despite appropriate management. They include diabetic foot ulcers, pressure ulcers, venous leg ulcers, neuropathic ulcers, delayed postoperative wounds, and other chronic refractory wounds (Ahmed et al. 2025; Gallagher et al. 2024; Jiang et al. 2021). Their prolonged course frequently results in persistent inflammation, recurrent infection, delayed tissue regeneration, and incomplete closure, thereby increasing morbidity and mortality among affected patients (Frykberg, 2015).

The global prevalence of chronic wounds has risen considerably, driven by increasing rates of diabetes mellitus, peripheral vascular disease, obesity, and aging populations.

Diabetes is a particularly important contributor, as prolonged hyperglycemia impairs angiogenesis, collagen synthesis, fibroblast proliferation, and immune function, all of which are essential for normal healing (Nirenjen et al. 2023; Song et al. 2025; Wan et al. 2021). Vascular insufficiency and peripheral neuropathy further reduce tissue perfusion and oxygen delivery, delaying regeneration and increasing the risk of infection. Chronic wounds have therefore become an increasingly important public health issue, particularly among elderly patients with multiple comorbidities (Redmond, 2025).

The burden of chronic wounds extends beyond delayed healing. Patients often experience prolonged hospitalization, repeated procedures, recurrent infections, chronic pain, reduced mobility, and diminished quality of life. In severe cases, chronic wounds may progress to osteomyelitis, systemic infection, or amputation, particularly in patients with diabetic foot ulcers. Management requires considerable resources, including frequent clinical visits, advanced dressings, antimicrobial therapy, debridement, and long-term care, contributing to substantial healthcare costs and underscoring the need for more effective therapeutic strategies (Peterson, 2025).

Wound healing itself is a highly coordinated and dynamic biological process involving multiple overlapping phases, including hemostasis, inflammation, proliferation, and tissue remodeling. During the hemostatic phase, platelet activation initiates clot formation and releases growth factors that trigger subsequent healing events. This phase is followed by an inflammatory response characterized by the migration of neutrophils and macrophages to eliminate microorganisms and cellular debris while producing cytokines necessary for tissue repair. The proliferative phase subsequently promotes fibroblast proliferation, angiogenesis, extracellular matrix formation, collagen deposition, and re-epithelialization. Finally, during the remodeling phase, collagen fibers undergo maturation and reorganization, restoring tissue strength and structural integrity. Successful wound healing therefore depends on adequate vascularization, oxygen delivery, cellular proliferation, collagen synthesis, inflammatory regulation, and extracellular matrix remodeling (Lohr, 2026).

These mechanisms are substantially impaired in chronic wounds, which remain trapped in a prolonged inflammatory phase marked by excessive inflammatory cytokine production, protease activity, bacterial colonization, oxidative stress, impaired angiogenesis, and reduced fibroblast activity and collagen production. These changes inhibit granulation tissue formation and epithelial migration, prevent normal wound closure, and further compromise local circulation, explaining why many chronic wounds resist conventional treatment despite prolonged management (Kurhaluk, 2026).

Current management focuses on controlling underlying causes while promoting regeneration through debridement, infection control, pressure off-loading, irrigation, advanced dressings, compression therapy, negative pressure wound therapy, pharmacological interventions, nutritional optimization, and management of systemic diseases. Although these interventions have improved wound care, outcomes remain inconsistent, particularly in patients with diabetes, peripheral arterial disease, neuropathy, obesity, renal disease, or advanced age, highlighting the limitations of conventional approaches (Fortuna, 2025).

Prolonged healing also carries significant psychosocial consequences, including restricted daily activity, reduced productivity, impaired social participation, and chronic

pain, odor, and exudate, which may contribute to anxiety, depression, and social isolation. Chronic wound management should therefore aim not only for complete wound closure but also for improved quality of life, motivating research into adjunctive therapies that accelerate repair while improving comfort and reducing costs (Yoon, 2024).

Given these limitations, increasing attention has been directed toward regenerative and photobiomodulation-based therapies as complementary approaches to conventional wound management. Among these emerging modalities, laser therapy has gained considerable interest because of its ability to stimulate biological processes involved in tissue repair without causing significant tissue damage (Hernández-Bule et al. 2024; Mussttaf et al. 2019; Samaneh et al. 2015). Various laser technologies have been investigated for wound healing, including Low-Level Laser Therapy (LLLT), Photobiomodulation Therapy (PBMT), and, more recently, High-Intensity Laser Therapy (HILT). Compared with conventional wound care alone, these technologies offer the potential to enhance cellular metabolism, improve microcirculation, stimulate collagen synthesis, and accelerate wound closure. Consequently, laser-based interventions have become increasingly incorporated into rehabilitation medicine, regenerative medicine, and chronic wound management protocols (Alayat, 2026).

Among the emerging noninvasive therapeutic modalities for chronic wound management, laser therapy has received increasing attention because of its ability to stimulate biological processes involved in tissue repair while minimizing tissue damage. Laser therapy has evolved considerably over recent decades and has become an important adjunctive treatment in rehabilitation medicine, regenerative medicine, dermatology, and musculoskeletal disorders. Different laser modalities have been investigated for wound management, including Low-Level Laser Therapy (LLLT), Photobiomodulation Therapy (PBMT), and High-Intensity Laser Therapy (HILT). Although these therapeutic approaches share similar biological principles, they differ substantially in wavelength, energy density, tissue penetration, treatment duration, and clinical applications. Among these modalities, HILT has recently emerged as a promising therapeutic option because of its ability to deliver higher energy levels with deeper tissue penetration while maintaining an acceptable safety profile (Pramesti, 2025).

HILT delivers pulsed laser energy with high peak power, typically using a neodymium-doped yttrium aluminum garnet (Nd:YAG) laser at approximately 1064 nm. Unlike conventional LLLT, which generally delivers lower power levels below 500 mW, HILT achieves substantially greater peak power with a very short pulse duration, allowing energy to penetrate deeper tissues without excessive thermal damage. This characteristic makes HILT suitable for chronic wounds involving extensive soft tissue damage, impaired vascularization, or delayed regeneration (Pramesti, 2025).

The therapeutic effects of HILT are mediated through several biological mechanisms that collectively enhance tissue repair. Following laser irradiation, photons are absorbed by intracellular chromophores, particularly within mitochondria, resulting in increased production of adenosine triphosphate (ATP). Enhanced ATP synthesis improves cellular metabolism and provides additional energy required for fibroblast proliferation, protein synthesis, collagen deposition, and tissue remodeling. Furthermore, HILT has been shown to stimulate endothelial cell activity, promote angiogenesis, improve microvascular circulation, and increase oxygen delivery to injured tissues. These physiological responses

collectively accelerate granulation tissue formation, epithelial migration, extracellular matrix production, and wound contraction, thereby promoting faster wound closure (Kurhaluk, 2026).

In addition to its regenerative properties, HILT demonstrates important anti-inflammatory and analgesic effects that further support wound healing. Laser irradiation has been reported to modulate inflammatory mediators by reducing proinflammatory cytokines while promoting anti-inflammatory responses within injured tissues. HILT also decreases oxidative stress through the regulation of reactive oxygen species and enhances local lymphatic drainage, thereby reducing tissue edema. These biological effects contribute to a more favorable microenvironment for tissue regeneration while simultaneously alleviating pain and improving patient comfort during treatment. Such characteristics are particularly beneficial for patients with chronic wounds who frequently experience persistent inflammation, severe pain, and repeated wound manipulation throughout prolonged treatment periods (Olteanu, 2024).

Another important advantage of HILT lies in its ability to stimulate collagen synthesis and extracellular matrix remodeling. Fibroblast activation induced by laser irradiation increases collagen production, promotes wound tensile strength, and facilitates tissue maturation during the remodeling phase of healing. Enhanced collagen organization improves structural integrity and decreases the likelihood of recurrent wound breakdown after complete closure. Furthermore, improved vascularization following HILT contributes to greater nutrient delivery, enhanced oxygenation, and accelerated removal of metabolic waste products from injured tissues. Collectively, these physiological mechanisms explain why HILT has attracted considerable attention as a potential adjunctive therapy for chronic wound management (Fortuna, 2025).

Growing interest in HILT has resulted in an increasing number of clinical studies evaluating its effectiveness in patients with chronic and delayed-healing wounds. Several randomized controlled trials have investigated HILT in diabetic foot ulcers, chronic refractory wounds, neuropathic ulcers, postoperative wounds, and other chronic wound conditions. Overall, these studies have reported encouraging findings regarding improvements in wound closure, wound surface area reduction, wound appearance, tissue regeneration, and overall healing outcomes. One of the earliest clinical investigations was conducted by Ebid et al. (2011), who evaluated pulsed Nd:YAG High-Intensity Laser Therapy in patients with chronic diabetic foot ulcers. The study demonstrated a significant reduction in wound surface area following HILT combined with standard medical treatment compared with conventional therapy alone, suggesting that laser irradiation effectively accelerates wound healing by promoting tissue regeneration and improving local circulation. These findings provided early clinical evidence supporting the use of HILT as an adjunctive treatment for diabetic wound management.

Subsequently, Basalamah et al. (2013) performed a randomized controlled trial involving patients with diabetic foot ulcers receiving pulsed Nd:YAG laser therapy. Compared with sham laser treatment, patients receiving HILT demonstrated significantly greater reductions in wound size and improved healing progression after eight weeks of intervention. The authors concluded that pulsed High-Intensity Laser Therapy represented a safe and effective noninvasive intervention capable of enhancing chronic diabetic wound

healing while reducing treatment duration. Further evidence was provided by Ebid et al. (2013), who investigated the therapeutic effects of pulsed Nd:YAG laser therapy in children with spina bifida presenting neuropathic foot ulcers. Their findings demonstrated substantial improvements in wound size reduction and wound appearance following HILT compared with conventional wound care. The study suggested that laser-induced stimulation of tissue regeneration may also be beneficial in neuropathic wounds characterized by impaired sensation and delayed healing.

Additional clinical support for HILT was reported by Thabet et al. (2018), who evaluated diabetic women with delayed Caesarean section wound healing. Patients receiving pulsed High-Intensity Laser Therapy in combination with standard medical treatment experienced significantly greater improvements in wound size reduction and wound appearance than those receiving sham laser therapy. These findings indicate that HILT may also provide therapeutic benefits for postoperative wounds complicated by diabetes mellitus and delayed tissue repair. More recently, Lu et al. (2021) conducted a randomized controlled trial investigating HILT in patients with chronic refractory wounds. The study assessed wound healing using the Bates-Jensen Wound Assessment Tool (BWAT) and the Pressure Ulcer Scale for Healing (PUSH). Patients treated with HILT demonstrated significantly greater improvements in both BWAT and PUSH scores compared with conventional wound care alone, indicating enhanced wound healing and tissue regeneration. These findings further strengthened the growing evidence supporting HILT as an effective adjunctive therapy for chronic wound management.

Although the majority of published studies have demonstrated favorable clinical outcomes, considerable variability remains among individual investigations. Differences in wound etiology, patient characteristics, laser wavelength, treatment parameters, irradiation protocols, energy dosage, treatment frequency, comparator interventions, follow-up duration, and outcome measurements contribute to substantial heterogeneity across studies. Consequently, direct comparisons between individual trials remain difficult, and the magnitude of the overall therapeutic effect of HILT cannot be accurately determined based solely on individual clinical studies (Pérez, 2025). Furthermore, most published studies have involved relatively small sample sizes, limiting their statistical power and external validity. Some investigations focused exclusively on diabetic foot ulcers, whereas others included chronic refractory wounds, postoperative wounds, or neuropathic ulcers, thereby increasing clinical heterogeneity. Variability in outcome assessments, including wound surface area, wound appearance, BWAT score, PUSH score, pain intensity, and healing time, also complicates the interpretation of existing evidence. As a result, despite promising findings, uncertainty remains regarding the overall efficacy of HILT across different chronic wound populations.

A comprehensive synthesis is therefore needed to determine whether HILT provides clinically meaningful benefits compared with standard care, conventional treatment, or sham laser therapy. Systematic reviews and meta-analyses offer the highest level of evidence for integrating findings across studies, allowing more precise effect estimation while evaluating methodological quality and heterogeneity and providing stronger support for clinicians considering HILT in practice.

Despite the growing body of literature investigating High-Intensity Laser Therapy (HILT) for wound healing, several important limitations remain. Although most published studies have reported favorable outcomes following HILT intervention, the available evidence is characterized by considerable methodological and clinical heterogeneity. Variations in patient populations, wound etiology, laser devices, irradiation parameters, treatment frequency, intervention duration, comparator groups, follow-up periods, and outcome measurements make it difficult to establish definitive conclusions regarding the clinical efficacy of HILT. Furthermore, many clinical studies have involved relatively small sample sizes, thereby limiting statistical power and reducing the generalizability of their findings. Another important limitation concerns the diversity of comparator interventions used across previous clinical trials. Some studies compared HILT with standard wound care, whereas others used conventional medical treatment or sham laser therapy as control interventions. Differences in comparator groups may influence the magnitude of treatment effects and contribute to inconsistencies among reported outcomes. Moreover, wound healing has been evaluated using various clinical indicators, including wound surface area reduction, wound appearance, Bates-Jensen Wound Assessment Tool (BWAT), Pressure Ulcer Scale for Healing (PUSH), healing time, and pain reduction. Although each of these outcome measures reflects different aspects of tissue repair, the lack of standardized outcome assessment complicates direct comparisons between studies and limits evidence-based clinical recommendations.

Previous literature reviews have summarized the role of laser therapy in wound management; however, many reviews evaluated laser therapy in general without distinguishing High-Intensity Laser Therapy from other photobiomodulation modalities such as Low-Level Laser Therapy (LLLT). Since HILT delivers substantially higher energy densities and deeper tissue penetration than LLLT, its biological mechanisms and clinical effects may differ considerably. Consequently, evidence obtained from studies investigating LLLT cannot be directly generalized to HILT. In addition, several previous publications were narrative reviews that primarily described available evidence without performing quantitative synthesis of treatment effects. Therefore, the overall efficacy of HILT compared with standard wound care, conventional treatment, or sham laser therapy remains incompletely understood (Yoon, 2024).

A systematic review accompanied by meta-analysis provides a more rigorous approach for synthesizing existing evidence by integrating findings from multiple clinical studies while evaluating methodological quality and estimating pooled treatment effects. Compared with individual clinical trials, systematic reviews and meta-analyses increase statistical precision, identify potential sources of heterogeneity, and provide stronger evidence to support clinical decision-making. Furthermore, evaluating the methodological quality of included studies using standardized appraisal tools enables more reliable interpretation of available evidence and facilitates the identification of areas requiring further investigation. The present study therefore seeks to address these limitations by systematically reviewing and quantitatively synthesizing the available clinical evidence regarding the efficacy of High-Intensity Laser Therapy in wound healing. Unlike previous narrative reviews, this study focuses specifically on interventional studies comparing HILT with standard wound care, conventional treatment, or sham laser therapy. The review evaluates multiple clinically

relevant outcomes, including wound surface area reduction, wound healing scores, wound appearance, pain reduction, healing time, and overall wound healing improvement. By integrating quantitative evidence from eligible studies, this systematic review and meta-analysis aims to provide a more comprehensive understanding of the therapeutic effectiveness of HILT in patients with chronic and delayed-healing wounds.

These findings are expected to provide clinicians, rehabilitation specialists, and other healthcare professionals with updated evidence on HILT's clinical application, assist policymakers in considering HILT within multidisciplinary wound care, and identify knowledge gaps and priorities for future trials with standardized protocols, larger sample sizes, and longer follow-up periods.

Although HILT shows promising potential, existing evidence remains fragmented and heterogeneous due to variability in study design, wound characteristics, laser parameters, comparators, and outcome measures. Because previous reviews have largely addressed laser therapy broadly or narratively, a comprehensive systematic review and meta-analysis specifically evaluating HILT against standard care, conventional treatment, or sham therapy is needed.

This study's novelty lies in synthesizing evidence specifically for HILT rather than laser therapy broadly, quantitatively evaluating its effectiveness through meta-analysis while comparing it with standard care, conventional treatment, and sham laser therapy across multiple clinically relevant outcomes, thereby providing a more robust evidence base and updated clinical recommendations.

Based on the background and research gap described above, this systematic review and meta-analysis was designed to address several key research questions regarding the efficacy of High-Intensity Laser Therapy for wound healing. The primary question examines whether High-Intensity Laser Therapy is more effective than standard wound care, conventional treatment, or sham laser therapy in promoting wound healing among patients with chronic and delayed-healing wounds. Additionally, this study investigates whether High-Intensity Laser Therapy significantly improves wound healing outcomes, including wound surface area reduction, wound healing scores, wound appearance, pain reduction, and healing time, compared with control interventions. Furthermore, this review evaluates the overall quality and strength of the available clinical evidence regarding the efficacy of High-Intensity Laser Therapy for wound healing. To address these questions, this study aims to evaluate the efficacy of High-Intensity Laser Therapy compared with standard wound care, conventional treatment, or sham laser therapy in promoting wound healing, synthesize current clinical evidence regarding its effects on various wound healing outcomes, and assess the methodological quality of included studies to provide evidence-based recommendations for clinical application. Ultimately, this research aims to contribute a comprehensive evidence synthesis on HILT's efficacy for wound healing, thereby strengthening the scientific basis for its integration into multidisciplinary wound management, supporting evidence-based clinical decision-making, and serving as a reference for optimizing future laser treatment protocols in wound care practice.

METHOD

Research Design

This research employed a systematic review and meta-analysis design to evaluate the efficacy of HILT in promoting wound healing among patients with chronic and delayed-healing wounds. The review was conducted in accordance with the PRISMA 2020 guidelines to ensure methodological transparency and reproducibility. The protocol included literature identification, study selection, eligibility assessment, quality appraisal, data extraction, and quantitative synthesis.

Data Sources and Search Strategy

A comprehensive literature search was conducted using four electronic databases, namely PubMed, Scopus, ScienceDirect, and Google Scholar. The search included all relevant studies published from database inception until May 2026. Both Medical Subject Headings (MeSH) and free-text keywords were used to maximize retrieval of eligible studies.

The primary search terms included:

a. "High-Intensity Laser Therapy" OR "HILT"
b. "Pulsed Nd Laser"
c. "High-Power Laser Therapy"
d. "Wound Healing"
e. "Chronic Wounds"
f. "Diabetic Foot Ulcer"
g. "Neuropathic Foot Ulcer"
h. "Delayed Wound Healing"

Boolean operators (AND, OR) were applied to combine keywords and optimize database searches.

Eligibility Criteria

The eligibility criteria were established according to the Population, Intervention, Comparison, Outcome, and Study Design (PICOS) framework.

Inclusion Criteria

Studies were included if they:

a. involved patients with chronic wounds, diabetic foot ulcers, neuropathic foot ulcers, chronic refractory wounds, or delayed postoperative wounds;
b. evaluated High-Intensity Laser Therapy (HILT), Pulsed Nd Laser, or High-Power Laser Therapy;
c. compared HILT with standard wound care, conventional treatment, standard medical treatment, or sham laser therapy;
d. reported quantitative wound healing outcomes, including wound surface area reduction, wound healing rate, wound appearance, BWAT score, PUSH score, healing time, or pain reduction;
e. employed randomized controlled trials (RCTs) or controlled clinical trials (CCTs);
f. were published in English.

Exclusion Criteria

Studies were excluded if they:

a. were review articles, systematic reviews, meta-analyses, conference abstracts, editorials, letters, or expert opinions;
b. were animal or in vitro studies;
c. investigated laser modalities other than HILT without separate outcome reporting;
d. lacked sufficient quantitative data for data extraction;
e. were duplicate publications.

Study Selection

All identified records were imported into reference management software to remove duplicate publications. Subsequently, titles and abstracts were screened according to the predefined eligibility criteria. Full-text articles of potentially relevant studies were independently assessed by two reviewers. Any disagreement regarding study eligibility was resolved through discussion until consensus was achieved.

Study Sample

The sample of this systematic review consisted of published clinical studies that fulfilled the eligibility criteria. Five interventional studies were finally included in the systematic review, comprising four randomized controlled trials and one controlled clinical trial. Among these studies, three provided sufficiently homogeneous quantitative data for inclusion in the meta-analysis.

Data Extraction

Data were extracted using a standardized data extraction form developed by the researchers. Information collected from each study included:

a. Author and publication year;
b. Country of study
c. Study design;
d. Sample characteristics;
e. Wound type;
f. Intervention protocol;
g. Laser parameters;
h. Comparator intervention;
i. Treatment duration
j. Follow-up period;
k. Outcome measures;
l. Principal findings.

The extracted data were independently verified to ensure completeness and accuracy before synthesis.

Quality Assessment

Methodological quality was assessed using the Jadad Scale, evaluating randomization (0–2), blinding (0–2), and reporting of withdrawals/dropouts (0–1), for a maximum score of five. Scores of three to five indicated good methodological quality; scores below three indicated poor quality.

Data Synthesis

A qualitative synthesis first summarized study design, patient characteristics, intervention protocols, comparators, outcomes, and findings. A quantitative meta-analysis was then conducted for studies reporting comparable wound surface area data, while studies using other instruments (BWAT, PUSH) were synthesized narratively.

Statistical Analysis

Meta-analysis used a random-effects model given anticipated heterogeneity. Pooled effects were expressed as mean difference (MD) with 95% CI, with heterogeneity assessed via Cochran's Q and I^2 (>75% indicating substantial heterogeneity); significance was set at $p<0.05$. Results were presented as forest plots. Because fewer than ten studies were included, funnel plots for publication bias were not performed, consistent with methodological guidance.

RESULTS AND DISCUSSION

Characteristics of Included Studies

A total of five interventional studies were included in this systematic review, comprising four randomized controlled trials (RCTs) and one controlled clinical trial (CCT) published between 2011 and 2021. These studies evaluated the efficacy of High-Intensity Laser Therapy (HILT) compared with standard wound care, conventional medical treatment, or sham laser therapy in patients with chronic diabetic foot ulcers, neuropathic foot ulcers associated with spina bifida, delayed Caesarean section wounds in diabetic women, and chronic refractory wounds. Although the wound etiologies varied, all included studies investigated whether HILT could improve wound healing outcomes when used as an adjunctive intervention alongside conventional wound management.

Intervention protocols varied in laser wavelength, irradiation parameters, frequency, duration, and follow-up. Most studies used pulsed Nd HILT, with comparators receiving standard care, conventional treatment, or sham laser therapy. Primary outcomes included wound surface area and size reduction, appearance, healing rate, BWAT, PUSH, and overall improvement.

Despite differing treatment protocols and outcome measures, the included studies consistently demonstrated favorable outcomes following HILT, with most reporting significantly greater wound size reduction, improved appearance, higher healing scores, and accelerated tissue repair compared with standard care, conventional treatment, or sham laser therapy.

Meta-analysis of Wound Surface Area Reduction

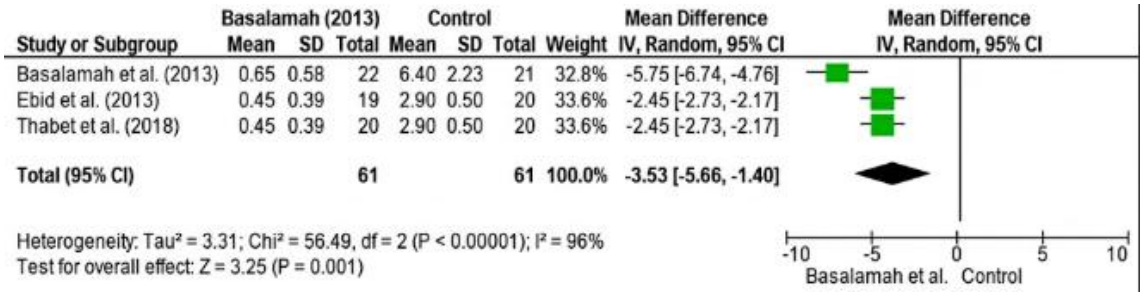

Figure 1. Forest Plot

Source: Author's meta-analysis using data extracted

Three studies reported comparable wound surface area data suitable for pooled meta-analysis, comparing HILT with standard wound care or sham laser therapy (Figure 2). The pooled mean difference was −3.53 (95% CI: −5.66 to −1.40; p = 0.001), demonstrating significantly greater wound surface area reduction and accelerated healing among patients receiving HILT compared with control interventions.

Substantial heterogeneity was observed among the included studies (I^2 = 96%), indicating considerable variability in study populations, wound characteristics, intervention protocols, and outcome assessment methods. The observed heterogeneity may be attributed to differences in wound etiology, laser parameters, treatment duration, comparator interventions, and follow-up periods. Consequently, a random-effects model was applied to obtain a more conservative pooled estimate. As illustrated in Figure 1, all three studies favored HILT over the control interventions. Basalamah et al. (2013) demonstrated the largest treatment effect, while Ebid et al. (2013) and Thabet et al. (2018) also reported significant reductions in wound surface area following HILT. The pooled estimate, represented by the diamond in the forest plot, remained entirely on the side favoring HILT, confirming a statistically significant overall treatment benefit.

The five included studies were conducted between 2011 and 2021 across Egypt, China, and Saudi Arabia. Despite differing healthcare settings, all shared the objective of evaluating HILT against standard care, conventional treatment, or sham laser therapy, reflecting growing scientific interest in laser-based regenerative therapies for chronic wounds over the past decade.

The included studies investigated several chronic wound conditions characterized by delayed tissue repair, including diabetic foot ulcers, neuropathic foot ulcers, chronic refractory wounds, and delayed postoperative Caesarean section wounds. Diabetic foot ulcers represented the most frequently investigated wound type because of their high prevalence and their association with infection, prolonged hospitalization, and lower-limb amputation. Chronic refractory wounds and delayed postoperative wounds were also evaluated to determine whether HILT could improve tissue regeneration in wounds resistant to conventional management. Sample sizes among the included studies ranged from 40 to 60 participants, with an overall study population of approximately 223 patients. Most participants were middle-aged or older adults and frequently presented with underlying comorbidities, particularly diabetes mellitus, which is recognized as one of the principal

factors contributing to delayed wound healing. These patient characteristics reflect the complexity of chronic wound management and emphasize the need for effective adjunctive therapies capable of enhancing tissue repair.

Most studies used pulsed Nd HILT at wavelengths of approximately 1064 nm, with treatment protocols differing in irradiation parameters, frequency, duration, and total energy delivered—reflecting the absence of standardized HILT protocols and partly explaining the heterogeneity observed. Comparators mainly consisted of standard wound care, conventional medical treatment, or sham laser therapy; the use of sham laser in several RCTs minimized placebo effects and strengthened internal validity.

Overall, despite clinical heterogeneity, the collective evidence consistently showed HILT achieving better wound healing outcomes than standard care, conventional treatment, or sham laser therapy, supporting its promise as an adjunctive intervention, though larger standardized trials remain necessary.

Methodological Quality Assessment

The methodological quality of the included studies was evaluated using the Jadad Scale, which assesses three key methodological domains: randomization, blinding, and reporting of withdrawals or dropouts. All five included studies underwent quality assessment because they employed interventional clinical designs. Overall, the methodological assessment demonstrated that the included studies were of good methodological quality, with Jadad scores ranging from 3 to 5. Three randomized controlled trials (Basalamah et al., 2013; Thabet et al., 2018; and Lu et al., 2021) achieved the maximum Jadad score of 5, indicating adequate randomization, appropriate blinding procedures, and complete reporting of participant withdrawals. Ebid et al. (2011) achieved a Jadad score of 3, while Ebid et al. (2013) achieved a score of 4, both of which also met the criteria for good methodological quality.

Table 1. Methodological Quality Assessment of Included Studies Using the Jadad Scale

Study	Randomization	Blinding	Withdrawals	Total	Quality
Ebid et al. (2011)	1	1	1	3	Good
Basalamah et al. (2013)	2	2	1	5	Good
Ebid et al. (2013)	2	1	1	4	Good
Thabet et al. (2018)	2	2	1	5	Good
Lu et al. (2021)	2	2	1	5	Good

Source: Author's assessment based on Jadad Scale criteria applied to included studies (2026)

Table 1 shows all studies achieved Jadad scores indicating good methodological quality, with clear description of randomization, intervention protocols, outcome assessment, and follow-up. Several RCTs used sham laser therapy as a control, strengthening blinding and minimizing performance bias, supporting the reliability of the synthesized evidence.

Despite generally high quality, some limitations were identified: complete blinding of participants and providers was difficult given the physical nature of laser therapy, and variation in laser wavelength, irradiation parameters, frequency, and duration may have

influenced outcomes, alongside differences in wound etiology, patient characteristics, and outcome assessment methods.

Beyond the pooled meta-analysis, two studies reported outcomes that could not be quantitatively synthesized due to differing instruments. Lu et al. (2021) found significant improvement in BWAT and PUSH scores following HILT compared with conventional wound care, indicating accelerated tissue repair.

The remaining studies also consistently reported favorable outcomes with HILT—greater wound surface area reduction, improved appearance, enhanced granulation tissue formation, faster contraction, and overall improvement—suggesting HILT enhances regeneration through improved microcirculation, fibroblast stimulation, collagen synthesis, and modulation of inflammation.

Overall, although differing protocols and outcome measures limited quantitative pooling, both the meta-analysis and qualitative synthesis consistently demonstrated favorable HILT effects, supporting it as a promising adjunctive therapy—though further high-quality, standardized RCTs with larger samples and longer follow-up are needed.

Efficacy of High-Intensity Laser Therapy Compared with Control Interventions

The present systematic review and meta-analysis was conducted to evaluate the efficacy of High-Intensity Laser Therapy (HILT) in promoting wound healing among patients with chronic and delayed-healing wounds. The pooled quantitative analysis demonstrated that HILT significantly reduced wound surface area compared with standard wound care, conventional treatment, and sham laser therapy, with a pooled mean difference of −3.53 (95% CI: −5.66 to −1.40; $p = 0.001$). These findings indicate that patients receiving HILT experienced greater wound contraction and faster healing progression than those receiving conventional treatment alone. The direction of the pooled effect consistently favored HILT, suggesting that this intervention provides clinically meaningful benefits when used as an adjunctive therapy in wound management.

Although the meta-analysis demonstrated a statistically significant treatment effect, substantial statistical heterogeneity was observed among the included studies ($I^2 = 96\%$). This finding indicates considerable variability in clinical and methodological characteristics across the included trials. Differences in wound etiology, patient demographics, treatment protocols, laser parameters, intervention duration, comparator interventions, and outcome assessment methods are likely to have contributed to the observed heterogeneity. Nevertheless, despite these variations, all studies included in the quantitative synthesis consistently demonstrated treatment effects favoring HILT over the comparator interventions. Therefore, while the magnitude of treatment benefit varied among studies, the overall direction of evidence remained consistent, supporting the efficacy of HILT in enhancing wound healing.

These findings align with Basalamah et al. (2013), who found diabetic foot ulcer patients treated with pulsed Nd:YAG HILT achieved significantly greater wound size reduction than those receiving sham laser plus standard care, attributing this to enhanced cellular metabolism and microcirculation. Because sham laser controlled for placebo effects, the improvement is more likely attributable to HILT's biological effects than to routine care alone.

Similarly, Ebid et al. (2011) found that combining HILT with conventional management produced significantly greater wound surface area reduction than conventional treatment alone in chronic diabetic foot ulcers—conditions marked by prolonged inflammation, impaired angiogenesis, neuropathy, and reduced perfusion—suggesting HILT effectively enhances tissue regeneration even under these challenging conditions.

Further support comes from Ebid et al. (2013), who evaluated children with spina bifida-related neuropathic foot ulcers—a difficult condition due to sensory impairment delaying wound recognition and increasing trauma risk. Patients receiving HILT showed significantly greater improvement in wound size and appearance than those receiving conventional care, suggesting benefits extend beyond diabetic wounds to neuropathic ulcers.

Thabet et al. (2018) similarly found that diabetic women with delayed Caesarean wound healing receiving HILT plus standard treatment achieved significantly greater wound size reduction than those receiving sham laser therapy. Given that delayed postoperative healing in diabetic patients often involves impaired vascularization and collagen synthesis, these findings suggest HILT may benefit postoperative wounds complicated by metabolic disorders.

The qualitative findings of this review were further supported by the randomized controlled trial conducted by Lu et al. (2021), which evaluated patients with chronic refractory wounds. Unlike the other included studies, Lu et al. assessed wound healing using the Bates-Jensen Wound Assessment Tool (BWAT) and the Pressure Ulcer Scale for Healing (PUSH), rather than wound surface area alone. Patients receiving HILT demonstrated significantly greater improvements in both BWAT and PUSH scores compared with those receiving conventional wound care. Although these outcomes could not be quantitatively pooled because of differences in measurement methods, they provide additional evidence supporting the beneficial effects of HILT on multiple aspects of wound healing, including tissue condition, wound appearance, and overall healing progression. Taken together, the findings from the included studies consistently indicate that High-Intensity Laser Therapy provides superior wound healing outcomes compared with conventional treatment approaches. Although individual studies differed with respect to patient characteristics, wound etiology, treatment protocols, and outcome measurements, the direction of treatment effects consistently favored HILT. This consistency strengthens the overall evidence supporting HILT as an effective adjunctive intervention for promoting wound healing in patients with chronic and delayed-healing wounds.

The superior clinical outcomes observed following HILT treatment may be explained by its unique photobiomodulatory properties. Unlike conventional wound care, which primarily focuses on controlling infection, maintaining an optimal wound environment, and preventing further tissue damage, HILT directly stimulates biological processes involved in tissue regeneration. High-energy laser irradiation has been shown to enhance mitochondrial activity, increase adenosine triphosphate (ATP) production, stimulate fibroblast proliferation, promote collagen synthesis, improve angiogenesis, and enhance local microcirculation. Collectively, these physiological responses create a more favorable environment for tissue repair, accelerate wound contraction, and facilitate earlier wound closure (Kurhaluk, *Photobiomodulation and Low-Level Laser Therapy as Complementary Strategies in Diabetes Treatment*, 2026).

These findings also align with Yoon (2024), who concluded that HILT shows promising potential for wound healing through tissue regeneration and inflammatory modulation, though prior evidence remained largely descriptive without quantitative synthesis. By incorporating pooled statistical analysis, this study extends previous evidence with stronger quantitative support for HILT's efficacy.

Overall, the findings of this systematic review and meta-analysis demonstrate that High-Intensity Laser Therapy is more effective than standard wound care, conventional treatment, and sham laser therapy in promoting wound healing among patients with chronic and delayed-healing wounds. Despite the substantial heterogeneity observed among the included studies, the consistency of favorable treatment effects across all interventional studies supports the use of HILT as a valuable adjunctive therapeutic modality. These findings directly answer the first research question of the present study and provide evidence that HILT may significantly enhance wound healing when integrated into comprehensive wound management programs.

Effects of High-Intensity Laser Therapy on Wound Healing Outcomes

Although wound surface area reduction constituted the primary outcome included in the quantitative meta-analysis, the findings of this systematic review indicate that the therapeutic benefits of High-Intensity Laser Therapy (HILT) extend beyond wound size reduction alone. Across the included studies, HILT consistently improved multiple clinical indicators of wound healing, including wound appearance, wound healing scores, tissue regeneration, granulation tissue formation, epithelialization, and overall healing progression. These findings suggest that HILT positively influences several biological and clinical aspects of tissue repair, thereby supporting its role as a comprehensive adjunctive treatment in chronic wound management.

One of the most consistent findings among the included studies was the significant reduction in wound surface area following HILT intervention. Reduction in wound size is widely recognized as one of the most reliable indicators of healing progression because it reflects successful wound contraction, granulation tissue formation, and restoration of tissue integrity. Patients treated with HILT consistently demonstrated greater decreases in wound surface area than those receiving standard wound care, conventional medical treatment, or sham laser therapy. These improvements were observed across different wound types, including diabetic foot ulcers, neuropathic foot ulcers, delayed postoperative wounds, and chronic refractory wounds, suggesting that the therapeutic effects of HILT are applicable across various clinical conditions characterized by impaired wound healing.

Among patients with diabetic foot ulcers, HILT demonstrated particularly encouraging therapeutic outcomes. Diabetic foot ulcers represent one of the most difficult wound conditions because prolonged hyperglycemia impairs angiogenesis, collagen synthesis, inflammatory regulation, and immune function. Peripheral neuropathy and microvascular dysfunction further compromise tissue perfusion and delay cellular regeneration. Despite these physiological challenges, both Ebid et al. (2011) and Basalamah et al. (2013) reported significantly greater wound size reduction among patients receiving HILT compared with control interventions. These findings indicate that HILT may partially overcome the impaired healing environment associated with diabetes mellitus by enhancing local circulation and stimulating cellular repair mechanisms.

The beneficial effects of HILT were also observed in patients with neuropathic foot ulcers secondary to spina bifida. In the randomized controlled trial conducted by Ebid et al. (2013), patients receiving HILT demonstrated significant improvements in both wound size reduction and wound appearance compared with conventional wound care. Neuropathic wounds are particularly susceptible to prolonged healing because impaired sensory function increases repetitive mechanical trauma while reducing protective responses. The favorable outcomes observed in this study suggest that HILT may facilitate tissue regeneration even in wounds complicated by neurological impairment.

Similarly, Thabet et al. (2018) demonstrated significant clinical improvement among diabetic women experiencing delayed Caesarean section wound healing. Participants receiving pulsed High-Intensity Laser Therapy in combination with standard medical treatment experienced greater wound contraction and more rapid healing progression than those treated with sham laser therapy. Delayed postoperative wound healing is frequently associated with impaired collagen deposition, persistent inflammation, and reduced tissue oxygenation, particularly among patients with diabetes mellitus. The positive findings reported by Thabet et al. therefore suggest that HILT may also provide therapeutic benefits for surgical wounds complicated by systemic metabolic disorders.

Unlike the studies included in the quantitative synthesis, Lu et al. (2021) evaluated wound healing using the Bates-Jensen Wound Assessment Tool (BWAT) and the Pressure Ulcer Scale for Healing (PUSH). Both assessment instruments provide comprehensive evaluation of wound condition by incorporating multiple clinical parameters rather than wound size alone. The BWAT evaluates wound dimensions, tissue type, exudate, granulation tissue, epithelialization, and surrounding skin condition, whereas the PUSH score incorporates wound surface area, exudate amount, and tissue characteristics. Patients treated with HILT demonstrated significantly greater reductions in both BWAT and PUSH scores than those receiving conventional wound care, indicating accelerated tissue repair and overall improvement in wound status. Although these outcomes could not be quantitatively pooled because of methodological differences, they provide important qualitative evidence supporting the efficacy of HILT across multiple dimensions of wound healing.

Several studies also reported improved wound appearance with HILT—healthier margins, cleaner beds, increased granulation, and earlier epithelialization—indicating progression from the inflammatory to proliferative and remodeling phases, and reflecting restored tissue viability and vascularization essential for complete closure.

Granulation tissue formation represents another important indicator of successful wound healing. Granulation tissue consists of newly formed capillaries, fibroblasts, inflammatory cells, and extracellular matrix that collectively provide structural support for tissue regeneration. Earlier development of healthy granulation tissue was consistently reported among patients treated with HILT. Accelerated granulation tissue formation enhances wound contraction, facilitates epithelial migration, and promotes collagen deposition, ultimately leading to more rapid wound closure. These findings are consistent with the known biological effects of laser-induced photobiomodulation on angiogenesis and fibroblast proliferation. Likewise, accelerated epithelialization was observed across several studies included in this review. Epithelialization is the process by which epithelial cells migrate across the wound surface to restore the protective barrier of the skin. Earlier

epithelial coverage reduces the risk of bacterial contamination, minimizes fluid loss, and enhances functional recovery of damaged tissues. The improved epithelialization observed following HILT treatment therefore represents an important clinical benefit that extends beyond simple reduction in wound size.

These outcomes are biologically plausible given known photobiomodulation mechanisms: HILT enhances mitochondrial ATP production, stimulating fibroblast activity, collagen synthesis, angiogenesis, and matrix remodeling while improving microcirculation and oxygen delivery. It also modulates inflammatory responses by reducing pro-inflammatory mediators and oxidative stress, facilitating the transition from inflammation to active regeneration (Kurhaluk, 2026).

Differences in wound assessment methods limited the number of studies eligible for quantitative synthesis—three provided comparable surface area data, while others used BWAT or PUSH—contributing to the observed heterogeneity and preventing full statistical integration. Nevertheless, the qualitative synthesis showed remarkable consistency, with all studies reporting improvement in at least one clinically relevant parameter following HILT.

Overall, the evidence synthesized in this systematic review indicates that High-Intensity Laser Therapy improves multiple dimensions of wound healing rather than wound size reduction alone. The observed improvements in wound surface area, wound healing scores, wound appearance, granulation tissue formation, epithelialization, and overall tissue regeneration collectively demonstrate that HILT provides clinically meaningful benefits for patients with chronic and delayed-healing wounds. These findings directly address the second objective of the present study by confirming that the efficacy of HILT extends across multiple clinically relevant wound healing outcomes and supports its application as an adjunctive therapeutic modality within comprehensive wound care programs.

CONCLUSION

The present systematic review and meta-analysis evaluated the efficacy of High-Intensity Laser Therapy (HILT) in promoting wound healing among patients with chronic and delayed-healing wounds. Based on the available evidence, HILT demonstrated superior therapeutic efficacy compared with standard wound care, conventional treatment, and sham laser therapy. The quantitative synthesis revealed that HILT significantly reduced wound surface area, with a pooled mean difference of −3.53 (95% CI: −5.66 to −1.40; $p = 0.001$), indicating greater wound contraction and accelerated healing progression among patients receiving HILT. Although substantial heterogeneity was observed among the included studies ($I^2 = 96\%$), the direction of treatment effects consistently favored HILT across all studies included in the meta-analysis. Beyond surface area reduction, the qualitative synthesis showed that HILT improved wound appearance, healing progression, granulation tissue formation, epithelialization, and validated wound assessment scores (Bates-Jensen Wound Assessment Tool [BWAT] and Pressure Ulcer Scale for Healing [PUSH]), suggesting benefits extending beyond wound closure to broader tissue regeneration through enhanced cellular metabolism, microcirculation, fibroblast proliferation, collagen synthesis, angiogenesis, and inflammatory modulation.

Methodological quality assessment indicated that the included evidence was generally reliable, with all studies achieving good quality scores on the Jadad Scale.

Nevertheless, variations in wound characteristics, treatment protocols, laser parameters, and outcome assessments contributed to substantial clinical heterogeneity, indicating the need for further high-quality randomized controlled trials with standardized HILT protocols. Overall, the findings of this systematic review and meta-analysis support the use of High-Intensity Laser Therapy as an effective adjunctive intervention for promoting wound healing in patients with chronic and delayed-healing wounds. When combined with comprehensive conventional wound management, HILT may accelerate tissue repair and improve clinical healing outcomes.

REFERENCES

Ahmed, A.-B., et al. (2025). Platelet-rich plasma (PRP) and recombinant growth factor therapies in cutaneous wound healing: Mechanisms, clinical applications, and future directions. *Journal of Clinical Medicine, 14*(23), 8583. https://doi.org/10.3390/jcm14238583

Alayat, M. S. (2026). The effectiveness of photobiomodulation therapy on perineal pain and wound healing after episiotomy: A systematic review and meta-analysis. *Clinical Medicine*.

Fortuna, D. (2025). High-intensity vs. high-power laser therapy: Biophysical implications of a semantic ambiguity and the distinct role of photoacoustic effects. *Applied Sciences*.

Frykberg, R. G. (2015). Challenges in the treatment of chronic wounds. *Comprehensive Invited Review*.

Gallagher, K. A., et al. (2024). Current status and principles for the treatment and prevention of diabetic foot ulcers in the cardiovascular patient population: A scientific statement from the American Heart Association. *Circulation, 149*(4), e232–e253.

Hernández-Bule, M. L., Naharro-Rodríguez, J., Bacci, S., & Fernández-Guarino, M. (2024). Unlocking the power of light on the skin: A comprehensive review on photobiomodulation. *International Journal of Molecular Sciences, 25*(8), 4483. https://doi.org/10.3390/ijms25084483

Jiang, Y., et al. (2021). Tissue repair and regeneration disorders: Repair and regeneration of chronic refractory wounds. In *Regenerative Medicine in China* (pp. 139–178). Springer.

Kurhaluk, N. (2026). Photobiomodulation and low-level laser therapy as complementary strategies in diabetes treatment. *International Journal of Molecular Sciences*.

Lohr, J. M. (2026). A synergistic multimodality treatment approach to address the key drivers of wound chronicity. *Journal of Vascular Surgery: Venous and Lymphatic Disorders*.

Lu, Q. (2020). Clinical effects of high-intensity laser therapy on patients with chronic refractory wounds: A randomised controlled trial. *BMJ Open*.

Mussttaf, R. A., Jenkins, D. F. L., & Jha, A. N. (2019). Assessing the impact of low level laser therapy (LLLT) on biological systems: A review. *International Journal of Radiation Biology, 95*(2), 120–143. https://doi.org/10.1080/09553002.2019.1524941

Nirenjen, S., et al. (2023). Exploring the contribution of pro-inflammatory cytokines to impaired wound healing in diabetes. *Frontiers in Immunology, 14*, 1216321. https://doi.org/10.3389/fimmu.2023.1216321

Olteanu, G. (2024). Advancements in regenerative hydrogels in skin wound treatment: A comprehensive review. *International Journal of Molecular Sciences*.

Orti, H. A. (2026). Comparison of the effectiveness of high-intensity laser therapy versus low-level laser therapy in musculoskeletal disorders: A systematic review and

network meta-analysis. *Lasers in Medical Science*.
Pérez, S. E. (2025). Effectiveness of hyperbaric oxygen therapy for musculoskeletal pain syndromes: A systematic review. *Muscles*.
Peterson, A. (2025). Preventing pressure injuries in individuals with impaired mobility: Best practices and future directions. *HHS Public Access*.
Pramesti, A. R. (2025). The effect of high intensity laser therapy on low back pain: A literature review. *International Journal of Medical Science and Clinical Research Studies*.
Redmond, M. C. (2025). A review of chronic wounds and their impact on negative affect, cognition, and quality of life. *International Wound Journal*.
Rashidi, S., et al. (2015). Laser therapy for wound healing: A review of current techniques and mechanisms of action. *Bioscience, Biotechnology Research Asia, 12*, 217–223.
Song, J., et al. (2025). Cell migration in diabetic wound healing: Molecular mechanisms and therapeutic strategies. *International Journal of Molecular Medicine, 56*(2), 126.
Wan, R., et al. (2021). Diabetic wound healing: The impact of diabetes on myofibroblast activity and its potential therapeutic treatments. *Wound Repair and Regeneration, 29*(4), 573–581. https://doi.org/10.1111/wrr.12942
Yoon, S. H. (2024). The efficacy of high-intensity laser therapy in wound healing: A narrative review. *Lasers in Medical Science*.