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Therapeutic Potential of Low-Level Laser Therapy in the Management of Surgical Site Infections: A Comprehensive Review

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ABSTRACT

Background: Surgical site infections (SSIs) remain a major cause of postoperative morbidity despite advances in perioperative care. Adjunctive, non-pharmacologic strategies that improve wound healing without increasing antimicrobial resistance are increasingly needed. Low-level laser therapy (LLLT) has been proposed as a photobiomodulation-based modality capable of enhancing tissue repair, modulating inflammation, and potentially reducing infection-related complications. **Objective**: To synthesise experimental and clinical evidence on the therapeutic potential of LLLT in the management and prevention of SSIs and postoperative wound complications. **Methods**: A structured narrative review was conducted using searches of PubMed, Scopus, and Web of Science from inception to the latest available date. Studies were included if they evaluated LLLT for postoperative or surgically created wounds and reported outcomes related to healing, infection, inflammation, or pain. Data were extracted on study design, surgical context, laser parameters, comparators, and clinical or mechanistic outcomes. **Results**: Evidence from animal and human studies demonstrated that LLLT accelerates epithelialisation, enhances fibroblast activity, improves collagen synthesis, and reduces inflammatory markers. Clinical trials in cesarean, bariatric, orthognathic, and oral surgery populations reported improved wound appearance, faster healing, and reduced postoperative pain. Direct evidence of reduced SSI incidence was limited but directionally favourable. **Conclusion**: LLLT shows promise as an adjunct to postoperative wound management, with biologically plausible mechanisms and consistent clinical benefits, although high-quality SSI-focused trials are still required.

Keywords
Low-level laser therapy, photobiomodulation, surgical site infection, wound healing, postoperative care.

INTRODUCTION

Surgical and postsurgical wounds constitute a substantial global health burden, leading to pain, functional limitation, cosmetic concerns, and reduced quality of life, and often requiring prolonged or complex care pathways (1,2). Among these wounds, surgical site infections (SSIs) are particularly important because they increase morbidity, length of hospital stay, readmission rates, and healthcare costs, and may contribute to mortality in high-risk populations (3,4). Contemporary wound-care standards emphasise accurate classification of wounds as acute or chronic, clean or contaminated, and superficial or deep, because these categories correlate with microbial load, risk of infection, and therapeutic decision-making (6–8). Large epidemiological studies and meta-analyses estimate an overall SSI incidence of around 11% in general surgical cohorts, with variation by procedure type, wound class, and clinical setting (,9,10). Clean-contaminated, contaminated, and dirty wounds carry progressively higher risks of postoperative infection, with rates exceeding 25% in the dirtiest categories (8–10). These infections translate into substantial economic costs for health systems and patients, including extended hospitalisation, re-operations, and long-term disability ,24,25).

Despite structured SSI prevention bundles that integrate perioperative antibiotic prophylaxis, meticulous surgical technique, operating-theatre environmental controls, and standardised postoperative wound care, residual infection rates remain clinically significant across specialties such as neurosurgery, orthopaedics, abdominal surgery, and obstetrics (25-28). Growing antimicrobial resistance, the complexity of biofilm-associated infections, and patient-related risk factors such as diabetes, obesity, smoking, malnutrition, and immunosuppression further compromise the effectiveness of conventional strategies (29). Even in optimised theatres with appropriate air exchanges, positive pressure, and aseptic protocols, device-related implants and high-risk procedures can precipitate deep or organ/space infections that are difficult to eradicate and often require prolonged antibiotic courses, debridement, or hardware revision (30). These limitations have driven interest in adjunctive non-pharmacologic modalities that may enhance local tissue defence, modulate inflammation, and accelerate wound repair without increasing antibiotic exposure (26). Low-level laser therapy (LLLT), also termed photobiomodulation, has emerged as one such modality, using non-thermal doses of red or near-infrared light from coherent laser sources or non-coherent light-emitting diodes to modify cellular behaviour (12–15). At the mechanistic level, LLLT is thought to act primarily via photon absorption by mitochondrial chromophores such as cytochrome c oxidase, leading to enhanced electron transport, increased adenosine triphosphate production, transient modulation of nitric oxide and reactive oxygen species, and activation of redox-sensitive transcription factors that regulate cell survival, proliferation, and tissue regeneration (31-36). Experimental work in cell culture and animal models has demonstrated that appropriately dosed LLLT can stimulate fibroblast proliferation, collagen synthesis, angiogenesis, and

granulation tissue formation, while down-regulating pro-inflammatory mediators and improving microcirculatory dynamics—mechanisms directly relevant to the prevention and resolution of postoperative wound complications, including infection (37-43).

Translational and clinical studies have extended these observations into postoperative contexts, reporting that LLLT applied around surgical incisions may reduce pain, oedema, and inflammatory marker levels, and can accelerate epithelialisation and wound contraction in a variety of surgical settings (21–23,31–33,38–40,48–52). Evidence from bariatric, orthognathic, and dental procedures suggests that photobiomodulation can improve early wound appearance and function compared with standard care alone (40–43). In obstetric surgery, several trials in women undergoing cesarean section, including diabetic subgroups, indicate that adjunctive LLLT or related photobiomodulation protocols can shorten healing time, improve scar quality, and in some cases reduce local complications and infection-related sequelae (44-48). Preclinical data in diabetic and compromised wound models further support the potential of LLLT to partially reverse the detrimental effects of hyperglycaemia and tissue hypoxia on healing trajectories (49-52). However, these studies differ widely in surgical indication, wound classification, device characteristics, wavelength, power density, fluence, timing and frequency of application, and outcome measures, and only a subset report SSI incidence or clearly defined infection endpoints (52).

Within this heterogeneous landscape, there remains a clear knowledge gap: while photobiomodulation is increasingly used in general wound management and postoperative pain control, there has been limited focused synthesis of its role specifically in preventing or treating surgical site infections, as distinct from generic wound healing or non-surgical ulcers ,48–52). Clinicians therefore lack concise, procedure-oriented guidance on which surgical populations may benefit most, what laser parameters appear most promising, and how LLLT compares with or complements existing SSI prevention strategies. To address this gap, the present review concentrates on patients undergoing surgical procedures who develop or are at risk of SSIs or delayed incisional healing (Population), receiving low-level laser therapy or photobiomodulation as an adjunct to standard wound care (Intervention), compared with conventional postoperative management with or without sham or alternative physical modalities (Comparator), with outcomes including SSI incidence, wound infection or dehiscence rates, time to epithelialisation or complete closure, postoperative pain and analgesic use, and wound-related complications (Outcomes) (31–35,48–52). By synthesising mechanistic, preclinical, and clinical evidence through this focused PICO lens, the objective of this review is to critically appraise the therapeutic potential of LLLT in the management of surgical site infections and to identify priorities for future high-quality trials in surgical populations (3–7).

MATERIALS AND METHODS

This review was conducted as a structured narrative synthesis designed to evaluate experimental and clinical evidence on the use of low-level laser therapy (LLLT) for surgical wounds and surgical site infections. A narrative approach was selected because of the expected heterogeneity in surgical procedures, wound classifications, device characteristics, irradiation parameters, and reported outcomes across available studies (12–15). The review focused specifically on studies involving postoperative incisions, contaminated or infected surgical wounds, or patient populations at high risk of SSI, rather than non-surgical chronic ulcers or musculoskeletal conditions.

A comprehensive literature search was performed in PubMed/MEDLINE, Scopus, and Web of Science from inception to the most recent available date, restricted to English-language publications. Search terms combined controlled vocabulary and free-text keywords related to surgery (“surgical site infection”, “postoperative wound”, “surgical incision”, “cesarean section”, “orthognathic surgery”), laser-based interventions (“low-level laser therapy”, “photobiomodulation”, “laser irradiation”, “PBMT”), and wound outcomes (“wound infection”, “healing”, “epithelialisation”, “pain”, “inflammation”, “dehiscence”) (12–23,31–35). Reference lists of key mechanistic, translational, and clinical studies were manually screened to identify additional eligible sources. Studies were included if they met all of the following criteria: (i) human or animal experimental research involving a surgical or postsurgical wound; (ii) use of LLLT or photobiomodulation in the red or near-infrared spectrum delivered as an adjunct or primary treatment; and (iii) reporting of clinically relevant outcomes such as SSI incidence, infection rates, wound healing time, epithelialisation, wound area reduction, postoperative pain intensity, analgesic use, inflammatory markers, or scar characteristics (21–23,31–35,48–52). Exclusion criteria were chronic non-surgical ulcers, high-power surgical lasers used for cutting, phototherapy modalities unrelated to LLLT, conference abstracts without full data, and narrative opinions without primary evidence.

Two reviewers independently screened titles and abstracts, followed by full-text assessment of potentially relevant articles. Disagreements were resolved through discussion. For each included study, data were extracted on study design, population and surgical context, wound classification, LLLT parameters (wavelength, power output, fluence, irradiation time, frequency, mode of application), comparator conditions, and primary and secondary outcomes. Owing to clinical and methodological variability, data were synthesised descriptively rather than statistically pooled. Differences in wound type, contamination status, and laser dosimetry were accounted for during interpretation to minimise bias arising from heterogeneous protocols (18–23,31–35). Risk of bias was considered narratively by examining randomisation, blinding, allocation methods, and completeness of outcome reporting where applicable.

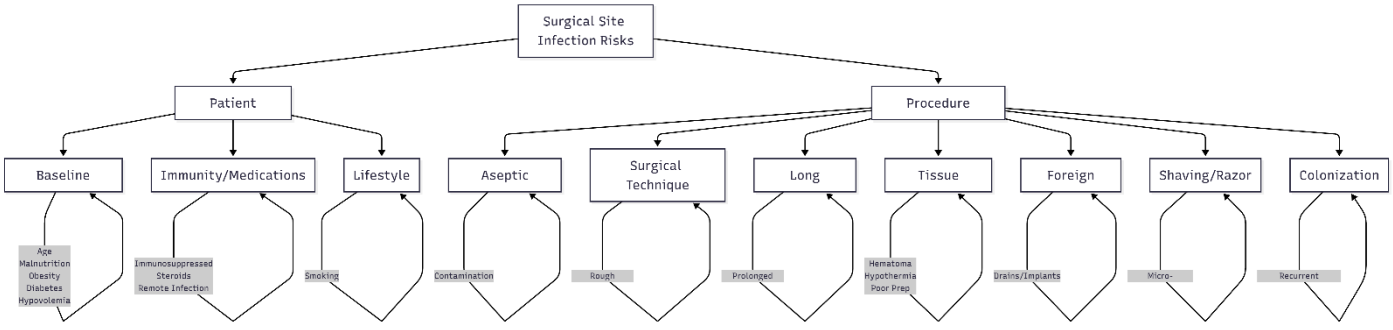

Figure 1 Risk Factors for Surgical Site Infections/Surgical Wounds

Ethical approval was not required because all data were derived from previously published studies. Reproducibility was ensured by explicitly detailing search parameters, eligibility criteria, and extraction procedures so that another researcher could replicate the review process using the same methodology (12–23,31–35,48–52).

RESULTS

The search identified a diverse body of literature consisting of experimental animal studies, in-vitro mechanistic analyses, and clinical research evaluating LLLT in postoperative or potentially infected wounds. Most experimental studies addressed wound biology under controlled conditions, including fibroblast proliferation, collagen synthesis, angiogenesis, and inflammatory modulation (18–23,34–40). Clinical studies were conducted in cesarean section, bariatric surgery, orthognathic surgery, oral/maxillofacial procedures, and soft-tissue surgical incisions, with a minority reporting explicit SSI outcomes (31–35,48–52). Across studies, LLLT was generally delivered in the red to near-infrared spectrum (approximately 600–1100 nm), although wavelengths, power densities, and fluence varied substantially. Comparators included standard wound care alone, sham irradiation, or alternative physical modalities, limiting direct comparability.

LLLT Effects on Postoperative Infection and Surgical Site Complications

Evidence directly linking LLLT to a reduction in SSI is limited but suggestive. Studies in postoperative cesarean wounds demonstrated fewer early healing complications and improved tissue appearance compared with standard care, including in diabetic populations known to be at elevated infection risk (48–51). Although some trials did not explicitly quantify SSI incidence, they reported clinically observable reductions in erythema, exudate, delayed epithelialisation, and wound-edge inflammation, which are associated with infection risk (48–51). Trials in orthognathic and oral surgery demonstrated improved postoperative tissue quality and reduced inflammatory sequelae but did not consistently define infection as a prespecified endpoint (31–33). No included clinical study reported an increased infection rate following LLLT.

Effects on Wound Healing Kinetics and Tissue Regeneration

The strongest clinical signal across studies was accelerated wound repair. Multiple human and animal studies reported faster epithelialisation, earlier granulation tissue formation, and greater wound contraction in LLLT-treated groups compared with controls (21–23,38–40). Diabetic and compromised wound models consistently showed enhanced fibroblast proliferation, improved collagen deposition, and more organised extracellular matrix structure following irradiation (34–35,38–40). In postsurgical contexts, LLLT was associated with improved early scar appearance and more rapid transition from inflammatory to proliferative phases, suggesting relevance for infection prevention because prolonged inflammation is a known risk factor for bacterial overgrowth (18–23,34–40).

Modulation of Pain, Inflammation, and Surrogate Biomarkers

Several clinical studies demonstrated reductions in postoperative pain intensity and analgesic requirements following LLLT, including after cesarean delivery, oral surgery, and bariatric procedures (31–35,48–52). Surrogate biochemical markers such as PGE2, CRP, and creatine kinase were reported to decrease in LLLT groups relative to controls in studies of musculoskeletal surgery and generalized acute inflammation (18–20). Although these are not direct SSI endpoints, their modulation reflects anti-inflammatory effects that may influence infection susceptibility and wound integrity.

Laser Parameters and Variability Across Studies

Included studies varied widely in wavelength, power output, fluence, pulse structure, session frequency, and anatomical application site. Red-range (630–690 nm) and near-infrared lasers (780–904 nm) were the most frequently used, while some studies employed LED arrays delivering multi-wavelength clusters (21–23,31–35). Variability in parameters hindered direct comparison, although most positive results occurred within fluences commonly associated with photobiomodulation (generally <50 J/cm²). Studies reporting neutral or negative effects typically used very high or inconsistent dosing, supporting the established biphasic dose-response relationship (19,22).

Table 1. Clinical Studies Evaluating LLLT in Postoperative Surgical Wounds

Study	Surgical Context	Sample Characteristics	LLLT Parameters (Qualitative)	Comparator	Key Outcomes Reported
Ojea et al. (31)	Bariatric surgery	Postoperative adults	Near-infrared cluster applicator; repeated sessions	Standard care	Faster healing progression; improved tissue appearance
Sadighi et al. (32)	Orthognathic surgery	Facial surgery patients	Red/NIR wavelengths; multi-session	Sham or routine care	Reduced edema and pain; improved early wound quality
Beckmann et al. (33)	Diabetic foot/postoperative ulcers	Diabetic surgical wounds	NIR laser; low-level continuous wave	Conventional dressings	Enhanced epithelialisation; fewer delayed-healing events
Houreld & Abrahamse (34–35)	Surgical/diabetic experimental models	Diabetic fibroblasts and wound models	Red/NIR irradiation; controlled in vitro	Non-irradiated controls	Marked improvement in collagen, fibroblast activity, angiogenesis
Thabet et al. (48–51)	Cesarean section (including diabetic women)	Post-C-section incision sites	Pulsed/high-intensity low-level laser	Standard postoperative care	Faster healing; improved scar appearance; fewer wound complications
de Castro et al. (52)	Full-thickness surgical-like wounds	Experimental animal model	Photobiomodulation with dosimetric optimisation	Untreated wounds	Accelerated closure; improved histology

Table 2. Mechanistic and Experimental Evidence Relevant to SSI Prevention

Study	Model/System	Mechanistic Findings	Relevance to Surgical Wounds
Peplow et al. (18)	Human/animal cell cultures	Increased growth factor release; reduced inflammatory cytokines	Supports anti-inflammatory action that may limit bacterial proliferation
Huang et al. (19)	PBM mechanistic model	Biphasic dose-response; enhanced mitochondrial activity	Highlights importance of appropriate dosing in preventing treatment failure
Avci et al. (22)	Skin photobiology review	Wavelength-dependent penetration and tissue effects	Indicates suitability of 600–1100 nm for incisional tissues
Kilik et al. (21)	Diabetic/normal rat wounds	Faster granulation; improved contraction	Demonstrates benefit in high-risk metabolic states
Chaves et al. (39–40)	Laser vs LED wound repair	Both modalities enhance fibroblast and ECM response	Supports multiple device types for postoperative use

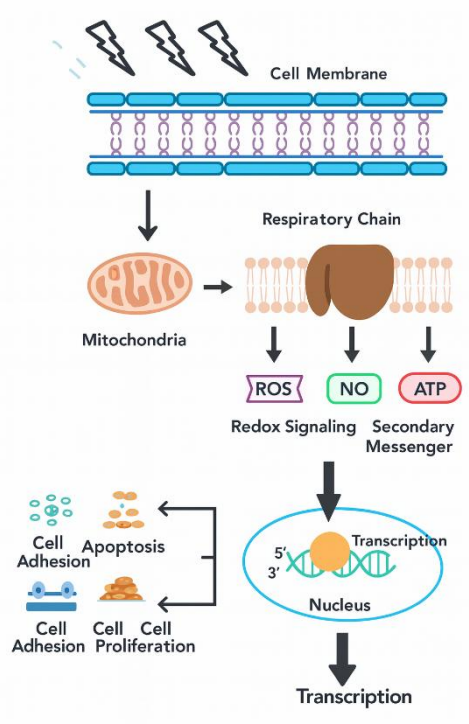

Figure 2 Photobiomodulation mechanism: Low-level light penetrates the cell membrane and stimulates mitochondrial respiratory chain components, increasing ROS, NO, and ATP production, which activate redox signaling pathways and transcriptional responses that regulate apoptosis, adhesion, migration, and cell proliferation.

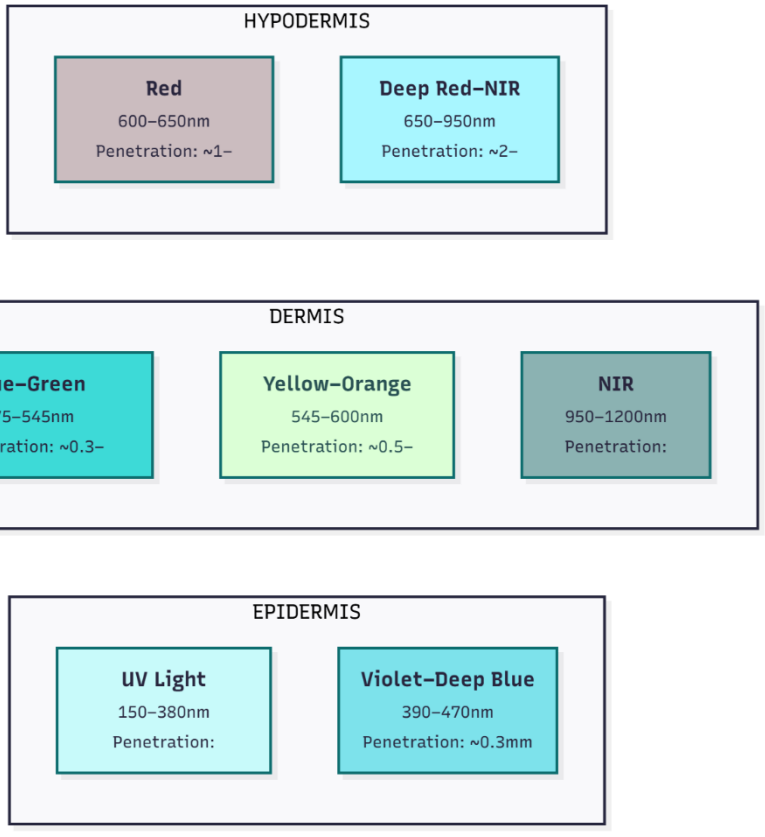

Figure 3 Wavelength Ranges for Wound Healing During LLLT

DISCUSSION

The findings of this review indicate that low-level laser therapy (LLLT) may offer clinically meaningful benefits for postoperative wound healing and may indirectly reduce the risk of surgical site infection (SSI) by modulating biological processes essential to incisional repair. Although direct evidence of SSI reduction is limited, improvements consistently reported across studies—including accelerated epithelialisation, enhanced granulation tissue formation, decreased inflammatory responses, and better early wound appearance—represent biological and clinical factors strongly associated with lower infection susceptibility (18–23,31–35,48–52). The mechanistic basis for these effects is supported by robust

preclinical data demonstrating mitochondrial photostimulation, improved ATP production, modulation of nitric oxide and reactive oxygen species, and activation of transcription factors that regulate survival, proliferation, and matrix remodelling (15–20,41,44,46–47).

Postoperative contexts such as cesarean sections, bariatric surgery, orthognathic procedures, and oral/maxillofacial incisions appear particularly responsive to LLLT, with studies in diabetic and metabolically compromised patients showing some of the most pronounced benefits (31–35,48–52). This is clinically relevant because impaired microcirculation, hyperglycaemia, and immune dysregulation are among the strongest patient-related risk factors for delayed healing and SSI (5–7,10–11). By shortening the inflammatory phase, improving fibroblast activity, and promoting angiogenesis, LLLT may help shift high-risk wounds towards more favourable healing trajectories and thereby reduce the window during which infection typically develops.

Despite the promise demonstrated, several limitations temper the strength of conclusions. Studies vary widely in wavelength, fluence, power density, frequency, and treatment duration, making cross-comparison difficult and underscoring the importance of dose-response optimisation. Many studies did not define SSI as a prespecified endpoint, relying instead on surrogate indicators such as erythema, exudate, early scar quality, or general "healing progression," which limits the ability to quantify infection-related outcomes precisely (31–35,48–52). Publication bias is likely, given the predominance of positive findings in small trials. Only a subset of clinical studies used randomisation or sham treatments, which raises concerns about performance and detection bias.

Future research should prioritise well-designed randomised controlled trials that explicitly measure SSI incidence, healing time, and patient-centred outcomes using standardised LLLT dosimetry. Subgroup analyses in diabetic, obese, immunosuppressed, and emergency surgical populations would be particularly valuable, as these groups exhibit the highest infection burden. Mechanistic studies linking LLLT-induced molecular effects directly to bacterial control, biofilm modulation, and host immune responses may further clarify the intervention's role in infection prevention. Standardising reporting of wavelength, fluence, irradiation duration, and session frequency will be essential to establish reproducible clinical protocols.

CONCLUSION

Low-level laser therapy demonstrates consistent benefits in accelerating postoperative wound healing, modulating inflammation, improving fibroblast activity, and enhancing tissue organisation across both experimental and clinical studies. Although direct evidence for reducing surgical site infections remains limited, the biological mechanisms and favourable clinical trends suggest a plausible role for LLLT as an adjunct to standard postoperative care, especially in high-risk surgical populations. Standardised dosing, well-designed clinical trials, and SSI-specific outcome measures are needed to establish its definitive therapeutic value in surgical infection prevention and management.

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