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Review

Utilizing Low-Intensity Light Therapy to Promote Healing and Alleviate Post-Surgical Pain: A Comprehensive Systematic Review and Meta-Analysis

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A R T I C L E I N F O

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A B S T R A C T

This study aimed to evaluate the effectiveness of low-intensity phototherapy in managing postoperative pain and promoting wound healing through a systematic review and meta-analysis following PRISMA guidelines. Studies were included without time restrictions, provided at least the abstract was available, and searches were conducted in multiple databases: CGF Specialized Register of Controlled Trials, Cochrane Central Register of Controlled Trials, MEDLINE (via Ovid), CINAHL (via EBSCO), Latin American and Caribbean Health Sciences Information Database, Science Citation Index-Expanded, and PubMed. Using the search strategy ("pain control" OR "wound healing") AND "low-intensity light therapy," 1,640 studies were identified, of which 21 met the inclusion criteria. Data were analyzed using Review Manager 5 software, employing random-effects models (Mantel-Haenszel) with a 95% confidence interval and a significance level of 0.05. Results indicated that low-intensity laser therapy was effective in pain control and wound healing, with a significant protective effect ($p < 0.05$). The findings support the potential of laser therapy as a postoperative intervention, though further controlled clinical trials are needed to address confounding factors related to patient profiles and differing methodologies, as well as to explore its applicability in other clinical scenarios supported by existing literature.

☆ Pre-registered hypothesis and protocol at the Open Science Framework (https://osf.io/).

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1 INTRODUCTION

Effective pain management is a cornerstone of patient care, particularly in hospitalized individuals, where unrelieved pain can significantly impact recovery and overall health outcomes. To achieve comprehensive control, it is essential to understand the multifaceted factors influencing pain, including physiological, psychological, and environmental components. Tailored interventions based on these factors can lead to more individualized and effective approaches, improving both the patient's clinical condition and quality of life[4]. Despite the importance of this issue, pain control often remains inadequate in various settings, with many interventions relying solely on conventional pharmacological treatments[3]. Pain itself is a complex nervous phenomenon triggered by the activation of sensory nerve endings, typically in response to injury, illness, or other health-related conditions. It can be classified based on its location, type, intensity, periodicity, and diffusion, all of which are influenced by the underlying cause and the patient's clinical status[1]. The healthcare approach directed toward managing pain can also significantly modify its characteristics, further underscoring the need for well-structured, evidence-based strategies[2].

In many cases, effective pain relief extends beyond pharmacological interventions. Non-pharmacological methods, while often supplemental, can play a critical role in improving outcomes, particularly due to their low cost and safety profile[6]. These measures, when integrated with pharmacological strategies, offer a multidimensional approach to pain management that can address gaps in current practices. The implementation of scientifically grounded recommendations can enhance recovery, reduce complications, and provide a more comprehensive treatment framework for patients[5].

In addition to pain control, the wound healing process is equally complex, following a consistent biological progression regardless of the injury's nature. Healing involves three distinct phases: inflammation, proliferation, and remodeling. The inflammatory phase initiates the repair cascade, marked by vasoconstriction, hemostasis, and leukocyte migration. Neutrophils play a pivotal role, guided by selectins expressed on the endothelium. The proliferative phase is characterized by fibroblast migration, angiogenesis, and extracellular matrix synthesis, culminating in re-epithelialization. Finally, the remodeling phase increases tissue tensile strength, with collagen I and III ratios gradually returning to pre-injury levels over time[7–14].

However, factors such as advanced age, obesity, and poor tissue oxygenation can impede this process. Aging reduces the elasticity of scar tissue and diminishes the inflammatory response, while obesity compromises blood supply to adipose tissue, increasing infection risk and delaying healing[11]. Other impediments include conditions like anemia and smoking, which reduce oxygen availability, and certain medications, such as steroids and chemotherapeutic agents, which suppress the inflammatory response and collagen synthesis[15]. Addressing these factors through targeted interventions is critical for optimizing healing and recovery.

The aim of the study was to analyze the effectiveness of low-intensity phototherapy in controlling postoperative pain and promoting wound healing through a systematic review with meta-analysis following the PRISMA protocol guidelines.

2 METHOD

This systematic review with meta-analysis, conducted in accordance with the PRISMA 7 protocol, aimed to evaluate the effectiveness of low-intensity light therapy in pain management and wound healing. Randomized clinical trials without time restrictions were included, provided at least the abstract was available, while qualitative studies and those with a high risk of bias were excluded. The review focused on adult participants undergoing at least two sessions of low-intensity light therapy. Studies using sporadic interventions or lacking conclusive effectiveness results were excluded. The primary outcome assessed was pain scale improvement, while the secondary outcome focused on wound healing. Searches were performed in Portuguese, English, and Spanish across seven databases: CGF Specialized Register of Controlled Trials, Cochrane Central Register of Controlled Trials, MEDLINE Ovid, CINAHL EBSCO, Latin American and Caribbean Health Sciences Information Database, Science Citation Index-Expanded, and PubMed.

The search strategy used terms such as "Pain Management" OR "Wound Healing" AND Low-Level Light Therapy to identify relevant studies. A three-step search process was conducted to ensure consistency and minimize variances in selection. The entire selection process was documented in a flowchart. Data extraction and analysis were conducted independently by two reviewers, with discrepancies resolved by a third reviewer. Key information extracted included year, authors, study design, participant demographics, intervention details, and outcomes. Bias risk was evaluated using the Review Manager 5 software, assessing factors such as allocation concealment, participant blinding, and outcome reporting.

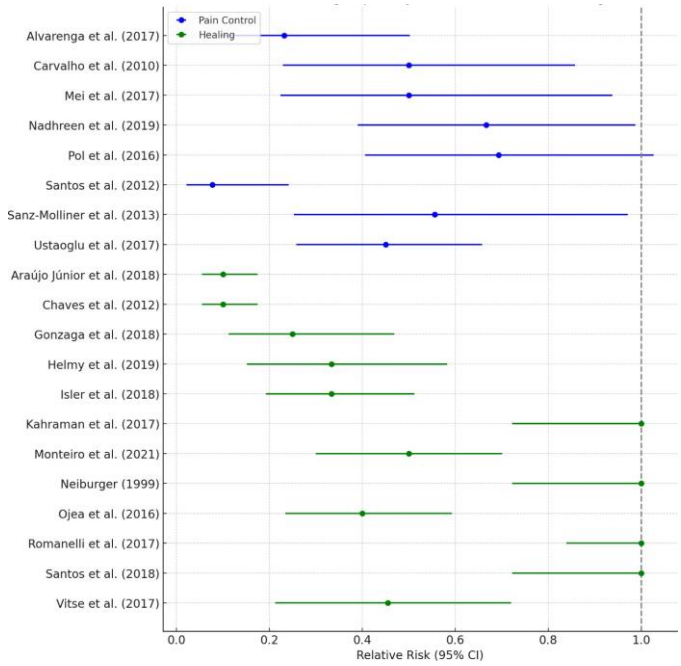
Heterogeneity among studies was assessed using homoscedasticity, with a threshold of 50% for acceptable homogeneity. Missing data were addressed through author contact or the multiple imputation method when unavailable. The GRADE system was employed to evaluate study quality and determine exclusion criteria for high-risk studies. General analysis utilized Mantel-Haenszel models with random effects, a 95% confidence interval, and a significance threshold of
0.05. Sensitivity analysis excluded studies with a high risk of bias, particularly regarding sequence generation, allocation concealment, and methodological obfuscation determined via funnel plot evaluations.

The results were analyzed from dichotomous and continuous perspectives to evaluate the effectiveness of low- intensity light therapy compared to conventional treatments. Inferential analysis assessed effect size and differences between groups, aiming to determine significant improvements in primary and secondary outcomes. The findings highlight the importance of rigorous methodological criteria in identifying the effectiveness of interventions, while ensuring study reliability through a comprehensive bias risk evaluation process.

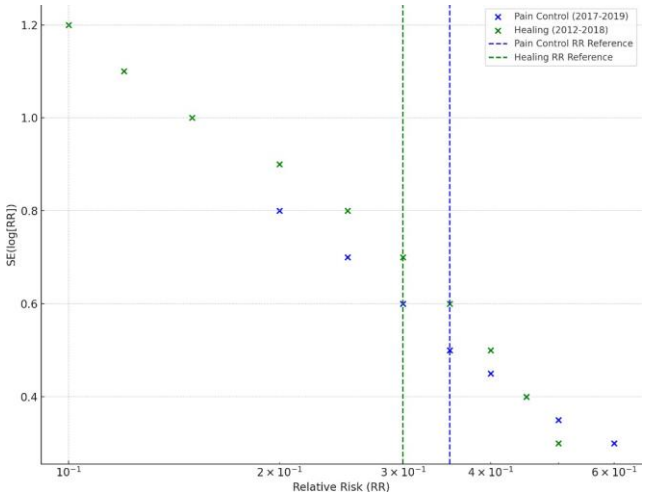
3 RESULTS

Initially, 2114 studies were found, of which 12 were included in the review after applying the inclusion and exclusion criteria. Figure 1 contains the result of the meta-analysis of studies regarding pain control. It was observed that the use of laser was effective, with p-value < 0.05 and protective effect.

Figure 1: pain control AND healing meta-analysis, 2022.



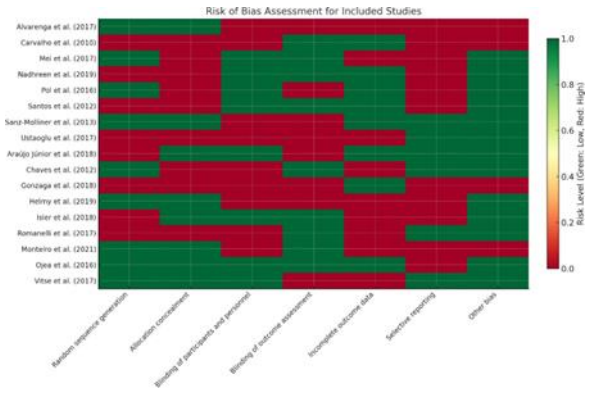
The figure presents a forest plot comparing the relative risk (RR) and 95% confidence intervals (CI) for two outcomes: "Pain Control" (blue) and "Healing" (green). Each study is listed on the vertical axis, with dots representing the RR for each outcome, and the horizontal lines indicating the 95% CI. Studies to the left of the dashed line (RR = 1) suggest a positive effect (reduced risk), while those



overlapping the
line indicate no significant effect. The plot highlights the variability in effectiveness across studies, with distinct groups for pain management and wound healing outcomes.Figure 2: Funnel plot combined.

Bias analysis of the studies did not identify general or individual bias (figure 3).

Figure 3: individual and general bias analysis of studies, 2022.



In figure 2, it is possible to observe the meta-analysis of the studies that are related to the healing process, in which it was also significantly effective in relation to the outcome. Figure 3 demonstrates in a complementary way that there was no identification of bias in the selected studies, which reaffirms the results found in the research. The figure illustrates a heatmap summarizing the risk of bias assessment for included studies across various categories, such as random sequence generation, allocation concealment, blinding, incomplete outcome data, selective reporting, and other biases. The green cells represent a low risk of bias, while the red cells indicate a high risk of bias, with intermediate shades denoting unclear or moderate risk. This visualization helps identify patterns and highlight specific areas where studies show methodological weaknesses, providing an overview of the reliability and quality of evidence.

4 DISCUSSION

Effective pain management in hospitalized patients is a complex issue influenced by various factors, including pre- existing pain levels, disease type, emotional stress, gender, age, and length of hospital stay[4]. Despite its importance, inappropriate prescribing of pain medication—often inconsistent with the intensity of pain—is observed in more than half of patients, underscoring the need to improve pain control protocols. For patients undergoing posterior lumbar interbody fusion surgery, the addition of an erector spinae plane (ESP) block to standard anesthetic care has shown potential for providing enhanced analgesia while reducing postoperative opioid requirements[9]. However, advancing pain management practices faces a major limitation: the lack of comprehensive studies that address the issue in depth. Most existing research tends to be superficial and fails to explore detailed interventions for different healthcare contexts.

The wound healing process, particularly in open wounds, involves the formation of granulation tissue—soft, fine, and red—which typically appears within 12 to 24 hours after trauma. This tissue is critical to healing but is sensitive and prone to excessive contraction, which can cause deformities and functional impairments if left untreated. Such issues can often be mitigated through skin grafts, while repeated excisions at wound edges significantly reduce contraction, improving outcomes[11]. Photodynamic therapy (PDT) has gained attention as an innovative approach for treating infected lesions. PDT relies on photosensitive substances activated by light, triggering chemical reactions that produce photochemical effects, leading to the selective destruction of pathological tissues without harming healthy cells. This method is non-invasive, cost-

effective, and well-tolerated, with minimal side effects. Although some studies on PDT have limited evidence and small samples, its potential for treating infected wounds deserves consideration[1418].

The exact pathophysiology of low-level laser therapy is not fully understood, yet its benefits in pain relief are supported by studies from various specialists, including physiologists, chiropractors, and rheumatologists. LLLT's effects are attributed to its ability to alter cellular functions, such as ATP production, protein synthesis, prostaglandin synthesis, and neurotransmitter release. These cellular changes, induced by high-energy yet low-quantity lasers, have been shown to impact tissues positively, offering a promising avenue for pain management and healing[19]. As research continues, the integration of these advanced therapies into clinical practice holds the potential to transform patient care in both acute and chronic settings.

The role of nutrition in pain management and wound healing cannot be overstated. Proper nutritional support plays a fundamental role in modulating the inflammatory response, supporting immune function, and facilitating tissue repair. Adequate intake of essential nutrients, such as amino acids, vitamins (particularly C and E), zinc, and omega-3 fatty acids, is critical to collagen synthesis, angiogenesis, and cellular proliferation, all of which are necessary for effective wound healing. Malnutrition or nutrient deficiencies can significantly impair these processes, leading to delayed recovery, increased infection risk, and suboptimal healing outcomes[18,19].

Moreover, tailored nutritional interventions can directly impact pain perception and management. Diets rich in anti- inflammatory compounds, such as those found in fruits, vegetables, and fatty fish, may reduce systemic inflammation and improve pain thresholds. Protein intake, in particular, supports muscle repair and maintains metabolic stability during recovery[18,19]. The research was inspired by the advancements promoted by the American Academy of Dermatology in innovative treatments focused on tissue regeneration and skin health. Renowned for its leadership in dermatological research and its support for emerging therapeutic technologies, the institution has emphasized the importance of non-invasive approaches, such as low-intensity light therapy, to enhance wound recovery and pain relief. This approach reflects a commitment to evidence-based practices and advancements that promote more effective and accessible care.

5 CONCLUSION

The level of determination of trials and other interventions can be carried out for other possible circumstances, as there is literature for the performance, as well as there is a need to carry out controlled clinical trials to determine the possible confounding results that give in the different profiles of patients.

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