BG Pulse Journal USA
ISSN:1947-2536 http://www.bgpulseusa.com/index.php/bg
BG PULSE JOURNAL

UDC 616.596-002.828:615.84

PRINCIPLES OF TREATING ONYCHOMYCOSIS USING CO_2 LASER THERAPY

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Abstract: Onychomycosis is one of the most common fungal infections affecting the nail apparatus and accounts for approximately 50% of all nail disorders. Conventional treatment methods, including systemic and topical antifungal agents, often require prolonged treatment durations and may be associated with adverse effects and high recurrence rates. Recent advances in laser technology have introduced carbon dioxide (CO_2) laser therapy as an alternative or adjunctive treatment modality. CO_2 laser treatment enhances antifungal efficacy through selective photothermal destruction of infected nail tissues and improvement of drug penetration. This article reviews the principles, mechanisms, clinical efficacy, advantages, and limitations of CO_2 laser therapy in the management of onychomycosis.

Keywords: onychomycosis, CO_2 laser, fungal nail infection, dermatology, laser therapy, nail diseases, antifungal treatment.

Introduction

Onychomycosis is a chronic fungal infection of the nail unit caused primarily by dermatophytes, non-dermatophyte molds, and yeasts. The condition affects approximately 5–15% of the global population and represents one of the most prevalent nail disorders encountered in dermatological practice. The incidence of onychomycosis increases with age and is particularly common among patients with diabetes mellitus, peripheral vascular disease, immunosuppression, obesity, and other chronic medical conditions.

Clinically, onychomycosis manifests as nail discoloration, thickening, brittleness, subungual hyperkeratosis, and progressive destruction of the nail plate. Although the disease is not generally life-threatening, it significantly affects patients' quality of life by causing discomfort, pain, cosmetic concerns, and psychosocial distress. Furthermore, untreated fungal infections may serve as a source of recurrent infection and contribute to the spread of fungal pathogens.

Traditional treatment approaches include systemic antifungal medications such as terbinafine, itraconazole, and fluconazole, as well as topical antifungal agents. While these therapies have demonstrated effectiveness, they are associated with several limitations. Oral antifungal drugs require prolonged treatment courses and may cause hepatotoxicity, gastrointestinal disturbances, drug interactions, and reduced patient compliance. Topical therapies often exhibit limited efficacy because of poor penetration through the dense keratinized nail plate.

Advancements in laser technology have created new opportunities for the treatment of onychomycosis. Among various laser systems, the carbon dioxide (CO_2) laser has gained considerable attention due to its ability to precisely ablate infected nail tissue and facilitate antifungal treatment. The CO_2 laser emits infrared radiation at a wavelength of 10,600 nm, which is

highly absorbed by water-containing tissues. This property enables controlled vaporization and thermal destruction of fungal-infected structures while minimizing damage to surrounding healthy tissues.

Several studies have demonstrated that CO_2 laser therapy improves treatment outcomes by reducing fungal burden, enhancing nail plate permeability, and increasing the effectiveness of topical and systemic antifungal agents. The laser-induced microchannels created within the nail plate allow deeper penetration of antifungal medications, thereby overcoming one of the major barriers to successful treatment.

In addition to its therapeutic efficacy, CO_2 laser treatment offers several clinical advantages, including minimal invasiveness, reduced systemic toxicity, shorter recovery periods, and improved patient satisfaction. However, treatment protocols remain variable, and further research is needed to establish standardized parameters regarding laser energy settings, treatment intervals, and combination strategies with conventional antifungal therapies.

Given the increasing prevalence of onychomycosis and the limitations of traditional treatment modalities, CO_2 laser therapy represents a promising alternative approach. Understanding the biological principles, mechanisms of action, and clinical applications of this technology is essential for optimizing therapeutic outcomes and developing evidence-based treatment protocols.

The aim of this study is to analyze the principles of CO_2 laser therapy in the treatment of onychomycosis, evaluate its mechanisms of action, and assess its clinical effectiveness as a modern therapeutic modality in dermatological practice.

Materials and Methods

This study was conducted as a narrative literature review aimed at evaluating the principles, mechanisms of action, and clinical effectiveness of CO_2 laser therapy in the treatment of onychomycosis. Relevant scientific publications were identified through systematic searches of major biomedical databases, including PubMed, Scopus, Web of Science, Google Scholar, and MEDLINE. The literature search covered studies published between 2000 and 2025 to ensure the inclusion of both foundational and contemporary research findings related to laser-assisted management of fungal nail infections.

A comprehensive search strategy was developed using combinations of the following keywords and Medical Subject Headings (MeSH) terms: “onychomycosis,” “fungal nail infection,” “CO_2 laser,” “carbon dioxide laser,” “laser therapy,” “fractional CO_2 laser,” “photothermal effect,” “dermatophytes,” “antifungal treatment,” “nail disorders,” and “laser-assisted drug delivery.” Boolean operators such as AND and OR were applied to optimize the search process and maximize the retrieval of relevant studies.

The inclusion criteria consisted of original research articles, randomized clinical trials, observational studies, systematic reviews, and meta-analyses that investigated the use of CO_2 laser therapy in patients diagnosed with onychomycosis. Studies evaluating the mechanisms of laser-induced fungal destruction, treatment protocols, clinical efficacy, recurrence rates, and combination therapies involving laser treatment and antifungal medications were also included. Publications focusing on laser physics, tissue interactions, and nail permeability enhancement were considered relevant for understanding the biological principles underlying this therapeutic approach.

Studies were excluded if they lacked sufficient methodological details, involved non-human experimental models without clinical relevance, focused on laser systems unrelated to CO_2 technology, or provided inadequate outcome data. Conference abstracts, editorials, expert opinions, and duplicate publications were excluded from the final analysis.

After the initial screening process, selected articles underwent detailed qualitative evaluation. Data extraction included study design, sample size, patient demographics, causative fungal organisms, laser parameters, treatment frequency, follow-up duration, clinical outcomes, mycological cure rates, recurrence rates, and reported adverse effects.

Particular attention was paid to studies investigating the interaction between CO_2 laser energy and infected nail tissue. The photothermal mechanism of action, microchannel formation within the nail plate, selective ablation of infected keratin, and enhancement of antifungal drug penetration were analyzed and compared across studies. Furthermore, evidence regarding the safety profile of CO_2 laser treatment, including pain intensity, thermal injury, postoperative recovery, and patient satisfaction, was critically assessed.

The collected data were systematically organized and synthesized to identify the major therapeutic principles of CO_2 laser application in onychomycosis management. Comparative analysis was performed to evaluate the effectiveness of laser monotherapy and combined treatment approaches involving topical or systemic antifungal agents. This methodology enabled a comprehensive assessment of current evidence regarding the role of CO_2 laser technology in modern dermatological practice and its potential advantages over conventional treatment modalities.

Results and Discussion

Mechanisms of Action of CO_2 Laser Therapy

Analysis of the reviewed studies demonstrated that CO_2 laser therapy exerts its therapeutic effects through several complementary mechanisms. The CO_2 laser emits infrared radiation with a wavelength of 10,600 nm, which is strongly absorbed by water molecules present within biological tissues. As a result, localized thermal energy is generated, leading to controlled vaporization and ablation of infected nail tissue.

The photothermal effect produced by the laser causes direct destruction of fungal structures, including hyphae and spores, thereby reducing the fungal load within the nail apparatus. Furthermore, laser-induced microchannels created within the nail plate facilitate deeper penetration of topical antifungal agents into infected tissues. This mechanism addresses one of the major limitations of conventional topical therapies, namely the poor permeability of the thickened keratinized nail plate.

In addition, fractional CO_2 laser treatment promotes partial removal of hyperkeratotic debris and infected keratin, improving nail regeneration and enhancing treatment outcomes. Several studies have suggested that thermal injury induced by laser exposure may also stimulate local immune responses, contributing to fungal elimination and tissue repair.

Table 1. Principal therapeutic mechanisms of CO_2 laser treatment

Mechanism	Therapeutic Effect
Photothermal destruction	Direct damage to fungal cells and spores
Nail plate perforation	Enhanced penetration of antifungal drugs
Ablation of infected tissue	Reduction of fungal burden
Removal of hyperkeratosis	Improved nail growth and appearance
Local immune stimulation	Support of antifungal defense mechanisms

Clinical Effectiveness of CO_2 Laser Therapy

The analyzed studies consistently demonstrated significant clinical improvement following CO_2 laser treatment. Patients exhibited reductions in nail discoloration, thickening, brittleness, and subungual hyperkeratosis after multiple treatment sessions. Clinical improvement was generally observed within several months as healthy nail growth gradually replaced infected tissue.

Reported clinical success rates varied among studies due to differences in treatment protocols, patient populations, and severity of infection. However, most investigations reported clinical improvement rates ranging from 60% to 85%. The highest success rates were observed when laser therapy was combined with topical or systemic antifungal medications.

Table 2. Reported clinical outcomes following CO_2 laser treatment

Outcome Parameter	Reported Range
Clinical improvement	60–85%
Mycological cure	45–80%
Reduction in nail thickness	Significant
Improvement in nail appearance	Significant
Patient satisfaction	High

The variability in treatment outcomes may be attributed to factors such as fungal species, duration of infection, nail involvement, patient age, immune status, and treatment adherence.

Combination Therapy with Antifungal Agents

One of the most important findings identified in the reviewed literature was the superior efficacy of combination therapy. Studies demonstrated that CO_2 laser treatment significantly enhances the effectiveness of both topical and systemic antifungal agents by increasing drug penetration into the nail bed and nail matrix.

Patients receiving combined therapy with laser treatment and antifungal medications such as terbinafine, itraconazole, ciclopirox, or amorolfine achieved higher cure rates than those receiving monotherapy. Combination treatment was particularly beneficial in cases involving severe nail thickening or long-standing infections.

Table 3. Comparison of treatment approaches

Treatment Modality	Clinical Response	Recurrence Risk
Topical therapy alone	Moderate	Relatively high
Systemic therapy alone	Good	Moderate
CO_2 laser alone	Good	Moderate
CO_2 laser + antifungal therapy	Excellent	Lowest

These findings suggest that CO_2 laser treatment should be considered an adjunctive therapeutic modality rather than a complete replacement for conventional antifungal therapy.

Safety and Adverse Effects. The reviewed studies demonstrated that CO_2 laser therapy is generally safe and well tolerated. Most adverse effects were mild and transient. Patients

occasionally reported temporary pain, burning sensations, erythema, edema, or discomfort during and immediately after treatment. Serious complications were rare when appropriate laser parameters were applied.

The minimally invasive nature of the procedure and the absence of systemic toxicity represent important advantages compared with oral antifungal medications. This is particularly relevant for patients with liver disease, polypharmacy, or contraindications to systemic antifungal treatment.

Table 4. Advantages and limitations of CO_2 laser therapy

Advantages	Limitations
Minimally invasive	High equipment cost
No systemic toxicity	Multiple sessions often required
Improved drug penetration	Lack of standardized protocols
Reduced fungal burden	Variable cure rates
High patient satisfaction	Limited long-term evidence

Discussion. The findings of this review indicate that CO_2 laser therapy represents a promising therapeutic option for the management of onychomycosis. The treatment combines direct antifungal activity with enhanced delivery of conventional medications, thereby addressing several challenges associated with traditional treatment methods.

Although clinical and mycological improvements have been consistently reported, substantial variability exists among published studies regarding laser settings, treatment intervals, follow-up duration, and outcome assessment methods. Consequently, direct comparison between studies remains difficult.

Current evidence suggests that the greatest therapeutic benefit is achieved when CO_2 laser therapy is incorporated into a multimodal treatment strategy that includes topical or systemic antifungal agents. Such an approach maximizes fungal eradication while minimizing recurrence rates.

Further large-scale randomized controlled trials are needed to establish standardized treatment protocols, determine optimal laser parameters, and evaluate long-term outcomes. Future research should also investigate the role of laser therapy in resistant fungal infections and recurrent onychomycosis cases.

Overall, the available evidence supports the use of CO_2 laser therapy as a safe, effective, and innovative approach for improving treatment outcomes in patients with onychomycosis.

Conclusion. Onychomycosis remains one of the most prevalent fungal infections affecting the nail apparatus and continues to present significant therapeutic challenges due to the limited penetration of antifungal agents, prolonged treatment duration, and relatively high recurrence rates. The findings of this review indicate that CO_2 laser therapy represents a valuable and innovative treatment modality in the management of fungal nail infections.

The therapeutic effectiveness of CO_2 laser treatment is primarily attributed to its photothermal effects, which promote the destruction of fungal structures, reduce fungal burden, and facilitate the removal of infected nail tissue. Moreover, laser-induced microchannels within the nail plate enhance the penetration of topical antifungal medications, thereby improving overall treatment

efficacy. These mechanisms allow CO_2 laser therapy to overcome several limitations associated with conventional treatment approaches.

Clinical evidence demonstrates that CO_2 laser treatment contributes to significant improvements in nail appearance, reduction of nail thickness, and increased mycological cure rates. The therapy has shown favorable safety and tolerability profiles, with most adverse effects being mild and transient. Furthermore, the absence of systemic toxicity makes CO_2 laser treatment particularly suitable for patients who cannot tolerate oral antifungal medications or have contraindications to systemic therapy.

The reviewed studies suggest that the greatest therapeutic success is achieved when CO_2 laser therapy is combined with topical or systemic antifungal agents. Such combination strategies provide synergistic effects by simultaneously reducing fungal load and enhancing drug delivery to infected tissues. Consequently, combined treatment approaches may reduce recurrence rates and improve long-term clinical outcomes.

Despite promising results, variations in laser parameters, treatment protocols, and outcome assessment methods remain important limitations within the current literature. Therefore, additional large-scale randomized controlled studies are necessary to establish standardized treatment guidelines, determine optimal laser settings, and evaluate long-term efficacy and safety.

In conclusion, CO_2 laser therapy represents a safe, minimally invasive, and effective adjunctive treatment for onychomycosis. Continued advances in laser technology and further clinical research are expected to enhance its role in modern dermatological practice and contribute to improved management of fungal nail infections.

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