Laser Treatment in Nail Disorders: A Comprehensive Review

Abstract

Background: Laser therapy has emerged as an innovative approach for managing various nail conditions, offering precise targeting, minimal invasiveness, and favorable safety profiles. This review analyzes the literature on laser therapy for nail indications, encompassing onychomycosis, nail psoriasis, nail warts, ingrown toenails, onychodystrophy, nail pigmentation disorders, and nail tumors. **Methods:** PubMed and Google Scholar databases were searched to identify articles on laser therapy using specific key terms related to nail conditions (e.g., onychomycosis, nail psoriasis). Relevant articles were shortlisted based on laser treatment in nail disorders, its mechanisms of action, research outcomes, and clinical applications. **Results:** Nd:YAG or CO_2 lasers showed efficacy in onychomycosis by targeting fungal cells. Studies suggest that laser treatments offer comparable results to traditional therapies, often enhancing outcomes when combined with topical agents such as calcipotriol/betamethasone in nail psoriasis. For nail warts, ingrown toenails, onychodystrophy, and nail pigmentation disorders, lasers provide alternative or adjunctive therapies, achieving positive outcomes lesion clearance and symptom improvement. **Conclusion:** This review underscores the transformative potential of laser therapy in nail disorder management, providing clinicians with innovative treatment alternatives. Nevertheless, further studies are needed to refine protocols, evaluate long-term outcomes and explore its application in specific conditions such as nail tumors.

Keywords: *Ingrown toenail, laser therapy, nail pigmentation/ melanonychia, nail psoriasis, nail tumor, nail warts,onychodystrophy, onychomycosis, pyogenic granulomas*

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Introduction

The nail is a keratin structure that covers the distal phalanges of fingers and toes and also protects and supports these areas. The visible part is the nail plate or body and below this is the nail bed. It is rich in blood vessels that give the nail its characteristic color. The nail matrix produces new cells and pushes older cells forward, contributing to nail growth. The cuticle or eponychium protects the existing nails emerging from the matrix and nail folds secure the nail in place. Changes in nail appearance, texture, or growth can indicate underlying diseases or conditions.[1]

The use of lasers in dermatology has greatly expanded to cover a broad spectrum of nail disorders, providing innovative treatment options for diverse nail conditions. Laser therapy is now recognized as a valuable modality owing to its precision in targeting specific tissues and its minimally invasive nature, offering advantages over conventional methods such as reduced pain, faster healing times, and lower recurrence rates, all while maintaining a favorable safety profile.[2] Nail disorders that can be effectively managed with lasers include onychomycosis, nail psoriasis, warts, ingrown toenails, melanonychia, pyogenic granulomas, onychodystrophy, and nail tumors [Figure 1]. The advent of specific laser technologies, such as pulsed dye lasers (PDL) and neodymium-doped yttrium aluminum garnet (Nd:YAG), erbium-doped yttrium aluminum garnet (Er:YAG), picosecond, CO_2 lasers, among others, has further enhanced treatment options. The literature review reveals a lack of articles discussing diverse laser treatments specifically for nail disorders.

Thus, this review provides an in-depth exploration of various laser treatments in nail disorders, their mechanisms of action, and research outcomes. Understanding the effectiveness of laser therapy, their potential side effects, and clinical results would empower dermatologists to address nail diseases/conditions with enhanced precision and efficacy.

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Methods

A comprehensive search of PubMed and Google Scholar databases was conducted using key terms related to specific nail conditions (e.g., onychomycosis, nail psoriasis, ingrown toenails, nail tumors) combined with "laser treatment." Relevant articles were selected based on laser therapy for nail indications, mechanisms of action, research outcomes, and clinical applications. After excluding irrelevant and duplicates, 10 articles were shortlisted and 103 studies were ultimately included in the final analysis.

Results and Discussion

Supplementary table 1 presents a comprehensive review of various laser treatments utilized for different nail disorders. Tables 1-4 and Supplementary Tables 2-5 outline the laser type, specific settings, treatment approach, study outcomes, and corresponding references.

Onychomycosis

Onychomycosis (OM) is a common nail disorder affecting 40–50% of all nail pathologies, primarily caused by dermatophytes such as *Trichophyton rubrum* and *T. mentragrophytes* var. *interdigitale*. Non-dermatophytic molds (NDMs) and yeasts such as *Candida albicans* and *Candida parapsilosis* are also common causative agents, particularly in immunocompromised individuals. OM is more common in males and older adults, with reported incidences ranging from 0.5–12% in India and 5% globally.[3]

Treatment options for OM include topical medications (efinaconazole and tavaborole), oral antifungals (terbinafine and itraconazole), and laser treatments (Nd:YAG, Q-switched lasers).[4] However, treating OM presents several challenges including poor treatment adherence, prolonged disease duration, and a high rate of relapse (6.5–53%).[5] Topical treatments struggle to penetrate the nail plate effectively and long-term use of oral antifungals such as terbinafine can lead to toxicity and drug interactions.[6]

Laser treatment for OM combines selective thermal (photothermolytic) and mechanical (photomechanical) effects on fungi, denaturing specific molecules within the pathogen and deactivating their functionality.[7] [Table 1]. Although the exact mechanism of lasers in OM therapy remains unclear,[8] it is hypothesized that Nd:YAG lasers, utilizing photothermolysis, exhibit fungicidal effects by raising temperatures above 55°C.[9] Achieving a temperature of 55°C is crucial for eradicating the fungus; however, excessive heat can risk damaging the nail bed, causing pain or deformities. To protect the nail, cooling systems, short pulses, fractional delivery, and thermal monitoring are used, along with lower fluence and multiple sessions to minimize damage. Patient feedback and critical evaluation by dermoscopy help to provide safe treatment.

The Q-switched Nd:YAG laser operates at specific wavelengths (e.g., 532 nm and 1064 nm) targeting key chromophores within fungal cells: the 532 nm wavelength targets red pigment (canthomegnin), causing mechanical damage to fungal colonies, whereas the 1064 nm wavelength affects other chromophores (such as melanin) in fungal cell walls, leading to fungal destruction.[10] Fractional CO_2 lasers effectively treat OM by vaporizing and decomposing local tissue, killing fungi at temperatures above 55°C, and enhancing the absorption of topical antifungal agents.[11] Additionally, laser impact may trigger photobiological or photochemical reactions within pathogen cells, potentially inducing an immune response against the organism. Mainly, these treatments are designed to protect the surrounding host tissue with minimal collateral damage.[7]

Kozarev and Vizintin[12] found that long-pulse Nd:YAG laser led to complete clearance of fungal infections

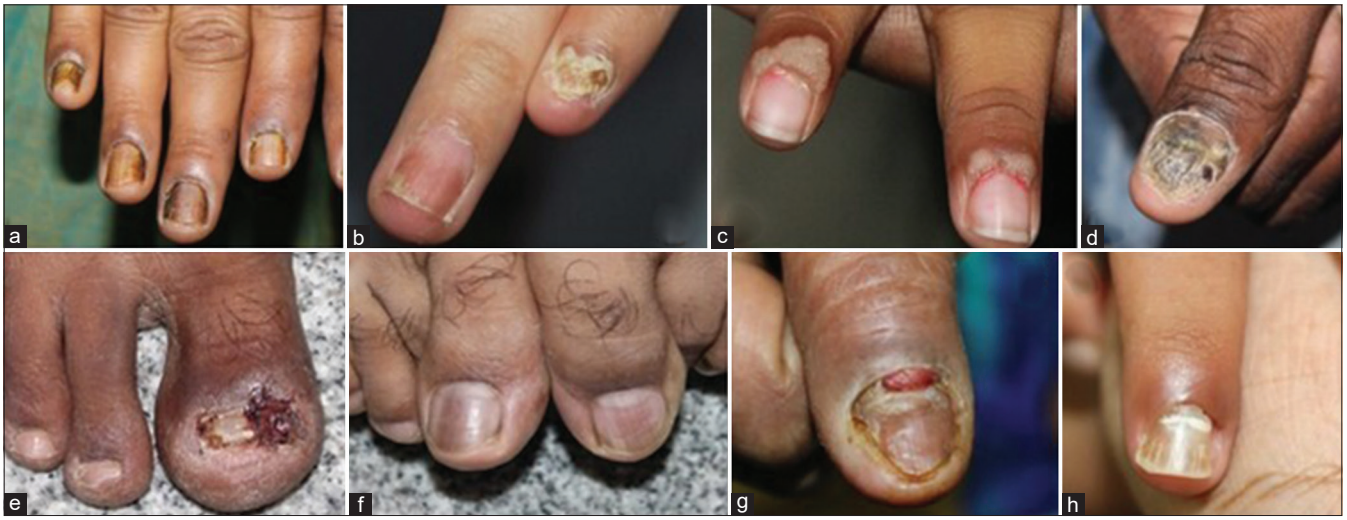

Figure 1: Various disorders of nails. (a) Onychomycosis, (b) Nail psoriasis, (c) Nail warts, (d) Nail dystrophy, (e) Ingrown nail, (f). Nail pigmentation, (g) Pyogenic granuloma, (h) Nail tumors

in all patients by 12 months. Zhang *et al*.[13] observed no significant difference in treatment effectiveness between groups receiving different numbers of laser sessions. However, Kim *et al*.[14] reported higher clinical improvements in elderly patients receiving multiple laser sessions, suggesting the need for additional or combined therapies to effectively address severe OM cases. Zhong *et al*.[15] reported significant improvement in clearance rate and clinical efficacy using a two-stage treatment with this laser in patients' nails predominantly infected with *Trichophyton rubrum*. However, Elmorsy *et al*.[16] reported relatively low mycological cure rates (MCR) with long-pulsed Nd (40%) and Q-switched Nd lasers (30%), indicating a need for further optimization of laser therapy protocols. The author's experience utilizing a Nd:YAG laser to treat onychomycosis is depicted in Figure 2.

Comparative studies have provided mixed results on the efficacy of laser treatments versus conventional therapies. For instance, Nasif *et al*.[17] found that long-pulsed Nd:YAG laser monotherapy yielded clinical outcomes similar to itraconazole pulse therapy. In contrast, Rovers *et al*.[3] criticized Nd:YAG laser therapy, citing poor efficacy rates compared to oral terbinafine and itraconazole. However, Khater and Khattab[18] demonstrated that combining Nd:YAG laser with pulse itraconazole led to superior clinical improvement outcomes and a reduced Onychomycosis Severity Index (OSI) score, highlighting the potential benefits of combination therapy. Similarly, Weber *et al*.[8] found that laser combined with topical antifungals led to faster healing and higher clinical improvement rates than laser treatment alone.

Kalokasidis *et al*.[7] conducted a clinical study treating 131 OM patients with Q-Switched Nd:YAG laser, reporting nearly 95.42% mycological cure at 3-month follow-up with high satisfaction and no side effects. Zawar and Sarda[19] detailed the successful treatment of severe OM using Q-switched Nd-Yag laser and no recurrence post-treatment. Kandpal *et al*.[9] compared Nd: YAG laser monotherapy with itraconazole where laser treatment showed faster nail clearance and higher mycological cure rates, especially effective against dermatophytes and non-dermatophytes.

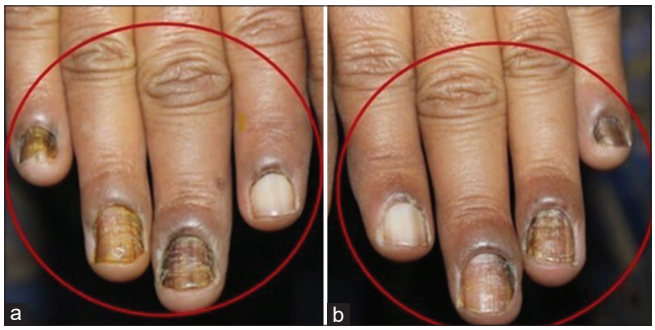

Figure 2: Laser treatment in onychomycosis. Nd:Yag laser with energy 35J/cm², 35 ms, 4 mm, 1–2 HZ and three passes. (a) before the treatment and (b) after six sessions of the treatment

CO_2 lasers have shown higher cure rates for OM.[20] Rajbanshi *et al*.[21] and Ranjan *et al*.[22] have demonstrated the promising efficacy of CO_2 laser therapies compared to conventional treatments. Fractional CO_2 laser therapy combined with terbinafine cream has shown higher efficacy than itraconazole pulse therapy alone, as reported by Zaki *et al*.[23] and Arora *et al*.[24] Moreover, combination therapies using fractional CO_2 laser with luliconazole cream (1%) or terbinafine cream have resulted in higher clinical efficacy rates and MCR, with mild side effects such as pain and burning sensations.

2940-nm Er:YAG laser with amorolfine lacquer 5%[25] and dual-diode lasers with varying ozone concentrations,[26] have also shown improved outcomes over monotherapies for managing OM. Thus, a comprehensive approach to selecting treatments for OM should consider ethical, evidence-based tailored to individual patient needs, budget, quality of life impact, and aesthetic goals.

Nail psoriasis

Psoriasis is a chronic autoimmune disorder that mainly targets the skin, joints, and nails. When psoriasis affects the nail bed or nail matrix, it leads to a condition known as nail psoriasis. This condition is marked by inflammation, scaling, and a range of nail alterations such as pitting, thickening, discoloration, onycholysis, subungual hyperkeratosis, and splinter hemorrhages.[27] Nail psoriasis can cause discomfort, pain, and functional impairment complicating daily activities and significantly impacting the patient's quality of life. Treatment options range from topical medications to systemic therapies such as methotrexate or biologics, as well as intralesional steroid injections, phototherapy, and laser therapy.[28] However, slow nail growth, poor drug penetration, and potential side effects pose challenges in managing the condition effectively.

Lasers such as PDL target vascular changes associated with psoriasis and eliminate abnormal blood vessels through selective photodermolysis, which also aids in controlling inflammation by reducing T-lymphocytes on the skin.[29,30] Al-Mutairi *et al*.[31] found that PDL was more effective than excimer laser, achieving significant reductions in Nail Psoriasis Severity Index (NAPSI) scores. Other studies including, Oram *et al*.[32] and Peruzzo *et al*.[29] observed substantial improvements in NAPSI scores using PDL, particularly in nail bed lesions. Wiznia *et al*. and Maranda *et al*.[33,34] also highlighted the potential of PDL and intense pulsed light in treating psoriatic nail lesions, though larger studies are needed to confirm their efficacy.

The Nd:YAG laser (1064 nm) also shows promise due to its deep penetration and selective targeting of hemoglobin in blood vessels. This laser's ability to reduce blood flow and nutrient supply to psoriatic lesions through selective photothermolysis makes it effective in treating nail matrix

Table 1: Summary of laser treatment articles in onychomycosis

Laser type	Laser settings & treatment approach	Results	Side effects	Authors
Group I- Long-pulsed Nd:YAG (1064 nm) laser Group II- Q-Switched Nd:YAG (1064 nm)	Fluence: 35 J/cm², pulse duration: 25 ms, Spot size: 5 mm, Frequency: 1 Hz Cooling system: off, Biweekly sessions 14 J/cm², 3 mm spot size, 5 Hz frequency, monthly session	Improvement in proximal nail measurements. Mycological cure: 40% (Group I), 30% (Group II). Higher patient satisfaction in Group II.	A mild to moderate pain sensation	Elmorsy *et al*.[16]
Long-pulsed Nd:YAG (1064 nm) laser	35–40 J/cm², 35 ms, 4 mm, 1 Hz. 3 passes, with 2 min pause between passes. Two-stage treatment Stage 1-1 session per week for 8 weeks Stage 2-1 session every 4 weeks for 16 weeks	Mycological clearance rate: 29% (1st stage), 69% (2nd stage) Clinical efficacy rate: 21% (1st stage), 35% (2nd stage) . Improved outcomes in the second stage.	Moderate pain. No side effects.	Zhong *et al*.[15]
Long-pulse Nd:YAG (1064 nm) laser	35–40 J/cm², 35 msec, 4 mm, 1 Hz temperature 45°C±5 with 2 minpause between passes. Four sessions with a 1-week interval	95.8% cleared of fungal infections at 3-month follow-up 100% cleared at 6 and 12-month follow-up. No noticeable side effects.	no noticeable side effects.	Kozarev & Vizintin[12]
Long-pulse Nd:YAG (1064 nm) laser	240–324 J/cm², 30 ms, 3 mm, 1 Hz with 2 min pause between passes. Eight sessions for group 1, four sessions for group 2 on days 0, 7, 14, and 21	Effective rates: Group 1-51%-63% at different follow-up points. Group 2-53%-68% at different follow-up points.	No significant complications or side effects	Zhang *et al*.[13]
Long-pulse Nd:YAG (1064 nm) laser	35–80 J/cm², 35 ms, 4 mm, 1 Hz with 3 passes for each session Four sessions with a 1-week interval	Recovery: 11.1% (laser group), 18.1% (topical group). Significant effect: 30.2% (laser group), 33.3% (topical group). Improvement: 46% (laser group), 48.5% (topical group) Inefficacy: 12.7% (laser group)	No side effects were reported.	Lu *et al*.[88]
Long-pulsed Nd:YAG 1064-nm	Group A: 0.3 ms, 5 mm, 16 J/cm², 10 Hz Shots/nail: 250–300 Group B: 0.6 ms, 2 mm, 225 J/cm², 5 Hz Shots/nail: 100–150	Clinical improvements at 12 weeks: Group A - 47.6%, Group B - 26.3%. Clinical improvements at 24 weeks: Group A - 57.1%, Group B - 36.8%. Mycological positive rates at 24 weeks: Approximately 40% in both groups	No side effects were reported.	Kim *et al*.[14]
1,064-nm Long-pulsed Nd:YAG	Fluence: 20 J/cm² (fingernails), 40 J/cm² (big toe nails), 50 J/cm² (thicker big toe nails). Pulse duration: 10 ms, Spot size: 7 mm, Repetition rate: 2 Hz, Pulses: 4 for fingernails, 6 for big toe nails. Cooling: None, Anesthesia: None. 5 sessions with 1–2 weeks interval.	Reduction in OSI scores indicating improvement in onychomycosis. Well-tolerated treatment with no marked discomfort	A local sensation of heat, needle pricking, and pain, disappeared as soon as the laser ended.	Espírito Santo & Deps[89]
1,064-nm Long-pulsed Nd:YAG	35–40 J/cm², 4 mm, 35 ms, 1 Hz with 1 min pause. Cooling: Zimmer Cryo 5 during and after treatment	Mycological cure achieved by 12.9% post-treatment. Visual improvements were noted in 32.3% post-treatment. Safe and effective for mild-to-moderate onychomycosis	No side effects were reported.	Ramzy *et al*.[90]
1,064-nm Submillisecond Nd:YAG	14 J/cm², 5 mm, 0.3 ms, 5 Hz, 100-200, 3, 4–8 weeks apart. Cooling: None - Anesthesia: None	Moderate to complete clearance in 81% of treated nails. No adverse events reported	no adverse events.	Kimura *et al*.[91]

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Table 1: Contd...

Laser type	Laser settings & treatment approach	Results	Side effects	Authors
0.65-millisecond (ms) 1,064-nm Pulsed Nd:YAG	223 J/cm^2, 2 mm, sessions- 2–3 treatments, 3 weeks apart. Cooling: none. Anesthesia: none	Seven out of eight subjects had negative post-treatment cultures. Well-tolerated treatment	no adverse events.	Hochman *et al*.[92]
Q-Switched Nd:YAG 1064 nm/532 nm Laser	1st pass- 1064 nm, 2.5 mm 14 joules/cm^2, 9 billionths of a second pulse duration, 5 Hz 2nd pass - 532 nm, 2.5 mm 14 joules/cm^2, 9 billionths of a second pulse duration, 5 Hz. 2 passes with 2 min gap.	95.42% mycological cure rate at 3-month follow-up. Patients were well satisfied with the treatment. No noticeable side effects.	No noticeable side effects	Kalokasidis *et al*.[7]
Q-Switched Nd:YAG 1064 nm	1064 nm, 350 mJ, 1 mm, 12 weekly sessions of 3 passes each 30 s gap between passes.	Significant improvement in OSI at 3 and 12 months. Higher mycological cure rate compared to itraconazole. Effective against both dermatophytes and non-dermatophytes.	No other side effects were noted.	Kandpal *et al*.[9]
Q-Switched Nd:YAG 1064 nm	- 500 mJ fluence, 1.5 mm, 2 passes with a 1-min pause between each pass. 3 sessions with 2-week intervals.	Clinically improved nails with negative mycology at 3-month follow-up.	No other side effects	Zawar *et al*.[19]
Q-Switched Nd:YAG 1064 nm	- 12.6 J/cm^2, 2 mm, 5 Hz, 6 biweekly sessions, 3-month follow-up period	Marked clinical improvement and dermoscopic cure in 19 cases. No adverse effects reported	No other side effects	Nasif *et al*.[17]
Long-pulsed 1.064-nm diode laser	4 mm, 8 W, 80 ms, 5.6 Hz. Total energy 500–800 J per session	Clinical improvement was achieved in 56%-69% of patients. Cultural healing in 63%-86%.	During therapy, mild pain No side effects.	Weber *et al*.[8]
Ablative CO_2 laser	10,060 nm, 110 mJ, 256 spots/cm^2, 0.1 ms, 2–10 mm	The treatment group showed significantly higher clinical efficacy and mycological cure rates.	No side effects.	Rajbanshi *et al*.[21]
Fractional CO_2 laser	110 mJ, 256 spots/cm^2, 0.5 mm, 0.1 ms, 2–10 mm	Significant improvement in OSI and MCR.	No side effects.	Arora *et al*.[24]
Fractional CO_2	10600 nm, 10–15 W power (according to nail thickness) - pulse shape: H-pulse of duration: 500 µs, spacing: 700–800 µm, Stack: 3. 5 sessions at 3 weeks intervals plus topical itioconazole 28% solution applied twice per day	Group A (CO2 laser + topical tioconazole): 55% complete clinical improvement. Group B (CO_2 laser only): 30% complete clinical improvement. Group C (topical tioconazole only): 25% complete clinical improvement.	No side effects.	Zaki *et al*.[23]
Fractional CO_2	Microbeam diameter: 0.6 mm, density: 166/mm^2. Three sessions at 4-week intervals. Energy: Incremental (50 mJ, 100 mJ, 150 mJ). Follow-up: 6 months. Adjunct therapy: daily application of ciclopirox nail lacquer (8%)	Clinical improvement was observed with distal clearing of nails, negative direct microscopy and culture at follow-up. Peculiar yellowish discoloration was observed post-laser.	A peculiar yellowish discoloration of the nail and deep-seated pain after the laser.	Grover *et al*.[93]
Fractional CO_2 laser	99 mJ, 410 spots/cm^2, 0.5 mm, 0.1 ms, 2-10 mm. A rectangular spot size of 2-10 mm length and 0.6-5 mm breadth. 2-6 passes were given at the same site over the affected area including 1 mm normal appearing areas around them. 3 sessions 4 weeks apart.	98.18% showed response to laser therapy combined with topical antifungal Potassium hydroxide treatment at 3 months follow-up. Fungal culture negative in the majority of patients after treatment.	Mild pain during laser treatment, no adverse events.	Bhatta *et al*.[94]

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Table 1: Contd...

Laser type	Laser settings & treatment approach	Results	Side effects	Authors
Fractional CO_2 laser	1 pass deep mode energy of 10-15 mJ, pulse duration of 0.5 to 1.0 seconds, spot size 4.0-10.0 mm, density 10% over the affected area including 2 to 3 mm normal appearing areas close to them. 12 sessions at 2-week interval	Higher clinical efficacy rate (CER) (69.6%) and MCR (57.4%,) when combined with a topical antifungal (luliconazole 1%).	No side effects.	Zhou *et al*.[11]
Fractional CO_2 laser	110 mJ, 256 spots/cm^2, a pulse interval of 0.5 mm, and a duration of 0.1 ms. Rectangular spot size=2–10 mm length, 0.6–5 mm breadth	Clinical improvement in 84.7% of nails treated with fractional CO2 laser and terbinafine cream.	No side effects.	Ranjan *et al*.[22]
Fractional CO_2 laser	15 mJ, 0.01–0.99 s, 0.12 mm, density 15% over the affected area including 2-3 mm normal-appearing areas close to them, 12 sessions at 2-week intervals	CER increased significantly post-treatment.	Tolerable mild burning sensation during laser treatment, but no side effects.	Shi *et al*.[95]

lesions.[35-37] Khashaba *et al*.[35] and Kartal *et al*.[38] both reported significant improvements in NAPSI scores with Nd:YAG laser treatments, supporting their use in managing nail psoriasis. Figure 3 illustrates the author's experience treating nail psoriasis using a Nd:YAG laser.

Combining laser therapy with topical agents has enhanced treatment outcomes. Ortner *et al*.[39] and Afify *et al*.[40] demonstrated that fractional CO_2 laser combined with topical methotrexate or a combination of calcipotriol and betamethasone effectively reduced the severity of nail psoriasis. The CO_2 laser facilitates drug penetration through laser-assisted drug delivery, creating precise microchannels in the thick nail plate to enhance the permeability of topical medications, optimizing treatment efficacy directly at the site of psoriatic lesions.[40,41] The combination approach has also been shown to be better tolerated than traditional treatments, such as intralesional injections, with fewer side effects reported[42] [Supplementary table 2].

Laser therapies, particularly PDL and long-pulsed Nd:YAG laser, show promise in treating nail psoriasis. Combining laser therapy with topical agents has further improved treatment outcomes and patient adherence. However, larger clinical trials are needed to establish the optimized protocols and confirm long-term efficacy.

Nail warts

Nail warts, also known as periungual or subungual warts, are caused by human papillomavirus (HPV) infection affecting the skin around or beneath the nails. These warts are often painful and challenging to treat due to their location and potential for recurrence.[43] They appear as raised, rough, or cauliflower-like growths around the nails, often with black dots (thrombosed capillaries) within the lesion, and can spread to adjacent nails or skin.

Various treatment options are available, ranging from topical medications such as keratolytic agents, immunomodulators, and virucidal agents. Surgical options such as cryotherapy, laser therapy, surgical excision, infrared coagulation, radiofrequency, or electrosurgery are used to manage nail warts.[43,44] In treating warts, the laser's mechanism involves disrupting dilated blood vessels within warts, leading to separation of the dermo-epidermal junction, epidermal necrosis, and destruction of blood vessels surrounded by inflammatory cells. This disruption likely affects wart nutrition and HPV-containing epidermal cells, with minimal damage to the surrounding tissue.[45]

Studies have explored innovative approaches to improve treatment outcomes and reduce recurrence and patient compliance. Suh *et al*.[46] reported a 68.4% complete clearance rate with bleomycin solution following fractional CO_2 laser treatment. Zorman and Koron[47] demonstrated the use of a 1064 nm Nd:YAG laser for wart removal without anesthesia. CO_2 laser combined with Nd:YAG or dye laser for non-facial warts, achieved high rates of resolution with low recurrence and minimal scarring.[48] The CO_2 laser causes thermal destruction of warts by removing the skin, which then heals through secondary intention.[46] [Supplementary file 3].When using fractional CO_2 lasers to treat nail warts, the procedure generates fumes containing viral particles, such as HPV, which pose a health risk to the operator. To ensure safety, a high-efficiency smoke evacuator should be used to capture fumes, and operators should wear N95 or FFP3 masks and eye protection. The treatment room should be well-ventilated. Gloves and protective gowns are essential to reduce skin contact. Additionally, proper disposal of contaminated materials is crucial to minimize the risk of exposure to infectious particles.

Further advancements include combining laser therapies with topical treatments. LP Nd:YAG laser with potassium

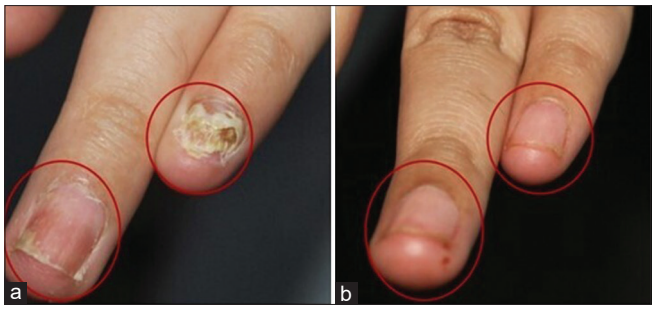

Figure 3: Laser treatment in nail psoriasis. LPNd: Yag laser with energy 35 J/cm^2, 35 ms, 4 mm and six passes. (a) before the treatment and (b) after eight sessions of the treatment

hydroxide (KOH) application showed reduced treatment sessions and improved clearance rates for recalcitrant warts.[49] Nd:YAG 1,064 nm target and heat cutaneous blood vessels to cause their rapid rupture, visible as purpura that resolves within days. Ablative CO_2 fractional laser with methyl aminolevulinate–photodynamic therapy (MAL-PDT) for periungual warts, achieved high clearance rates without recurrence.[50] These combined approaches offer potential solutions for challenging wart cases, optimizing therapeutic outcomes and patient satisfaction.

Ingrown toenail (IGTN)

This condition, also known as onychocryptosis or unguis incarnatus, affects the big toe causing significant pain when the edge of the toenail compresses or penetrates the lateral nail fold. This condition can lead to inflammation, and infections often triggered by improper nail trimming, ill-fitting footwear, foot hygiene issues, and anatomical or genetic predispositions.[51] Mozena's classification system, IGTN, is categorized into five groups: I-inflammation stage, IIa and IIb-abscess stage, III-hypertrophic stage, and IV-distal hypertrophic stage.[52]

Traditional treatments for IGTN, such as partial or total nail avulsion, wedge resection, cryotherapy, and chemical cauterization, have varying success rates and are often associated with pain, erythema, and short-term disability.[53] The phenol–alcohol technique, while promising to reduce recurrence, still struggles with high relapse rates.[51]

Laser treatment offers a less invasive alternative, with benefits including reduced pain, less bleeding, and recurrence. Laser-assisted Emmet's operations lead to reduced pain, swelling, and faster wound healing compared to conventional methods.[54] Specifically, CO_2 laser works by vaporizing water within cells, enabling precise tissue cutting and cauterization, which minimizes bleeding and promotes better healing.[55-57] Similarly, the LP-Nd laser penetrates deeply into tissues, facilitating coagulation and removing inflammatory granulation tissue effectively.[58-60]

When using a fractional CO_2 laser for tissue ablation in the treatment of an ingrown toenail, the operator must carefully determine the endpoint to avoid excessive tissue damage while achieving effective results. Key indicators for deciding the endpoint include:

- **Visual Clues:** The operator should look for a change in tissue appearance, such as the blanching of soft tissue or a change in the color and texture of the nail matrix. The tissue should appear uniformly ablated without charring or deep crater formation.
- **Reduction in Thickness:** The nail fold or hypertrophic tissue should thin out as the laser removes excess tissue, restoring the nail contour and resolving the pressure that causes ingrown toenails.
- **Ablation Depth:** The laser should effectively remove the lateral nail matrix or hypertrophic tissue but avoid going too deep into the dermis to prevent scarring and prolonged healing. The depth of ablation can be controlled by using the laser in short pulses and observing the tissue response.
- **Absence of Bleeding:** Minor pinpoint bleeding is expected during ablation; however, significant bleeding indicates deeper tissue damage and should be avoided.
- **Patient Feedback:** Real-time feedback from the patient ensures the procedure remains within safe limits, particularly concerning discomfort or sensitivity in surrounding areas.

In conclusion, laser-based surgical interventions, such as CO_2 and Nd laser, treatments provide good alternatives for managing IGTN, with superior outcomes in pain relief, wound healing, and recurrence rates compared to traditional approaches [Table 2].

Onychodystrophy

Onychodystrophy is characterized by structural abnormalities of the nails, including changes in the attachment, surface, or color. It is associated with conditions such as psoriasis, onychomycosis, lichen planus, alopecia areata, endocrine disorders, and drug photosensitivity.[61] Treatment typically involves avoiding predisposing factors, keeping nails short, and drug therapy, with intralesional corticosteroid injections being the most reliable.[62]

Laser modalities have shown promise, particularly in refractory cases where traditional therapies have failed. Lee *et al*.[63] found significant clinical improvement in idiopathic onychodystrophy with 1064 nm picosecond Nd laser treatment. Case reports by Paichitrojjana[64] and Choi *et al*.[65] highlighted successful outcomes using PDL and quasi-long pulsed Nd:YAG laser, respectively. The PDL targets vascular structures, reducing inflammation and stimulating tissue remodeling,[66] whereas the 1064-nm Nd:YAG laser improvement mechanism is not fully understood, but several hypotheses exist. Firstly, nonspecific tissue heating may enhance local blood circulation and immune response. Secondly, laser irradiation reduces oxidative stress and boosts antioxidant enzyme activity, potentially reducing inflammation and cytokine levels in the nail matrix and proximal nail fold.

Table 2: Overview of articles on laser therapy for the treatment of ingrown nail

Laser Type	Laser Settings & Treatment Approach	Results	Side effects	Authors
Long-pulsed Nd:YAG	Coagulation of inflammatory granulation with high fluence (150 J/cm^2, 15 ms) - Softening and correction of pincer nails with low fluence (14 J/cm^2, 0.3 ms, 10 Hz) followed by manual correction using mosquito forceps	Resolution of inflammatory granulation in 90% of ingrown toenails. Correction and pain relief in 100% of pincer nails. 6.4% recurrence rate for ingrown toenail	slight pain and heat during the procedure but did not report any adverse events.	Kinoshita *et al*.[58]
CO_2 Laser	V-shaped excision of proximal nail fold. CO_2 laser in superpulse mode at 3.0 watts.	- Success rate of 93.6% for ingrown toenails treated with partial matricectomy using CO_2 laser. Recurrence observed in 6.4% of cases. Minimal tissue damage, rapid healing, and reduced postoperative pain and swelling.	No reported side effects.	Kim *et al*.[53]
CO_2 Laser	Staining of nail matrix with methylene blue. Partial matricectomy using CO_2 laser (4 W of 1 mm continuous mode) under direct vision for cauterization	No recurrence in 94.4% of treated nail borders after a mean follow-up of 13.4 months. Satisfactory cosmetic improvement. No serious complications reported	Postoperative pain was complained of for 1 day on average. No side effects.	Ozawa *et al*.[55]
CO_2 Laser	Nail matrix staining with methylene blue. Partial nail matricectomy using CO_2 laser (5 watts in superpulse mode for incision, 2.5 watts in continuous mode for matrix cauterization)	Good functional and cosmetic results observed in patients treated with CO_2 laser matricectomy for ingrown nail. Low recurrence rate (below 7%). Minimal tissue damage, reduced bleeding, inflammation, and complications	No reported adverse effects.	Cocunubo-Blanco *et al*.[96]
Er:YAG Laser	Destruction of nail matrix by Er:YAG laser pulses with spot size of 1.6 mm, frequency 8-10 Hz, fluence 11.3 J/cm2	Lower pain scores and less swelling observed postoperatively with Er: YAG laser procedure compared to Emmet's operation. Faster healing and lower complication rates. No infections or relapses reported	In one case, spicules occurred after 5 months. No other side effects were noted.	Wollina[54]
1064-nm Diode Laser	1064-nm diode laser with 400-µm optical fiber	Minimal postoperative pain reported by patients. Quicker postoperative healing and return to daily activities. Minor recurrence compared to incisional procedures. Successful outcomes in treating onychocryptosis with diode laser matrixectomy	No reported adverse effects.	Sánchez & Zalacaín-Vicuña[56]
CO_2 Laser	Partial nail matricectomy (PNM) using CO2 laser vs. lateral nail fold excision (LNFE). Continuous CO_2 laser on focus point (10–15 W). Lateral incision of proximal nail fold. Selective destruction of lateral horn of matrix	Cure rates: PNM 85.5% vs. LNFE 78.5%. Fair cosmetic outcomes: PNM 67.9% vs. LNFE 84.0%. Infection rates: PNM 4.8% vs. LNFE 3.1%	No reported adverse effects.	Kavoussi *et al*.[59]
CO_2 Laser	Continuous CO_2 laser at 10–15 W power. Incision of proximal nail fold. Selective destruction of lateral horn of matrix	Recurrence rate: 3%. Spicules observed in 5% of cases. Minimal bleeding, low post-operative pain, rare infections, good cosmetic results.	No reported adverse effects.	Andre[57]
CO_2 Laser	CO_2 laser (with 20 W on-tissue capability) partial matricectomy for recurrent onychocryptosis	Recurrence rate: 1.45%; Spicules in lateral nail groove: 4%; No postoperative local infections or prolonged drainage. Effective for recurrent onychocryptosis	No reported adverse effects.	Serour[97]

Additionally, laser treatment stimulates collagen synthesis and inhibits matrix metalloproteinase activity, promoting collagen rejuvenation in the nail matrix, bed, and proximal nail fold.[65]

Furthermore, CO_2 laser therapy combined with topical steroids has also been effective in treating pediatric[67] and adult cases,[68] enhancing nail texture and appearance without adverse effects. Ablative fractional CO_2 laser therapy promotes scar remodeling, and enhances topical agent penetration, into the nail matrix or nail bed.[68] The fractional CO_2 laser creates controlled dermal damage, aiding the penetration of topical medications and stimulating nail bed rejuvenation.[69] This approach presents a noninvasive and potentially more tolerable option, particularly beneficial for young patients [supplementary table 4].

Melanonychia/nail pigmentation

Melanonychia, characterized by longitudinal streaks of gray, brown, or black within the nail plate, can arise from melanocytic activation or hyperplasia. Melanocytic activation involves increased melanocyte activity without a notable increase in cell numbers, whereas hyperplasia results in excessive pigment-producing cell growth in the nail matrix.[70,71]

Picosecond lasers, known for their efficacy in pigment clearance with minimal thermal damage, have shown promise in treating various forms of melanonychia. Letrozole-induced benign melanonychia achieved complete resolution using a picosecond laser. This laser works by fragmenting melanin through photoacoustic effects.[71-73] The use of a picosecond laser at 1064 nm ensures deep penetration into the nail plate, effective pigment clearance, and minimal damage to surrounding tissues, making it a promising treatment for melanonychia [Table 3].

Pyogenic granulomas

Pyogenic granuloma (PG), is a non-cancerous vascular tumor commonly triggered by minor trauma or skin injuries, prevalent in children, adolescents, and pregnant women. Traditional treatments such as curetting, electrocoagulation, and surgery can be inadequate for larger tumors and delicate areas such as the nail matrix, often causing pain, prolonged bleeding, or residual effects.[74] Laser therapy offers numerous advantages, including reduced invasiveness, minimized hemorrhage during surgery, improved surgical visibility, and the ability to perform suture less procedures with reduced postoperative discomfort.[75]

Successful outcomes were achieved using PDL therapy with a 15 mm pyogenic granuloma.[76] Patients treated with a multi-spot Nd-YAG laser achieved complete lesions,[77] in cases resistant to conventional treatments.[78,79] PDL primarily targets superficial vessels[75] where as the Nd-YAG laser penetrates deeper, effectively treating the entire lesion, including deeper structures such as the mid-dermis and nail bed, making it ideal for challenging anatomical areas.[80] Additionally, a Nd:YAG laser typically requires fewer treatment sessions compared to PDL, offering effective and safe treatment options for PG[76-78,80] [Supplementary table 5].

Nail tumors

A nail tumor is an abnormal growth affecting the nail apparatus, including the nail matrix, nail bed, or surrounding areas. Common types of nail tumors include onychocytic matricoma glomus tumors, onychopapilloma, subungual

Table 3: Summary of the studies on longitudinal melanonychia using laser therapy

Laser Type	Laser Settings & Treatment Approach	Results	Side effects	Authors
Picosecond (ps) Laser (1064 nm)	Pulse width of 450 ps, spot size of 5 mm, fluence of 1.6 J/cm^2 for two sessions at 1 month interval.	Nail pigmentation turned whitening after first session, became lighter after one month, completely resolved without observable nail damage	No adverse events were reported.	Liu & Tsai[72]
Picosecond Laser (1064 nm)	Pulse width of 750 ps, spot size of 3–4 mm, fluence from 4.8 to 5.0 J/cm^2	Hyperpigmentation of treated nail completely resolved without observable nail damage; mild black discolorations with transverse white lines observed on other fingernails.	No side effects were reported.	Tsai *et al*.[71]
ps Nd: YAG Laser	350 ps pulse duration, 532 nm, fluence of 0.5 J, spot size of 3 mm, 2 Hz and a total of 72 shots	95% pigment reduction after single session without nail damage or side effects, no recurrence at six months follow-up	No side effects.	Fritz and Salavastru[73]
ps Nd: YAG) Laser (1064 nm and 532 nm)	Proximal half treated with 1064-nm ps Nd: YAG laser (4-mm spot, 1.5 J/cm^2, 1 pass); Distal half treated with 532-nm ps Nd: YAG laser (2-mm spot, 0.5 J/cm^2, 1 pass)	Immediate whitening of nail pigmentation after first treatment, some residual pigmentation observed after three weeks.	No side effects.	Han *et al*.[70]

Table 4: An overview of research articles on laser therapy-treated nail tumor

Laser Type	Laser Settings & Treatment Approach	Results	Side effects	Authors
		ONYCHOPAPILLOMA		
Pulsed Dye Laser (595 nm)	Pulse duration: 1.5 ms, spot diameter: 3-5 mm, energy fluence: 11.5-13.5 J/cm^2	Overall effective rate of 77%; effective rates for erythronychia, leukonychia, and melanonychia were 88%, 67%, and 50%, respectively.	No side effects.	Fan *et al*.[84]
		GLOMUS TUMOR		
Pulsed Dye Laser (595 nm)	Spot size: 7 mm, fluence: 20 J/cm^2, pulse duration: 20 ms, 5 pulses per treatment session with 50% overlap, 30-second intervals between each pulse	Complete resolution of the lesion after five treatment sessions with no recurrence or scarring noted during follow-up.	Bruising on the fingernail after the treatment, no other side effects.	Vergilis-Kalner *et al*.,[87]

exostosis malignant melanoma. Diagnosis involves clinical examination, dermoscopy, imaging studies, and biopsy when necessary.[81]

Onychopapilloma, a rare benign tumor of nail matrix and bed, manifests such as longitudinal erythronychia, leukonychia, and melanonychia. Surgical resection is the standard treatment; however, it has limitations such as recurrence rate and associated complications.[82,83] Onychopapilloma treated with PDL has been successfully used to treat a painful glomus tumor in a 9-year-old girl's nail bed, the lesion resolved completely without scarring or recurrence.[84] PDL targets erythrocytes within blood vessels, causing coagulation that alters microcirculation. This process corrects the capillary abnormalities and promotes tissue healing.[85,86] In glomus tumors condition, PDL eliminates ectatic vessels, resulting in tumor shrinkage[87] [Table 4].

While reviewing the literature, the authors noted a lack of articles discussing the use of laser therapy for treating nail tumors. This emphasizes the importance of conducting more research in this area.

Conclusion

Studies on onychomycosis have shown mixed outcomes, with some demonstrating significant improvements in nail appearance and mycological cure rates. Laser therapy effectively manages nail psoriasis by targeting vascular changes and enhancing drug delivery, with combinations of laser and topical agents enhancing treatment outcomes. In treating warts, ingrown toenails, onychodystrophy, and even nail pigmentation disorders such as melanonychia. For nail tumors, such as onychopapilloma and glomus tumors, laser therapy presents an alternative to surgical resection, providing pain relief and improvement in nail appearance. Despite the promising results, more research is needed to optimize laser treatment protocols and establish their long-term effectiveness in managing diverse nail disorders.

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Conflicts of interest

There are no conflicts of interest.

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Supplementary Table 1: Summary of lasers used for different nail disorders

Lasers → Indication ↓	LP Nd Yag (1064nm)	Nd Yag (1064nm)	QS Nd Yag (1064nm)	Pulsed Nd Yag (1064 nm)	QS Nd Yag (532nm)	Diode laser	Ablative CO_2	Fractional CO_2	Pulse dye laser (595 nm)	CO_2 laser	Picosecond laser (1064nm)	Picosecond NdYag laser (532 nm)	Ultra pulse CO_2	Multispot Nd Yag (1064 nm)	Er: YAG
Onychomycosis	✓	-	✓	-	✓	✓	✓	✓	-	-	-	-	-	-	-
Nail psoriasis	✓	✓	-	-	-	-	-	✓	✓	-	-	-	-	-	-
Nail warts	✓	-	-	-	-	-	✓	✓	✓	✓	-	-	-	-	-
Ingrown nail	✓	-	-	-	-	✓	-	-	-	✓	-	-	-	-	✓
Onychodystrophy	-	✓	-	-	-	-	-	✓	✓	✓	-	-	✓	-	-
Longitudinal melanonychia	-	-	-	-	-	-	-	-	-		✓	✓	-	-	-
Pyogenic granulomas	✓	-	-	✓	-	-	-	-	✓		-	-	-	✓	-
Onychopapilloma	-	-	-	-	-	-	-	-	✓	-	-	-	-	-	-
Glomus tumor	-	-	-	-	-	-	-	-	✓	-	-	-	-	-	-

Supplementary Table 2: Laser treatment approaches, settings, and outcomes in nail psoriasis

Laser type	Laser settings & treatment approach	Results	Side/adverse effects	Authors
Long-pulsed Nd:YAG (1,064 nm)	6 mm Beam diameter, laser energy: 10 J/cm^2 with pulse duration of 15 ms at a repetition rate of 1.5 Hz.	Significant reduction in NAPSI scores after 3 treatment sessions was 5.7±4.3. Both nail bed and matrix lesions responded well.	No adverse effects.	Kartal *et al*.[38]
Long-pulsed Nd:YAG (1,064 nm)	5 mm, 40 J/cm^2, 35 ms with pulse duration and 3–5 s pre-cooling using integrated contact cooling with ice packs. 4 sessions monthly.	Significant improvement in NAPSI scores and dermoscopic features. Nail bed showed better improvement than nail matrix.	No adverse side effects, except mild tolerable pain.	Khashaba *et al*.[35]
Nd:YAG (1,064 nm)	Beam diameter: 2.5 mm, laser energy: started with 110 J/cm^2 and increased to 130 J/cm^2, single pulse frequency - shallow depth. 6 sessions monthly.	No statistically significant difference in total NAPSI and nail bed scores but significant improvement in nail matrix score. Dermoscopic improvement observed.	Except mild pain in few, no side effects.	Elwan *et al*.[37]
Fractional CO_2 laser	Group A: Fractional CO_2 laser followed by topical methotrexate Group B: Fractional CO_2 laser followed by topical calcipotriol (0.05 mg/g) + betamethasone (0.5 mg/g) combination. Pulse width: 4,006 ms, stack: 3, dwell time: 500 ms, spot size: 3 mm × 3 mm and energy: 180.2 mJ/cm^2. 4 treatment sessions, once every 2 weeks.	Significant decrease in total NAPSI score in both the groups. Combined laser with topical treatment was effective.	pain and bleeding were reported in few patients.	Afify *et al*.[40]
Fractional CO_2 laser	Power: 10 W, stack: 3, dwell time: 500 ms, spacing: 600 mm. 2-week interval for 6 sessions. Followed by topical application of 0.1 mL methotrexate (25 mg/mL) per digit	Fractional CO_2 laser-assisted delivery of methotrexate is an effective and well-tolerated alternative to intralesional injection in nail psoriasis.	Mild pain, subungual hematoma in injection group. No adverse effects in laser group.	Alakad *et al*.[42]
Pulsed dye laser (595 nm)	Power: 10 W, laser energy: 8.0 to 10.0 J/cm^2, stack: 3, dwell time: 500 ms, spacing: 600 mm, spot size: 7 mm, beam diameter: 7 mm, cryogen spurt: 30 ms with 30 ms delay	Subungual hyperkeratosis and onycholysis showed significant improvement. Nail pitting was the least responsive	Mild hyperpigmentation in a few patients.	Al-Mutairi *et al*.[31]
Pulsed dye laser (595 nm)	7 mm beam diameter, 1.5 ms of pulse duration. Laser energy: 8.0 to 10.0 J/cm^2. Cryogen Spurt: 30 ms with 30 ms delay. Once monthly for 3 months.	Significant improvement in NAPSI scores post-treatment. The nail bed lesions, particularly onycholysis and subungual hyperkeratosis, responded best to the treatment.	Mild tolerable pain.	Oram *et al*.[32]
Pulsed dye laser (595 nm)	Spot size: 7 mm, pulse duration: 0.45 ms, fluence: 6 J/cm^2. Three sessions at four-week intervals	Median improvement in NAPSI scores: 44.2% overall, 50% for nail bed, and 65.1% for nail matrix.	Light pain during the laser application.	Peruzzo *et al*.[29]

Supplementary Table 3: Summary of the studies treating Nali warts using laser therapy

Laser Type	Laser Settings & Treatment Approach	Results	Side effects	Authors
LPNd:YAG Laser (1064 nm)	Spot size: 5 mm; Pulse duration: 20 msec; Fluence: 200 J/cm^2. 1-2 pass of slightly overlapping passes on the wart itself and a 1-mm margin, 4 sessions 4 weeks apart	A high clearance rate (96%) was achieved for warts.	pain during treatment (82%), posttreatment numbness (15%), hemorrhagic bullae (7%), hyperpigmentation (5%), and hypopigmentation (4%). A crust formed in most patients and was removed within 1 to 2 weeks.	Han *et al*.[45]
LPNd:YAG Laser (1064 nm)	Handpiece: R33-T; Spot size: 2-4 mm; Pulse duration: 20-25 ms; Fluence: 130-270 J/cm^2. 35-40 shots	Mean VAS pain score: 6 (range: 2-10); Mean number of sessions: 2.2 (range 1-7); Effective treatment for warts	Negligible side effects	Zorman & Koran[47]
LPNd:YAG Laser & PDL	Nd: YAG- Spot size: 7 mm; Energy: 100 J/cm^2; Pulse duration: 20 ms PDL- spot size, 7 mm; energy, 8 J/cm (2); and pulse duration, 0.5 ms.	Similar efficacy between PDL and Nd:YAG in treating plantar warts. but PDL had fewer complications (8.7%) than Nd: YAG (43.5%).	Nd:YAG laser is more painful than PDL	El-Mohamady *et al*.[98]
LPNd:YAG Laser (1064 nm)	Pulse duration: 500 msec, pause 1.0 sec, power 30 W, and fluence 212 J/cm^2	Successful treatment was achieved after average of 3.6 sessions and cure rate was approximately 84%.	No adverse events.	de Planell-Mas *et al*.[99]
LPNd:YAG Laser (1064 nm)	Group 1: Spot size: 5 mm; Pulse duration: 10 ms; Fluence: 120 J/cm^2 Group 2: LPNd: YAG Laser + daily 10% KOH application at night	LP Nd:YAG laser combined with 10% KOH showed faster clearance (2.2 sessions) compared to LP Nd:YAG (3.1 sessions) alone.	Blisters, crusts, escars, hyperpigmentation, hypertrophic scar and VAS was mild to severe in both groups.	Khattab *et al*.[49]
LPNd:YAG Laser	Spot size: 3 mm; Fluence: 160 J/cm^2; Pulse width: 30 ms; Frequency: 1 Hz	Disappearance of warts after two days of laser treatment.	No side effects were reported.	Fatani *et al*.[100]
FDQS Nd:YAG Laser (532 nm)	Fluence: 2.5 J/cm^2; Pulse duration: 10 ns; Spot size: 3 mm	Absence of recurrent lesions, pigmentary, and textural changes on the treated areas after 6 months.	No side effects were reported.	Li & Yang[101]
CO_2 Laser	1-2 passes, continuous mode, 15-25 watts, spot size 1 mm (focused mode) and 5 cm distance (unfocused mode)	Median sessions for resolution of warts in CO2 Laser group was 1 (range 1-2) whereas cryotherapy group was 3 (range 1-12)	Moderate bleeding during laser therapy, managed by coagulation with the CO_2 laser unfocused mode.	Boroujeni & Handjani[102]
CO_2 Laser (10600 nm)	Focus vaporization method, power varied based on wart type (verruca plana: 3-4 W; filiform warts and small verruca vulgaris: 5-9 W; large/thick verruca vulgaris and periungual lesions: 10-14 W)	Complete cure rates: CO2 laser - 83.6%; Electrocautery - 87.3%; High frequency radiosurgery ablation - 98.3%. High frequency radiosurgery had lesser complications compared to other treatments	Pigmentary changes- Hyper, hypo and depigmentation was reported. Scarring and pain was the major complaint. Few showed excessive bleeding from the lesion(s) during or following the procedure.	Haroon *et al*.[103]
Ablative CO_2 Fractional Laser	Single-pulse treatment: 15-18 mJ per 150 mm diameter microbeam, 0.45-5 ms pulse width produced microcolumns of ablation with border coagulation up to 100 mm wide and 150 mm deep. Methyl 5- aminolevulinic acid cream + red light at a dose of 50 J/cm^2 for 15 minutes	Mean clearance of 100% achieved in 90% of warts after a mean of 2.2 treatments per wart; no recurrences in warts that achieved 100% clearance during 6-month follow-up	Side effects during and after the treatment were mostly mild pain and erythema.	Yoo *et al*.[50]

Contd...

Supplementary Table 3: Contd...

Laser Type	Laser Settings & Treatment Approach	Results	Side effects	Authors
CO_2 Laser, LPNd:YAG laser & Dye laser	1st session- CO_2 Laser - Super-pulsed mode; with a beam diameter of 0.1–0.2 mm, power 0.3–0.8 W, frequency 10 Hz. 2nd session – LPNd: YAG Laser- 90–120 J/cm^2, 5 mm spot size, slightly defocused, double pulse (5 ms–15 ms) with a 10 ms interval, performing multiple passes. 3rd session- 595 nm dye laser- 10 mm spot size, fluence 9–10 J/cm^2, frequency 0.5/s, performing multiple passes.	Almost all patients reported complete resolution of lesions, with no scarring.	No severe side effects were reported.	Bennardo *et al*.[48]

Supplementary Table 4: Summary of research article on onychodystrophy using laser treatment

Laser Type	Laser Settings & Treatment Approach	Results	Side effects	Authors
CO_2 laser	Case 1: Combination of fractional CO_2 laser treatment (30 W, 160 mJ, 150 spots/cm^2, 4 mm spot size with round shape) and topical 0.3% diflucortolone valerate ointment. Case 2: Ablative fractional CO_2 laser therapy (Pulse energy: 160 mJ, power: 30 W, density: 150 spots/cm^2 , spot size: 4 mm, shape: round) with topical methylprednisolone aceponate ointment	Case 1: Significant improvement after 6 sessions of laser treatment. Mild pain reported during treatment. No adverse events. Case 2: Significant improvement in nail appearance and texture after four treatment sessions. No scarring reported.	no adverse events were reported.	Lee *et al*.[67]
Fractional CO_2 laser	160 mJ and a density of 150 spots/cm^2; three passes (480 mJ) per nail, 4 week intervals.	Significant clinical improvement of all fingernails after 3 sessions of laser treatment.	No adverse events were reported.	Lim *et al*.[68]
PDL (595 nm)	10 ms pulse duration, 7 mm beam diameter, 7–8.0 J/cm^2 energy; four times at two-week intervals	Significant improvement of dystrophic thumbnails observed within four weeks of treatment. No recurrence after ten-month follow-up.	Mild pain without any other adverse reactions.	Paichitrojjana[64]
1064-nm Nd:YAG laser	Pulse energy: 3.0–5.0 J, Spot size: 7–8 mm, Pulse duration: 300 microseconds, Rate: 5–10 Hz	Good response observed on right thumbnail, fair response on left thumbnail after ten treatment sessions. Patient satisfied with results	Severe pain during the treatment. No other side effects were reported.	Choi *et al*.[65]
Ultra pulse CO_2 laser	50 mJ, 5% density, Rate of 250 Hz, Square shape, Spot size of 6 with a single pulse and a single pass	Significant functional improvement and scar softening observed after single laser treatment.	No adverse events were reported.	Krakowski *et al*.[104]

Supplementary Table 5: Review of studies on Pyogenic granuloma treated with lasers

Laser Type	Laser Settings & Treatment Approach	Results	Side effects	Authors
Pulsed Nd:YAG laser (1064 nm)	Fluences: 90-140 J/cm^2, pulse length: 20-30 ms, spot size: 5-7 mm	Success rate of 93% in 14 out of 15 patients treated with Nd: YAG laser for PG.	No adverse effect.	Gex-collet *et al*.[80]
Pulsed Dye Laser (595 nm)	Fluences: 5.3-9.4 J/cm^2 or 15 J/cm^2, spot size: 7 mm - 3 passes per treatment session	Effective treatment for PG lesions <5 mm with PDL alone; shave-excision + PDL for larger lesions	No adverse effect.	Sud & Tan[76]
LPNd:YAG laser (1064-nm)	Pulse duration: 40 ms, spot size: 5 or 7 mm	Effective and low-risk treatment for PG, with good cosmetic outcomes.	Crusting occurred, no side effects.	Hammes *et al*.[78]
Multispot Nd-YAG laser (1064 nm)	Pulse width: 10.5-13.5 ms, energy: 100-125 J/cm^2, spot size: 6 mm	Effective treatment with Nd: YAG laser for PG located on fingers and toes.	Pain during and a few hours after treatment, swelling around the lesions, bleeding, slight scarring.	Dong *et al*.[77]