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Research Article

Innovative Therapy for Diabetic Foot: Synergism of Superpulsed Laser with Pulsed Magnetic Field in the Treatment of Wounds and Osteomyelitis

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ABSTRACT

We are experiencing a growing global epidemic of diabetes and prediabetes with their associated complications. The International Diabetes Federation estimates that 588,7 million people worldwide have diabetes and the proportion of people with type 2 diabetes continues to rise. Of this extremely expressive population, approximately 50% will develop neuropathy, the most common and expensive complication of diabetes. Diabetic neuropathy encompasses clinical syndromes caused by damage to peripheral and autonomic nerves. Such involvement progresses with chronic pain and sensory deficit that evolve with the formation of ulcers. These ulcers usually become infected, evolve into osteomyelitis and have amputation as their main outcome. Although amputation aims to save the patient's life, it significantly increases cardiac output, proportional to the amputation level. This leads to severe motor restriction, loss of independence in daily activities and compromised personal hygiene. To demonstrate the mechanism of action and clinical feasibility of superpulsed laser associated with low intensity pulsed magnetic field in the treatment of osteomyelitis secondary to diabetic foot ulcer. Review of the literature on diabetic foot complications, pulsed magnetic field (PEMF) in the treatment of vasculopathies and neuropathies (modulating inflammatory response and stimulating neovascularization) and superpulsed laser therapy focusing on the effect of the therapy as a bactericidal agent (such as the effects of photobiomodulation, mitochondrial stimulation and blue laser therapy), as well as the effects of cellular metabolic optimization and trophic improvement in irradiated tissue to maximize the biological response against the infectious process. To demonstrate the practical effect of this treatment through a case report. Superpulsed laser therapy can function as a bactericidal agent while acting at the cellular level in the treated area, maximizing the tissue response against bacteria and curing the infection, while the low intensity pulsed magnetic field will act to improve microvascular complications and neuropathy associated with diabetes. The association of low-intensity PEMF with superpulsed laser therapy can be considered an adjuvant therapeutic option in the treatment of diabetic foot complications.

Keywords: Superpulsed Laser, Pulsed Magnetic Field, Diabetes Mellitus, Diabetic Pain, Ulcers, Osteomyelitis

1. Introduction

The growing global prevalence of diabetes mellitus (DM) and prediabetes represents one of the greatest public health challenges today, affecting hundreds of millions of people. It is estimated that 588,7 million individuals live with diabetes worldwide, with a predominance of type 2 diabetes - a condition whose incidence continues to increase exponentially, especially among middle-aged and older adults, but also with worrying growth among young adults[1-5].

Among the various complications of diabetes, peripheral diabetic neuropathy is one of the most frequent and costly, affecting up to 50% of diabetic patients and about 10% of pre-diabetic patients[3,5,6]. It is a set of clinical syndromes resulting from peripheral and autonomic nerve injuries, often associated with chronic pain, sensory loss and the development of ulcers in the lower limbs. These ulcers, in turn, tend to become infected, evolving to severe osteomyelitis and often culminating in amputations[5,7,8].

Brazil ranks fourth among the countries with the highest number of people with diabetes mellitus, with an estimated prevalence of 8% of the population. Data from the Global Burden of Disease study (2020) point to diabetes as one of the main causes of years of life lost due to disability[1-5]. Regardless of the political, economic or social context, MD impacts both developed and developing countries, making it an issue of international relevance.

From the pathophysiological point of view, DM is characterized by disturbances in insulin secretion or action, resulting in chronic hyperglycemia and profound alterations in the metabolism of carbohydrates, lipids and proteins. This dysfunctional metabolic state is closely related to the exacerbated production of reactive oxygen species, promoting widespread vascular damage. Such damage is clinically manifested by microvascular (retinopathy, neuropathy, nephropathy) and macrovascular (coronary artery disease, stroke and amputations) complications, often requiring prolonged hospitalizations[3,9,10].

Neuropathic foot ulcers, aggravated by diabetic vasculopathy, have a high rate of infection and progression to osteomyelitis. The most common outcome in these cases is amputation, which, although necessary for infectious control and preservation of life, has drastic functional and social consequences. After amputation, patients face significant motor limitation, loss of independence and high mortality - about 80% within five years[3,10].

All this contextualization serves to demonstrate that diabetes mellitus is not only a regional, national or even continental issue. It is a global problem that affects countries indistinctly and the treatment of its complications should be seen as a priority by the world scientific society. As this is a serious public health problem, whose therapeutic options are not successful in the real resolution of this problem, the use of innovative technologies to solve old problems is necessary and imperative, which is why this study was designed.

1.1. Study objective

To investigate the mechanism of action and clinical feasibility of the synergy between superpulsed laser and low intensity pulsed magnetic field (PEMF) in the treatment of infectious complications of the diabetic foot, with a special focus on osteomyelitis secondary to infected ulcer.

2. Literature Review

2.1. Definition and etiology of diabetic foot

Diabetic neuropathy is one of the most prevalent and debilitating complications of diabetes mellitus, affecting approximately 50% of individuals with the disease[11]. This condition results from injuries to the peripheral nerves, leading to manifestations such as pain, tingling, numbness and loss of sensation[12]. Peripheral neuropathy is a determining factor in the development of ulcers and amputations in diabetic patients, contributing significantly to increased morbidity and mortality[13].

The etiopathogenesis of diabetic neuropathy involves several interconnected factors, with chronic hyperglycemia being one of the main elements. Prolonged exposure to elevated levels of glucose leads to microvascular damage that compromises neural nutrition and oxygenation[12]. Glucotoxicity, mediated by the formation of advanced glycation products (AGEs), promotes structural and functional changes in neurons[12]. Simultaneously, oxidative stress, caused by the imbalance between reactive oxygen species and antioxidant mechanisms, aggravates neuronal injury[12,14].

Chronic inflammation also plays a vital role in this process. Elevated inflammatory markers, such as C-reactive protein and proinflammatory cytokines, have been associated with neuropathy progression[12]. This inflammatory environment perpetuates neural damage and accelerates axonal degeneration. Studies still suggest the influence of genetic factors on the predisposition to neuropathy, although the molecular mechanisms are not yet fully elucidated[12].

Understanding the complexity of the etiopathogenesis of diabetic neuropathy is critical for the development of preventive and therapeutic strategies.

Diabetic vasculopathy, in turn, results from structural and functional changes in the micro and macro vasculature in response to prolonged hyperglycemia. Endothelial dysfunction, induced by glucotoxicity and oxidative stress, contributes to the formation of atherosclerotic plaques and the impairment of tissue perfusion[15]. This ischemia hinders wound healing and favors the appearance of ulcers, especially in association with the loss of sensitivity caused by neuropathy[16,17].

The pathophysiology of diabetic foot, therefore, is multifactorial and involves the synergistic interaction between neuropathy and ischemia. Foot injuries often go unnoticed due to sensory loss and poor perfusion compromises tissue repair mechanisms[12,13,15-17]. This scenario favors the formation of chronic wounds, often infected, whose resolution is difficult even with an intensive multidisciplinary approach, including glycemic control, dressings, load restriction, antibiotic therapy and surgeries[18]. Despite these strategies, healing is often slow and incomplete, increasing the risk of serious complications such as systemic infection, amputation and death.

2.2. Conventional and emerging therapeutic approaches

2.2.1. Conventional techniques for treating ulcers in diabetic foot: The treatment of ulcers in diabetic feet is based on a set of conventional interventions that aim to control infection, promote healing and prevent recurrences. The main approaches include strict glycemic control, debridement of lesions, use of appropriate dressings, relief of pressure on the ulcer, in addition to infection management and revascularization when indicated[19,20].

Glycemic control is essential for the prevention and treatment of chronic complications of diabetes, including peripheral neuropathy and poor perfusion, which are key factors in the development and perpetuation of ulcers[4,8]. High glucose levels compromise the immune response and increase susceptibility to infections, as well as delay healing.

Debridement is one of the most important classic techniques in the local treatment of lesions. It consists of the removal of necrotic, devitalized or infected tissue, promoting a clean bed that is favorable to healing. Debridement modalities include surgical, enzymatic, autolytic and mechanical, with surgical being the most used in ulcers with extensive necrotic tissue[21,22].

The use of modern dressings also represents an important pillar in conventional treatment. Hydrogel, hydrocolloid, calcium alginate and polyurethane foams are often indicated, as they maintain the ideal moist environment for healing and favor the granulation process[21,23]. The choice of dressing depends on the stage of the injury, the presence of infection and the amount of exudate.

Pressure relief (offloading) is a crucial strategy, as the continuous mechanical stress on the injury prevents its healing. Devices such as removable plaster boots (total contact cast) or custom orthopedic footwear are widely used[24].

The presence of infection requires targeted systemic antibiotic treatment, based on culture and antibiogram. Severe infections or those with suspected osteomyelitis may require hospitalization and surgical intervention[9,24].

Finally, in cases with vascular involvement, endovascular revascularization or open surgery should be considered to restore perfusion and allow adequate healing[15,17].

Given the limitations of conventional treatments, the search for innovative technologies capable of promoting not only symptomatic relief, but also tissue regeneration and reversal of the deleterious effects of chronic hyperglycemia has intensified.

Among the interventions studied for the treatment of diabetic foot complications, the following stand out: shockwave therapy, use of platelet-rich plasma (PRP) and other orthobiological products, negative pressure therapy (vacuum-assisted closure), among others[18,21,22,24-27]. However, the results of these treatments - whether surgical or not - remain inconsistent, with a limited and variable success rate according to the sample studied.

The development of non-invasive, effective and well-tolerated therapeutic protocols is therefore a priority in the management of chronic diabetic foot ulcers.

2.2.2. Photoceuticals (laser therapy): Phototherapy or laser therapy, is based on the application of photons with specific wavelengths of the electromagnetic spectrum to stimulate cell regeneration and modulate inflammatory processes. The so-called photoceuticals - lasers applied in non-thermal parameters - have been extensively investigated as a therapeutic alternative for chronic ulcers in the diabetic foot[6,17].

Studies show that laser therapy promotes increased local perfusion, stimulates mitochondrial production of ATP (the increase in the production of adenosine triphosphate (ATP) in the mitochondria of cells. The energy generated by the laser is absorbed by cytochrome C oxidase, a chromophore presents in mitochondria and involved in the Krebs cycle, promoting cellular respiration and ATP production, which is essential for cell metabolism and healing processes)[28], induces neo angiogenesis and favors cell proliferation[17,29-32]. It also stimulates the production of collagen, a protein essential for tissue structure and other key components for healing[17,32]. In addition, neovascularization or the formation of new blood vessels, is encouraged, which improves the supply of oxygen and nutrients to the affected areas, maximizing healing[33].

In addition, phototherapy has antimicrobial and immunomodulatory effects and can reduce bacterial load and local inflammation[17,30,34]. Clinical benefits include reduced healing time, pain relief and improved quality of life for patients[17,31,32].

While superpulsed laser therapy has significant advantages, it is important to follow it up with the knowledge of its limitations. The laser is most effective in tissues where its penetration is optimal, usually in superficial to intermediate layers of the skin and its use should be carefully considered in cases of deep infections.

In addition to superpulsed laser, blue light therapy is emerging as a promising tool in infection control, especially for its antimicrobial action. Operating within the wavelength range of 405 to 470 nm, blue light interacts with porphyrins present in bacteria, generating reactive oxygen species (ROS) that damage bacterial cell membranes and DNA[35]. This makes blue light an interesting alternative, especially for superficial infections, such as those often found on skin damaged by diabetes or in cases of ulcers, fistulas and wounds with dehiscence, in which the laser can easily penetrate deeper levels.

Although blue light has limited penetration (approximately 1 mm), its focused use in superficial infections allows for targeted treatment while minimizing potential damage to healthy tissues[35,36]. In combination with laser therapy, it can create a more robust multifaceted approach in diabetic foot care.

Although blue light therapy is considered safe and non-invasive, it is important to recognize the potential for cytotoxicity with prolonged or excessive exposure. Studies have shown that while blue light is effective at killing bacteria, it can also cause damage to healthy cells if used incorrectly. For this reason, treatment protocols must carefully balance the dose and duration of blue light exposure to avoid unintended harm[35,36].

Doctors should follow recommended treatment guidelines, ensuring that blue light is used at appropriate durations and at the correct wavelengths. Overexposure can lead to oxidative stress in healthy cells, potentially compromising the healing process. By following best practices, clinicians can minimize the risk of cytotoxicity while maximizing the therapeutic benefits of blue light therapy.

Safety, non-invasive character and minimal risk of side effects make photoceuticals an attractive alternative for the management of complicated diabetic foot[6,17,31,32,37].

2.2.3. Pulsed magnetic field (PEMF): The propagation of the electromagnetic impulse in biological tissues has shown to be a promising strategy for the treatment of several conditions, including diabetic foot, a common complication that results from micro- and macrovascular changes in diabetic individuals. This therapeutic approach is based on the use of electromagnetic fields to promote tissue repair, reduce inflammation and improve wound healing[38].

This therapeutic modality employs low-intensity PEMF with the aim of stimulating tissue repair, modulating inflammatory processes and providing analgesia[38,39]. In a randomized, double-blind, placebo-controlled clinical trial involving thirteen participants with chronic diabetic foot ulcers, daily 60-minute sessions of PEMF (12 Hz and twelve gauss) applied for three weeks led to an 18% reduction in wound area, while the placebo group had only 10%. In addition, a significant improvement in tissue microcirculation was observed, with a 28% increase in capillary flow velocity and a 14% expansion in capillary diameter[40].

The vector density of magnetic flux is a fundamental element in electromagnetic therapies, as it governs the physical-biological interactions between magnetic fields and organic tissues. These interactions can be understood in the light of mathematical models that consider the spatiotemporal distribution of electromagnetic vectors in biological media. The specific dielectric and conductive properties of each fabric directly influence its response to the applied field. Several studies have shown that such exposures can modulate the activation of calcium channels, influencing the processes of depolarization and repolarization of membranes and, consequently, significantly affecting cell signaling. In addition, that electromagnetic therapy promoted the repolarization of cell membranes previously compromised by chronic inflammation and oxidative stress, resulting in functional improvement, increased membrane potentiation and reduced apoptosis rates, which reinforces its regenerative potential in the clinical context[39,41-44].

The therapeutic response to PEMF depends on the spatiotemporal modulation of the applied impulses. Lower frequencies are associated with improvements in tissue oxygenation and perfusion, while higher frequencies favor anti-inflammatory and proliferative effects. These responses stem from interactions with polarizable structures - such as lipids and membrane proteins - that trigger multiple cells signaling pathways[45,46].

These effects are mediated by interactions with polarizable structures in the medium, such as lipids and proteins in cell membranes, influencing several cells signaling pathways.

At the molecular level, PEMF have been shown to promote osteogenic differentiation of human mesenchymal stem cells and increase the expression of regenerative markers such as BMP2, type I collagen and osteocalcin. These biophysical effects underlie the synergistic potential of PEMF with other modalities, such as phototherapy, in the regeneration of tissues in lesions associated with diabetes[34,40,44-46].

In a preclinical model with diabetic rats, PEMF promoted myofibroblast proliferation and significantly accelerated the proliferative phase of healing, corroborating its regenerative effect[47]. A study by Choi, et al. demonstrated that the application of PEMF at 25 Hz and 10 mT improved the mechanical resistance of the scar tissue - evidenced by an increase in energy absorption capacity - during the initial repair phase in rodents diabetic wounds.

Systematic reviews confirm that PEMF accelerates the healing of chronic wounds by stimulating angiogenesis, cell proliferation and reduced inflammation. Another clinical study showed that PEMF is also effective in improving skin perfusion and relieving pain in patients with peripheral diabetic neuropathy[49].

In summary, clinical, preclinical and mechanistic evidence converge to indicate that magnetotherapy can be an effective therapeutic resource in the treatment of chronic diabetic foot ulcers, potentially amplifying the beneficial effects when combined with complementary physical therapies such as laser therapy.

3. Methodology

This study aims to propose a new adjuvant therapeutic plan for the treatment of infected diabetic foot, based on recent evidence on photoceuticals and PEMF. To this end, a review of the scientific literature and planning of a therapeutic protocol based on the mechanisms of action and synergistic pathways of these therapies was conducted. Next, the protocol was clinically applied to a patient with an ulcerated diabetic foot complicated by osteomyelitis, performing eight applications with a frequency of two applications per week of Multiradiance Medical's Shower Superpulsed Laser with BTL's premium model 4920 pulsed magnetic field. aiming to demonstrate the safety, feasibility and preliminary efficacy of this approach. The patient's evolution was evaluated based on Ulcer Healing (digital photograph with planimetry, depth, wound bed characteristics such as granulation tissue, exudate, infection), osteomyelitis evolution (serial radiographs, inflammatory markers), pain (VAS - Visual Analogue Scale).

4. Clinical Case Report

4.1. History of current disease (HDA)

A 55-year-old male patient with a previous diagnosis of type 2 diabetes mellitus with more than 15 years of evolution and peripheral neuropathy sought care with severe pain in the right foot for 10 months, associated with the presence of exudative ulcers and foul odor. He reported difficulty walking and performing basic activities. He reported that the condition began after the use of inappropriate footwear, evolving to edema, hyperemia and ulcer formation on the medial aspect of the forefoot, with purulent secretion **(Figure 1)**.

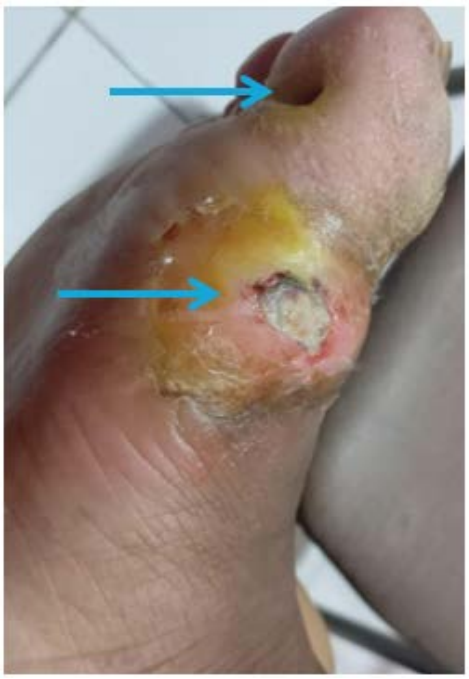

Figure 1: Presence of multiple ulcers with purulent secretion with a foul odor on admission.

After being evaluated by three vascular surgeons, he received an indication for limb amputation. In the initial consultation, the patient demonstrated intense psychological distress, total denial of the proposed treatment and suicidal ideation **(Figure 2)**.

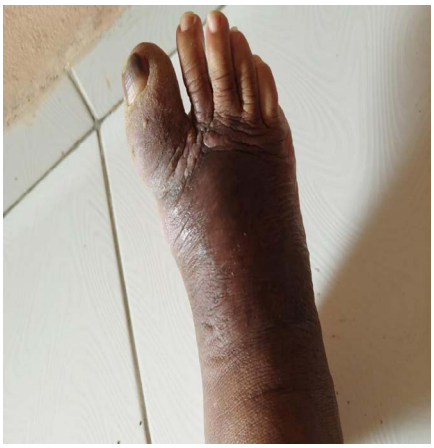

Figure 2: Appearance of the patient's foot at admission, showing chronic vasculopathy with alteration of the skin appendages, edema and change in skin color.

4.2. Physical examination

On admission, the patient had VAS 8, allodynia and hyperalgesia in the feet, in addition to loss of sensation. An X-ray of the right foot revealed bone destruction compatible with osteomyelitis of the hallux and first metatarsal. The diagnostic hypothesis was an ulcerated diabetic foot infected with osteomyelitis **(Figure 3)**.

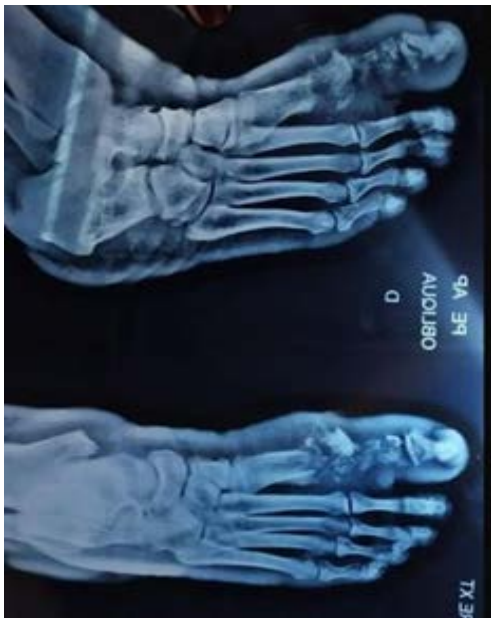

Figure 3: Radiograph presented on admission, demonstrating chronic osteomyelitis of the hallux and metatarsal with intense bone destruction.

4.3. Planning and consent

After a diagnostic discussion and explanation of the risks and benefits of the proposed therapy, the patient signed the Informed Consent Form for experimental treatment with superpulsed laser therapy associated with a low intensity PEMF, as described in this article.

4.4. Treatment

The treatment protocol combined magnetotherapy and superpulsed laser therapy, using specific parameters to promote tissue regeneration and analgesia. Magnetotherapy was performed with a device equipped with a 30 cm diameter solenoid, applying two distinct protocols. The trophic improvement protocol used a PEMF of 58 Gauss, lasting 30 minutes, while the circulation improvement protocol applied a pulsed magnetic field of 70 Gauss for the same period. Superpulsed laser therapy was applied with Multiradiance Medical's Shower laser, an equipment with multiple wavelengths (470 nm, 660 nm, 875 nm and 905 nm), totaling 70 Joules per session, applied in an area of approximately 30 cm², focusing on infection treatment, bio stimulation, analgesia and tissue regeneration. The sessions were held twice a week for four weeks, totaling eight sessions throughout the protocol **(Figure 4)**.

Figure 4: Application of superpulsed multiradiant laser therapy on diabetic foot.

Over the four weeks of treatment, a progressive reduction in purulent secretion was observed, indicating improvement in the infectious condition. The patient presented greater stability and comfort when walking, demonstrating an improvement in gait pattern. In addition, pain was significantly reduced, with an EVA scale reaching level 1 at the end of treatment, showing substantial symptom relief. Tissue regeneration was visible both clinically and through control radiography, which revealed signs of bone neoformation in the areas previously affected by osteomyelitis. The patient expressed great satisfaction with the treatment, reporting a positive functional and emotional feedback, reinforcing the effectiveness of the therapeutic approach adopted **(Figure 5)**.

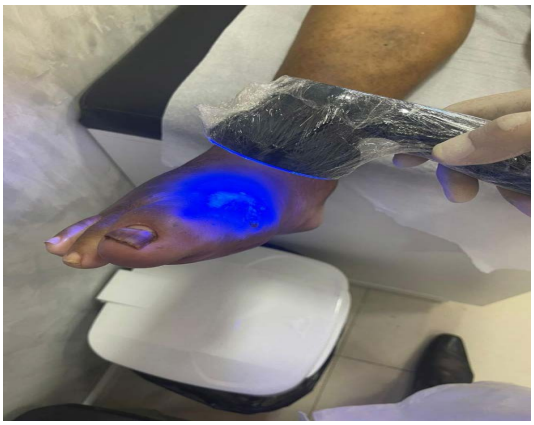

Figure 5: Application of blue light laser therapy in the therapeutic protocol proposed in this article.

4.5. Evolution

To monitor the efficacy of the treatment, evaluation criteria

based on serial photographic documentation of the lesions were used, allowing the analysis of the clinical evolution throughout the sessions **(Figure 6)**. The X-ray of the affected foot.

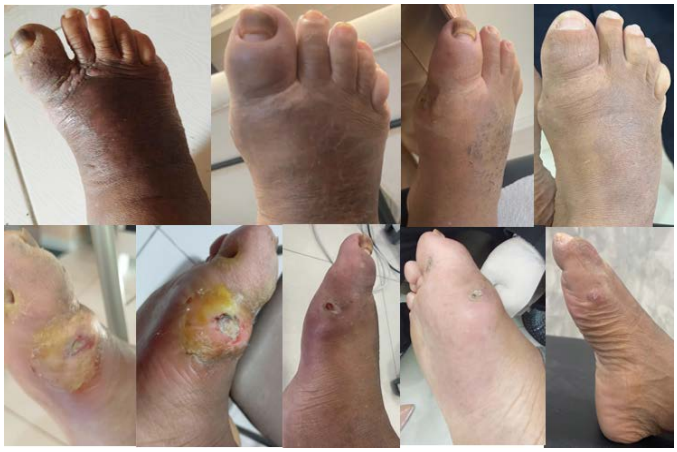

Figure 6: Photographic evolution of the lesion.

Before and after the treatment made it possible to verify signs of bone regeneration. In addition, neurological clinical tests were conducted to assess the sensitivity of the lower limbs. The VAS scale was used to measure the analgesic impact of the treatment, while a patient satisfaction questionnaire recorded the patient's qualitative perception of the therapeutic experience and perceived benefits.

5. Results

Diabetic neuropathy is one of the main complications of diabetes mellitus, affecting up to 50% of patients and contributing significantly to ulcer formation and risk of amputations[11-13]. Its pathophysiology involves glucotoxicity, oxidative stress, chronic inflammation and peripheral ischemia[12-15].

During the follow-up of the case, a progressive reduction in purulent secretion and healing of the ulcers were observed. Post-treatment radiographic examination showed partial bone regeneration of the first metatarsal. There was a significant reduction in pain (VAS from 8 to 1), improvement in gait and functional reestablishment of the foot. The patient reported an overall improvement in quality of life **(Figure 7)**.

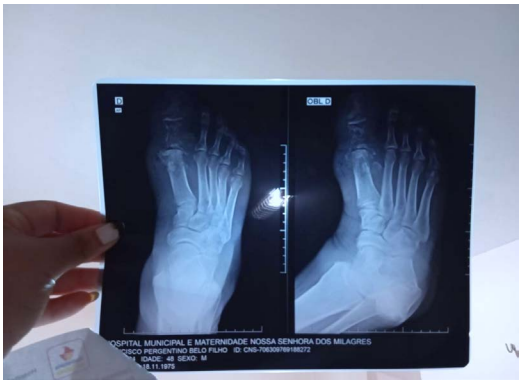

Figure 7: Radiographic aspect after treatment demonstrating bone regeneration of the hallux and first metatarsal.

This evolutionary pattern proved in clinical practice the theoretical assumptions raised in the methodology of the present study, demonstrating that the association of regenerative technologies was not only able to reverse the tissue damage caused by the association between the microvascular lesion of DM and the tissue damage resulting from the infection, but was also able to improve the symptoms. the sensitivity and appearance of the whole treated limb. Such evolution confirms the pathophysiological basis and the impact of regenerative technologies in the treatment of diabetic foot **(Figure 8)**.

Figure 8: Association between neuropathy and vasculopathy generated by chronic inflammation, oxidative stress and glucotoxicity involved in the etiopathogenesis of diabetic foot. In this approach, trophic improvement was observed throughout the therapeutic protocol, with a reduction in edema, improvement in the appearance and color of the skin and nails.

6. Discussion

As medicine advances, technologies such as superpulsed laser therapy have emerged as an effective option for promoting healing and fighting infections in patients with a range of conditions. This therapy uses laser beams with specific properties to interact with biological tissues, resulting in numerous therapeutic benefits[30,37,39,40].

The association between superpulsed laser, PEMF and blue light therapy has demonstrated a robust synergistic effect in promoting neovascularization, tissue regeneration, inflammatory modulation and antimicrobial action, as supported by previous evidence on the isolated use of low-level therapy (LLLT) and magnetotherapy[50]. Specifically, studies indicate that LLLT alone can reduce the area of diabetic ulcers by up to 40% when compared to conventional treatments - a result that underscores its clinical impact[51]. The combination of therapies investigated in this study emerges as an innovative, safe and effective approach in the management of advanced complications of the diabetic foot, providing a viable alternative to invasive surgical interventions.

In the context of photobiomodulation, the superpulsed laser acts in a multifactorial way on healing: it stimulates the mitochondrial production of ATP through the excitation of cytochrome C oxidase - a crucial chromophore in the Krebs cycle - intensifying cell metabolism and favoring tissue proliferation.

In addition, it promotes collagen synthesis and stimulates neovascularization, which, together, increases the supply of oxygen and nutrients to the injured areas. Its anti-inflammatory effects are equally relevant, since chronic inflammation, typical of the pathological environment of diabetic foot, can compromise regenerative processes and taking the progression of lesions[6,31-34].

The therapeutic application of PEMF - or magnetotherapy - complements the effects of photobiomodulation. The interaction between magnetic fields and biological tissues is based on the vector density of magnetic flux, which modulates cellular responses by altering membrane potential and ion channel activity. Biological tissues with different dielectric and conductive properties respond differently to electromagnetic exposure, which influences the spatial and temporal distribution of the therapeutic response **(Figure 9)**. These fields can stimulate the activation of calcium channels, regulating intracellular signaling and promoting the expression of growth factors involved in regeneration. Studies have also shown that this modality can restore the polarization of cell membranes affected by inflammation and oxidative stress, reducing apoptosis and optimizing cell function[38-43].

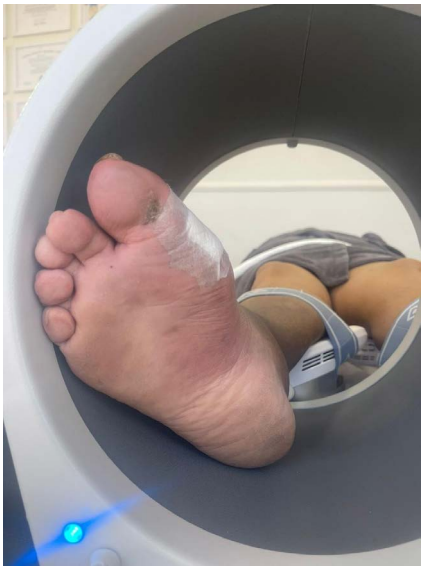

Figure 9: Application of the PEMF in the affected foot.

The biophysical effects of magnetotherapy vary with the frequency and intensity of the pulses applied. Low-frequency fields are associated with improved blood perfusion and tissue oxygenation-critical factors in ulcer healing in diabetic patients. High-frequency drugs, on the other hand, stimulate anti-inflammatory pathways and cell proliferation, supporting regeneration. These interactions with polarizable structures, such as lipids and cell membrane proteins, modulate several molecular signaling pathways, resulting in an environment conducive to sustained healing[40,41-47,52-54].

Blue light therapy, in turn, represents a recent technological advance with immense potential in infection control. With a wavelength between 405 and 470 nm, it interacts with porphyrins present in bacteria, promoting the generation of reactive oxygen species (ROS). These free radicals induce structural damage to cell membranes and bacterial DNA, leading to the death of the microorganism - including in multidrug-resistant strains such as methicillin-resistant Staphylococcus aureus (MRSA). This characteristic is particularly relevant in the current scenario of antimicrobial resistance, offering an effective alternative to conventional antibiotic therapy[35-37].

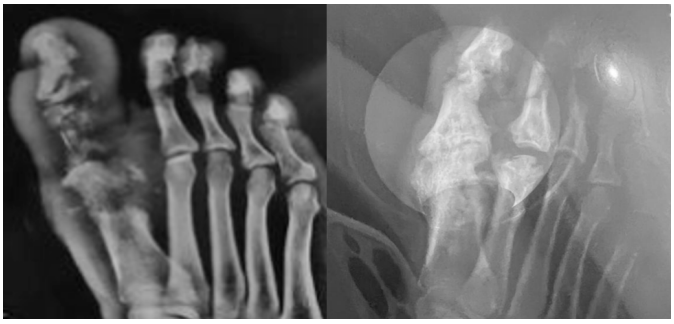

Figure 10: Radiographic evolution showing bone regeneration.

Although blue light has low tissue penetration (approximately 1 mm), its efficacy in superficial infections, such as those seen in diabetic ulcers oral cavity, dermatitis and wounds with dehiscence, is remarkable. Its localized use allows selective antimicrobial action, minimizing the impact on healthy tissues **(Figure 10)**. However, the risk of cytotoxicity in human cells with prolonged or inadequate exposure requires rigor in the definition of clinical protocols. Overexposure can induce oxidative stress and compromise the healing process, which is why the dose, application time and wavelength should be carefully established, in accordance with best clinical practices[35].

The integration of blue light with traditional photobiomodulation, such as red or near-infrared light, further amplifies the therapeutic effects. While blue light acts as the first line of defense in surface antimicrobial control, red light penetrates deeper levels, activating pathways that accelerate tissue repair and remodeling. This combination has especially promising application in surgical settings, such as orthopedic or abdominal wounds, where superficial infection control is critical for postoperative success[35].

Photobiomodulation promotes tissue repair, increased mitochondrial ATP production, collagen stimulation and neovascularization[6,17,29-31]. PEMF, on the other hand, contributes to reducing inflammation, stimulating mesenchymal stem cells and increasing the expression of tissue growth factors.

The convergence between optical and electromagnetic technologies thus represents an emerging frontier in the treatment of complex lesions, such as diabetic foot. This multimodal approach enhances the therapeutic effects by combining mitochondrial repair, infection control and cell regeneration, composing an outpatient, painless, lower cost and high safety treatment.

Previous studies have evaluated these modalities in isolation. However, the combination of these therapies can generate a synergistic effect, enhancing their regenerative benefits. In a context of high prevalence and significant socioeconomic impact of diabetes complications, these integrated modalities offer a less invasive and more affordable alternative to conventional surgical interventions, contributing to the prevention of amputations and improving the quality of life of patients.

7. Conclusion

The combination of superpulsed laser therapy and blue light therapy offers a powerful synergistic approach in diabetic foot treatment, providing complementary benefits that can maximize healing and reduce complications.

The two therapies, when used together, can optimize healing by simultaneously addressing the inflammatory and infectious challenges that often affect diabetic patients. The reduction of inflammation caused by the association of the PEMF with laser can facilitate the action of blue light, which acts against pathogens, minimizing the risk of infectious complications that could compromise the integrity of the tissue and delay healing. This synergy not only accelerates regenerative processes, but also enhances the effectiveness of treatment, offering an integrated and effective care plan.

Therefore, this multimodal approach can represent a significant advance in the management of diabetic foot, contributing to the reduction of morbidity and improving the quality of life of patients. The continuity of research in this area will be essential to optimize clinical protocols and enhance this therapeutic synergy.

The association between superpulsed laser therapy and low-intensity PEMF has potential as an adjuvant treatment in the management of infected ulcers and osteomyelitis in patients with diabetic foot, with advantages such as: antimicrobial effect and inducer of tissue regeneration; stimulation of neovascularization (Lievens effect); osteoblast activation and bone regeneration; reduction of oxidative stress. All this in an outpatient treatment and low cost compared to amputation.

Randomized clinical trials with larger sample sizes, longitudinal follow-up and control groups are recommended for statistical validation and consolidation of the method as a gold standard in the treatment of infected diabetic foot.

8. References

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