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Review Paper: A Review on Vibration Therapy, Compression Garments and Spinal Cord Stimulation as Interventions for Phantom Limb Pain

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Abstract: ***Phantom limb pain (PLP) remains to be among the most severe complications of limb amputation, with conventional medications and surgical procedures typically providing temporary or intermittent relief. This study explores non-pharmacological and non-surgical therapies that target the neurological and psychosocial factors that characterize PLP. The effectiveness, accessibility, and patient results of different approaches are reviewed, including vibration therapy, compression clothing, and sensory discrimination training. Study demonstrates that these approaches not only ameliorate pain perception but also boost functional rehabilitation by addressing cortical reorganization, maladaptive sensory feedback and positively responding to neuroplasticity. While no singular intervention has proven universally successful, integrating multiple methods often promotes long-term pain management. A comparative analysis of non-invasive methods with conventional medical treatments highlights both their potential and current limitations. This review evaluates the value of non-drug, non-surgical strategies as promising, patient-centered approaches in treating PLP and underscores the need for more meticulously designed standardized trials to strengthen clinical guidelines.***

Keywords: Amputation, Compression Garments, Phantom Limb Pain, Prosthetic Liners, Sensory Discrimination Training, Vibration Therapy

1.Introduction

The Phantom Limb Pain (PLP) is a neuropathic pain syndrome in which a person experiences distress and somatic disturbance post a Limb amputation. In spite of the physical absence of the limb, the patient continues to experience extreme discomfort as the brain perceives the pain to emanate from the missing limb. In the United States 30,000 to 40,000 amputations are conducted each year, out of which 79.9% of the patients declare to experience the PLP.[1]

An individual experiencing PLP encompasses a spectrum of sensory unease such as burning, stabbing, throbbing, cramping, tingling, and paresthesia[2.] These symptoms may give rise to mild or chronic pain, with duration ranging from transient episodes to long term persistent experiences, depending on factors such as the person's age, gender, and the extent of the amputation. Nonetheless it is important to note that these sensations often result due to the activation of special neural activities, however the exact origin of this pain is unknown therefore until now only theories have been projected to understand this phenomenon.[3]

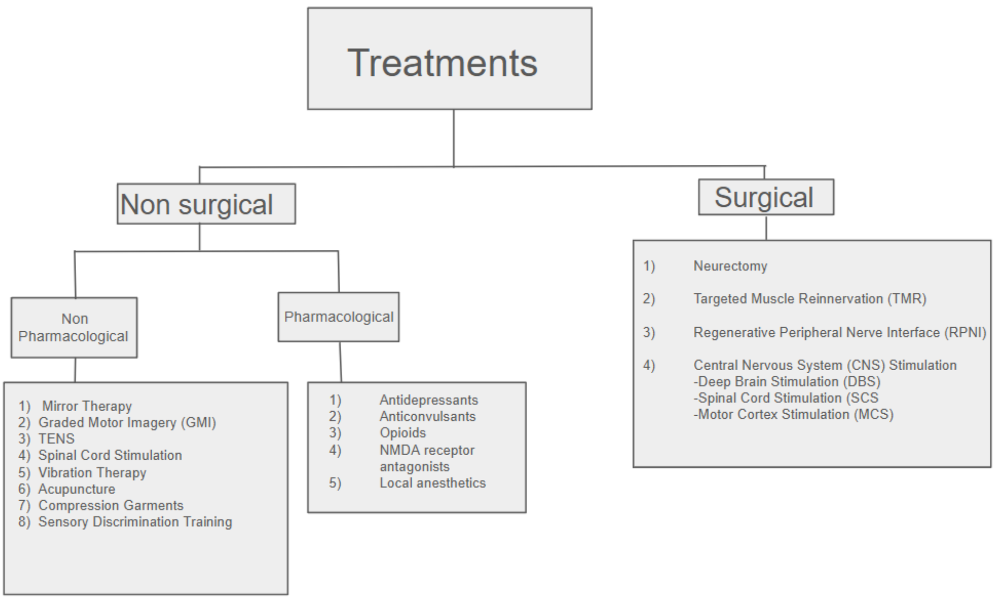

Figure 1.1

The preceding table fig 1.1 outlines different treatment approaches that have been employed for the management of PLP, categorized into pharmacological and non-pharmacological approaches. This report explicitly focuses on non-pharmacological interventions, particularly those that are less extensively practiced and relatively recent in clinical investigation.

Well renowned interventions such as Mirror Therapy, Graded Motor Imagery (GMI), Transcutaneous Electrical Nerve Stimulation (TENS), Spinal Cord Stimulation, and Acupuncture have been extensively studied and implemented in clinical environments. Due to their prevalence in existing literature and mainstream usage, this report will refrain from examining them in depth.

Instead, the priority will be on less popular and emerging interventions such as:

- Vibration Therapy
- Compression Garments
- Sensory Discrimination Training (SDT)

These methods, although can be promising, remain underrepresented in wide-ranging trials and clinical guidelines. The aim of this paper is to crucially assess the available evidence for their effectiveness in treating PLP, thus contributing to a more meticulous understanding of alternative therapeutics.

Vibration Therapy

Vibration Therapy, a treatment option that maneuvers based on the gate control theory of pain (painless sensory input can "close a gate" in the spinal cord, avoiding or reducing movement of pain signals to the brain.) Vibrating devices or special prosthetic liners with embedded motors are directly vibrated onto the residual limb.

According to a study conducted in 2021, 12 amputees were subjected to a test where they were provided with a vibrating liner for stimulation for 10 minutes 3 times a day. After 30 days of treatment the subjects were asked to report their pain using the Visual Analogue Scale (VAS). Patients initially reported an average pain score of 8/10 on the VAS. After 30 days of vibrational therapy using the silicone liner, the score significantly reduced to 2/10, indicating a 75% decrease in PLP. While these results highlight the potential efficacy of vibrational therapy in order to treat PLP, the small sample size of 12 participants limits the generalizability of the findings to the broader population. Additionally, since the patient knew they were using a vibrating device, psychological effects could influence pain score leading to bias. To avoid this a double-blind study could ameliorate and strengthen this case. This has been effective for patients such who have undergone unilateral below-knee amputation [4].

An early clinical trial by Lundeberg (1985) assessed the effects of peripheral vibratory stimulation on PLP in 24 patients. The study involved either providing vibrational therapy or a placebo (non-contact vibration) to treat the PLP. The pain intensity was measured using a 0–10 Numerical Rating Scale (NRS). Post the treatment patients reported an average pain reduction of 75% using vibrational therapy, while only 44% using the placebo. With the help of vibrational therapy 10 patients experienced more than a 50% decrease in pain, with 7 reporting complete relief (NRS score reduced from a mean of 8/10 to 0). Furthermore, the duration of relief exceeded 3 hours in most cases and lasted over 6 hours in some. And since a comparison has been done using a controlled group (patients using placebo), it is easy to isolate the effects of vibrational therapy and determine its effectiveness. This allows for more reliable conclusions about causality and reduces the impact of potential biases. Nonetheless the study also possesses several limitations, such as lack of long term follow up data, a small sample size, limiting the findings to a wider population, and technological restrictions as the study was conducted in 1985 it may not reflect the precision of current vibrational therapy devices. This approach has proven beneficial however the degree of amputation remains unknown.[5]

A 2024 pilot study published in *Sensors* investigated the use of vibration therapy to reduce PLP in amputees using a novel prosthetic liner embedded with vibratory actuators onto the amputated limb. The study involved 2 transfemoral amputees, each with over ten years of prosthesis use. Over a 4-week period, participants wore the vibration-enabled liners and self-administered Vibrational Therapy during events of phantom pain. Pain intensity was measured using self-reported pain ratings before and after each episode. Both participants experienced a significant decrease in PLP after using vibrational therapy. One patient reported notable ease in both the residual and phantom limb, while the other described amplified non-painful phantom sensations. The embedded device was accepted with positive feedback on comfort and ease of integration into daily use. Although the paper was published recently and does employ modern technical methods to treat PLP it is important to point out certain limitations such as the extremely small sample size and lack of specification on the standardized pain scale used to measure improvement. Nevertheless, the authors have concluded on the need for ongoing research, further design refinements, expanded clinical trials and finding the optimal vibration frequencies to eliminate maximum pain relief. This method has reliably alleviated the pain for transfemoral (above-knee) amputees.[6]

Compression Garments

Compression garments are professional elastic sleeves or stockings meticulously designed to apply controlled pressure on the residual limb of amputees. These garments are commonly used to manage swelling, boost circulation, and enhance proprioceptive feedback. Until today only two randomized controlled trials have taken place using compression stockings to ameliorate the PLP. While orthodox compression garments have not been directly studied in randomized trials for PLP, a related treatment involving prosthetic liners with gentle compressive properties has shown impressive results.

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In a randomized, double-blind, crossover trial conducted in 2006, 22 amputees used a prosthetic liner interlaced with metal threads (called Medipro Liner Relax). It was created to provide electromagnetic shielding, testing its prevalence on treating PLP. Each participant wore the active liner and a placebo liner (identical in appearance but without metal weave) for two weeks. Pain was measured using a Numerical Rating Scale (NRS) from 0–10. The results showed a significant reduction in PLP during the active liner phase, with average pain scores dropping from 5.1 to 3.2. Though compression was not the primary mechanism evaluated, this study highlights how garments that combine mild compression with additional sensory inputs may contribute to PLP relief. The study demonstrates minimal bias, however lacks technological advancements and fails to address the usage of only compression garments to treat PLP. This approach has been successful in managing the pain for lower limb (leg) amputees.[7]

In another randomized, double-blind, placebo-controlled crossover trial conducted in 2016, studied **20 transtibial amputees** reporting chronic PLP. Patients wore a silicone liner interwoven with metal fibers using **Umbrella® technology** for two weeks and an optically identical placebo liner for another two weeks. Pain was measured using a 0–10 Numeric Rating Scale and out of the 20 patients, 14 completed the trial. Results indicated an average of pain reduction from 5.6 to 3.9 while using the silicone liner with the metal fibers. (also known as the active liner). Additionally, the study suggests no significant improvement was observed with the placebo liner (liner without metal fibers). The active liner also led to better well-being scores. Although light compression was present, the observed effects were attributed primarily to electromagnetic shielding rather than compression alone. The study is conducted with utmost accuracy and provides a positive result in treatment of PLP, however due to lack of long-term data and small sample size the veracity of the study is questionable.[8]

Until now no clinical trials have been conducted precisely to assess the effectiveness of compression garments alone in the intervention of PLP. Current studies often involve combined treatments or alternative mechanisms like electromagnetic shielding, making it arduous to conclude on the effects of compression itself. This highlights a crucial gap in present research. Therefore, there is a major need for leading edge clinical trials that focus extensively on compression therapy to better understand its potential in managing and treating PLP.

Spinal Cord Stimulation

Spinal Cord Stimulation (SCS) is known to be a promising mediate to treating PLP. It works similarly to TENS by sending electrical impulses to alter or conceal pain signals before they reach the brain. However instead of using electrodes a small device is implanted under the skin (usually at the abdomen or the gluteal region) and electrical signals are delivered directly to the spinal cord in order to relieve the pain [9].This minimally invasive surgical treatment involves a two stage process, first using a temporary graft in order to ensure the pain is alleviated, once this trial is successful a permanent implantation is carried out [10]. The exact mechanism isn't fully understood, but it's thought to involve influencing the neurochemistry of the spinal cord and activating inhibitory pathways[11].

According to a study conducted in 2016, 3 patients complaining of PLP and limb ischemia were treated with epidural spinal cord stimulation (SCS), with leads situated at the thoracic level. The procedure was conducted under fluoroscopic guidance and the pain levels were measured using the Visual Analog Scale (VAS), and all three patients reported a significant decrease in pain from initial scores of 7–8/10 to 2–3/10 post the treatment. The study explores strong evidence for the potential use of SCS in managing PLP, especially in patients with simultaneous vascular conditions. Nonetheless, due to the small sample size and absence of a control group, the findings are restricted in their broader applicability. Overall, while the results are promising, further large-scale clinical trials are a must to establish the effectiveness of SCS for PLP treatment [12]. This intervention has demonstrated efficacy in treating lower limb amputees.

According to a study in published in 2025, A patient suffering with spinal cord injury and PLP had undergone an implantation of a 10 kHz spinal cord stimulator. Over half a year, the patient reported complete relief from pain, better sleep, mood, and discontinued opioid use. Pain was measured qualitatively through patient-reported outcomes. Nonetheless, the report is valid for highlighting high-frequency SCS as a possible treatment as the report also mentions the reduction in pain over a 6 month follow up period, however, due to its single-patient design and qualitative responses, the findings are not generalizable, hence further research is needed to confirm its effectiveness. Nonetheless This therapy has brought measurable benefits to the patient suffering from complete spinal cord injury at the thoracic level and complained of PLP in the lower limb[13].

Another case report published in 2023 employed 3 individuals with transtibial amputations to explore the case of transcutaneous spinal cord stimulation (tSCS) on treating PLP. The report showed insight that after using the intervention for 5 consecutive days the pain was assessed using the McGill Pain Questionnaire (MPQ), Visual Analog Scale (VAS), and pain pressure threshold (PPT) testing. On average, MPQ scores lowered marginally from 34 ± 7 to 18 ± 7, and VAS scores decreased by 1.8 to 3.5 points, depending on the individual. Although the results suggested that tSCS may offer clinically relevant pain relief and regularity in the spinal circuit, the small sample size, short duration of treatment, and lack of a control group limit the strength and relevance to the wider population. Nonetheless, this study highlights the potential of non-invasive spinal cord stimulation as a promising intervention for PLP and supports the need for larger, controlled trials. This treatment consistently delivers favorable results for unilateral, below-knee (transtibial) amputees[14].

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Evaluation

On the basis of the evidence examined, each of the three primary interventions reviewed in this paper - vibration therapy, compression garments and spinal cord stimulation, each portray distinct advantages for specific amputee populations. Vibration therapy alone, particularly through prosthetic liners, has generated notable improvements in transfemoral and transtibial amputees, improving both pain scores and comfort levels. Compression garments, as researched in lower-limb amputees, have showcased a considerable decline in PLP, emphasizing strong potential for this group. And SCS has persistently demonstrated significant relief in chronic, therapy-resistant PLP among lower-limb amputees, making it the most robustly substantiated approach in the present literature.

However, the validity of these results is restricted due to the limited availability of rigorous empirical evidence. As a result of scant clinical trials for each modality, and having most of them focused on a single amputation type, it remains ambiguous whether these interventions may prove to be equally, or perhaps more, effective for other degrees of amputations. Moreover, combining these treatment options with other PLP interventions have produced variable outcomes, for instance in some cases combinations have enhanced pain relief, according to a report published in April 2024 by the American Society of Interventional Pain Physicians, a 63-year-old with a thigh amputation was treated with compression garments (liner prosthesis) along with pregabalin and duloxetine (pharmacological drugs). Although the reduction in pain was not numerically recorded the patient did report a great withdrawal in pain over the course of the treatment[15]. While on the other hand in some cases the benefits have been comparatively attenuated relative to its use in isolation. For instance, a study conducted 2024 mentioned usage of mirror therapy along with high doses of analgesics and an epidural stimulator on a 26-year-old woman suffering from PLP after an amputation on the proximal third of the leg. The report suggested despite combining multiple interventions there was no progression on the pain intensity. The report further suggests post 35 sessions of CMR (Cognitive Multisensory Rehabilitation) the patient was successfully able to notice great reduction in pain which further alleviated their lifestyle significantly improving their recovery journey[16].

2.Conclusion

It is therefore extremely vital that future research progresses towards well structured, precisely powered clinical trials that examine these interventions both individually and in combination across varied amputation types. Persistent, credible evidence will allow clinicians to prescribe treatments with utmost accuracy, aligning the choice of therapy to the exact degree and site of amputation. Only through such systematic trials can PLP management progress from inconsistent, mixed outcomes to a standard of care that is grounded scientifically and optimally tailored to maximise amputees' recovery and quality of life.

Conflict of interest: This paper does not involve any conflict of interest.

References

[1] Hanyu-Deutmeyer AA, Cascella M, Varacallo M. Phantom limb pain. InStatPearls [Internet] 2023 Aug 4. StatPearls Publishing.
[2] Sherman RA. Phantom pain. Springer Science & Business Media; 2013 Mar 14.
[3] Curatolo M. Central sensitization and pain: pathophysiologic and clinical insights. Current neuropharmacology. 2024;22(1):15-22.
[4] Farahmand B, Turkeman O, Saghafi M, Yazdani M, Cham MB. Phantom pain decreases with vibrating silicone liner in lower limb amputees: a prospective study. Current Orthopaedic Practice. 2021 Mar 1;32(2):181-6.
[5] Lundeberg T. Relief of pain from a phantom limb by peripheral stimulation. Journal of neurology. 1985 May;232(2):79-82.
[6] Roehrich K, Goldberg M, Fiedler G. Robotic-Enhanced Prosthetic Liners for Vibration Therapy: Reducing Phantom Limb Pain in Transfemoral Amputees. Sensors. 2024 Aug 3;24(15):5026.
[7] Flor H, Elbert T, Knecht S, Wienbruch C, Pantev C, Birbaumers N, Larbig W, Taub E. Phantom-limb pain as a perceptual correlate of cortical reorganization following arm amputation. Nature. 1995 Jun 8;375(6531):482-4.
[8] Fisher K, Oliver S, Sedki I, Hanspal R. The effect of electromagnetic shielding on phantom limb pain: A placebo-controlled double-blind crossover trial. Prosthetics and Orthotics International. 2016 Jun;40(3):350-6.
[9] Hanyu-Deutmeyer AA, Cascella M, Varacallo M. Phantom limb pain. StatPearls.
[10] Pak DJ, Gruber J, Deer T, Provenzano D, Gulati A, Xu Y, Tangel V, Mehta N. Spinal cord stimulator education during pain fellowship: unmet training needs and factors that impact future practice. Regional Anesthesia & Pain Medicine. 2019 Mar 1;44(3):407-14.
[11] Guan Y. Spinal cord stimulation: neurophysiological and neurochemical mechanisms of action. Current pain and headache reports. 2012 Jun;16(3):217-25.
[12] De Caridi G, Massara M, Serra R, Risitano C, Giardina M, Acri IE, Volpe P, David A. Spinal cord stimulation therapy for the treatment of concomitant phantom limb pain and critical limb ischemia. Annals of Vascular Surgery. 2016 Apr 1; 32:131-e11.
[13] Park RJ, Boesel TW, Di Ieva A. High-frequency spinal cord stimulation in treatment of phantom lower limb pain following spinal cord injury: A case report. Pain practice: the official journal of World Institute of Pain. 2025 Jan;25(1): e13437.
[14] Nanivadekar AC, Bose R, Petersen BA, Okorokova EV, Sarma D, Madonna TJ, Barra B, Farooqui J, Dalrymple AN, Levy I, Helm ER. Restoration of sensory feedback from the foot and reduction of phantom limb pain via closed-loop spinal cord stimulation. Nature biomedical engineering. 2024 Aug;8(8):992-1003.

[15] Scott W. The psychosocial context of chronic pain in people living with HIV. Pain Reports. 2019 Mar 1;4(2): e721.
[16] Zernitz M, Rizzello C, Rigoni M, Van de Winckel A. Case Report: Phantom limb pain relief after cognitive multisensory rehabilitation. Frontiers in Pain Research. 2024 Apr 25; 5:1374141.