Review of Contemporary Philosophy
ISSN: 1841-5261, e-ISSN: 2471-089X
Vol 22 (1), 2023
Pp 3653 - 3671

Wound Healing: Main Role of Physical Therapy and Health Information System-An Updated Review

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Abstract:

Background: Wound healing (WH) presents significant challenges in healthcare, with both acute wounds (AWs) and chronic wounds (CWs) causing long-term impacts. AWs, such as burns or surgical trauma, often result in scarring, while CWs, frequently linked to systemic conditions like diabetes, malnutrition, and vascular abnormalities, pose a greater risk of morbidity. Among the most common CWs are diabetic foot ulcers (DFU), leg ulcers (LU), and pressure ulcers (PU). Despite treatment advancements, scarring remains a major concern. This review highlights the growing role of physical therapy (PT) and health information systems (HIS) in improving WH outcomes.

Aim: This review aims to explore the contribution of physical therapy techniques, such as laser therapy, electrical stimulation, and low-level laser therapy, in facilitating wound healing, particularly in chronic wound management. It also investigates the integration of health information systems in tracking and optimizing wound care interventions.

Methods: The review synthesized recent studies on PT modalities in wound care, examining their biological mechanisms and clinical efficacy. Additionally, it explored the application of HIS in wound management to improve documentation, communication, and treatment planning. The reviewed studies were selected based on their relevance to PT in WH and the integration of HIS in chronic wound care.

Results: PT modalities, including electrical stimulation, low-level laser therapy, and photodynamic therapy, were found to enhance the healing process by promoting cellular regeneration and reducing inflammation. The role of HIS in wound care was found to be essential in improving treatment consistency and patient outcomes by ensuring timely interventions, data accuracy, and seamless coordination among healthcare providers. Integration of HIS in wound management aids in real-time monitoring, leading to more personalized and efficient care.

Conclusion: Physical therapy plays a crucial role in improving the healing of both acute and chronic wounds, with evidence supporting its efficacy in promoting tissue regeneration and reducing scarring. Health information systems are instrumental in supporting the clinical decision-making process by providing comprehensive data and facilitating the management of complex wound care. Future studies should continue to focus on the integration of these therapies to further optimize healing outcomes.

Keywords: Wound Healing, Physical Therapy, Health Information Systems, Chronic Wounds, Laser Therapy, Electrical Stimulation, Scarring, Patient Outcomes

Received: 16 october 2023 **Revised:** 29 November 2023 **Accepted:** 13 December 2023

Introduction:

Wound healing (WH) remains a significant health challenge in contemporary society. Acute wounds (AWs) often result in scarring and disfiguring lesions, while chronic wounds (CWs) lead to substantial morbidity and impose high economic burdens. Typically, AWs occur due to surgery, trauma, or burns, whereas CWs are frequently linked to underlying systemic conditions, such as diabetes, aging, vascular abnormalities, or malnutrition. In clinical practice, comprehensive wound care guidelines serve as an essential reference, providing clear and structured approaches to wound management [1]. Among the most prevalent CWs encountered are leg ulcers (LU), diabetic foot ulcers (DFU), and pressure ulcers (PU). The primary treatment strategies for CWs include appropriate wound dressing, debridement, and pressure relief. Despite these interventions, a critical gap remains in effectively addressing scarring, as this outcome is often unavoidable, and CWs may persist for prolonged periods. This review aims to offer clinicians an updated, evidence-based guide on the fundamental aspects of WH, with a particular focus on the enhancement of physical therapies. Extensive research in the realm of WH is currently investigating advanced therapeutic modalities, such as cellular transplantation therapies [2,3], vascular enhancement agents [4], regenerative materials [5], and nanoparticles in hydrogels [6]. However, despite the promising nature of these innovative therapies, their clinical application remains distant. In contrast, physical therapy (PT) is a widely applied modality in clinical practice and has shown some utility in WH [7]. This review explores various PT techniques, including laser therapy, low-level laser light therapy, photodynamic therapy, and electrical stimulation, and examines their role in promoting effective wound healing.

General Approach to Wounds:

Epidemiology:

The failure of WH, dermal fibrosis, and scarring present significant challenges, as highlighted by existing literature on the subject. Scarring impacts individuals across all ethnicities, with keloids and hypertrophic scars (HS) being more prevalent in American, African, and Asian populations, affecting up to 16% of individuals in these groups [8]. Several factors contribute to excessive scarring, including genetic predispositions, hypertension, endocrine dysfunctions, autoimmune diseases, and hormonal imbalances [9]. Specifically, genetic factors related to polymorphisms in genes such as TGF-beta have been associated with fibrosis formation and represent potential therapeutic targets [10]. Additionally, endothelial dysfunction, particularly in individuals with hypertension, has been linked to an increased risk of scarring and other fibrotic diseases [11]. The type of injury also plays a crucial role in determining the extent and nature of scarring, as evidenced by clinical observations [12]. Scars are primarily categorized into two types: keloids and hypertrophic scars. Hypertrophic scars are typically confined to the boundaries of the original wound, characterized by an excess of cicatricial tissue, whereas keloids extend beyond the wound's edge, resulting in invasive scarring [12]. The interaction between the wound environment and keloids is multifaceted, with factors such as diet, smoking, stress, and physical exercise influencing the scarring process [11]. The failure to properly heal a wound, resulting in a chronic wound (CW), also significantly impacts the patient's quality of life. A CW is defined as a wound that does not adequately repair within three months [13]. Epidemiological estimates suggest that approximately 1–2% of the population is affected by CWs, with more than 6.5 million individuals in the United States alone suffering from these conditions [14,15].

Process and Stages of Wound Healing:

Wound healing is an intricate biological process involving a series of biological pathways and mechanisms. It is traditionally divided into distinct phases: hemostasis/inflammatory, proliferation, and remodeling [2,16].

Hemostasis/Inflammatory Stage:

The immediate response to injury involves the constriction of blood vessels and the activation of platelets to form a fibrin clot, thereby preventing further blood loss [3]. Platelets are activated upon exposure to collagen within the subendothelial matrix, initiating primary hemostasis. Subsequently,

secondary hemostasis is initiated through the activation of the coagulation cascade [17]. Within minutes, local mast cell degranulation occurs, releasing mediators such as histamine and tumor necrosis factor-alpha (TNF-α) [18]. The first immune cells to infiltrate the wound site are neutrophils, which are typically absent from uninjured skin. Neutrophils represent an essential component of innate immunity and are recruited to the site of injury through the action of interleukin-1 (IL-1), TNF-α, and bacterial toxins [19,20]. Once activated, neutrophils eliminate bacteria and cellular debris, while generating reactive oxygen species (ROS), antimicrobial peptides, and proteolytic enzymes that facilitate a conducive environment for WH. Neutrophil clearance occurs through apoptosis or necrosis, followed by phagocytosis by macrophages. The completion of hemostasis and the inflammatory phase typically spans a period of 72 hours [2].

Proliferation:

During the proliferation phase, the fibrin clot is gradually replaced by connective or granulation tissue, accompanied by processes such as neovascularization, re-epithelialization, and immunomodulation. This phase is mediated by a variety of cytokines and growth factors, including members of the transforming growth factor-beta (TGF-β) family and vascular endothelial growth factors (VEGF) [2,16]. These mediators are integral to the mechanism of action of physical therapies employed in WH, thus warranting focus in therapeutic strategies. The proliferation phase typically lasts between 3 and 21 days [21].

Maturation/Remodeling:

The final phase of WH involves the gradual replacement of the cells within the initial fibrin clot, resulting in wound contraction. This phase is closely associated with the maturation of type I collagen and the removal of type III immature collagen, with the process being regulated by metalloproteases (MMPs) and collagenases, which are secreted by macrophages, myofibroblasts, and keratinocytes [3,16]. The remodeling phase can extend from 3 weeks to 6 months, during which time the wound continues to strengthen and mature [21].

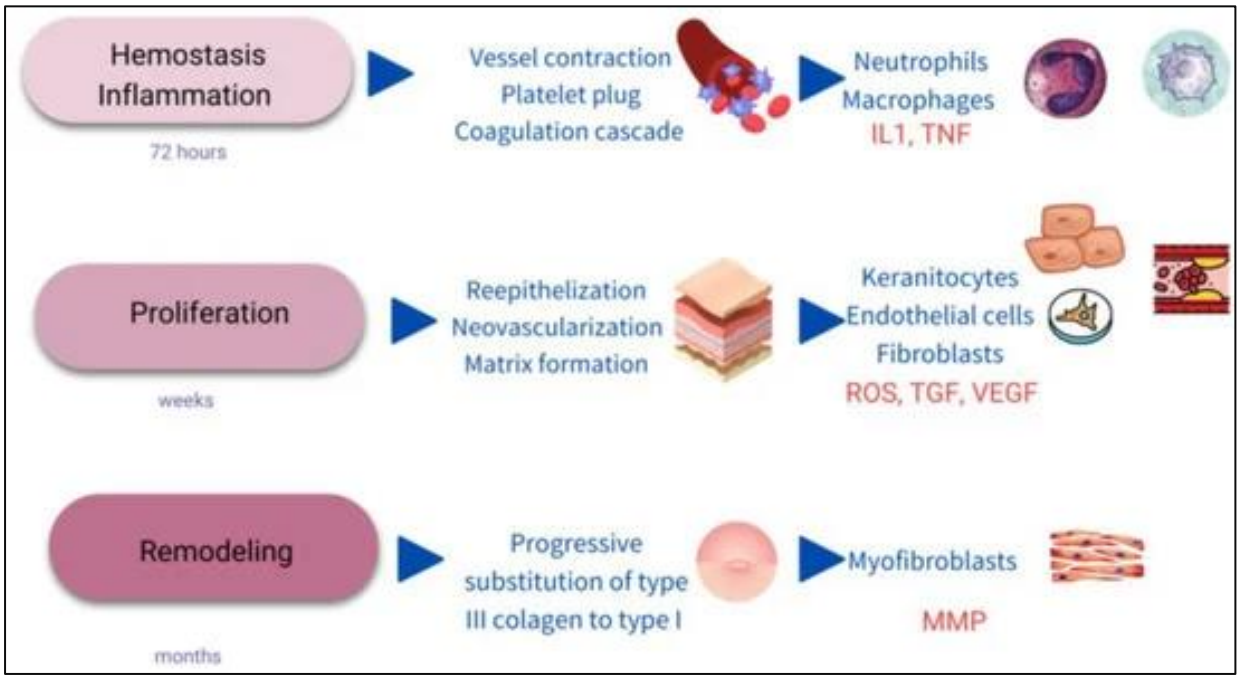

Figure 1: Wound Healing Stages.

Chronic Wounds

A chronic wound (CW) is defined as a wound that fails to repair itself or remains unhealed for a period exceeding 12 weeks [1]. The majority of chronic wounds are categorized as diabetic ulcers (DU), pressure ulcers (PU), or venous leg ulcers (VU), based on their clinical characteristics and etiology.

Diabetic Ulcer

Diabetic ulcers (DU) represent a serious complication of diabetes mellitus and are the leading cause of lower limb amputations [23]. These ulcers typically occur on the foot and result from neuropathy and vascular pathology, both of which impair the ability to perceive pain or injury. Generally, DU are deep and crater-like, often exposing underlying tendons and bones, with a surrounding hyperkeratotic tissue forming a callus-like ring. Imaging tests, such as radiography, may be employed to rule out the presence of osteomyelitis [1,13].

Pressure Ulcer

Pressure ulcers (PU) develop in areas subjected to sustained pressure, typically over bony prominences such as the sacrum or heels. The pressure impairs blood flow, leading to ischemia and subsequent dermatitis. If this pressure persists, it results in tissue necrosis. The causes of PUs are multifactorial, including prolonged immobility, nutritional deficiencies, systemic diseases, and advanced age [1]. These ulcers are classified into four stages, with Stage IV being the most severe, characterized by full-thickness skin loss. In such cases, surgical intervention is often necessary, and physical therapy plays a minimal role.

Venous Ulcer

Venous ulcers (VU) are predominantly found on the lower limbs, particularly in the area above the medial malleolus. Risk factors for VU include obesity and venous insufficiency. VU account for approximately 75% of all chronic ulcers, making them the most prevalent type, affecting 1–5% of the general population [24]. Clinical examination typically reveals signs of venous dysfunction such as edema, hemosiderosis, skin atrophy, lipodermatosclerosis, and the absence of appendages. Duplex ultrasonography may be used to confirm the diagnosis when necessary. The treatment of VUs involves general chronic wound management practices, supplemented by compressive therapy and, when feasible, correction of the venous insufficiency through surgical means [13,25]. Adjunctive therapies include dietary adjustments, nutritional supplementation, physical exercise, and pharmacological interventions aimed at improving circulation, such as pentoxifylline. Despite appropriate treatment, VUs may take between 6 to 12 months to heal, with a high incidence of recurrence in the following year [13,24,25].

General Management of Chronic Wounds

The management of chronic wounds and the associated scarring process is complex, influenced by multiple interacting factors. Some of these factors, such as age, vascular abnormalities, comorbidities, malnutrition, and smoking, are beyond the control of healthcare providers [1]. Consequently, wound management remains challenging, necessitating multiple interventions and ongoing visits, with the involvement of various healthcare professionals [1], thus contributing to significant indirect costs. The treatment of all chronic wounds follows the TIME principles: Tissue debridement, Infection control, Moisture balance, and Edge management [13]. Debridement, which should be performed weekly, is the cornerstone of CW treatment and has been shown to accelerate healing by more than 72% [26]. Biofilm, present in the extracellular matrix, is a significant contributor to the persistence of infections in CW, being implicated in 80% of these cases [27]. Biofilm is not visible to the naked eye, and a variety of techniques are under investigation to detect its presence beyond skin biopsy. Despite the challenges in detecting biofilm, it must be eradicated, as it perpetuates the inflammatory phase of wound healing [28]. Infection is typically controlled with topical antibiotics, silver dressings, or other topical agents. In addition, proper wound management requires maintaining an optimal environment. The wound should not be exposed to air, and if the surrounding skin is dry, a moisturizer should be applied to the dressing. In contrast, if excessive drainage is present, the wound should be cleaned and dried. Should the wound edges exhibit hyperproliferation, excision is necessary to facilitate epithelization [29].

Cellular Mechanisms in Chronic Wounds

Chronic wounds are characterized by several alterations in the local cellular response. These include excessive inflammation, diminished secretion of growth factors, an imbalance in proteolytic enzymes, and cellular senescence, all of which contribute to the persistence of the unhealed wound [25]. Consequently, chronic wounds are populated with an increased number of mast cells, neutrophils, and dendritic cells, accompanied by elevated levels of pro-inflammatory cytokines and proteases. These inflammatory cells not only prolong the wound healing process but also heighten the risk of infection [22]. Furthermore, the expression and activation of matrix metalloproteinases (MMPs) are altered, which exacerbates damage to the granulation tissue and contributes to the production of wound exudates [30]. The cells involved in remodeling and re-epithelialization are also dysfunctional. Fibroblasts, for example, become senescent, and the excessive activity of wound-associated proteases (MMPs, elastase, cathepsin G, and urokinase-type plasminogen activator (uPA)) leads to the degradation of the extracellular matrix, growth factors (e.g., VEGF, TGF-beta), and cytokines (e.g., TNF-alpha) [22]. In addition, keratinocytes at the wound edge become hyperproliferative, resulting in hyperkeratosis, which hinders wound closure. Microbiome profiles of elderly and diabetic patients with chronic wounds exhibit reduced alpha-diversity, further complicating healing [3,20,30].

Wound Cellular Mechanisms Mediators

- **Inflammation, Exudates, Infection**: These processes are characterized by an excessive number and dysfunction of neutrophils, defective macrophage activity, and a high number of mast cells. There is also a loss of microbiome diversity. Key mediators include oxidative stress and wound proteases such as MMPs, elastase, cathepsin G, and urokinase-type plasminogen activator (uPA), along with an increase in inflammatory cytokines.
- **Hyperkeratotic edge of the wound**: Keratinocyte hyperproliferation and malfunction are driven by elevated levels of b-catenin and c-myc, which contribute to the failure of wound closure.
- **Failure to heal and close**: Senescent fibroblasts lead to the degradation of essential growth factors such as VEGF, TGF-beta, and TNF-alpha, impairing the wound healing process and perpetuating the chronic state.

General Prevention of Scarring

Excessive wound healing (WH) or scarring results from the overproduction of extracellular matrix, which is primarily generated by myofibroblasts. In this context, myofibroblasts are not replaced by fibroblasts during the proliferative phase. This pathological fibrosis is characterized by an overexpression of matrix proteins such as alpha-smooth muscle actin (alpha-SMA), coupled with a reduction in the expression of matrix metalloproteinases (MMPs), leading to an accumulation of collagen [12]. Keloid and hypertrophic scarring (HS) are clinical manifestations of this disorder and can be regarded as successive stages of the same proliferative issue. Both conditions share an initial purulent inflammatory skin lesion, followed by fibroblast hyperfunction and excessive deposition of the extracellular matrix. However, whereas HS predominantly consists of type III collagen, keloids contain both type I and type III collagen [31]. The general approach to preventing scarring involves early recognition of any alterations, which is crucial for initiating timely treatment [32]. Since the healing process varies across individuals, managing the procedure, preventing infection, and providing tailored wound care remain central to both prevention and treatment strategies [33].

Prevention and Treatment Strategies

- Prevention: Early diagnosis
- Treatment: Silicone gel or dressing, topical retinoids, careful wound care, topical imiquimod, topical 5-fluorouracil, intralesional bleomycin
- Alternative Therapies: Peelings, microneedling, dermabrasion, radiotherapy, sun protection, avoidance of risk areas, and risk patients

The Role of Physical Therapies in Hard-To-Heal Chronic Wounds

Principles and Basis

Understanding the mechanisms behind impaired wound healing (WH) clarifies the role of physical therapies (PT). These therapies offer theoretical mechanisms that can impact all stages of the wound healing process, complementing traditional treatments while ensuring safety. The key guidelines for managing chronic wounds (CW) are extensive, but the foundational aspects include promoting patient adherence to treatment, debridement, infection control, appropriate dressing application, and, when necessary, effective compression therapy [1]. Physical therapies can be introduced into treatment regimens in two ways: either as proactive management during the early stages of wound healing or as an adjunctive therapy when chronic wounds, hypertrophic scarring, or keloids are already present. These strategies not only depend on the physician's clinical judgment but also require consultation with the patient, as treatment decisions must be individualized based on the specific circumstances.

Physical Therapies in Assisted Healing and Scar Prevention

Laser

Laser therapy is primarily employed for the treatment and prevention of scarring, although there is limited published research on its role in wound healing (WH). Various lasers can be used to address different aspects of hypertrophic scars (HS) or keloids, each targeting specific therapeutic goals [34]. Laser treatment offers flexibility and can involve the combination of multiple laser types within a single session. Fractional lasers, often used in conjunction with vascular lasers and lasers targeting melanin, are the most commonly applied in clinical settings [35]. There are two primary categories of fractional lasers: ablative lasers (with wavelengths ranging from 2790 to 10,600 nm) and non-ablative lasers (ranging from 1320 to 1927 nm). Both types of lasers have become the gold standard for scar treatment, although ablative lasers are generally more prevalent in practice [36].

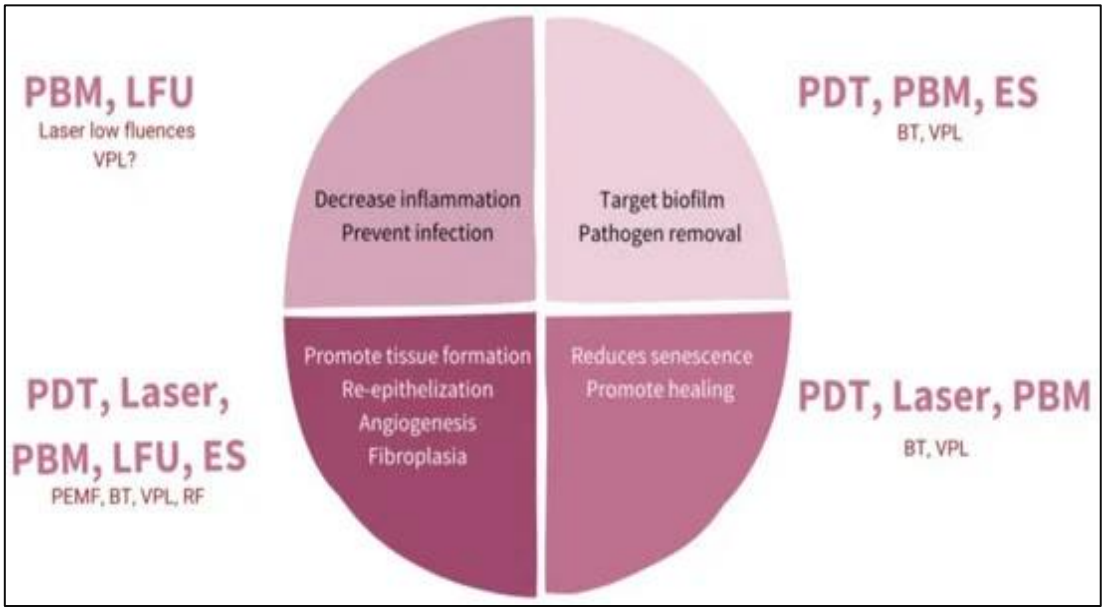

Figure 2: Physical Therapy Targets.

Ablative lasers, such as the Erbium (Erbio) and CO2 lasers, are designed to target water in the skin, inducing selective burns. These lasers operate in fractional mode, creating separate columns of thermal damage while leaving surrounding skin intact, which facilitates regeneration. The treatment promotes selective thermal necrosis, which enhances collagen remodeling, particularly by increasing the production of collagen type III after three months, resulting in thinner, more flexible skin [37]. Vascular lasers, on the other hand, target small blood vessels and are primarily used to reduce erythema in HS and keloids by decreasing excessive neovascularization. The pulsed dye laser (PDL) is widely recognized as one of the most effective vascular lasers. Research indicates that PDL reduces connective tissue growth factor expression in

keloids, inhibits fibroblast proliferation in vitro, and increases collagen type III following vessel coagulation and induced hypoxia [38][39][40].

While laser therapy is commonly used for scar management, several studies have also investigated its role in enhancing WH and preventing scarring right from the initial days following surgery, yielding varied results. Unlike other physical therapies, which require a healing period before application, lasers can be applied immediately after surgery. In split-face studies, immediate application of CO2 lasers showed no differences in the treated area compared to untreated areas; however, other studies have reported improved healing and cosmetic outcomes when scars are treated with lasers shortly after surgery [41][42][43]. PDL and non-ablative fractional lasers have been demonstrated to improve scarring when applied early, although differences with untreated areas were not statistically significant [44]. Combining different laser types in the same session, such as PDL with ablative fractional CO2 laser, has been suggested as an optimal treatment combination for scar management [45]. The literature recommends starting laser treatment early for scar prevention, with the optimal interval between sessions being 5 to 6 weeks over several months [46]. In these early treatment applications, lower parameters are typically used to avoid excessive damage [40]. While further clinical trials with extended follow-up are needed to solidify the evidence on the efficacy of laser treatments for HS, keloids, and WH, expert panels have endorsed lasers as a first-line therapy for scarring management [47][48].

Photobiomodulation (Low-Level Light Therapy - LLLT)

Low-level light therapy (LLLT), also known as photobiomodulation (PBM), has been extensively studied for its role in wound healing. The most commonly used wavelengths for LLLT are near-infrared light (NIR) between 800 and 900 nm and red light (600–700 nm). LLLT works by using light in a non-thermal manner, where photons are absorbed by receptors in skin cells. The three primary chromophores in the skin—melanin in the epidermis, hemoglobin in the dermis, and water throughout the skin—are influenced by light exposure, with longer wavelengths providing deeper penetration [49]. LLLT induces hormesis, a biological process where low doses of light or energy activate cellular responses, while higher doses lead to inhibition [50]. This process results in the production of nitric oxide (NO), a vasodilator and anti-inflammatory agent, contributing to improved wound healing [51]. LLLT has demonstrated positive effects across various stages of wound healing, including promoting anti-inflammatory responses, enhancing vasodilatation, aiding matrix formation, and supporting epithelial cell function. Key mediators involved in these processes include reactive oxygen species (ROS), NO, interleukins (IL6, IL13, IL15), transforming growth factor-beta (TGF-beta), and matrix metalloproteinases (MMPs), which regulate the progression of inflammation, proliferation, and remodeling phases of healing [7][50][51]. In animal models, LLLT has been shown to increase collagen production and reduce oxidative and nitroxidative stress in diabetic wounds [51]. In vitro studies have also observed enhanced keratinocyte expression of cyclin D1 and cytokeratin, indicating a boost in cell proliferation and maturation [52][53].

Although not as widely utilized as laser therapy, LLLT is considered safer, with fewer adverse reactions such as swelling, crusting, or purpura. Unlike lasers, LLLT is easier to apply, covers larger treatment areas, and is available in wearable devices, offering the possibility of self-treatment. Additionally, LLLT is less expensive than laser therapy. The primary drawback of LLLT is the need for frequent sessions, typically on a near-daily basis [54]. While studies on LLLT in wound healing have yielded mixed results, there is evidence of its effectiveness. For example, in venous ulcers (VU), red light therapy did not show additional benefits over conventional treatments [55]. However, in pressure ulcers (PU) and diabetic ulcers (DU), red light was found to accelerate healing and improve outcomes compared to near-infrared light [56]. In a small study, NIR light (LED 805 nm) was shown to be effective in preventing keloid formation when used prophylactically, with patients self-administering the treatment at home for one month [57]. Overall, LLLT has been found to improve inflammation, alleviate pain, and promote healing in clinical settings. Despite the extensive research on its benefits, more studies are needed to establish standardized protocols for its use in routine clinical practice [54].

Blue Light Emission Diode

The development of blue light-emitting diodes (LEDs) significantly advanced in the 1980s, thanks to the groundbreaking work of Akasaki, Amano, and Nakamura on gallium nitride crystals. This innovation enabled the production of white light from LED sources, revolutionizing the application of radiation in various fields [58]. Blue-light photobiomodulation (PBM) triggers a cascade of cellular events following the absorption of photons by intracellular photoreceptors. Among the observed effects are increased cell proliferation, migration, differentiation, cytokine modulation, growth factor synthesis, and anti-inflammatory responses, all of which contribute to improved healing [59][60]. In wounds treated with blue light, accelerated healing is evident, accompanied by better dermal collagen deposition and improved collagen morphology compared to untreated wounds. Additionally, treated wounds exhibit enhanced modulation of the inflammatory response, with mast cells playing a pivotal role in this process [50].

Photodynamic Therapy

Photodynamic therapy (PDT) represents a non-invasive, safe, and efficient procedure designed to enhance wound healing (WH); however, further research is required to establish a definitive protocol. Despite this, PDT is recognized for its versatility, although the presence of pain during treatment and the necessity for repeated sessions remain notable limitations. PDT is commonly employed in dermatology for conditions such as actinic keratosis, basal cell carcinoma, and Bowen disease [61]. While PDT has been examined for its potential in wound healing and scar prevention, its efficacy remains inconclusive for the treatment of keloids and hypertrophic scars (HS). One of the principal advantages of PDT over other phototherapies in wound healing is its capacity to address infections without the development of antibiotic resistance.

PDT involves the application of a photosensitizer (PS) to the target tissue, followed by exposure to an appropriate light source to induce necrosis and apoptosis in the tissue. A variety of light sources and PS agents have been tested for use in wound healing, with a preference for topically applied PS due to their relatively lower side effects. Several light sources within the PpIX absorption spectrum are suitable for PDT, though light-emitting diodes (LEDs) are most commonly utilized due to their simplicity and minimal adverse effects [62,63]. The majority of light sources fall within the red spectrum [63], although studies utilizing green light have also been conducted. One of the primary challenges in standardizing PDT for wound healing is the lack of consistent protocols and dosing, which hinders the development of conclusive treatment guidelines [64]. In PDT, the PS increases the intracellular production of protoporphyrin IX (PpIX), which absorbs light and triggers a photochemical reaction. This leads to the generation of reactive oxygen species (ROS), which are responsible for tissue destruction through oxidative stress. The mechanisms of PDT are well-established; in addition to tumor necrosis, PDT elicits a range of biological responses that hold promise for broader applications in wound healing [65].

PDT induces acute inflammation during wound healing, thereby stimulating the natural healing process, with an increase in neutrophils, TNF-alfa, and IL6 levels [66]. Additionally, PDT promotes neovascularization through vascular endothelial growth factor (VEGF), which is essential for the remodeling phase of healing [30]. Furthermore, research indicates that early activation of fibroblasts, re-epithelialization, and mast cell degranulation play significant roles in the healing of chronic wounds. Notably, interactions between the immune and nervous systems are critical in regulating wound healing. Recent studies have highlighted the influence of neuropeptides such as CGRP, NGF, NKA, NPY, SP, PGP 9.5, and VIP, which are often found in chronic wounds. These interactions are associated with the secretion of extracellular matrix components by fibroblasts, increases in TGF-beta levels, and responses of cellular infiltrates [18,30]. Subsequently, PDT is shown to negatively regulate inflammation through the expression of IL10 and the downregulation of IL1 and IL6 [67]. It has been suggested that the modulatory effects of PDT on the immune system, as well as the induction of necrosis versus apoptosis, depend on the intensity of the protocol, particularly the levels of ROS. An elevated intracellular ROS concentration may shift the effect from tissue repair to destructive processes (a phenomenon known as hormesis) [69]. PDT has been observed to elevate MMP levels after three weeks, with histological improvements appearing around nine

months. Additionally, PDT exhibits antibacterial activity, particularly against biofilms, and is effective in reducing chronic inflammation [30,70].

Electrical Stimulation

Endogenous bioelectric fields (EBFs), generated by Na+/K+ ATPase in the epidermis, naturally occur during wound healing. These fields influence cell migration, proliferation, gene expression, and protein synthesis [71]. Electrical stimulation (ES) seeks to mimic these bioelectric fields and is applied to chronic wounds (CW) to promote healing. Theoretically, ES is most beneficial during the proliferative and remodeling phases of wound healing, occurring several days post-injury, as it enhances cell proliferation and the remodeling process. In cases of chronic wounds, ES can reduce inflammation and the risk of infection. In vitro studies have shown that ES can decrease the growth of pathogens such as *Staphylococcus aureus*, *Pseudomonas aeruginosa*, and *Escherichia coli* [72]. Positive outcomes have been reported in chronic wounds, venous ulcers (VU), and leg ulcers (LU), with a reported 30–42% reduction in wound area following ES treatment [72,73]. ES is a safe, simple, and cost-effective procedure with minimal adverse effects.

Several forms of ES, including direct current, alternating current, and pulsed current, can be utilized with either mono- or bipolar devices. However, the variability of ES modalities complicates the identification of the most effective protocol. Moreover, no comparative studies have been conducted between these modalities, although pulsed current is generally considered the most physiologically relevant [25,71,72]. Not all forms of ES are beneficial at all stages of wound healing, with alternating current being most effective during the early days post-injury [25]. There remains a paucity of standardized protocols in the literature [73]. Based on its mechanism of action, ES is believed to be most effective during the proliferative and remodeling phases of wound healing, which typically occur days to months after injury, particularly in acute wounds (AW) to prevent scarring, or in chronic wounds to promote healing [73]. ES is often used in conjunction with conventional wound care as a complementary treatment. The typical application of ES involves placing electrodes around the wound, with sessions lasting between 45 minutes and several hours and conducted on a weekly basis. These sessions may extend over several months, presenting a significant limitation in terms of time commitment and patient convenience. Consequently, ES may be reserved for patients at high risk of wound healing failure. However, emerging devices, such as home-use units, electric dressings, or electric fields, offer promising alternatives for enhancing patient compliance and accessibility [71].

Ultrasound Therapy

Ultrasound therapy (UT) involves the application of sound waves that generate both thermal and non-thermal effects on tissues. When UT is applied intensively to the skin, the temperature may rise to approximately 40°C, inducing increased blood flow, cell proliferation, collagen production, and tissue regeneration. Additionally, UT exhibits anti-inflammatory effects. The non-thermal effects are primarily due to acoustic streaming, which displaces particles, and cavitation, which produces microenvironmental gas bubbles. Cavitation helps to debride necrotic tissue while preserving healthy tissue [74]. UT has been shown to accelerate the reduction in wound size compared to control treatments in lower extremity ulcers (LU), and it has been approved by the FDA as an adjunctive treatment in wound healing (WH) [75,76]. There are two main types of therapeutic ultrasound: low-frequency ultrasound (LFU), which ranges from 30 to 40 kHz, and high-frequency ultrasound (HFU), which ranges from 1 to 3 MHz. HFU has been utilized for several decades in the treatment of musculoskeletal conditions in sports medicine. A variant of HFU, micro-focused ultrasound in high-intensity mode (MFU, HIFU), has also gained popularity in aesthetic medicine due to its ability to reduce wrinkles and skin laxity [75]. In contrast, LFU has demonstrated considerable efficacy in the management of WH and has been successfully applied in the treatment of LU. LFU is typically applied directly to the skin around the wound for a duration of 5 to 10 minutes, with the use of a topical gel placed between the skin and the applicator [74]. UT is contraindicated in patients with metal prostheses in the leg, neuropathy, infection, or thrombophlebitis [75]. Although UT shows promise in the treatment of WH, there are no clinical studies specifically examining its effects on WH or scar prevention. Most existing evidence

pertains to LU, and further randomized clinical trials and protocols are required to fully evaluate its efficacy in this area [75,76].

Electromagnetic Fields

Low-frequency pulsed electromagnetic fields (PEMF) have been demonstrated to accelerate wound healing (WH) by promoting the generation of connective tissue, enhancing the vascular endothelial growth factor (VEGF) pathway, and stimulating the production of collagen type I. Several studies have reported positive outcomes in the treatment of pressure ulcers (PU), venous leg ulcers (VLU), and diabetic ulcers (DU). PEMF therapy can be conveniently administered at home using portable devices, as multiple treatment sessions are typically required [77,78].

Biophotonic Therapy

Biophotonic therapy (BT) involves the application of photobiomodulation (PBM) using a specialized gel that contains chromophores over the chronic wound (CW). An LED lamp emitting a hyper-pulsed beam of low energy light is then used to activate the gel. One particular device, the "Lumihel®," has been evaluated and shown to improve the healing of CWs while enhancing the quality of life for patients without causing any adverse events. However, the study had limitations, such as the inclusion of various types of wounds, including venous ulcers (VU), LU, and PU, as well as weekly treatment sessions over a period of 8 weeks [79].

Visible Polarized Light

Visible polarized light (VPL) is utilized as a complementary therapy for wound healing (WH). The device used emits light similar to natural sunlight but without the harmful ultraviolet radiation, ensuring the light is safe. The light is characterized as low energy, polychromatic, incoherent, and polarized. The polarization of the light allows it to effectively penetrate flat surfaces, enhancing its therapeutic action. Although the molecular mechanisms underlying the effects of VPL are not well understood, several studies have reported improvements in CWs treated with VPL [80,81]. While VPL appears to hold promise as a potential treatment for WH, further investigation is needed to elucidate its full therapeutic potential [82].

Radiofrequency

Radiofrequency (RF) therapy involves the application of a high-frequency electromagnetic field, typically between 3 kHz and 300 GHz, which induces molecular oscillation and friction in the target tissue. This results in tissue hyperthermia, which can degrade collagen and stimulate neocollagenesis and tissue remodeling. RF therapies are primarily indicated for skin tightening, wrinkle reduction, and scar treatment. Some studies have explored the efficacy of RF in WH, showing favorable results, particularly in pain relief. However, multiple sessions over a 2 to 4-week period are usually required. RF technology continues to evolve, with new advancements such as micro-needling devices and fractionated delivery methods, which have shown promising results in the treatment of acne scars, hypertrophic scars (HS), and keloids [21,83,84].

Summary of Clinical Trials of Physical Therapies in Wound Healing

It is important to note that there is a limited number of published clinical trials focusing on the use of physical therapies (PT) in wound healing (WH). A search of the term "Physical therapies skin wounds" in PubMed, filtered by the last 10 years and clinical trials, yielded 66 results. After further selection, only 8 studies were related to skin wounds, and only 6 specifically addressed chronic wounds (CWs). Despite the limited evidence, PT is not included in clinical guidelines for the management of CWs, and it is primarily utilized as an adjunctive therapy [1].

In a notable study, Polak investigated the use of electrical stimulation (ES) on pressure injuries in patients with neurological impairments. A total of 43 patients were divided into three groups: anodal, cathodal, and placebo. The results indicated a reduction in pro-inflammatory blood cytokines in the ES-treated groups, correlated with an improvement in peripheral inflammation and a significant reduction in

wound size compared to the placebo group. Other studies have also explored the combination of ES with silver dressings for CWs. In these studies, 10 patients received treatment on a single wound, with significant improvements observed when compared to controls. ES has been shown to not only accelerate wound healing but also alleviate pain in CWs [85,86]. In another study, 10 patients received treatment with ES, while another 10 patients were treated with a placebo. The ES-treated group showed improvements in the blood levels of VEGF and nitric oxide (NO) in diabetic ulcers (DU) [87]. Additionally, a comparison study between ultrasound (US) and ES for the treatment of pressure ulcers (PUs) revealed that both treatments significantly improved WH in 27 patients, with no significant differences between the two therapies [88]. Another comparative study conducted by Polak involved 77 patients with PUs, who received either standard wound care, US, or ES. Those treated with PT showed a significant reduction in ulcer size compared to the placebo group, but no significant differences were observed between US and ES treatments [89-90]. The main limitation of these clinical trials lies in the difficulty of controlling other factors that could influence wound healing outcomes.

Role of Health Information System:

Health Information Systems (HIS) are increasingly recognized for their role in enhancing healthcare delivery, particularly in specialized fields such as physical therapy for burn victims. The management of burn injuries involves complex and multidisciplinary care, including physical therapy to address both the physical and psychological effects of burns. The integration of HIS in burn therapy not only streamlines clinical workflows but also improves patient outcomes through better monitoring, coordination, and personalization of care. This paper explores the significant role of HIS in the physical therapy of burns, focusing on its contribution to patient assessment, treatment planning, monitoring, and overall care management.

Enhanced Patient Assessment and Documentation

One of the primary roles of HIS in burn rehabilitation is the improvement of patient assessment and documentation. Physical therapists require detailed and accurate information about the patient's medical history, burn severity, and response to previous treatments. HIS facilitates this by providing a centralized platform where patient data, including burn severity, anatomical location of the injury, and progress in healing, can be securely stored and accessed by the care team. Burn injuries are categorized based on their depth and extent, with each classification requiring specific therapeutic interventions. The use of HIS allows physical therapists to access digital images, such as burn wound assessments from initial evaluations, and track progress over time. For instance, the application of electronic health records (EHRs) enables accurate documentation of range of motion (ROM) assessments, wound healing, pain levels, and functional limitations. This information can be updated in real-time, allowing for more efficient communication and ensuring that the physical therapist is working with the most up-to-date data. Moreover, HIS can integrate clinical decision support tools that provide evidence-based guidelines for burn treatment. These tools help physical therapists determine the appropriate interventions, based on the severity of the burn and the specific needs of the patient, while ensuring that care plans are consistent with current best practices.

Personalized Treatment Plans

The creation of personalized treatment plans is another crucial area where HIS contributes to burn rehabilitation. Physical therapy for burn victims is highly individualized, considering factors such as the patient's age, overall health, the extent of the burn injury, and psychosocial needs. HIS enables the development of tailored rehabilitation plans by centralizing patient data and helping physical therapists make informed decisions. For example, HIS can allow the integration of multi-disciplinary care teams, including burn specialists, physiatrists, and occupational therapists. Such collaboration ensures that the burn survivor's rehabilitation is holistic, addressing not only the physical aspects of recovery but also the psychological and social challenges associated with burn trauma. HIS can provide a shared platform for clinicians to develop and update personalized goals, such as restoring ROM, improving strength, reducing

pain, and addressing functional limitations caused by scarring or contractures. Furthermore, HIS can assist in tracking patient preferences, which is essential for ensuring that treatment goals align with the patient's values and expectations. For burn patients, issues such as body image, emotional well-being, and quality of life are critical in the rehabilitation process. HIS can provide tools for incorporating these subjective measures into clinical decision-making, ensuring that physical therapy is not only effective but also patient-centered.

Monitoring and Outcome Measurement

The monitoring of patient progress is an essential aspect of burn rehabilitation, where HIS plays a pivotal role. Regular assessment of burn healing, mobility, and function is required to ensure that patients are on the path to recovery and to make necessary adjustments to treatment plans. HIS facilitates this by allowing the collection of standardized clinical data over time, providing physical therapists with a comprehensive view of the patient's progress. Burns often lead to long-term complications such as scar formation, contractures, and loss of function, which necessitate ongoing physical therapy. HIS can track clinical outcomes using specific metrics, such as changes in ROM, strength, and the degree of functional independence. Additionally, HIS can integrate outcome measurement tools such as the Visual Analog Scale (VAS) for pain, the Barthel Index for daily function, or the American Burn Association (ABA) criteria for assessing burn severity and progress. These data points can be reviewed periodically, allowing the care team to adjust therapeutic interventions based on objective findings. In cases of severe burns, physical therapists may need to use advanced techniques such as splinting, pressure garments, or aquatic therapy. HIS can track the application and effectiveness of these interventions, providing valuable feedback on their success or the need for modification. For example, HIS can alert clinicians if a patient's skin is showing signs of contracture or if their ROM is not improving as expected, prompting earlier intervention.

Efficient Communication and Coordination

Effective communication and coordination among the multidisciplinary burn care team is crucial for successful rehabilitation. HIS plays a significant role in ensuring that all healthcare providers involved in a patient's burn care have access to the same information, which reduces the risk of errors, duplicative tests, and fragmented care. In burn rehabilitation, communication between physical therapists, burn surgeons, pain specialists, and nurses is essential. HIS ensures that these healthcare providers can easily exchange patient data and progress updates, facilitating a coordinated approach to treatment. For instance, if a burn surgeon changes a patient's treatment plan or provides new insights into wound care, this information is immediately available to the physical therapist, who can adjust the rehabilitation regimen accordingly.

Moreover, HIS improves the continuity of care by enabling remote monitoring and telemedicine consultations. For patients who live in rural or underserved areas, or those who are unable to attend physical therapy sessions in person due to mobility limitations, HIS allows physical therapists to offer remote consultations or virtual therapy sessions. This not only improves access to care but also ensures that patients continue their rehabilitation without disruption. Health Information Systems are revolutionizing the management of burn injuries, particularly in the field of physical therapy. By enhancing patient assessment, facilitating personalized treatment plans, improving monitoring and outcome measurement, and ensuring efficient communication and coordination, HIS contributes significantly to the effective rehabilitation of burn victims. As burn care continues to evolve, the integration of HIS will remain a cornerstone in improving patient outcomes, streamlining clinical workflows, and supporting a more holistic, patient-centered approach to burn therapy. Given the complexity of burn rehabilitation and the long-term nature of recovery, HIS holds the potential to substantially improve the quality of life for burn survivors while promoting evidence-based, efficient, and coordinated care.

Conclusion:

Wound healing (WH) remains a critical aspect of medical care, particularly in patients suffering from chronic wounds (CWs) such as diabetic foot ulcers (DFU), pressure ulcers (PU), and venous leg ulcers

(VU). While traditional approaches to wound care, including appropriate dressings, debridement, and infection control, have shown effectiveness, the integration of physical therapy (PT) and health information systems (HIS) provides a new frontier in enhancing healing outcomes and reducing scarring. Physical therapy, through various modalities such as electrical stimulation, laser therapy, and photodynamic therapy, has demonstrated significant potential in promoting tissue regeneration, reducing inflammation, and improving circulation. These therapeutic interventions work by stimulating cellular processes that accelerate the healing phases of inflammation, proliferation, and remodeling, which are crucial for both acute and chronic wounds. Furthermore, these therapies help to prevent or reduce the severity of scarring, a common and often distressing consequence of improper or delayed wound healing. The review highlighted the emerging role of health information systems in optimizing wound care. HIS facilitates the collection and analysis of patient data, ensuring that clinicians have access to real-time information that can guide decision-making. This data-driven approach enhances the management of chronic wounds, providing healthcare providers with insights into patient progress, enabling early interventions, and supporting treatment adjustments based on individual patient responses. Moreover, HIS promotes coordination among healthcare professionals, ensuring a more integrated and effective treatment plan. The seamless communication provided by HIS reduces the risk of missed treatments, incorrect medication administration, and other common issues that can hinder recovery. In addition to its benefits in promoting healing, the integration of HIS supports better documentation and more personalized care plans, ultimately leading to improved patient outcomes. The ability to monitor healing progress through standardized systems helps identify any barriers to healing, such as infection or inadequate blood flow, which can be addressed promptly to avoid complications. However, the effective use of HIS requires comprehensive training for healthcare staff and the establishment of a robust system that aligns with clinical workflows. In conclusion, the combined use of physical therapy techniques and health information systems represents a promising approach to improving wound healing, particularly in chronic cases. These modalities not only enhance the biological processes involved in healing but also contribute to the overall efficiency and effectiveness of wound care management. Continued research and integration of these approaches are necessary to further refine treatment protocols and ensure that patients receive the best possible care, with a focus on minimizing scarring and maximizing healing outcomes.

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شفاء الجروح: الدور الرئيسي للعلاج الطبيعي ونظام المعلومات الصحية - مراجعة محدثة

الملخص:

الخلفية :يشكل شفاء الجروح (WH) تحديات كبيرة في الرعاية الصحية، حيث تؤدي الجروح الحادة (AWs) والجروح المزمنة (CWs) إلى تأثيرات طويلة الأمد. تؤدي الجروح الحادة، مثل الحروق أو الصدمات الجراحية، غالباً إلى تكوّن الندوب، بينما الجروح المزمنة، المرتبطة في كثير من الأحيان بحالات نظامية مثل السكري وسوء التغذية والاضطرابات الوعائية، تشكل خطراً أكبر على المرض. من بين أكثر الجروح المزمنة شيوعًا، توجد تقرحات القدم السكري(DFU) ، وتقرحات الساق(LU) ، وتقرحات الضغط .(PU) على الرغم من التقدم في العلاجات، تظل الندوب مصدر قلق رئيسي. تبرز هذه المراجعة الدور المتزايد للعلاج الطبيعي (PT) ونظام المعلومات الصحية (HIS) في تحسين نتائج شفاء الجروح.

الهدف :تهدف هذه المراجعة إلى استكشاف مساهمة تقنيات العلاج الطبيعي، مثل العلاج بالليزر، والتحفيز الكهربائي، والعلاج بالليزر منخفض المستوى، في تسهيل شفاء الجروح، خاصة في إدارة الجروح المزمنة. كما تدرس دمج أنظمة المعلومات الصحية في تتبع وتحسين التدخلات الخاصة برعاية الجروح.

الطرق :قامت المراجعة بتجميع الدراسات الحديثة حول أساليب العلاج الطبيعي في رعاية الجروح، مع فحص آلياتها البيولوجية وفعاليتها السريرية. بالإضافة إلى ذلك، تم استكشاف تطبيق أنظمة المعلومات الصحية في إدارة الجروح لتحسين التوثيق، والتواصل، وتخطيط العلاج. تم اختيار الدراسات التي تمت مراجعتها بناءً على صلتها بالعلاج الطبيعي في شفاء الجروح ودمج نظام المعلومات الصحية في رعاية الجروح المزمنة.

النتائج :تبين أن أساليب العلاج الطبيعي، بما في ذلك التحفيز الكهربائي، والعلاج بالليزر منخفض المستوى، والعلاج الضوئي الديناميكي، تعزز عملية الشفاء من خلال تحفيز تجديد الخلايا وتقليل الالتهاب. كان دور أنظمة المعلومات الصحية في رعاية الجروح أساسياً في تحسين اتساق العلاج ونتائج المرضى من خلال ضمان التدخلات في الوقت المناسب، ودقة البيانات، والتنسيق السلس بين مقدمي الرعاية الصحية. يساعد دمج أنظمة المعلومات الصحية في إدارة الجروح في المراقبة في الوقت الفعلي، مما يؤدي إلى رعاية أكثر تخصيصًا وكفاءة.

الخلاصة :يلعب العلاج الطبيعي دورًا حاسمًا في تحسين شفاء الجروح الحادة والمزمنة، مع وجود دليل يدعم فعاليته في تعزيز تجديد الأنسجة وتقليل الندوب. أنظمة المعلومات الصحية أساسية في دعم عملية اتخاذ القرارات السريرية من خلال توفير بيانات شاملة وتسهيل إدارة رعاية الجروح المعقدة. يجب أن تواصل الدراسات المستقبلية التركيز على دمج هذه العلاجات لتحسين نتائج الشفاء.

الكلمات المفتاحية : شفاء الجروح، العلاج الطبيعي، أنظمة المعلومات الصحية، الجروح المزمنة، العلاج بالليزر، التحفيز الكهربائي، الندوب، نتائج المرضى