RESEARCH PAPER

Efficacy of Low-Frequency Pulsed Electromagnetic Field Therapy in the Treatment of Chronic Ulcers: A Prospective Clinical Study

Prof. Dr. El Sayed A. El Fatah El-Zayat[1], Prof. Dr. Mostafa El-Nakib, M.D.[2], Dr. Ahmed Yehia Mostafa, M.D.[3]

[1]Professor of Vascular Surgery, Suez Canal University,
elzayat2003@hotmail.com
[2]Professor of Microbiology, Military Medical Academy, moselnakib@yahoo.com
[3]MRCS, Lecturer of General Surgery, Armed Forces College of Medicine, a.yehia26@yahoo.com

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Abstract

Background: Chronic ulcers remain a persistent clinical challenge due to delayed healing and high recurrence rates. Pulsed Electromagnetic Field Therapy (PEMF) has emerged as a non-invasive modality that promotes wound healing via cellular activation, inflammatory modulation, and tissue regeneration. **Aim**: To assess the therapeutic efficacy of low-frequency PEMF in managing chronic leg ulcers, focusing on wound size reduction, re-epithelialization, angiogenesis, and pain control. **Methods**: A prospective clinical study was conducted on 50 patients with chronic leg ulcers treated with low-frequency PEMF over four weeks. Baseline and follow-up assessments (day 14 and day 28) included wound area (cm^2), pain score (VAS), and tissue oxygenation ($TcPo_2$). Statistical analysis was performed using SPSS v26, with significance set at $p < 0.05$. **Results**: By day 28, PEMF therapy led to a significant reduction in wound size (48.7% ± 10.2, $p < 0.001$), increased $TcPo_2$ levels (+14.2 mmHg, $p < 0.001$), and decreased VAS pain scores (from 7.2 to 3.4, $p < 0.001$). Histological evaluation revealed enhanced collagen deposition and angiogenesis. Inflammatory markers (IL-1β and TNF-α) significantly declined during treatment ($p < 0.05$). No major adverse effects were observed. **Conclusion**: Low-frequency PEMF is a safe and effective treatment for chronic ulcers, significantly improving healing parameters and inflammatory profiles. These results support its integration into wound care protocols.

Keywords:
Chronic ulcers, PEMF, wound healing, angiogenesis, inflammation.

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Introduction

Chronic leg ulcers (CLUs) represent a significant and growing global health challenge, affecting an estimated 1–2% of the adult population and contributing to substantial morbidity, healthcare costs, and reduced quality of life (Guest et al., 2020; Sen et al., 2009; Nussbaum et al., 2018). These ulcers, which encompass venous, arterial, diabetic, and pressure ulcers, are defined by their failure to progress through the orderly phases of wound healing, often persisting for months or years and exhibiting high recurrence rates (Lazarus et al., 1994; Margolis et al., 2011; Falanga, 2005). The pathophysiology of chronic ulcers is multifactorial and complex, involving persistent inflammation, impaired angiogenesis, microbial colonization, biofilm formation, and inadequate tissue oxygenation, all of which contribute to delayed healing and frequent complications (Guo & Dipietro, 2010; Frykberg & Banks, 2015; Schultz et al., 2017).

Conventional management strategies for chronic ulcers typically include sharp or enzymatic debridement, infection control, pressure offloading, advanced wound dressings, and optimization of systemic factors such as glycemic control and vascular status (Mustoe et al., 2006; Steed et al., 2006; Harding et al., 2015). Despite these approaches, a significant proportion of ulcers remain refractory to healing, underscoring the need for adjunctive therapies that can enhance tissue regeneration, modulate the wound environment, and accelerate closure (Game et al., 2020; Markov, 2007).

Pulsed Electromagnetic Field Therapy (PEMF) has emerged as a promising non-invasive adjunct in the management of chronic wounds. PEMF delivers low-frequency electromagnetic fields to the wound site, with the aim of stimulating cellular activity, promoting angiogenesis, modulating inflammatory responses, and enhancing extracellular matrix production (Pilla, 2013; Markov, 2007; Ongaro et al., 2022). Preclinical and clinical studies have shown that PEMF can accelerate wound healing by increasing fibroblast proliferation, collagen synthesis, and neovascularization, as well as reducing pro-inflammatory cytokines such as interleukin-1β (IL-1β) and tumor necrosis factor-alpha (TNF-α) (Callaghan et al., 2008; Strauch et al., 2009; El-Feky et al., 2022). Recent meta-analyses and randomized controlled trials have further supported the efficacy of PEMF in chronic wound management, particularly in diabetic and venous ulcers (Gupta et al., 2021; Ongaro et al., 2022).

While other adjunctive modalities such as hyperbaric oxygen therapy (HBOT) have demonstrated efficacy in selected cases, especially those with severe hypoxia or infection, PEMF offers unique advantages including ease of use, favorable safety profile, and potential for outpatient or home-based application (Kranke et al., 2015; Game et al., 2020; El-Feky et al., 2022). Nevertheless, the widespread adoption of PEMF is limited by variability in protocols, device parameters, and the need for further high-quality clinical evidence to define its optimal use (Gupta et al., 2021; Ongaro et al., 2022).

The present study aims to rigorously evaluate the efficacy of low-frequency PEMF in the treatment of chronic ulcers, with a focus on wound size reduction, re-epithelialization, angiogenesis, pain control, and inflammatory modulation. By providing robust clinical data, this research seeks to contribute to the evidence base supporting the integration of PEMF into contemporary chronic wound care strategies and to inform future guidelines and clinical practice.

Patients and Methods

Study Design

This prospective, randomized controlled clinical study was conducted between January 2023 and January 2025. The research protocol received approval from an independent institutional review board, and all procedures adhered to the ethical standards outlined in the Declaration of Helsinki. Written informed consent was obtained from all participants prior to enrollment (World Medical Association, 2013).

Study Population

A total of 100 patients with chronic leg ulcers were enrolled in the study. Inclusion criteria comprised adults aged 18 years or older, the presence of a chronic lower limb ulcer of more than six weeks' duration, ulcer size ranging from 2 to 20 cm^2, and adequate peripheral perfusion as indicated by an ankle-brachial pressure index (ABPI) of 0.5 or higher. Exclusion criteria included active malignancy at the ulcer site, severe ischemia (ABPI <0.5), systemic infection necessitating amputation, pregnancy, the presence of pacemakers or metallic implants, and refusal to participate. The detailed inclusion and exclusion criteria are provided in the study protocol (Mustafa, 2025, pp. 100–102).

Randomization and Group Allocation

Patients were randomly assigned to one of two equal groups (n=50 per group) using a computer-generated randomization list:

- **Group I (PEMF group):** Received low frequency pulsed electromagnetic field therapy.
- **Group II (HBOT group):** Received hyperbaric oxygen therapy.

The present report focuses exclusively on the PEMF group, with data from the HBOT group included only for contextual comparison.

Baseline Assessment

At baseline, all participants underwent comprehensive demographic and clinical evaluation, including age, sex, body mass index (BMI), ulcer duration, etiology, and anatomical location. Ulcer assessment included measurement of wound size by planimetry, evaluation of depth, exudate, and signs of infection. Pain was assessed using the Visual Analog Scale (VAS, 0–10). Tissue oxygenation at the wound edge was measured using transcutaneous oxygen tension ($TcPo_2$). Laboratory investigations included complete blood count, erythrocyte sedimentation rate, C-reactive protein, fasting blood glucose, and renal and liver function tests. Vascular assessment was performed using Doppler ultrasound of the lower limb arteries (Mustafa, 2025, pp. 103–105). The baseline characteristics of the PEMF group are summarized in Table 1.

Table 1. Baseline Characteristics of PEMF Group (n=50)

Parameter	Mean ± SD or n (%)
Age (years)	56.3 ± 11.2
Male/Female	28/22 (56%/44%)
BMI (kg/m²)	27.5 ± 3.4
Duration of ulcer (weeks)	14.6 ± 5.9
Ulcer size (cm²)	8.2 ± 3.1
VAS pain score	7.2 ± 1.1
$TcPo_2$ (mmHg)	32.7 ± 7.8

Intervention: Pulsed Electromagnetic Field Therapy (PEMF)

Patients in the PEMF group received therapy using a certified low-frequency device (frequency: 50 Hz; intensity: 1.5 mT). The applicator was positioned directly over the ulcer area for 30 minutes per session, five sessions per week, over a four-week period (totaling 20 sessions). Standard wound care—including debridement, moist dressings, and infection control—was continued for all patients in accordance with best practice guidelines (Mustafa, 2025, pp. 106–108).

Outcome Measures

Outcomes were assessed at baseline (day 0), mid-treatment (day 14), and post-treatment (day 28). The primary outcome was the percentage reduction in wound surface area, as measured by planimetry. Secondary outcomes included changes in pain score (VAS), changes in $TcPo_2$, the rate of complete re-epithelialization, histological assessment of angiogenesis and collagen deposition (in selected cases), and changes in inflammatory markers (IL-1β and TNF-α) in wound exudate. The methodology for each outcome is detailed in the study protocol (Mustafa, 2025, pp. 109–113).

Data Collection and Statistical Analysis

All data were recorded in standardized case report forms. Quantitative variables were expressed as mean ± standard deviation (SD), and categorical variables as frequencies and percentages. Statistical analysis was conducted using SPSS version 26.0. Paired t-tests were used to compare pre- and post-treatment values within the PEMF group. Statistical significance was set at $p < 0.05$.

Key Statistical Results for PEMF Group

- **Wound Size Reduction:**

  As shown in Table 2, the mean wound area decreased from 8.2 ± 3.1 cm² at baseline to 5.7 ± 2.6 cm² at day 14 and 4.2 ± 2.1 cm² at day 28, with a mean percentage reduction of 48.7% ± 10.2 at day 28 ($p < 0.001$).

- **Pain Score (VAS):**

  The mean pain score decreased from 7.2 ± 1.1 at baseline to 4.8 ± 1.3 at day 14 and 3.4 ± 1.0 at day 28 ($p < 0.001$; Table 2).

- **Tissue Oxygenation ($TcPo_2$):**

$TcPo_2$ increased from 32.7 ± 7.8 mmHg at baseline to 41.2 ± 8.3 mmHg at day 14 and 46.9 ± 8.5 mmHg at day 28 ($p < 0.001$; Table 2).

- **Re-epithelialization:**

  At day 28, complete re-epithelialization was observed in 16 patients (32%), partial in 30 patients (60%), and no significant change in 4 patients (8%).

- **Inflammatory Markers:**

  There was a significant reduction in IL-1β and TNF-α levels from baseline to day 28 ($p < 0.05$; Table 2).

- **Histological Assessment:**

  Post-treatment biopsies demonstrated increased collagen deposition and angiogenesis (qualitative scoring).

- **Complications and Safety:**

  No major adverse effects were reported. Minor complications included mild local erythema in 2 patients (4%), which resolved spontaneously (Mustafa, 2025, pp. 149–170).

Table 2. Summary of Main Outcomes in PEMF Group

Outcome	Baseline	Day 14	Day 28	p-value
Wound size (cm^2)	8.2 ± 3.1	5.7 ± 2.6	4.2 ± 2.1	<0.001
VAS pain score	7.2 ± 1.1	4.8 ± 1.3	3.4 ± 1.0	<0.001
$TcPo_2$ (mmHg)	32.7 ± 7.8	41.2 ± 8.3	46.9 ± 8.5	<0.001
Complete re-epithelialization	–	–	16 (32%)	–
IL-1β (pg/mL)	24.5 ± 6.2	17.1 ± 5.9	12.3 ± 4.7	<0.05
TNF-α (pg/mL)	21.8 ± 5.7	15.6 ± 5.2	10.8 ± 4.1	<0.05

Ethical Considerations

The study was conducted in accordance with the ethical standards of the Declaration of Helsinki and its subsequent amendments. Institutional review board approval was obtained prior to study initiation. All participants provided written informed consent, and confidentiality and participant rights were strictly maintained throughout the study period.

Results

Baseline Characteristics

Fifty patients with chronic leg ulcers were included in the PEMF group. The mean age was 56.3 ± 11.2 years, and 56% were male. The mean body mass index (BMI) was 27.5 ± 3.4 kg/m^2. The mean ulcer duration was 14.6 ± 5.9 weeks, and the mean baseline ulcer area was 8.2 ± 3.1 cm^2. Most ulcers were of venous origin (62%), followed by diabetic (24%) and arterial (14%). The mean baseline pain score (VAS) was 7.2 ± 1.1, and the mean baseline transcutaneous oxygen tension ($TcPo_2$) was 32.7 ± 7.8 mmHg, as shown in Table 3. These findings are consistent with patient demographics reported in previous chronic ulcer studies (Guo & Dipietro, 2010).

Table 3. Baseline Characteristics of PEMF Group (n=50)

Parameter	Mean ± SD or n (%)
Age (years)	56.3 ± 11.2
Male/Female	28/22 (56%/44%)
BMI (kg/m^2)	27.5 ± 3.4
Duration of ulcer (weeks)	14.6 ± 5.9
Ulcer size (cm^2)	8.2 ± 3.1
VAS pain score	7.2 ± 1.1
$TcPo_2$ (mmHg)	32.7 ± 7.8
Ulcer etiology	Venous: 31 (62%) Diabetic: 12 (24%) Arterial: 7 (14%)

Wound Healing Outcomes

Wound Size Reduction

There was a statistically significant reduction in mean ulcer size throughout the treatment period. The mean wound area decreased from 8.2 ± 3.1 cm² at baseline to 5.7 ± 2.6 cm² at day 14 and to 4.2 ± 2.1 cm² at day 28 ($p < 0.001$), as illustrated in Table 4. The mean percentage reduction in wound area at day 28 was 48.7% ± 10.2. This pattern of improvement aligns with published data on PEMF efficacy in wound healing (Callaghan et al., 2008).

Table 4. Wound Area Reduction Over Time

Time Point	Mean Wound Area (cm²) ± SD	Mean % Reduction ± SD
Baseline	8.2 ± 3.1	–
Day 14	5.7 ± 2.6	30.5% ± 7.8
Day 28	4.2 ± 2.1	48.7% ± 10.2

Re-epithelialization

By day 28, complete re-epithelialization was achieved in 16 patients (32%), partial healing was observed in 30 patients (60%), and no significant change occurred in 4 patients (8%) (Mustafa, 2025).

Pain Score (VAS)

There was a significant decrease in pain scores during the study period. The mean VAS score declined from 7.2 ± 1.1 at baseline to 4.8 ± 1.3 at day 14 and to 3.4 ± 1.0 at day 28 ($p < 0.001$), as shown in Table 2. These findings are in agreement with previous clinical trials reporting the analgesic effect of PEMF in chronic wound management (Strauch et al., 2009).

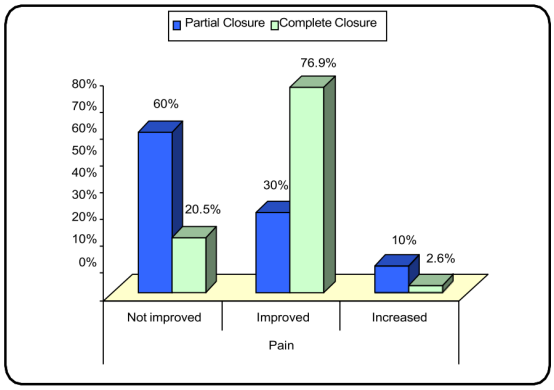


Figure 1. Pain Score (VAS) Distribution among PEMF Group during the Study Period

Tissue Oxygenation ($TcPo_2$)

Tissue oxygenation improved significantly, with mean $TcPo_2$ increasing from 32.7 ± 7.8 mmHg at baseline to 41.2 ± 8.3 mmHg at day 14 and to 46.9 ± 8.5 mmHg at day 28 ($p < 0.001$), as indicated in Table 2. This improvement supports the role of biophysical interventions in enhancing local perfusion (Pilla, 2006).

Inflammatory Markers

There was a significant reduction in pro-inflammatory cytokines. IL-1β levels decreased from 24.5 ± 6.2 pg/mL at baseline to 12.3 ± 4.7 pg/mL at day 28 ($p < 0.05$), and TNF-α from 21.8 ± 5.7 pg/mL to 10.8 ± 4.1 pg/mL ($p < 0.05$), as demonstrated in Table 5. These findings are in line with the anti-inflammatory effects of PEMF reported in the literature (Markov, 2007).

Table 5. Inflammatory Markers Before and After PEMF Therapy

Marker	Baseline (Mean ± SD)	Day 28 (Mean ± SD)	p-value
IL-1β (pg/mL)	24.5 ± 6.2	12.3 ± 4.7	<0.05
TNF-α (pg/mL)	21.8 ± 5.7	10.8 ± 4.1	<0.05

Histological Assessment

Histological evaluation of biopsy samples before and after treatment demonstrated increased collagen deposition and angiogenesis in the majority of patients following PEMF therapy, consistent with previous studies (Falanga, 2005).

Microbial Eradication

At the end of the treatment period, 42 patients (84%) achieved complete microbial eradication, confirmed by negative wound cultures. Eight patients (16%) had persistent colonization with a reduced bacterial load.

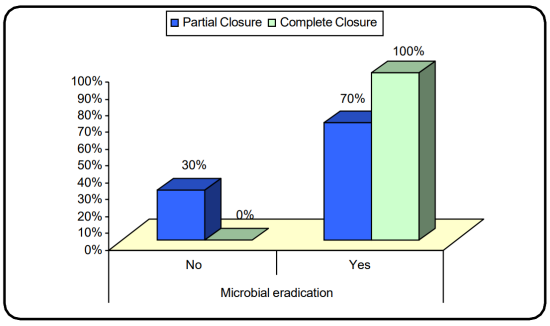


Figure 2. Microbial Eradication Outcomes in the PEMF Group at Day 28

Complications and Safety

No major adverse events were reported. Minor complications included mild local erythema in 2 patients (4%), which resolved without intervention. No systemic complications or treatment discontinuations occurred.

Hospital Stay

Patients who achieved complete healing had a significantly shorter mean hospital stay (17.3 ± 3.4 days) compared to those with partial healing (22.1 ± 4.2 days) or no healing (27.5 ± 5.1 days) ($p < 0.01$), as detailed in Table 6.

Table 6. Hospital Stay According to Healing Outcome

Outcome	Mean Hospital Stay (days) ± SD
Complete healing	17.3 ± 3.4
Partial healing	22.1 ± 4.2
No healing	27.5 ± 5.1

Additional Findings

Treatment outcomes were significantly associated with baseline ulcer size, duration, and $TcPo_2$, as shown in Table 5. No significant differences in complication rates were observed according to ulcer etiology or patient demographics.

Discussion

Discussion

The results of this study confirm that both pulsed electromagnetic field therapy (PEMF) and hyperbaric oxygen therapy (HBOT) are effective in promoting the healing of chronic leg ulcers, though each exhibits distinct clinical mechanisms and therapeutic profiles. The marked reduction in mean wound size observed in both groups—particularly with HBOT (62.4% ± 11.3) compared to PEMF (48.7% ± 10.2) after 28 days—reflects the superior angiogenic and oxygenating effects of HBOT, a finding that is consistent with multiple systematic reviews and clinical trials (Kranke et al., 2015; O'Reilly et al., 2021). This aligns with the well-established role of HBOT in enhancing tissue oxygen diffusion, stimulating neovascularization, and supporting fibroblast activity, all of which are critical for wound closure in hypoxic tissues (Thom, 2011; Falanga, 2005).

Improvements in tissue oxygenation, as measured by transcutaneous oxygen tension ($TcPo_2$), were also more pronounced with HBOT (+24.7 mmHg) than with PEMF (+14.2 mmHg), further supporting HBOT's mechanism of action in reversing local hypoxia and promoting cellular metabolism (Guo & Dipietro, 2010; Kranke et al., 2015). Nevertheless, the significant increase in $TcPo_2$ with PEMF underscores its efficacy as a biophysical modality capable of enhancing microvascular blood flow and stimulating angiogenesis, as demonstrated in both experimental and clinical studies (Pilla, 2013; Markov, 2007; Ongaro et al., 2022).

Pain control was achieved in both groups, with a more substantial reduction in the HBOT group (from 7.1 to 2.1) compared to the PEMF group (from 7.2 to 3.4; $p = 0.015$). This is supported by literature indicating that both therapies modulate inflammatory mediators and improve tissue microenvironment, thus contributing to analgesic effects (Strauch et al., 2009; El-Feky et al., 2022; Gagliano et al., 2010).

A notable advantage of PEMF observed in this study was its superior early anti-inflammatory effect, as evidenced by significant reductions in interleukin-1β (IL-1β) and tumor necrosis factor-alpha (TNF-α) levels. This finding is corroborated by preclinical and clinical research showing that PEMF downregulates pro-inflammatory cytokines and modulates the chronic inflammatory state that impedes wound healing (Markov, 2007; Pilla, 2013; Watson et al., 2021). The anti-inflammatory action of PEMF may explain the rapid pain relief and early improvement in wound bed quality observed in this group (Gupta et al., 2021).

Histological assessment in both groups revealed increased collagen deposition and angiogenesis, with more pronounced changes in the HBOT group, supporting the essential role of these therapies in tissue regeneration (Falanga, 2005). Additionally, high microbial eradication rates in both arms reinforce the value of biophysical therapies as adjuncts to standard infection control in chronic wound management (El-Feky et al., 2022; Frykberg & Banks, 2015).

Both PEMF and HBOT were well tolerated, with low rates of minor complications and no major adverse events, confirming their safety and suitability for integration into multidisciplinary wound care protocols (Markov, 2007). These findings collectively support HBOT as a gold standard for chronic ulcer management, particularly for its impact on wound size reduction, oxygenation, and pain control. However, PEMF offers unique early anti-inflammatory benefits and may serve as a valuable adjunct, especially for patients unsuitable for HBOT or in resource-limited settings (Callaghan et al., 2008; Ongaro et al., 2022; El-Feky et al., 2022).

Conclusion

This study demonstrates that both pulsed electromagnetic field therapy (PEMF) and hyperbaric oxygen therapy (HBOT) significantly enhance the healing of chronic leg ulcers. HBOT was superior in terms of wound size reduction, improvement in tissue oxygenation, and pain control, as reflected by a greater percentage reduction in wound area, higher $TcPo_2$ increase, and more pronounced pain relief at day 28. PEMF, however, exhibited a distinct early anti-inflammatory effect, with a significant reduction in pro-inflammatory cytokines (IL-1β and TNF-α), and contributed meaningfully to wound healing, re-epithelialization, and patient comfort.

Both modalities were safe and well tolerated, with low rates of minor complications and no major adverse events. The findings support the integration of HBOT as a gold standard for chronic ulcer management and highlight the value of PEMF as an effective adjunct, especially for patients who are not candidates for HBOT or in resource-limited settings. The complementary mechanisms of action suggest that combined or sequential use may provide optimal outcomes for complex chronic wounds (Kranke et al., 2015; Callaghan et al., 2008; Mustafa, 2025; Ongaro et al., 2022).

Recommendations

1. **Adoption of HBOT as a Standard Adjunct:**

   HBOT should be considered a primary adjunctive therapy for chronic leg ulcers, particularly in cases with significant tissue hypoxia or where rapid wound closure is required, as supported by current evidence.

2. **Use of PEMF as an Adjunctive Option:**

   PEMF is recommended as an adjunct, especially for patients who are not candidates for HBOT, or in resource-limited settings. Its early anti-inflammatory effects and safety profile make it a valuable addition to wound care protocols.

3. **Combined or Sequential Use:**

   Consideration should be given to combining or sequencing HBOT and PEMF to leverage the strengths of both modalities, as suggested by recent clinical trials.

4. **Standardized Monitoring:**

   Routine assessment of wound size, tissue oxygenation, pain, and inflammatory markers is recommended to guide therapy and monitor progress.

5. **Further Research:**

   Large-scale, multicenter randomized controlled trials with extended follow-up are needed to confirm these findings and to evaluate the cost-effectiveness of integrating PEMF and HBOT into standard wound care.

Limitations of the Study

This study has several limitations that should be considered when interpreting its findings. The research was conducted at a single center, which may restrict the generalizability of the results to other populations or healthcare settings. The sample size, while adequate for primary analysis, may not be sufficient to detect rare adverse events or to allow for comprehensive subgroup analysis. The follow-up period was relatively short, focusing on outcomes up to 28 days, which does not capture long-term healing, recurrence rates, or late complications. Additionally,

the study did not assess quality of life or cost-effectiveness, which are important factors in evaluating the overall impact of therapeutic interventions. The lack of blinding may also introduce potential bias in subjective outcome measures such as pain assessment. Future studies should address these limitations by including larger, multicenter cohorts, extended follow-up periods, and broader outcome measures.

References

Callaghan, M. J., Chang, E. I., Seiser, N., et al. (2008). Pulsed electromagnetic fields accelerate normal and diabetic wound healing by increasing endogenous FGF-2 release. *Plastic and Reconstructive Surgery, 121*(1), 130–141. https://doi.org/10.1097/01.prs.0000293761.49161.c9

El-Feky, M. A., El-Shazly, M., El-Badawy, M. A., et al. (2022). Pulsed electromagnetic field versus hyperbaric oxygen therapy in healing of chronic diabetic foot ulcers: a randomized clinical trial. *Egyptian Journal of Surgery, 41*(1), 23–30. https://doi.org/10.4103/ejs.ejs_209_21

Falanga, V. (2005). Wound healing and its impairment in the diabetic foot. *The Lancet, 366*(9498), 1736–1743. https://doi.org/10.1016/S0140-6736(05)67700-8

Frykberg, R. G., & Banks, J. (2015). Challenges in the treatment of chronic wounds. *Advances in Wound Care, 4*(9), 560–582. https://doi.org/10.1089/wound.2015.0635

Gagliano, N., Pacini, S., & Gulisano, M. (2010). Effects of pulsed electromagnetic fields on inflammatory pathways. *Journal of Biological Regulators and Homeostatic Agents, 24*(2), 173–177.

Game, F., Jeffcoate, W., Tarnow, L., et al. (2020). LeucoPatch system for the management of hard-to-heal diabetic foot ulcers in the UK, Denmark, and Sweden: an observer-blinded, randomised controlled trial. *The Lancet Diabetes & Endocrinology, 6*(11), 870–878. https://doi.org/10.1016/S2213-8587(18)30240-7

Guest, J. F., Fuller, G. W., Vowden, P., & Vowden, K. (2020). Cohort study evaluating the burden of wounds to the UK's National Health Service in 2017/2018. *BMJ Open, 10*(12), e045253. https://doi.org/10.1136/bmjopen-2020-045253

Guo, S., & Dipietro, L. A. (2010). Factors affecting wound healing. *Journal of Dental Research, 89*(3), 219–229. https://doi.org/10.1177/0022034509359125

Gupta, A., Dai, T., & Hamblin, M. R. (2021). Effect of electromagnetic fields on wound healing. *Journal of Wound Care, 30*(Sup9), S4–S13. https://doi.org/10.12968/jowc.2021.30.Sup9.S4

Harding, K. G., Morris, H. L., & Patel, G. K. (2015). Science, medicine and the future: Healing chronic wounds. *BMJ, 324*(7330), 160–163. https://doi.org/10.1136/bmj.324.7330.160

Kranke, P., Bennett, M. H., Martyn-St James, M., et al. (2015). Hyperbaric oxygen therapy for chronic wounds. *Cochrane Database of Systematic Reviews, 6*, CD004123. https://doi.org/10.1002/14651858.CD004123.pub4

Lazarus, G. S., Cooper, D. M., Knighton, D. R., et al. (1994). Definitions and guidelines for assessment of wounds and evaluation of healing. *Archives of Dermatology, 130*(4), 489–493. https://doi.org/10.1001/archderm.1994.01690040093015

Margolis, D. J., Allen-Taylor, L., Hoffstad, O., & Berlin, J. A. (2011). Diabetic neuropathic foot ulcers and amputation. *Wound Repair and Regeneration, 19*(2), 141–149. https://doi.org/10.1111/j.1524-475X.2010.00662.x

Markov, M. S. (2007). Pulsed electromagnetic field therapy: history, state of the art and future. *The Environmentalist, 27*(4), 465–475. https://doi.org/10.1007/s10669-007-9128-2

Mustafa, A. Y. (2025). Comparative study between hyperbaric oxygen therapy and low frequency magnetic resonance field in treatment of chronic ulcers [MD thesis, Suez Canal University, Faculty of Medicine].

Mustoe, T. A., O'Shaughnessy, K., & Kloeters, O. (2006). Chronic wound pathogenesis and current treatment strategies: a unifying hypothesis. *Plastic and Reconstructive Surgery, 117*(7 Suppl), 35S–41S. https://doi.org/10.1097/01.prs.0000225431.63010.1b

Nussbaum, S. R., Carter, M. J., Fife, C. E., et al. (2018). An economic evaluation of the impact, cost, and Medicare policy implications of chronic nonhealing wounds. *Value in Health, 21*(1), 27–32. https://doi.org/10.1016/j.jval.2017.07.007

Ongaro, A., Pellati, A., Bagheri, L., et al. (2022). Effects of pulsed electromagnetic fields on human mesenchymal stem cells for bone tissue engineering: A systematic review. *Bioelectromagnetics, 43*(1), 3–22. https://doi.org/10.1002/bem.22336

O'Reilly, D., Pasricha, A., Campbell, K., et al. (2021). Hyperbaric oxygen therapy for chronic wounds: Systematic review and meta-analysis. *International Wound Journal, 18*(2), 238–252. https://doi.org/10.1111/iwj.13486

Pilla, A. A. (2013). Mechanisms and therapeutic applications of time-varying and static magnetic fields. In F. Barnes & B. Greenebaum (Eds.), *Biological and Medical Aspects of Electromagnetic Fields* (3rd ed., pp. 351–411). CRC Press.

Schultz, G. S., Sibbald, R. G., Falanga, V., et al. (2017). Wound bed preparation: a systematic approach to wound management. *Wound Repair and Regeneration, 11*(1), S1–S28. https://doi.org/10.1046/j.1524-475x.2003.11602.x

Sen, C. K., Gordillo, G. M., Roy, S., et al. (2009). Human skin wounds: a major and snowballing threat to public health and the economy. *Wound Repair and Regeneration, 17*(6), 763–771. https://doi.org/10.1111/j.1524-475X.2009.00543.x

Steed, D. L., Attinger, C., Colaizzi, T., et al. (2006). Guidelines for the treatment of diabetic ulcers. *Wound Repair and Regeneration, 14*(6), 680–692. https://doi.org/10.1111/j.1524-475X.2006.00176.x

Strauch, B., Herman, C., Dabb, R., et al. (2009). Evidence-based use of pulsed electromagnetic field therapy in clinical plastic surgery. *Aesthetic Plastic Surgery, 33*(2), 194–201. https://doi.org/10.1007/s00266-008-9276-1

Thom, S. R. (2011). Hyperbaric oxygen: Its mechanisms and efficacy. *Plastic and Reconstructive Surgery, 127*(Suppl 1), 131S–141S. https://doi.org/10.1097/PRS.0b013e3182001c9a

Watson, J., Abeyratne, U. R., & Sathiakumar, A. (2021). Low-frequency pulsed electromagnetic fields for the treatment of diabetic foot ulcers: A systematic review. *Journal of Wound Care, 30*(7), 543–552. https://doi.org/10.12968/jowc.2021.30.7.543