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Effectiveness of Exercise Interventions for Diabetic Foot Ulcer Healing: A Systematic Review

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Abstract

Background: Diabetic foot ulcer is a serious complication of diabetes mellitus that is frequently associated with delayed wound healing, infection, and an increased risk of lower-limb amputation. Despite standard wound care and off-loading, outcomes often remain suboptimal, prompting interest in exercise as an adjunct therapy.

Objective: This systematic review evaluated the effectiveness of exercise interventions on wound-healing outcomes in patients with diabetic foot ulcers.

Methods: PubMed, Scopus, Google Scholar, and Semantic Scholar were searched for randomized controlled trials and controlled clinical trials of structured exercise in adults with diabetic foot ulcers. Two reviewers independently screened studies and extracted data. Methodological quality was assessed using the Physiotherapy Evidence Database (PEDro) scale. Because of heterogeneity, results were synthesized narratively.

Results: Five studies with intervention durations of 8–12 weeks were included. Non–weight-bearing aerobic exercise and structured foot exercises generally produced greater wound-area reduction and/or faster healing progression than standard care, with several trials reporting significant between-group differences ($p < 0.05$). Resistance training and passive lower-limb movement exercises yielded mixed results and were often non-significant for wound closure, although some studies reported improvements in metabolic or perfusion-related outcomes.

Conclusion: Exercise may be a feasible adjunct to standard diabetic foot ulcer care, particularly non–weight-bearing aerobic and structured foot exercise programs; however, evidence is heterogeneous and of low-to-moderate methodological quality, supporting the need for well-designed trials with standardized outcome reporting.

Keywords
Diabetic Foot; Exercise Therapy; Wound Healing; Physical Activity; Rehabilitation.

Introduction

Diabetes mellitus is a global health problem with a continuously increasing prevalence and a substantial contribution to chronic complications, one of the most serious being diabetic foot ulcer (DFU).[1] The International Diabetes Federation (IDF) estimates that the number of people living with diabetes will exceed 640 million by 2040, positioning diabetes as one of the greatest public health challenges of the 21st century.[2] DFU is a severe complication commonly associated with peripheral neuropathy, vascular impairment, and delayed wound healing, leading to an increased risk of infection, lower-limb amputation, and reduced quality of life.[3,4] Despite the development of various wound-care strategies, DFU healing remains a complex and persistent clinical challenge.[5]

Standard DFU management generally includes glycemic control, structured wound care, infection management, and off-loading strategies to reduce plantar pressure.[6] However, these approaches are often insufficient to optimize wound healing, particularly in patients with impaired peripheral perfusion and limited mobility.[7] Other studies have also shown that advanced adjunctive therapy and revascularization techniques are used to maximize wound healing when routine diabetic foot ulcer (DFU) therapy is inadequate, especially when peripheral perfusion is impaired and movement is limited.[8] Consequently, additional interventions that are safe, feasible, and easily integrated into routine care are required to support optimal DFU healing.[9]

Physical exercise has been widely investigated as part of diabetes management due to its established benefits in improving insulin sensitivity, blood circulation, and vascular function. In the context of DFU, physical exercise particularly non-weight-bearing modalities is hypothesized to provide additional benefits by enhancing peripheral perfusion and metabolic conditions without imposing excessive mechanical stress on the ulcerated area.[10,11] Several interventional studies have reported improvements in wound-healing outcomes when exercise is implemented as an adjunct to standard care, although findings across studies remain inconsistent.[12]

The types of exercise evaluated in DFU populations are highly heterogeneous, ranging from supervised aerobic exercise and structured foot exercises to lower-extremity resistance training, passive movement, and postural exercises.[12] Variability in study design, patient characteristics, intervention duration, and outcome measures contributes to substantial heterogeneity in reported results, complicating the formulation of definitive conclusions regarding the effectiveness of physical exercise on DFU healing.

Although previous reviews have addressed the role of physical activity in patients with diabetes in general, systematic reviews that specifically evaluate the effectiveness of different exercise modalities on DFU-related wound-healing outcomes remain limited. Furthermore, the methodological quality and consistency of outcome reporting among available primary studies vary considerably, underscoring the need for a more focused and critical synthesis of the existing evidence.[13]

Therefore, this systematic review was conducted to evaluate the effectiveness of various forms of physical exercise in supporting the healing of diabetic foot ulcers. This review aims to identify the most effective exercise modalities, assess their safety and feasibility for clinical implementation, and clarify the extent to which physical exercise provides clinically meaningful benefits. The

findings of this synthesis are expected to inform healthcare professionals in designing evidence-based exercise programs integrated into comprehensive DFU management, with the potential to reduce amputation rates and improve patient quality of life.

Methods

This study was conducted as a systematic review to evaluate the effectiveness of exercise interventions on wound-healing outcomes in patients with diabetic foot ulcers. The preparation and reporting of this review followed the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) 2020 guidelines to ensure transparency, methodological rigor, and reproducibility. The research question, eligibility criteria, search strategy, and data synthesis approach were defined a priori to minimize the risk of selective reporting.

Study Design and Protocol Registration

The review employed a systematic review design focusing on randomized controlled trials and controlled clinical trials investigating exercise-based interventions in individuals with diabetic foot ulcers. The study protocol was not registered in the International Prospective Register of Systematic Reviews (PROSPERO) or the Open Science Framework. This decision was based on the timing of protocol development; however, all methodological steps, including inclusion criteria and planned analyses, were determined before the literature search commenced to enhance transparency and methodological consistency.

Data Sources and Search Strategy

A comprehensive literature search was conducted across multiple electronic databases, including PubMed and Scopus as the primary sources because of their extensive coverage of biomedical and clinical research. Google Scholar and Semantic Scholar were additionally searched as supplementary sources to identify potentially relevant studies not indexed in the primary databases. The search strategy was developed using combinations of keywords and controlled vocabulary related to diabetic foot ulcers, physical exercise, and wound healing. Boolean operators were applied to optimize sensitivity and specificity, and search syntax was adapted to the requirements of each database.

In PubMed, the search combined Medical Subject Headings and free-text terms related to diabetic foot ulcers, exercise, and wound healing. In Scopus, searches were conducted within the title, abstract, and keyword fields using equivalent terms. Searches in Google Scholar and Semantic Scholar employed free-text keywords with similar conceptual combinations. Although minor variations in syntax were necessary across databases, the core search concepts were consistently maintained. Detailed search strategies for each database are provided in Appendix A.

Eligibility Criteria

Studies were included if they met the following criteria: publications written in English or Indonesian; randomized controlled trials or controlled clinical trials; study populations consisting of adults with diabetes mellitus and active diabetic foot ulcers; interventions involving structured physical exercise, including aerobic exercise, walking programs, resistance training, combined exercise programs, or passive lower-extremity exercise; and reporting outcomes directly related to wound healing, such as wound area reduction, time to healing, healing progression, or perfusion-related parameters. Studies were excluded if they were observational in design without an exercise intervention, review articles or editorials, studies focusing solely on biochemical or laboratory outcomes without wound-healing endpoints, or articles for which the full text was unavailable.

Study Selection

The study selection process was performed independently by two reviewers to reduce selection bias. Initially, titles and abstracts of all identified records were screened for relevance according to the predefined eligibility criteria. Full-text articles were subsequently retrieved and assessed for eligibility. Any disagreements between reviewers during the screening or eligibility assessment phases were resolved through discussion until consensus was achieved. The overall selection process, including the number of records identified, screened, excluded, and included, was documented using a PRISMA flow diagram.

Assessment of Methodological Quality

The methodological quality and risk of bias of the included studies were assessed using the Physiotherapy Evidence Database (PEDro) scale. This tool was selected because it is specifically designed to evaluate internal validity and statistical reporting quality in trials involving physiotherapy and exercise interventions. Each randomized controlled trial was assessed across 11 PEDro criteria, including random allocation, baseline comparability, blinding procedures, adequacy of follow-up, intention-to-treat analysis, and completeness of outcome reporting. Scores were calculated based on items 2 through 11, yielding a total score ranging from 0 to 10, with higher scores indicating better methodological quality. The quality assessment was conducted independently, and discrepancies were resolved through discussion.

Data Extraction

Data extraction was performed independently by the reviewers using a standardized framework based on the Population, Intervention, Comparison, and Outcome (PICO) approach. Extracted data included study characteristics, participant demographics, ulcer classification, details of the exercise intervention, intervention duration and frequency, comparator conditions, outcome measures, and main findings related to wound healing. This structured approach facilitated systematic comparison across studies and supported the narrative synthesis of results.

Data Synthesis

Because of substantial heterogeneity in exercise modalities, intervention duration, participant characteristics, and outcome measures across the included studies, a quantitative meta-analysis was not conducted. Instead, findings were synthesized narratively by comparing and summarizing results across studies, with attention to patterns of effectiveness associated with different types of exercise interventions. The narrative synthesis focused primarily on wound-healing outcomes while also considering relevant secondary outcomes reported in the included studies.

Ethics Considerations

As this study was a systematic review of previously published data, ethical approval was not required. No individual patient data were collected, and all analyses were based on information available in the public domain.

Results

Study Selection

The database search identified 260 records. After removal of 60 duplicates, 200 records were screened based on titles and abstracts. Of these, 182 records were excluded because they did not meet the inclusion criteria, primarily due to the absence of exercise interventions or wound-healing outcomes. Eighteen full-text articles were assessed for eligibility, and 13 were excluded because they did not evaluate structured exercise interventions or failed to report relevant outcomes. Ultimately, five studies met all inclusion criteria and were included in the qualitative synthesis. The study selection process is presented in the PRISMA flow diagram (Figure 1).

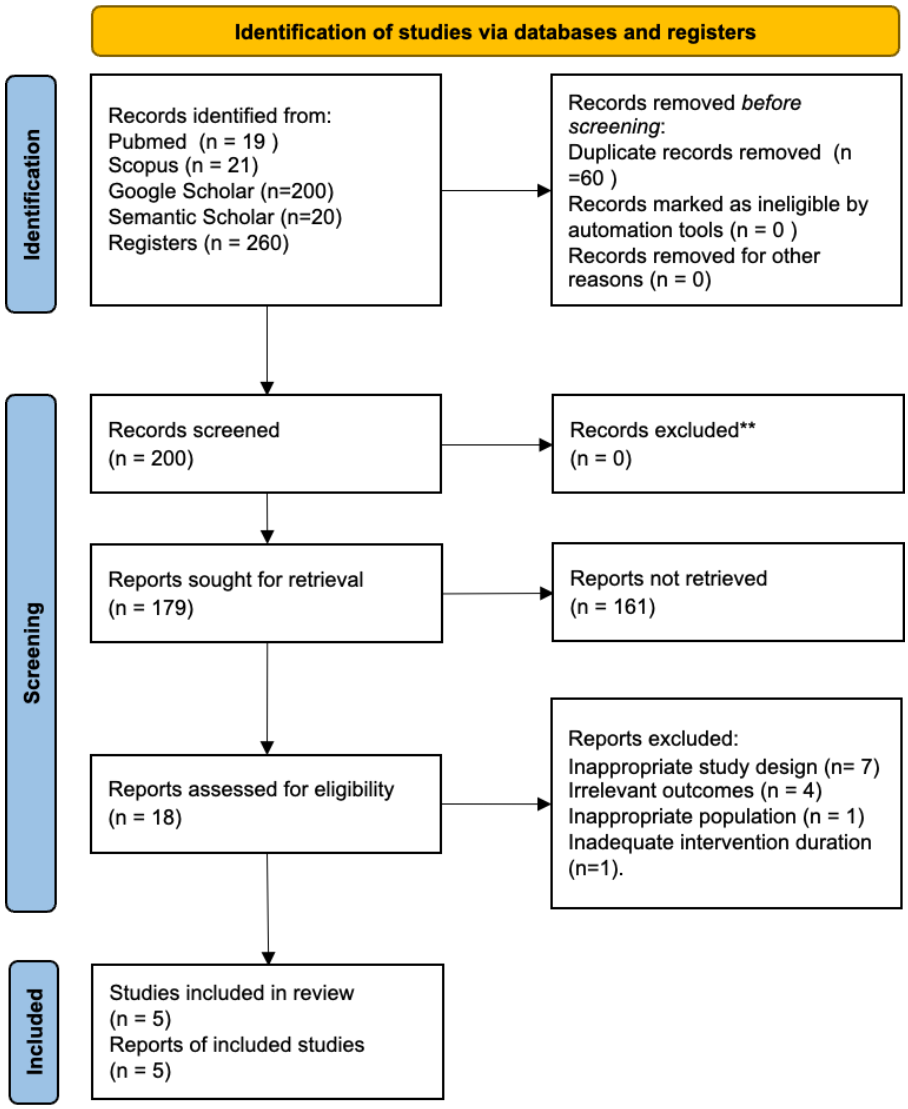

Figure 1. PRISMA Flow Chart

Characteristics of Included Studies

Five studies were included, comprising three randomized controlled trials and two controlled clinical trials. The studies were conducted in Asia, Europe, and Africa and involved adult patients with diabetes mellitus presenting with diabetic foot ulcers, predominantly Wagner grade 1–2. Sample sizes ranged from 18 to 61 participants. Exercise interventions varied and included non–weight-bearing aerobic exercise, structured foot exercises, lower-limb resistance training with breathing regulation, passive lower-limb movement, and Buerger–Allen exercise. Comparator groups received standard wound care or routine ulcer management. Detailed study characteristics are summarized in Table 1.

Table 1. Characteristics of Included Studies

Study (Year)	Country	Study Design	Sample Size (I/C)	DFU Severity	Exercise Intervention	Duration	Comparator	Primary Outcomes
Eraydin & Avşar (2018)	Turkey	RCT	30 (15/15)	Wagner 1–2	Non–weight-bearing foot exercises	12 weeks	Standard care	Wound area, healing rate
Nwankwo et al. (2014)	Nigeria	RCT	61 (31/30)	DFU ≥30 days	Aerobic exercise (cycle ergometer)	12 weeks	Routine care	Wound area, glucose
Jørgensen et al. (2016)	Denmark	CCT	18 (9/9)	Mixed	Passive lower-limb movement	8 weeks	Usual care	Wound area, epithelialization
Padma Priya et al. (2025)	India	RCT	60 (30/30)	Neuropathic DFU	Buerger–Allen exercise	4 weeks	Routine care	Wound healing score
Wu et al. (2025)	Taiwan	RCT	59 (31/28)	Wagner 1–2	Resistance training + breathing regulation	12 weeks	Standard treatment	Wound size, QoL

Methodological Quality of Included Studies

Methodological quality assessed using the Physiotherapy Evidence Database (PEDro) scale indicated low-to-moderate quality across the included studies, with total scores ranging from 3 to 4. Common methodological limitations included the absence of allocation concealment, lack of participant and therapist blinding, and the absence of intention-to-treat analysis. All studies reported between-group comparisons and provided point estimates with measures of variability. Detailed PEDro scores are presented in Table 3.

Effects of Exercise on Wound-Healing Outcomes

Across the five studies, exercise interventions demonstrated heterogeneous effects on wound-healing outcomes. Three studies reported statistically significant improvements, while two studies showed favorable but non-significant trends. Structured foot exercises and Buerger–Allen exercise were associated with the most consistent improvements in wound-healing outcomes. Aerobic exercise produced variable effects, with greater wound area reduction observed but inconsistent statistical significance. Resistance training improved metabolic and quality-of-life outcomes without significantly affecting wound size. Passive lower-limb movement resulted in numerical wound reduction that did not reach statistical significance.
A summary of exercise effects on wound-healing outcomes is provided in Table 2.

Table 2. Summary of Exercise Effects on Wound-Healing Outcomes

Study	Exercise Type	Wound Area Reduction	Healing Rate / Closure	Statistical Significance
Eraydin & Avşar	Foot exercises	Significant reduction	Faster healing progression	Yes
Nwankwo et al.	Aerobic exercise	Large reduction	Not reported	Partial
Jørgensen et al.	Passive movement	Moderate reduction	Increased epithelialization	No
Padma Priya et al.	Buerger–Allen	Reduced size & depth	Improved healing score	Yes
Wu et al.	Resistance training	No significant change	Not reported	No

Table 3. Methodological Quality of Included Studies Assessed Using the PEDro Scale

PEDro Item	Wu & Yeh (2025)	Nwankwo (2014)	Jørgensen (2016)	Eraydin & Avşar (2018)	Ajith (2025)
Eligibility criteria specified*	Yes	Yes	Yes	Yes	Yes
Random allocation	Yes	Yes	Yes	Yes	Yes
Allocation concealed	No	No	No	No	No
Groups similar at baseline	No	No	Yes	Yes	No
Blinding of subjects	No	No	No	No	No
Blinding of therapists	No	No	No	No	No
Blinding of assessors	No	No	Yes	No	No
Adequate follow-up (>85%)	No	No	No	Yes	No
Intention-to-treat analysis	No	No	No	No	No
Between-group comparisons	Yes	Yes	Yes	Yes	Yes
Point estimates and variability	Yes	Yes	Yes	Yes	Yes
Total PEDro score (2–11)	4	3	4	4	3

*Item 1 is not included in the total PEDro score.

Adverse Events

None of the included studies reported adverse events directly attributable to the exercise interventions. Events such as infection or amputation occurred in both intervention and control groups and were not considered related to exercise participation.

Discussion

This systematic review synthesizes current evidence regarding the role of physical exercise as a supportive intervention for wound healing in patients with diabetic foot ulcers (DFUs).[14] Overall, the findings indicate that structured exercise interventions show potential to support wound-healing processes and improve peripheral perfusion, metabolic control, and quality of life when implemented alongside standard DFU care.[15] However, the magnitude and consistency of these effects vary across exercise modalities and study designs.[16,17]

Non–weight-bearing aerobic exercise demonstrated a tendency toward greater reductions in wound area compared with standard care, although statistical significance was not consistently achieved across studies.[14,18] These findings suggest that aerobic exercise performed without plantar loading may create a more favorable physiological environment for wound healing without increasing mechanical stress on ulcerated tissue.[19] Nevertheless, these benefits were observed within supervised and structured programs, indicating that careful monitoring and individualized prescription are essential for clinical application.

Structured foot exercises showed more consistent improvements in wound-healing progression, particularly in patients with Wagner grade 1–2 DFUs.[19] Exercises targeting distal lower-extremity mobility may enhance local circulation and tissue function, thereby supporting healing.[20,21] Despite favorable outcomes, heterogeneity in outcome measures and intervention protocols limits direct comparison with other exercise modalities. Significant improvement in muscle stiffness among those performing toe exercises.[21]

Passive lower-limb movement exercises yielded mixed results. Although greater numerical reductions in wound area were observed in intervention groups, these differences did not consistently reach statistical significance.[22] Nonetheless, the absence of adverse events and good tolerability suggest that passive exercise may represent a feasible supportive option for patients with limited mobility or higher risk profiles.[19]

Lower-limb resistance training did not demonstrate significant short-term effects on wound size; however, consistent improvements in glycemic control and quality of life were reported.[11] These systemic benefits may indirectly contribute to improved wound-healing capacity over longer follow-up periods, even if immediate effects on wound closure are not evident.[23]

Evidence from a limited number of controlled studies evaluating Buerger–Allen exercise suggests potential benefits in wound-healing scores and peripheral circulation.[24] However, interpretation of these findings should be cautious due to methodological limitations and the use of score-based outcomes rather than objective wound-area measurements.[25] Consequently, such findings should be considered supportive rather than definitive.

The heterogeneity observed across studies in terms of exercise type, intervention duration, sample characteristics, and outcome measures precluded quantitative synthesis and underscores the need for individualized exercise prescription in DFU management.[26] Exercise selection should consider ulcer severity, functional capacity, and the risk of mechanical loading.[27]

Several limitations should be acknowledged. The number of included studies was limited, with small to moderate sample sizes and variable methodological quality. Outcome heterogeneity prevented meta-analysis, and the absence of prospective protocol registration may increase the risk of reporting bias, although all methods were predefined prior to literature screening.

Conclusion

This systematic review evaluated the effectiveness of exercise interventions as adjunctive strategies for wound healing in patients with diabetic foot ulcers. Overall, the findings indicate that physical exercise may play a supportive role in enhancing wound-healing outcomes when integrated with standard diabetic foot ulcer care. Among the exercise modalities examined, structured foot exercises and Buerger–Allen exercise demonstrated the most consistent benefits, particularly in terms of wound-healing progression, reductions in wound size and depth, and improvements in perfusion-related indicators. These interventions appear to be especially relevant for patients with mild to moderate diabetic foot ulcers, as they enhance lower-extremity circulation while minimizing mechanical stress on the ulcerated area.

In contrast, aerobic and resistance-based exercise interventions produced more variable effects on direct wound-healing outcomes. While non–weight-bearing aerobic exercise was associated with favorable trends in wound area reduction, statistically significant effects were not consistently observed across studies. Resistance training and passive lower-limb movement exercises primarily yielded indirect benefits, such as improvements in metabolic control, peripheral perfusion, or quality of life, rather than clear short-term effects on wound closure. These findings suggest that exercise modality, loading characteristics, and intervention duration are critical determinants of clinical effectiveness in this population.

Despite the potential benefits observed, the overall quality of evidence remains limited by methodological weaknesses, small sample sizes, heterogeneity in outcome measures, and inconsistent reporting of standardized effect sizes. Consequently, current evidence is insufficient to recommend a single exercise modality as a standalone intervention for diabetic foot ulcer healing. From a clinical perspective, exercise should be considered a complementary component of multidisciplinary diabetic foot ulcer management and should be individualized according to patient condition, ulcer severity, and risk profile, with appropriate professional supervision.

Future research should focus on high-quality randomized controlled trials with larger samples, standardized and objective wound-healing outcomes, longer follow-up periods, and rigorous methodological reporting. Such efforts are essential to strengthen the evidence base and to inform clear, evidence-based guidelines for exercise prescription in the management of diabetic foot ulcers.

Author Contribution

Conceptualization: Nadiya Izzatul Jannah.
Methodology: Nadiya Izzatul Jannah.
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Writing—review and editing: Nadiya Izzatul Jannah.
Supervision: Nadiya Izzatul Jannah.

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Conflict of Interest Statement

The author declares no conflict of interest.

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Ethics Statement

Ethical approval was not required for this study because it was a systematic review of previously published data and did not involve the collection of new data from human participants.

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