RESEARCH PAPER

Impact of Resistance Training with and without Venous Occlusion on Strength and Function Post Hand Burn: An Open-Label Randomized Controlled Trial

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ABSTRACT
Background: Hand burns result in substantial deficits in muscle strength, dexterity, and functional independence, making effective rehabilitation essential. Resistance exercise is a key component of post-burn recovery; however, conventional training is often constrained by the high mechanical loads required. Blood flow restriction (BFR) training has emerged as a potential adjunct that promotes neuromuscular adaptations at lower loads. Methods: This open-label randomized controlled trial included 34 patients with second- and third-degree hand burns after complete wound healing, randomly allocated to two groups. Group A (n = 17) received conventional therapy combined with handgrip resistance training without venous occlusion, while Group B (n = 17) received conventional therapy combined with handgrip resistance training under venous occlusion (60 mmHg cuff pressure, 60% maximal voluntary contraction, 20 minutes/session, three sessions/week for four weeks). Primary outcome was hand grip strength measured using an electronic dynamometer. Upper limb function assessed with the QuickDASH questionnaire was the secondary outcome. Results: Both groups showed significant post-intervention improvements in grip strength and QuickDASH scores ($p < 0.001$). Group A improved grip strength by 138.65% and QuickDASH by 48.93%, whereas Group B achieved gains of 178.46% and 64.85%, respectively. Between-group comparisons revealed significantly superior outcomes in Group B for both grip strength and function ($p < 0.01$). Conclusion: Resistance training effectively improves hand strength and function following burn injury, with venous occlusion providing additional benefits. BFR is a clinically relevant adjunct to post-burn rehabilitation after wound closure, enhancing recovery while reducing mechanical load demands.

Keywords: Blood flow restriction; Hand burn; Hand grip; Resistance exercise; Venous occlusion
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1.INTRODUCTION

Burn injuries disrupt patients' lives both physically and psychologically. Although advances in acute burn care have significantly reduced mortality rates, morbidity remains substantial—particularly when the hands are involved. The American Burn Association classifies hand burns as serious injuries because of their profound functional consequences, with the hands affected in approximately 80–90% of severe burn cases (Watzinger et al., 2024). Despite accounting for less than 5% of total body surface area, hand injuries can result in disproportionate functional loss, severely compromising independence. Activities of daily living such as bathing, dressing, eating, and social interaction become challenging due to the superficial location and vulnerability of critical anatomical structures, including nerves, muscles, ligaments, tendons, and joints (Lin et al., 2013).

Hand burn trauma significantly affects patients' life roles, particularly employment and participation in daily activities. Early and structured rehabilitation is therefore essential to preserve mobility, prevent contractures, and restore hand function with optimal cosmetic outcomes. Rehabilitation aims to reduce edema and pain, maintain muscle strength, improve joint range of motion, and prevent deformities, thereby supporting functional recovery, social reintegration, and return to work (Kara et al., 2023). Given the hand's intricate anatomy and its essential role in environmental interaction, even minor impairments can result in substantial disability (Lacoursière et al., 2023). Common post-burn complications—such as claw hand, web space contractures, thumb-in-palm deformity, tendon adhesions, boutonniere deformity, nerve compression syndromes, and heterotopic ossification—can further compromise functional outcomes and negatively affect psychological well-being and quality of life (Choi et al., 2011).

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The hand serves complex sensory and motor functions, acting as an extension of the central nervous system while enabling precise and powerful movements. Grip strength and object manipulation are fundamental to daily functioning, and prolonged impairment can lead to long-term disability and occupational limitations (Araujo et al., 2012). Although hand burns are rarely life-threatening, they frequently result in edema, contractures, deformities, sensory deficits, and reduced skin integrity, all of which necessitate specialized rehabilitation. These impairments are associated with delayed return to work, increased healthcare and employer costs, and reduced workforce reintegration (Lin et al., 2012).

Resistance training is a cornerstone of burn rehabilitation, aimed at improving muscle strength, restoring functional capacity, and preventing long-term disability. It facilitates recovery of mobility and enhances performance in activities of daily living. However, conventional resistance training presents challenges in clinical settings, including difficulty in applying consistent and quantifiable loads, therapist fatigue, and limited patient engagement. Common alternatives, such as elastomeric resistance tools, lack precise load measurement and may become monotonous, reducing adherence (Park et al., 2019). Moreover, repetitive dynamic or static resistance exercises increase muscle fluid content, elevating intramuscular pressure and enhancing capillary perfusion even at low contraction intensities (Yamauchi & Hargens, 2008).

Blood flow restriction (BFR) training has emerged as a promising rehabilitation strategy capable of inducing significant muscular adaptations using low mechanical loads. By partially restricting venous outflow, BFR creates a hypoxic and metabolically stressful environment that stimulates hypertrophy and strength gains comparable to those achieved with high-intensity resistance training (Wortman et al., 2021). The ischemic conditions induced during BFR exercise promote metabolite accumulation, muscle cell swelling, anabolic signaling, increased fiber recruitment, and elevated lactate levels, collectively enhancing muscle mass and strength while minimizing joint stress (Franz et al., 2022; Hornikel et al., 2023; Watson et al., 2022).

Despite these promising physiological mechanisms, quantitative evidence comparing resistance exercise with and without venous occlusion in burn rehabilitation—particularly for hand and wrist injuries—remains limited. Therefore, this study was designed to compare the therapeutic outcomes of conventional resistance training and resistance training combined with blood flow restriction, with a specific focus on handgrip strength and functional recovery following hand and wrist burns.

2. MATERIALS AND METHODS

2.1. Research Design

This study was conducted as an open-label randomized controlled trial designed to evaluate the therapeutic outcomes of resistance exercise with and without venous occlusion in patients with hand burns.

2.2. Participants

Thirty-four patients with hand burns were recruited after complete wound healing. Participants were aged 17–70 years (21 males, 13 females) and had second- or third-degree thermal burns involving the hand. Patients were recruited from Om Elmasryeen Hospital and the Mansoura Educational Hospital Clinic and were randomly allocated into two equal groups (17 patients per group). Eligibility criteria included patients of either sex with thermal hand burns involving less than 60% of total body surface area (TBSA), reduced hand grip strength, resting blood pressure <140/90 mmHg, resting heart rate <90 bpm, and the ability to understand and comply with study procedures. Only patients with second- or third-degree burns were included. Patients were excluded if they had cardiovascular, metabolic, or pulmonary disease; resting blood pressure ≥140/90 mmHg; injuries limiting exercise participation (e.g., fractures, amputations, brain or peripheral nerve injuries); first- or fourth-degree burns; severe burns involving tendon or muscle damage; finger amputation; previous injuries or congenital hand deformities affecting function; non-compliance with monthly follow-up; or were taking medications that could influence hemodynamic responses.

2.3. Ethics Approval

The study was approved by the Ethics Review Committee of the Faculty of Physical Therapy, Cairo University, Egypt (Approval No. P.T.REC/012/006079). In addition, the trial was prospectively registered with ClinicalTrials.gov under the Protocol Registration and Results System (PRS) (Identifier: NCT07228780).

2.4. Sample Size

Sample size estimation was performed using G*Power software version 3.1.9.7. The calculation indicated that a total sample of 34 patients (17 per group) was required to detect a statistically significant difference between groups. The calculation was based on a significance level of p = 0.05, statistical power of 80%, a moderate effect size of 0.503, and a MANOVA repeated-measures design with within–between interaction.

2.5. Randomization

Participants were randomly assigned to one of two groups using a simple 1:1 randomization ratio based on the predetermined sample size. Allocation was performed by an independent investigator. Group assignments were concealed using sealed, opaque envelopes containing group codes to minimize allocation bias.

2.6. Outcome Measurements

Outcome measures were assessed at two time points: baseline (pre-intervention) and after completion of the four-week intervention period.

Primary Outcome: Hand Grip Strength

Hand grip strength was measured using an electronic handheld dynamometer (EH1006). Participants were seated with the tested arm positioned alongside the body, the elbow flexed at 90°, and the hand holding the dynamometer in a neutral position, while the contralateral hand rested on the thigh or beside the participant. Three maximal voluntary contractions were performed, each lasting 3 seconds, with 30-second rest intervals between trials. The mean value of the three trials was used for statistical analysis (Costa et al., 2017).

Secondary Outcome: Hand and Upper Limb Function

Upper limb functional performance was evaluated using the Quick Disabilities of the Arm, Shoulder, and Hand (QuickDASH) questionnaire. This validated 11-item instrument assesses upper extremity disability and symptoms. The first six items address difficulty performing physical activities, while the remaining five items assess sleep quality, social and daily activities, and the severity of pain and numbness. Scores range from 0 to 100, with higher scores indicating greater disability and lower scores reflecting better functional performance (Gummesson et al., 2006).

2.7. Intervention

Patients in both groups received conventional physical therapy, including active and passive range-of-motion exercises for the wrist and hand, soft tissue stretching, edema management, scar mobilization, and functional hand exercises (Pector.,2010), in addition to their respective resistance training programs as follows:

Group A (Control Group: Resistance Exercise without Venous Occlusion)

Participants in the control group performed dynamic and static handgrip exercises targeting grip strength. Training consisted of six sets of 30-second contractions with 10-second rest intervals. Dynamic exercises involved repetitive gripping and relaxation at maximal frequency. Sessions were conducted three times per week for four consecutive weeks (Bryant et al., 2023).

Group B (Experimental Group: Resistance Exercise with Venous Occlusion)

Participants in the experimental group performed handgrip exercises using an electronic hand dynamometer (EH1006) at 60% of maximum voluntary contraction (MVC) for 20 minutes per session, three times per week for four weeks (12 sessions). Venous occlusion was applied using a blood pressure cuff around the cubital fossa, inflated to 60 mmHg throughout the exercise session. One-minute rest periods were allowed after every 5 minutes of exercise while the cuff remained inflated (Credeur et al.,2010).

All sessions for both groups were conducted under standardized conditions and supervised by the same physical therapist. Exercise intensity was individually adjusted based on baseline grip strength, participants were instructed to avoid compensatory movements, and any adverse effects were monitored and recorded throughout the intervention period.

2.8. Statistical Analysis

Statistical analysis was performed using the Statistical Package for Social Sciences (SPSS) version 27 for Windows (IBM SPSS, Chicago, IL, USA). An unpaired t-test was used to compare age, TBSA, and onset of physiotherapy between groups, while the chi-square test was used to compare sex distribution, degree of burn, and affected side. Normality of data distribution was assessed using the Shapiro–Wilk test, and homogeneity of variances was examined using Levene's test. Between-group comparisons of hand grip strength and QuickDASH scores were conducted using unpaired t-tests, while within-group pre- and post-treatment comparisons were analyzed using paired t-tests. The level of statistical significance was set at $p < 0.05$.

3. RESULTS:

Figure 1 depicts the flowchart of patient progression throughout the study. A total of 41 patients with second- and third-degree thermal hand burns were screened for inclusion. Of these, six participants did not meet the eligibility criteria, and one withdrew from the study. Consequently, 34 participants were deemed eligible and were randomly assigned into two groups. No participants experienced or reported any adverse effects during or after the intervention period.

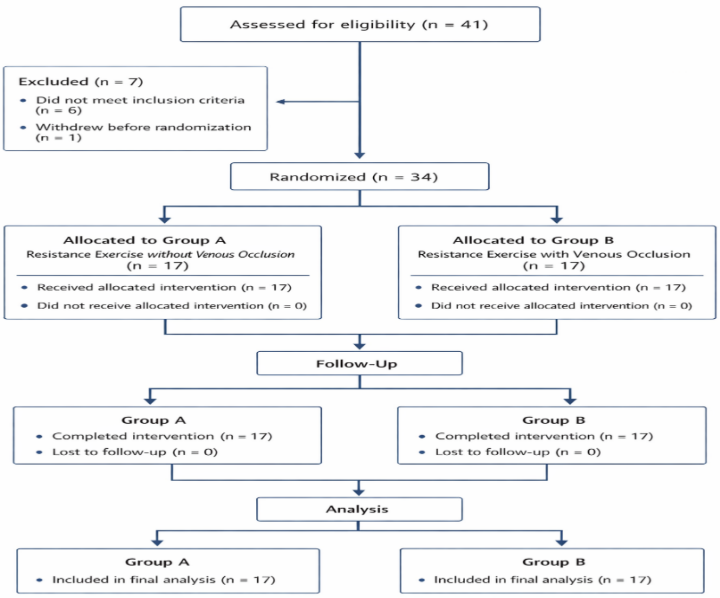

Figure 1. The flowchart of the trial.

3.1. Subject characteristics

Table (1) shows the subject characteristics of group A and B. There was no significant difference between groups in age, TBSA, onset of physiotherapy post burn, sex, degree of burn and affected hand distribution (p > 0.05).

Table 1. Subject characteristics.

	Group A	Group B	MD	t- value	p-value
	Mean ± SD	Mean ± SD			
Age (years)	37.00 ± 14.13	36.94 ± 15.18	0.06	0.01	0.99
TBSA (%)	22.41 ± 13.66	23.18 ± 14.18	-0.77	-0.16	0.87
Onset of physiotherapy post burn (weeks)	3.76 ± 0.97	3.94 ± 1.03	-0.18	-0.51	0.61
Sex, n (%)					
Females	6 (35%)	7 (41%)		$\chi^2 = 0.13$	0.72
Males	11 (65%)	10 (59%)			
Degree of burn, n (%)					
2nd degree	13 (76%)	15 (88%)		$\chi^2 = 0.81$	0.37
3rd degree	4 (24%)	2 (12%)			
Affected hand, n (%)					
Dominant hand	13 (76%)	14 (82%)		$\chi^2 = 0.18$	0.67
Non dominant hand	4 (24%)	3 (18%)			

SD, standard deviation; MD, mean difference; χ2, Chi squared value; p-value, level of significance

3.2. Effect of treatment on hand grip strength and quick DASH

- Within group comparison:

There was a significant increase in hand grip strength and a significant decrease in quick DASH post treatment in group A and B compared with that pretreatment (p < 0.001). The percentage of change in hand grip strength and quick DASH in group A was 138.65 and 49.93% respectively, and that of group B was 178.46 and 64.85% respectively, (Table 2).

- Between groups comparison:

There was no significant difference between groups pre-treatment (p > 0.05). Comparison between groups post treatment revealed a significant increase in hand grip strength (p < 0.01) and a significant decrease in quick DASH (p < 0.01) of group B compared with that of group A, (Table 2).

Table 2. Mean Hand grip strength and quick DASH pre and post treatment of both groups:

	Pretreatment	Post treatment				
	Mean ± SD	**Mean ± SD**	**MD**	**% of change**	**t- value**	**p value**
Hand grip strength (lb)						
Group A	12.47 ± 4.35	29.76 ± 8.80	-17.29	138.65	-12.79	0.001
Group B	13.88 ± 5.69	38.65 ± 10.52	-24.77	178.46	-12.92	0.001
MD	-1.41	-8.89				
t- value	-0.81	-2.67				
	p = 0.42	***p = 0.01***				
Quick DASH (%)						
Group A	56.28 ± 16.69	28.74 ± 9.66	27.54	48.93	8.72	0.001
Group B	57.49 ± 14.92	20.21 ± 10.13	37.28	64.85	9.91	0.001
MD	-1.21	8.53				
t- value	-0.22	2.51				
	p = 0.83	***p = 0.01***				

SD, standard deviation; MD, mean difference; p-value, probability value

4. DISCUSSION:

Hand burns represent a disproportionately high burden in post-burn rehabilitation due to their functional importance and complex anatomy (Araujo et al., 2012). Impairments in grip strength and dexterity significantly reduce independence and quality of life, underscoring the need for effective rehabilitation strategies (Williams et al.,2012). This study investigated the effects of conventional resistance training and resistance training combined with venous occlusion on hand grip strength and functional performance in patients with hand burns.

Group B demonstrated superior improvements compared with Group A, with greater gains in hand grip strength (178.46% vs. 138.65%) and functional performance (64.85% vs. 49.93%). This enhanced effect can be explained by the additional physiological stimuli induced by blood flow restriction (BFR). Venous occlusion creates a hypoxic and metabolically stressful environment that accelerates type II fiber recruitment, stimulates anabolic signaling, and promotes hypertrophy and vascular remodeling, even under low mechanical loads (Loenneke et al., 2012; Dugis et al., 2023; Evans et al., 2010). Repeated reductions in perfusion enhance endothelial function, neovascularization, and capillarization, supporting improved tissue perfusion and functional recovery (Hunt et al., 2012; Dastagir et al., 2023). Metabolite accumulation, lactate buildup, and increased H^+ ion concentrations at the occluded site further amplify neuromuscular activation and perceived effort, optimizing the adaptive response (Sumide et al., 2009; Wilk et al., 2018).

In addition, exercise-induced improvements in peak capacity are partly mediated by elevations in anabolic hormones such as growth hormone (GH) and insulin-like growth factor-1 (IGF-1). The GH response, which is influenced by exercise characteristics and metabolic stress, plays a critical role in muscle hypertrophy and strength development and is particularly pronounced during blood flow restriction training (Abe et al., 2006).

Comparatively, while conventional resistance training primarily relies on mechanical overload to stimulate adaptations, BFR magnifies metabolic stress without increasing mechanical load, making it particularly effective in populations with fragile or healing tissues. These mechanisms collectively explain why Group B achieved more pronounced improvements than Group A in both strength and functional performance.

These findings are consistent with previous research in orthopedic and sports populations, which demonstrates that BFR enhances strength outcomes compared with conventional resistance exercise (Fahs et al., 2012). Although some studies report mixed results regarding quality-of-life improvements (Ruaro et al., 2019), the present study's focus on hand-specific functional recovery highlights that BFR can accelerate gains in maximal dynamic strength and daily activity performance.

Clinically, the enhanced gains in Group B translate into faster recovery of hand function, improved performance in daily activities, and greater independence for burn survivors. BFR provides a safe, low-load alternative to high-intensity exercise, minimizing tissue stress while maximizing neuromuscular and vascular adaptations. Nevertheless, careful monitoring and specialized equipment are required, which may limit widespread implementation in some settings.

STRENGTHS, LIMITATIONS AND FUTURE DIRECTIONS:

This study has several strengths, including its randomized controlled design, which enhances internal validity, and the use of both objective measures (hand grip strength) and patient-reported outcomes (QuickDASH), allowing a comprehensive assessment of functional recovery. It addresses clinically relevant population—patients with hand burns—where evidence for optimal rehabilitation strategies is limited and directly compares conventional resistance training with resistance training combined with venous occlusion, providing insight into enhancing rehabilitation outcomes.

Several limitations should be noted. The sample size was modest, and the intervention period was relatively short, limiting long-term generalizability and the assessment of sustained functional gains. Only hand-specific outcomes were evaluated, without broader measures such as dexterity, quality of life, or return-to-work metrics. Objective assessments of vascular or muscular remodeling were not included, which could have provided additional mechanistic understanding. The requirement for specialized BFR equipment and careful monitoring may also limit the intervention's accessibility in some clinical settings.

Future research should involve larger, multicenter trials with longer follow-up periods to assess the durability of functional gains, optimize occlusion pressures and progression models, and include broader functional and patient-reported outcomes. Long-term safety, particularly regarding vascular integrity, scar tissue remodeling, and tissue tolerance in burn patients, should also be investigated to fully establish the clinical utility of blood flow restriction as a rehabilitation adjunct.

5. CONCLUSION:

Structured resistance exercise is effective in improving hand grip strength and functional performance in patients with hand burns. The addition of venous occlusion via blood flow restriction (BFR) amplifies these benefits, promoting greater neuromuscular and vascular adaptations under low mechanical loads. BFR represents a safe and clinically relevant adjunct to conventional rehabilitation, offering an effective strategy to accelerate functional recovery, enhance independence, and restore hand function in burn survivors. Future studies are warranted to confirm long-term efficacy, optimize training protocols, and evaluate broader functional and patient-reported outcomes.

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