Plyometric intervention for enhancing upper extremity strength and function in children with burn injuries: a randomized controlled trial

Intervención pliométrica para mejorar la fuerza y la función del miembro superior en niños con quemaduras: ensayo controlado aleatorizado

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Abstract

Introduction: Children with burn injuries commonly experience persistent physical impairments that compromise functional status, restrict participation in physical activity, promote sedentary behavior, and adversely affect quality of life for years after injury. Therefore, effective rehabilitation strategies are needed to address these long-term sequelae.
Objective: To investigate the effects of a 12-week upper-limb plyometric exercise program on muscle strength, power, and movement speed in children with burn injuries.
Methodology: A randomized controlled trial was conducted involving 52 children with upper extremity burn injuries. Participants were randomly allocated to either a plyometric exercise group (n = 26) or a control group (n = 26). Both groups completed supervised exercise programs twice weekly for 12 weeks. Outcome measures were assessed before and after the intervention and included elbow flexor and extensor muscle strength, upper-body power measured by the medicine ball throw test, and upper-limb movement speed.
Results: Following the 12-week intervention, the plyometric group demonstrated significantly greater improvements compared to the control group. Improvements were seen in elbow flexors strength (MD = 2.15 kg, 95% CI [0.38, 3.93], P = 0.02, η^2= 0.11), elbow extensors strength (MD = 2.89 kg, 95% CI [0.88, 4.89], P = 0.006, η^2= 0.14), medicine ball throw (MD = 32.12 cm, 95% CI [12.48, 51.75], P = 0.002, η^2 = 0.18), and upper extremity movement speed (MD = −3.74 seconds, 95% CI [−5.71, −1.78], P < 0.001, η^2= 0.23).
Conclusions: A 12-week upper-extremity plyometric training program may be more effective than conventional exercise approaches for improving muscle strength, muscle power, and upper-limb function in children with burn injuries.

Keywords

Burn injuries; muscle strength; muscle power; plyometric training; rehabilitation.

Resumen

Introducción: Los niños con quemaduras suelen presentar alteraciones físicas persistentes que comprometen el estado funcional, restringen la participación en la actividad física, favorecen el comportamiento sedentario y afectan negativamente la calidad de vida durante años después de la lesión. Por lo tanto, se requieren estrategias de rehabilitación eficaces para abordar estas secuelas a largo plazo.
Objetivo: Investigar los efectos de un programa de ejercicios pliométricos para el miembro superior de 12 semanas sobre la fuerza muscular, la potencia y la velocidad de movimiento en niños con quemaduras.
Metodología: Se realizó un ensayo controlado aleatorizado en 52 niños con quemaduras en la extremidad superior. Los participantes fueron asignados aleatoriamente a un grupo de ejercicio pliométrico (n = 26) o a un grupo control (n = 26). Ambos grupos completaron programas de ejercicio supervisado dos veces por semana durante 12 semanas. Las medidas de resultado se evaluaron antes y después de la intervención e incluyeron la fuerza muscular de los flexores y extensores del codo, la potencia de la parte superior del cuerpo medida mediante la prueba de lanzamiento de balón medicinal y la velocidad de movimiento del miembro superior.
Resultados: Tras la intervención de 12 semanas, el grupo pliométrico mostró mejoras significativamente mayores en comparación con el grupo control. Se observaron mejoras en la fuerza de los flexores del codo (MD = 2.15 kg, IC del 95% [0.38, 3.93], P = 0.02, η^2 = 0.11), la fuerza de los extensores del codo (MD = 2.89 kg, IC del 95% [0.88, 4.89], P = 0.006, η^2 = 0.14), el lanzamiento de balón medicinal (MD = 32.12 cm, IC del 95% [12.48, 51.75], P = 0.002, η^2 = 0.18) y la velocidad de movimiento de la extremidad superior (MD = −3.74 segundos, IC del 95% [−5.71, −1.78], P < 0.001, η^2 = 0.23).
Conclusiones: Un programa de entrenamiento pliométrico para el miembro superior de 12 semanas puede ser más eficaz que los enfoques convencionales de ejercicio para mejorar la fuerza muscular, la potencia muscular y la función del miembro superior en niños con quemaduras.

Palabras clave

Lesiones por quemaduras; fuerza muscular; potencia muscular; entrenamiento pliométrico; rehabilitación.

Introduction

Children with chronic illnesses or physical disabilities are generally more limited in their participation in physical activity compared with their healthy peers (Maggio et al., 2010). A similar pattern may also be observed in children recovering from burn injuries. Individuals with burns frequently experience long-term psychological and physical challenges that reduce their functional status, limit their participation in physical activity, promote sedentary behaviors, and negatively affect quality of life for up to five years after injury. These challenges often necessitate prolonged care and rehabilitation (Akkerman et al., 2017; Grice et al., 2015; Jeschke et al., 2011).

Major burn injury is associated with a physiological response marked by systemic inflammation, substantial skeletal muscle catabolism, and elevated resting energy expenditure (Hart et al., 2000; Jeschke et al., 2008). Skeletal muscle, which constitutes a substantial proportion of lean body mass, serves as the primary store of protein and a key source of amino acids during recovery. These amino acids support wound healing, synthesis of acute-phase and inflammatory proteins, and hepatic gluconeogenesis (Hart et al., 2000). The resulting hypermetabolic and catabolic state may persist for up to two years post-injury (Hart et al., 2000; Jeschke et al., 2011), leading to progressive loss of muscle mass and strength and delayed functional recovery. Furthermore, emerging evidence suggests that burn injury may impair muscle energy metabolism, contributing to an earlier onset of fatigue and prolonged recovery following exercise (Akkerman et al., 2017; Jeschke et al., 2011).

Numerous studies have highlighted the role of exercise in mitigating the adverse effects of prolonged bed rest, with post-discharge rehabilitation being essential for preserving hand function, maintaining lean body mass and improve quality of life following major burn injury (Basha et al., 2022; Hardee et al., 2014; Kamel & Basha, 2021). Consequently, interventions aimed at preserving muscle mass and function are critical for improving long-term outcomes.

Plyometric training is an explosive mode of exercise that involves brief, high-intensity muscle actions aimed at improving strength, power, and movement speed (Sáez-Sáez de Villarreal et al., 2010). It relies on the stretch–shortening cycle, in which a rapid eccentric contraction is immediately followed by a forceful concentric contraction. During the eccentric phase, elastic energy is stored within the muscle–tendon unit and the stretch reflex is activated, contributing to greater force production during the subsequent concentric phase. This mechanism enhances the rate of force development, muscle power, and neuromuscular efficiency (Davies et al., 2015; Sáez-Sáez de Villarreal et al., 2010).

Plyometric training has been suggested as a practical, effective, and safe intervention for enhancing physical performance in children with musculoskeletal and neuromotor disorders. A growing body of literature supports the effectiveness of plyometric training in pediatric populations with physical limitations (Elnaggar et al., 2024; Elnaggar et al., 2026; Garcia-Carrillo et al., 2024). However, existing research has predominantly focused on the lower extremities, and, to date, no studies have specifically examined upper-limb plyometric training in children with burn injuries.

Therefore, the objective of this study was to investigate the effects of a 12-week upper-limb plyometric training program on muscle strength, power, and movement speed in children with burn injuries. It was hypothesized that plyometric training would lead to superior improvements in rehabilitation outcomes compared with standard care.

Method

Design, Participants, and Ethics

The present study employed a single-blind randomized controlled trial design. Fifty-two children with burn injuries were recruited from the outpatient clinic of the Faculty of Physical Therapy, Cairo University, Egypt. Parents or legal guardians of potentially eligible children were approached by the researcher, informed about the purpose and procedures of the study, and invited to allow their children to participate. The study protocol was approved by the Research Ethics Committee of the Faculty of Physical Therapy, Cairo University (Reference No. P.T.REC/012/005691), and all procedures were conducted in accordance with the Declaration of Helsinki. Written informed consent was obtained from the parents or legal guardians of all participants prior to study entry. In addition, the participants and their guardians were clearly informed that participation was voluntary and that they were free to withdraw from the study at any stage without consequence.

Children were included if they were aged 10–17 years, had burn injuries involving the dominant upper extremity, and were at least 1-year post-injury. Exclusion criteria included the presence of unhealed or open wounds, as well as any musculoskeletal or neurological disorders. All participants exhibited similar lifestyle patterns, including regular school attendance and participation in standard physical education classes twice weekly. None of the children had participated in structured strength and conditioning programs or organized extracurricular physical activities. All children had previously received routine rehabilitation following hospital discharge.

Randomization and Group Assignment

Participants were randomly allocated to two intervention groups using a permuted block randomization method to ensure balanced group sizes and minimize selection bias. A total of 52 children were assigned to either the plyometric exercise group (n = 26) or the control group (n = 26). The randomization sequence was generated using blocks of varying sizes, with each block containing an equal number of allocations to both groups, arranged in a random sequence. Upon enrolment, each participant was assigned a unique identification number, and group allocation was determined according to a concealed randomization sequence, thereby ensuring allocation concealment throughout the enrolment process. Randomization was carried out by an independent burn physical therapist who was not involved in outcome assessment, or treatment administration.

Sample size calculation

An a priori sample size calculation was performed using G*Power software (version 3.1.9.7; Universität Düsseldorf, Germany). The analysis was based on F tests, MANOVA: repeated measures, within–between interaction. This model was selected to detect the interaction effect between the two study groups (plyometric and control) across the two assessment time points (pre-intervention and post-intervention) for elbow flexor strength, which was specified as the primary outcome measure. The following parameters were specified in the analysis: test family = F tests; statistical test = MANOVA: repeated measures, within–between interaction; number of groups = 2; number of measurements = 2; type I error rate (α) = 0.05; and statistical power (1 − β) = 0.80. The effect size used for the power analysis was based on the primary outcome measure, elbow flexor strength, and was derived from findings reported in a previous study (Elnaggar et al., 2024), where the partial eta squared (η^2) was 0.15. To obtain the corresponding Cohen's f value (effect size) required for G*Power, the standard conversion formula was applied:

$$f = \sqrt{\frac{\eta^2}{1 - \eta^2}}$$

Substituting $\eta^2 = 0.15$ yields:

$$f = \sqrt{\frac{0.15}{1 - 0.15}} \approx 0.42$$

Based on these assumptions, G*Power indicated that at least 47 participants were required to detect a statistically significant group × time interaction with adequate power. To compensate for possible dropout, the calculated sample size was increased by 10%. Accordingly, 52 participants were enrolled and allocated equally between the two groups (26 per group).

Intervention

Plyometric Exercise Regimen

One week prior to the intervention, participants attended two familiarization sessions during which all exercises were demonstrated and explained to ensure correct technique and safe execution for all participants. During subsequent training sessions, continuous verbal and visual feedback was provided to reinforce proper performance. The plyometric group completed a physical therapist–supervised plyometric exercise program performed twice weekly for 12 consecutive weeks, with a minimum recovery interval of 2 days between sessions, in accordance with the safety guidelines of the National Strength and Conditioning Association (Faigenbaum et al., 2009).The program comprised ten explosive exercises primarily targeting upper-limb strength and power, with details of training volume and progression presented in Table 1. Training progression was implemented through three sequential blocks by gradually increasing the number of repetitions based on an initial performance assessment used to determine the appropriate starting load (Elnaggar et al., 2024; Elnaggar et al., 2026; Garcia-Carrillo et al., 2024). Each training session began with a standardized 10-minute dynamic warm-up including stretching exercises targeting the pectoral muscles, scapular protractors, and latissimus dorsi, together with dynamic upper-limb movements. Additionally, each session ended with a 5-minute cool-down period consisting of low-intensity mobility and stretching activities.

Standard Exercise Regimen

Participants in the control group underwent a standardized training program conducted twice weekly for twelve consecutive weeks under the supervision of an experienced physical therapist. The program was adapted from previously published protocols and implemented in accordance with the guidelines of the American College of Sports Medicine (Hardee et al., 2014; Thompson et al., 2013). Each training session began with a 10-minute dynamic warm-up, similar to that performed by the plyometric group, and concluded with a 5-minute cool-down period consisting of low-intensity exercises and stretching. The program comprised resistance, conditioning, and aerobic exercise components targeting the major muscles of the upper extremity. The resistance component included bench press, push-ups, shoulder press, biceps curls, triceps extensions, and resistance-band exercises, whereas the conditioning and aerobic components included arm circles and swings, arm-crank ergometry, seated boxing drills, and continuous ball passing. Training intensity and workload were progressively increased throughout the intervention period to maintain the desired training stimulus. Resistance training was performed using variable-resistance machines or free weights. The load was gradually increased from 50-60% of the three-repetition maximum at the beginning of the program up to 80-85% of the three-repetition maximum at the end of the program.

Procedures

All participants attended a familiarization session prior to testing, during which proper techniques were demonstrated and standardized instructions were provided. During this session, the three-repetition maximum was determined for each participant. Outcome measures were evaluated at two time points, baseline (pre-intervention) and after completion of the 12-week training program (post-intervention), by a blinded independent assessor who was not involved in participant recruitment, randomization, or intervention delivery. Participants were advised to refrain from strenuous physical activity for twenty-four hours before testing and to avoid food, caffeine, and energy drinks for at least 2 hours prior to assessment.

Outcome measures

Muscle strength

Maximal voluntary isometric strength of the elbow flexors and extensors was measured using a handheld dynamometer (HHD; Model 01163, Lafayette Instrument Company, Lafayette, IN, USA), with force values recorded in kilograms-force. Before testing, the dynamometer was calibrated in accordance with the manufacturer's instructions. Participants first completed three submaximal isometric contractions to familiarize themselves with the procedure and to provide a standardized warm-up. This was followed by three maximal voluntary isometric contractions of 5 seconds' duration for each muscle group, with 30-second rest intervals between trials. Standardized verbal encouragement was provided to ensure maximal effort, and the highest value obtained across the three trials was used for analysis. Testing procedures, participant positioning, and dynamometer placement were standardized according to previously published protocols. (Elnaggar et al., 2024; Elnaggar et al., 2026). A handheld dynamometer has demonstrated good-to-excellent reliability for the assessment of upper-limb muscle strength. Intra-rater reliability was excellent for elbow flexors (r = 0.94) and elbow extensors (r = 0.89), while inter-rater reliability was good to excellent for elbow flexors (r = 0.89) and elbow extensors (r = 0.87) ($p < 0.001$) (Péran et al., 2025).

Muscle power

The seated medicine ball throw test is considered a valid and reliable measure of upper-limb power. (Ferreira et al., 2021) demonstrated good inter-examiner reliability (ICC = 0.84) and intra-examiner reliability (ICC = 0.77) for the seated medicine ball throw. Participants were positioned in a seated posture on the floor with the head, shoulders, and back maintained in contact with a wall**,** and the lower limbs extended. Each participant held the medicine ball with both hands in a standardized starting position. To facilitate accurate measurement, the ball was lightly coated with gymnastic chalk to leave a visible mark at the point of landing. A measuring tape was aligned on the floor over a 10-m distance, and participants were instructed to throw the ball forward in a straight line as far as possible while maintaining full contact of the head, shoulders, and back with the wall. Following three familiarization trials**,** participants performed four test trials, with a 1-minute rest interval between attempts. To account for individual differences in arm length, the initial reach distance was determined by allowing the participant to hold the ball with the arms extended forward, and this distance was subtracted from the total throwing distance. The final score was recorded as the adjusted throwing distance (Borms et al., 2016).

Upper-Limb Movement Speed

Upper-limb movement speed was assessed using the Plate Tapping Test, as described in the Eurofit test battery (Tomkinson et al., 2018). This test is valid and reliable as a field-based measure of upper-limb movement speed and coordination (Tsigilis et al., 2002). The test was performed using a height-adjustable table, two circular discs (20 cm in diameter), a central rectangular plate (10 × 20 cm), and a stopwatch. The two discs were positioned 60 cm apart along the edge of the table, with the rectangular plate placed equidistant between them. Participants were instructed to place the non-dominant hand on the central plate while using the dominant hand to alternately tap the two discs as rapidly as possible. A total of 25 cycles (50 taps) were completed. Two trials were performed, and the best performance, defined as the shortest completion time, was used for analysis. Time was recorded to the nearest 0.1 second, with lower values indicating better upper-limb movement speed.

Table 1. Details of the plyometric exercise program: training load and progression schedule.

Exercise	Week 1 – 4	Week 5 – 8	Week 9 - 12
Wall push-up	1 set - 10 reps	2 sets -12 reps	3 sets - 10 reps
Wall ball chest passes.	1 set - 10 reps	2 sets -12 reps	3 sets – 10 reps
Wall ball side throws.	1 set - 10 reps	2 sets -12 reps	3 sets - 10 reps
Wall ball underhanded throws	1 set - 10 reps	2 sets -12 reps	3 sets - 10 reps
Wall ball overhead throws.	1 set - 10 reps	2 sets -12 reps	3 sets - 10 reps
Crunch wall ball throws.	1 set - 10 reps	2 sets -12 reps	3 sets - 10 reps
Medicine Ball Overhead Throw	1 set - 10 reps	2 sets -12 reps	3 sets - 10 reps
Medicine Ball Reverse Rotational Toss	1 set - 10 reps	2 sets -12 reps	3 sets - 10 reps
Ball slams	1 set - 10 reps	2 sets -12 reps	3 sets - 10 reps
Bench push-up	1 set - 10 reps	2 sets -12 reps	3 sets - 10 reps

Statistical analysis

All statistical analyses were performed using the Statistical Package for the Social Sciences (version 25; IBM Corp., Armonk, NY, USA). Continuous data were summarized as mean ± standard deviation (SD), while categorical variables were expressed as frequencies and percentages. Baseline comparability between the plyometric and control groups was assessed using independent-samples t-tests for continuous variables and chi-square tests for categorical variables.

To evaluate the effects of the intervention over time across multiple dependent variables, a two-way mixed multivariate analysis of variance (mixed MANOVA) was performed. The model included one between-subject factor, Group (plyometric vs. control), and one within-subject factor, Time (baseline and 12 weeks). The dependent variables were elbow flexor strength, elbow extensor strength, medicine ball throw, and plate tapping test. Before conducting the analysis, the assumptions of MANOVA were assessed. Normality of the dependent variables was examined using the Shapiro–Wilk test and inspection of Q–Q plots. Homogeneity of variance-covariance matrices was evaluated using Box's M test, and homogeneity of variances was tested using Levene's test. Multicollinearity among the dependent variables was examined through correlation matrices. Because the within-subject factor included only two assessment points, the assumption of sphericity was inherently satisfied.

Multivariate effects were evaluated using Wilks' Lambda (λ). When a statistically significant multivariate effect was identified, follow-up univariate analyses were performed to determine the effect on each individual outcome variable. To reduce the risk of Type I error associated with multiple testing, Bonferroni-adjusted significance levels were applied to these follow-up analyses. Between-group differences at 12 weeks and within-group changes over time were additionally explored using mean differences (MD) with 95% confidence intervals (CI). Effect sizes were reported as partial eta squared (η^2) to quantify the magnitude of the observed effects. Statistical significance was set at a two-tailed p value of < 0.05.

Results

Initial eligibility screening was conducted for 61 participants. Of these, 52 met the inclusion criteria and were subsequently randomized into the two study groups. Four participants did not complete the intervention or failed to attend the post-treatment assessment, including two in the plyometric group and two in the control group. The reasons included scheduling difficulties, relocation outside the study area, and unexplained causes. Missing data were handled using an intention-to-treat approach, whereby all randomized participants were included in the analysis. To account for incomplete observations, multiple imputation techniques were employed under the assumption that the data were missing at random. Both study groups demonstrated strong adherence throughout the intervention period. Participants in the plyometric group attended a mean of 22.38 out of 24 scheduled sessions (93.25%), whereas those in the control group attended an average of 22.27 sessions (92.79%). Compliance with the prescribed exercise protocols during supervised sessions was consistently high across all participants. Importantly, no participants were withdrawn due to noncompliance or safety-related concerns.

As shown in Tables 2 and 3, there were no statistically significant differences between the plyometric and control groups at baseline with respect to demographic or clinical characteristics ($p > 0.05$). The two groups were comparable in terms of age, anthropometric characteristics, burn-related variables, and all baseline outcome measures.

A mixed-design multivariate analysis of variance (MANOVA) was conducted to evaluate differences between groups over time across the combined outcome measures. The analysis revealed statistically significant multivariate effects for the main effect of group Wilks' $\lambda = 0.72$, $F_{(4,47)} = 4.67$, $p = 0.003$, $\eta^2 = 0.28$, for time, Wilks' $\lambda = 0.02$, $F_{(4,47)} = 531.8$, $p < 0.001$, $\eta^2 = 0.98$, and for the interaction between groups and time, Wilks' $\lambda = 0.19$, $F_{(4,47)} = 51.57$, $p < 0.001$, $\eta^2 = 0.81$, indicating that the pattern of change over time differed between the two groups.

Elbow flexor and extensor muscle strength

At baseline, no statistically significant differences were observed between the two groups for either measure ($p > 0.05$). Following the 12-week intervention, the plyometric group demonstrated significantly greater improvements compared to the control group. For elbow flexor strength, the plyometric group exhibited a significantly higher post-intervention value compared to the control group (MD = 2.15 kg, 95% CI [0.38, 3.93], $p = 0.02$, $\eta^2 = 0.11$; Table 4). Within-group analysis showed significant improvements in both groups ($p < 0.001$), with a greater magnitude of change observed in the plyometric group (MD = 4.42 kg) compared to the control group (MD = 3.0 kg; Table 5). Similarly, elbow extensor strength improved significantly in both groups; however, the improvement was significantly greater in the plyometric group (MD = 2.89 kg, 95% CI [0.88, 4.89], $p = 0.006$, $\eta^2 = 0.14$; Table 4). Within-group comparisons confirmed statistically significant gains in both groups ($p < 0.001$), with a larger change observed in the plyometric group (MD = 3.50 kg) relative to the control group (MD = 2.42 kg; Table 5).

Medicine ball throw

Upper limb power, assessed using the medicine ball throw, improved significantly in both groups following the intervention period. However, the plyometric group demonstrated a significantly greater improvement compared to the control group. At 12 weeks, the between-group difference was statistically significant (MD = 32.12 cm, 95% CI [12.48, 51.75], $p = 0.002$, $\eta^2 = 0.18$; Table 4). Within-group analyses revealed significant improvements in both groups ($p < 0.001$), with a markedly greater change in the plyometric group (MD= 65.0 cm) compared to the control group (MD = 30.0 cm; Table 5).

Plate tapping

Upper limb movement speed, as measured by the plate tapping test, also showed significant improvements in both groups. The plyometric group demonstrated a significantly greater reduction in completion time compared to the control group at post-intervention (MD = −3.74 seconds, 95% CI [−5.71, −1.78], $p < 0.001$, $\eta^2 = 0.23$; Table 4). Within-group comparisons indicated statistically significant improvements in both groups ($p < 0.001$), with a larger improvement observed in the plyometric group (MD = - 5.27 seconds) compared to the control group (MD = - 2.3 seconds; Table 5).

Overall, both groups demonstrated statistically significant improvements across all outcome measures over the 12-week intervention period. However, the magnitude of improvement was consistently greater in the plyometric group. The presence of significant group-by-time interaction effects, along with moderate-to-large effect sizes, indicates that the addition of plyometric training resulted in greater improvements in muscle strength, upper limb power, and movement speed compared to the control intervention.

Table 2. Baseline Demographic Characteristics of participants (N=52) *

Characteristics	Plyometric Group (n=26)	Control Group (n=26)	MD (95% CI)	P Value
Age(years)	13.87 ±1.51	14.0 ±2.09	- 0.12 (-1.14, 0.89)	0.81
Weight(kg)	51.46±8.23	54.81±9.97	-3.35 (-8.44, 1.75)	0.19
Height(cm)	154.77±8.05	157.58±12.87	-2.81 (-8.79, 3.17)	0.35
BMI (kg/m^2)	21.34±1.87	21.94±1.82	- 0.59 (-1.62, 0.44)	0.25
Burn Duration (Months)	17.04±2.96	16.69±2.45	0.35(-1.17,1.86)	0.65
TBSA (%)	42.15±7.60	42.96±7.50	- 0.81(-5.01, 3.40)	0.7
3rd Degree Burn (%)	18.65±5.12	20.08±4.26	- 1.42(-4.05, 1.20)	0.28
Dominance, n (%)				
Right side	20 (76.92%)	18(69.23%)	X^2= 0.39	0.53
Left side	6(23.08%)	8 (30.77%)		
Gender, n (%)				
Male	15 (57.69%)	12(46.15%)	X^2= 0.69	0.41
Female	11(42.31%)	14 (53.85%)		

BMI, body mass index; TBSA, Total Body surface Area; X^2, Chi Square; MD, Mean Difference; Kg, kilogram; CI, confidence interval. * Data are mean ± SD for all demographics except dominance and gender (%), P-Value < 0.05 indicate statistical significance.

Table 3. The baseline clinical characteristics of all outcome variables (N=52) *

Outcomes	Plyometric Group (n=26)	Control Group (n=26)	MD (95% CI)	P Value
Elbow Flexors (kg)	14.35±3.95	13.62±3.56	0.73 (-1.36,2.82)	0.49
Elbow Extensors (kg)	12.08±3.68	10.27±3.27	1.81 (-0.13, 3.75)	0.07
MBT (cm)	309.81±38.87	312.69±45.15	-2.89(-26.35,20.58)	0.81
Plate Tapping (sec.)	25.11±3.86	25.89±3.96	-0.78(-2.96, 1.40)	0.48

MBT: Medicine ball Throw; Kg: kilogram; cm: centimeter; sec: seconds; MD: Mean Difference; CI, confidence interval; * Data are mean ± SD, P-Value < 0.05 indicate statistical significance.

Table 4. Clinical Characteristics of participants after 12 weeks of intervention for all outcome variables (N=52) *

Outcomes	Plyometric Group (n=26)	Control Group (n=26)	MD (95% CI)	P Value	Partial η^2
Elbow Flexors (kg)	18.77±3.68	16.62±2.59	2.15 (0.38,3.93)	0.02	0.11
Elbow Extensors (kg)	15.58±4.02	12.69±3.11	2.89 (0.88, 4.89)	0.006	0.14
MBT (cm)	374.81±31.83	342.69±38.37	32.12 (12.48, 51.75)	0.002	0.18
Plate Tapping (sec.)	19.84±3.26	23.58±3.79	-3.74 (-5.71, -1.78)	< 0.001	0.23

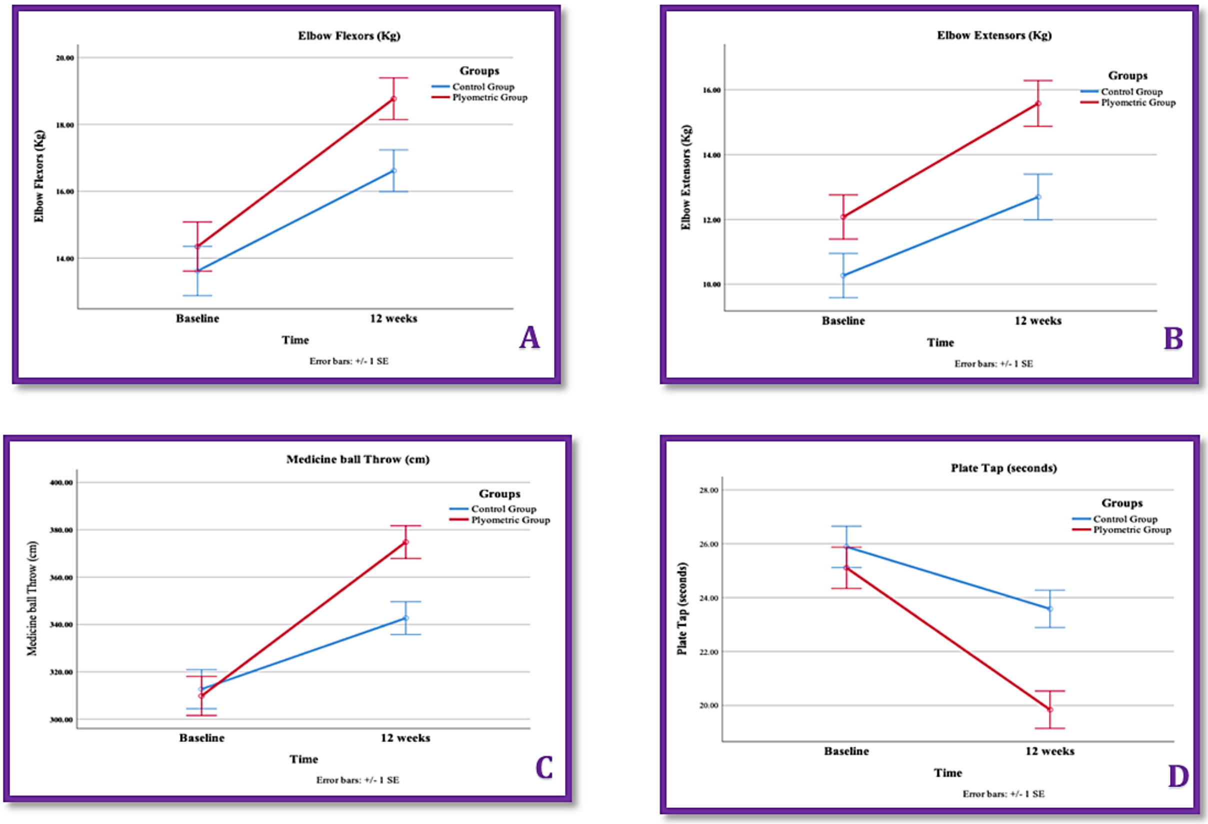
MBT: Medicine ball Throw; Kg: kilogram; cm: centimeter; sec: seconds; MD: Mean Difference; CI, confidence interval; * Data are mean ± SD, P-Value < 0.05 indicate statistical significance.

Table 5. Within-groups Comparisons of all outcome measures.

Outcomes	Plyometric Group (n=26)		Control Group (n=26)	
	Change from baseline to 12 weeks		Change from baseline to 12 weeks	
	MD (95% CI)	P Value	MD (95% CI)	P Value
Elbow Flexors (kg)	4.42 (3.94, 4.91)	< 0.001	3.0 (2.51, 3.49)	< 0.001
Elbow Extensors (kg)	3.5 (3.18, 3.82)	< 0.001	2.42 (2.1, 2.74)	< 0.001
MBT (cm)	65.0 (60.54, 69.46)	< 0.001	30.0 (25.54, 34.46)	< 0.001
Plate Tapping (sec.)	-5.27 (-5.72, -4.82)	< 0.001	-2.3 (-2.75, -1.85)	< 0.001

MBT: Medicine ball Throw; Kg: kilogram; cm: centimetre; sec: seconds; MD: Mean Difference; CI, confidence interval; * Data are mean± SD, P-Value < 0.05 indicate statistical significance. Change scores are calculated as (post – pre); positive values indicate increases, and negative values indicate decreases. Improvements correspond to increases in strength and medicine ball throw performance and decreases in plate tapping time.

Figure 1. Estimated marginal means in both groups for A) Elbow flexors strength B) Elbow extensors strength C) Medicine ball throw D) Plate Tapping



Discussion

This randomized controlled trial examined the clinical efficacy of an upper-extremity plyometric exercise program in children with burn injuries. The primary finding was that the 12-week plyometric training program produced statistically significant and clinically meaningful improvements in upper-extremity muscle strength, specifically in the elbow flexors and extensors, power, and movement speed. These findings suggest that upper-limb plyometric training may be a useful adjunct to rehabilitation in this population.

These findings are clinically important because paediatric burn survivors commonly exhibit persistent physical inactivity, elevated sedentary behaviour, and long-term deficits in physical fitness and functional independence (Akkerman et al., 2017; Grice et al., 2015; Jeschke et al., 2011). Physical performance may remain 20–30% below normative values, underscoring the need for targeted, rehabilitation strategies that effectively address both neuromuscular impairments and functional limitations (Abouzeid et al., 2022). Within this context, the present findings indicate that plyometric training may contribute to improved upper-limb performance after burn injury.

Although the therapeutic benefits of plyometric training are well established in pediatric populations, the current evidence base is largely confined to lower extremity interventions (Fonseca et al., 2022; Mancilla et al., 2023; Velasco, 2022). Importantly, the fundamental mechanisms underpinning plyometric training—namely enhanced rate of force development, improved motor unit recruitment, and increased movement velocity—are not limb-specific (Blazevich et al., 2003; Markovic & Mikulic, 2010). This provides a strong theoretical rationale for extending plyometric paradigms to the upper extremities, particularly in pediatric burn survivors, where upper limb dysfunction frequently limits performance of essential unimanual and bimanual tasks (Abouzeid et al., 2022).

The present findings are consistent with previous studies showing that plyometric training can improve upper-extremity strength and physical performance in children with hemiplegic cerebral palsy (Elnaggar et al., 2026) and in children with obstetric brachial plexus injury (Elnaggar et al., 2024). Improvements in upper-extremity power following medicine ball–based plyometric training have also been reported in school-aged youth and athletic populations. Previous studies have demonstrated gains of approximately 19% following short-term (6-week) interventions and gains ranging from 10% to 14% in longer or combined training programs (Faigenbaum & Mediate, 2006; Faigenbaum et al., 2007; Szymanski et al., 2007). Evidence from athletic populations further indicates that medicine ball training enhances upper-limb power, including throwing performance and bench press and shoulder press power, compared with control conditions (Ignjatovic et al., 2012).

To our knowledge, no previous study has specifically evaluated an upper-extremity-focused plyometric program in pediatric burn survivors. Accordingly, the present results not only align with prior research but also extend the existing literature by providing preliminary evidence for a novel therapeutic application. However, these findings should be interpreted as preliminary and should not be generalized beyond children with similar burn characteristics and rehabilitation status. More broadly, these findings support the premise that rehabilitation strategies incorporating rapid, task-specific, and functionally oriented movements may be beneficial for improving clinically relevant upper-limb performance (Moreau et al., 2012).

The improvements in muscle strength and power observed in the present study are likely underpinned by a combination of neural and structural adaptations. Enhanced neural drive to the agonist muscles, together with improved intermuscular coordination, may have contributed to more efficient force production (Markovic & Mikulic, 2010). In addition, plyometric training has been associated with alterations in muscle architecture and muscle–tendon mechanical properties that may improve force-generating capacity and movement efficiency (Blazevich et al., 2003; Grosset et al., 2009; Malisoux et al., 2007). Neural adaptations, including faster motor unit recruitment and improved motor unit synchronization, may also contribute to enhanced muscular power (Elnaggar, 2022; Malisoux et al., 2007; Malisoux et al., 2006). Although these mechanisms are biologically plausible and supported by previous literature, they were not directly measured in the present study and therefore should be interpreted with caution.

In addition to these neuromuscular adaptations, the task-specific nature of the intervention, which incorporated arm push-ups and ball-handling activities, may have provided proprioceptive stimulation through varied mechanical loading. This may have enhanced proprioceptive acuity and motor control, thereby improving the efficiency of force application during complex upper-limb movements (Elnaggar et al., 2024; Elnaggar et al., 2026; Molla & Vieira, 2024). The observed association between gains in strength and power further suggests that improvements in force-generating capacity translated into enhanced movement velocity. In this context, plyometric training may offer advantages over conventional exercise-based rehabilitation by helping bridge the gap between strength development and functional movement performance (Elnaggar et al., 2024; Elnaggar et al., 2026; Molla & Vieira, 2024). However, direct comparative studies are needed to confirm whether this approach is superior to other rehabilitation strategies in pediatric burn populations.

Limitations

Several limitations should be acknowledged. First, the relatively small sample size may limit the generalizability of the findings and reduce the ability to detect smaller treatment effects. Second, the absence of long-term follow-up prevents determination of whether the observed improvements were maintained over time. Third, although the intervention incorporated playful, game-based activities intended to enhance motivation, engagement, and adherence, these factors were not formally quantified. Fourth, habitual physical activity levels and psychosocial determinants were not assessed, despite their potential influence on recovery trajectories in pediatric burn populations. Fifth, the potential differential impact of hand involvement on upper-limb function was not analyzed separately, which may have contributed to heterogeneity in functional outcomes. Finally, although randomization and blinded outcome assessment were used to reduce bias, potential sources of bias, including performance bias and residual confounding from unmeasured behavioral or environmental factors, cannot be fully excluded. Future studies should include larger samples, longer follow-up periods, and objective psychosocial and activity-related measures to further clarify the role of upper-extremity plyometric training in pediatric burn rehabilitation.

Clinical implications

The results support a shift from traditional low-velocity strength training toward more dynamic, high-velocity, and engaging game-based approaches such as upper-extremity plyometric exercise. Incorporating plyometric training as an adjunct to conventional rehabilitation may provide an effective strategy for increasing muscle strength, power, and upper-limb function in children with burn injuries. The task-specific and interactive nature of these activities may also enhance motivation and adherence, which are particularly important in pediatric populations. Importantly, the observed functional gains suggest that early integration of such interventions during key developmental stages may promote greater independence in of daily living activities and contribute to better overall quality of life.

Conclusions

This study demonstrates that a 12-week upper-extremity plyometric training program may be more effective than conventional exercise approaches in improving muscle strength, power, and upper- limb function in children with burn injuries. These results provide novel evidence supporting the incorporation of plyometric training into pediatric burn rehabilitation and extend its potential clinical application beyond traditionally studied populations and lower-extremity-focused interventions.

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