

THE IMPACT OF REHABILITATIVE EXERCISE ON FUNCTIONAL RECOVERY IN SEVERE BURN PATIENTS

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Abstract

Severe burn injuries in children, particularly those affecting more than 30% of total body surface area (TBSA), lead to profound physiological and psychological challenges that significantly impact their long-term recovery. This review focuses on pediatric studies that highlight the role of structured rehabilitative exercise, including resistance and aerobic training, in improving physical function, muscle strength, lean body mass, and cardiorespiratory fitness in children recovering from severe burns. Findings suggest that early introduction of rehabilitative exercise significantly enhances functional outcomes, reduces the need for corrective surgeries, and promotes psychological well-being. The benefits of exercise extend beyond the initial recovery phase, with long-term follow-up data indicating that improvements in muscle mass, strength, and aerobic capacity are sustained for months post-intervention. These findings support the integration of rehabilitative exercise into standard pediatric burn care to optimize recovery outcomes and improve the quality of life for pediatric burn survivors.

Key Words: *pediatric burn rehabilitation, severe burns, muscle strength, cardiorespiratory fitness, resistance training, aerobic exercise, psychological well-being, lean body mass, long-term recovery, pulmonary function.*

INTRODUCTION

Severe burn injuries in children, particularly those involving over 30% of the total body surface area (TBSA), pose a significant medical challenge due to the extensive and lasting damage they cause to various physiological systems. In pediatric patients, these injuries trigger a complex and prolonged metabolic response, marked by a substantial increase in resting energy expenditure, heightened muscle catabolism, insulin resistance, and chronic inflammation (1,2). The combination of these factors results in the loss of critical lean body mass, impairing physical growth and development.

For pediatric burn survivors, the initial trauma is often just the beginning of a lengthy and challenging recovery process, with persistent muscle wasting, delayed growth, reduced physical function, and diminished quality of life (3,4).

Children, due to their ongoing growth and development, are especially vulnerable to the long-term impacts of hypermetabolism and muscle catabolism following burn trauma. Despite advances in acute burn care that have significantly improved survival rates, long-term rehabilitation remains an underdeveloped aspect of pediatric burn care (1). The current standard of care primarily focuses on wound healing, nutritional support, infection prevention, and managing scar formation (2).

While these interventions are crucial for survival and immediate recovery, they often fail to address the profound muscle loss and functional impairments that can persist for months or years post-injury. Even with aggressive nutritional support aimed at countering the increased metabolic demands of burn injuries, many pediatric patients continue to experience prolonged muscle wasting, reduced physical function, and impaired mobility (3,4).

Rehabilitative exercise, particularly when introduced early in the recovery process, has emerged as a highly effective intervention for addressing these long-term deficits in pediatric burn survivors. Structured exercise programs that include resistance training to build muscle mass and aerobic training to improve cardiorespiratory function have been shown to yield substantial benefits.

Pediatric patients who participate in rehabilitative exercise demonstrate significant improvements in muscle strength, lean body mass, and overall physical function (1). Exercise also helps reduce the risk of secondary complications, such as contractures and joint stiffness, and can prevent the need for multiple corrective surgeries, which are common in children recovering from severe burns (5).

In addition to its physical benefits, rehabilitative exercise has been linked to improvements in psychological well-being, which is critical for pediatric burn patients who often struggle with the emotional and psychological impact of their injuries. Exercise programs that combine physical rehabilitation with group-based activities can improve social interaction, reduce feelings of isolation, and enhance overall quality of life (3). Despite these benefits, structured rehabilitative exercise is not yet widely

integrated into the post-acute care of pediatric burn patients, possibly due to the logistical challenges of implementing these programs and the lack of standardized exercise protocols for children with burns (2).

Research demonstrates that when exercise is introduced early—often within the first six months post-injury—it can lead to significant improvements in both short-term and long-term outcomes for pediatric patients. Studies have shown that exercise can accelerate recovery, reduce the need for surgical interventions, and improve functional independence, allowing children to return to school and normal activities sooner than those receiving standard care alone (3,5). Given these findings, there is a growing recognition of the need for rehabilitative exercise to be a core component of pediatric burn rehabilitation protocols, ensuring that patients receive comprehensive, long-term care that addresses both their physical and emotional needs.

This paper reviews the evidence supporting the use of structured rehabilitative exercise in the long-term recovery of pediatric burn survivors. The central hypothesis is that rehabilitative exercise training (RET) will restore lean body mass, improve muscle strength, and enhance physiological function at a faster and higher rate than standard care alone. This review will focus on the physiological impacts of exercise on pediatric burn recovery, the optimal timing for introducing exercise into rehabilitation protocols, and the potential benefits of combining exercise with other therapeutic interventions to maximize recovery outcomes (1,2).

MATERIALS AND METHODS

This review synthesizes findings from several clinical trials and observational studies that specifically examined the effects of rehabilitative exercise training (RET) in pediatric burn survivors. Each of the studies included children with burns covering at least 30% of their total body surface area (TBSA).

The research primarily involved controlled trials comparing groups of children who underwent structured exercise programs with those receiving standard outpatient care. Follow-up assessments were typically conducted at 6 and 12 months post-injury to determine the effectiveness of RET in improving functional outcomes.

Participants were children aged 7-18 years with severe burns ($\geq 30\%$ TBSA). All children included in the studies had completed acute hospital care and were enrolled in outpatient rehabilitation programs. The children were randomized into either an intervention group, where they participated in structured rehabilitative exercise programs, or a control group that received standard care without structured exercise. Studies ensured that the children had healed sufficiently from their injuries to engage in physical activity safely.

The rehabilitative exercise programs typically included a combination of aerobic and resistance exercises designed to improve cardiovascular fitness, muscle strength, and lean body mass. Exercise sessions were conducted three times per week, for 12 weeks, with gradual progression in intensity. In one study, children participated in a 12-week exercise program starting 6 months post-injury, which included treadmill running, cycling, and strength exercises focused on major muscle groups. Another study incorporated resistance training exercises focusing on compound movements such as leg presses, chest presses, and rowing, performed at 50–80% of their three-repetition maximum.

Primary outcomes included improvements in lean body mass, measured through dual-energy X-ray absorptiometry (DXA), and enhancements in muscle strength, evaluated using isokinetic dynamometry. Cardiorespiratory fitness, assessed by peak oxygen uptake (VO_2 max), was another critical outcome. Secondary outcomes included improvements in pulmonary function, flexibility, and quality of life. Additionally, the studies examined the number of corrective surgeries required after participation in rehabilitative exercise programs.

LITERATURE REVIEW

Pathophysiology of Burn Injury in Children

Severe burn injuries in children result in a unique and prolonged stress response, which significantly impacts their growth, metabolism, and physical development. The immediate aftermath of a burn triggers the release of catecholamines, cytokines, and glucocorticoids, leading to a state of hypermetabolism. This hypermetabolic state can persist for months to years and is characterized by elevated resting energy expenditure,

often increasing by 20-100% compared to normal levels (3). This prolonged metabolic stress results in substantial muscle catabolism, where muscle proteins are broken down to meet the body's increased energy needs, leading to cachexia and severe muscle wasting in pediatric burn survivors.

Children's developing bodies are particularly vulnerable to the adverse effects of hypermetabolism and muscle wasting, as their baseline metabolic demands are already high due to growth. Despite aggressive nutritional support, including caloric intake far exceeding normal needs, pediatric patients with large burns often experience significant deficits in lean body mass during recovery (4). The persistent muscle breakdown cannot be fully counteracted by nutritional interventions alone, as metabolic precursors, such as amino acids, are diverted toward wound healing and immune responses, leaving little available for muscle regeneration (6).

These metabolic challenges necessitate the development of additional interventions to counteract the long-term physiological impairments faced by pediatric burn survivors. While pharmacotherapy and nutritional support are essential, rehabilitative exercise has emerged as a potential strategy to enhance recovery by directly addressing muscle wasting and functional impairments.

Current Standard of Care for Pediatric Burn Patients

The current standard of care for pediatric burn patients is focused on addressing acute issues such as wound healing, pain management, infection prevention, and nutritional support. Nutrition plays a crucial role in mitigating the hypermetabolic response and supporting the energy demands of recovery. However, while nutritional interventions, including high-protein diets, are critical, they are insufficient in reversing the extensive muscle loss seen in children with severe burns (2).

Traditional rehabilitation programs in pediatric burn care often emphasize wound care, scar management, and physical therapy for mobility, but they generally lack structured and progressive exercise programs specifically aimed at restoring muscle mass and physical function (3). As a result, many pediatric burn survivors continue to experience long-term deficits in strength, endurance, and overall physical function, even years after their initial recovery (1). The lack of structured rehabilitative

exercise in the outpatient care of pediatric burn patients limits the full restoration of functional capacity.

Despite evidence of the positive effects of exercise in other pediatric populations with chronic conditions, such as asthma and congenital heart disease, structured exercise programs are still not routinely incorporated into pediatric burn rehabilitation (3). This gap in care highlights the need for more comprehensive rehabilitation strategies that include tailored exercise interventions to address the unique physiological and developmental needs of children recovering from severe burns.

The Role of Exercise in Pediatric Burn Rehabilitation

Rehabilitative exercise has emerged as an essential strategy for improving physical function and overall recovery in pediatric burn survivors. Studies focusing on pediatric populations have shown that structured exercise programs, particularly those involving both resistance and aerobic training, can significantly improve muscle strength, lean body mass, and cardiorespiratory fitness. Resistance training, which involves progressively increasing muscle load, has been particularly effective in promoting muscle growth and improving functional outcomes in children recovering from severe burns.

One study involving severely burned children ($\geq 50\%$ TBSA) found that a 12-week progressive resistance exercise training (RET) program led to marked improvements in muscle strength, lean body mass, and overall functional capacity when compared to standard care (Suman et al., 2001). Children in the exercise group participated in both aerobic and resistance exercises three times per week. At the end of the program, they showed significant gains in muscle strength and physical performance, with no reported worsening of hypermetabolism.

Another pediatric study focused on the impact of exercise on pulmonary function in children with large burns. Researchers found that children who engaged in regular aerobic exercise, including treadmill running and cycling, experienced significant improvements in VO₂ peak, a key indicator of cardiorespiratory fitness (3). These improvements were not observed in the control group, which received standard outpatient care without structured exercise. Improved cardiorespiratory fitness is critical

for pediatric burn patients, as it enables them to regain endurance and participate in daily activities at a higher level of function.

Furthermore, rehabilitative exercise has been associated with secondary benefits beyond physical fitness, such as improved psychological well-being and a reduction in the number of corrective surgeries required post-burn. Children who engaged in structured exercise programs not only demonstrated better physical outcomes but also experienced enhanced quality of life, reporting reduced anxiety and depression related to their injuries (5). This highlights the importance of incorporating exercise into the holistic rehabilitation of pediatric burn patients to support both physical and emotional recovery.

Despite these clear benefits, the integration of structured exercise into pediatric burn rehabilitation programs remains limited. This may be due to logistical challenges, including the need for specialized equipment and trained personnel to safely administer exercise programs for children with extensive physical limitations. Additionally, there is still a need for more research to determine the optimal timing, intensity, and duration of exercise interventions for pediatric burn survivors.

RESULTS

The review of pediatric-focused studies demonstrates that structured rehabilitative exercise programs significantly improve physical function, muscle mass, and cardiorespiratory fitness in children recovering from severe burn injuries. The studies consistently highlight the multifaceted benefits of exercise in enhancing recovery, with significant improvements observed in muscle strength, aerobic capacity, psychological well-being, and long-term physical function. The following findings emerged across the reviewed studies:

A. Muscle Strength and Lean Body Mass

Multiple studies confirm that resistance exercise training (RET) yields significant improvements in muscle strength and lean body mass in pediatric burn survivors. Resistance exercises, which focus on progressively overloading muscle groups, play a crucial role in rebuilding the muscle tissue lost due to severe burns.

For example, Suman et al. (1) evaluated the effects of a 12-week RET program on children with burns covering 50% or more of their total body surface area (TBSA). The children who participated in the structured exercise regimen experienced a marked increase in both muscle strength and lean body mass compared to those who received only standard care. Specifically, children in the exercise group demonstrated a 25% increase in lean body mass, and their muscle strength improved by 20%, as measured through isokinetic dynamometry. These gains were not only significant during the exercise program but were also maintained at follow-up, indicating the long-lasting impact of structured exercise in restoring muscle function and preventing further muscle atrophy.

The ability of RET to produce sustained improvements highlights its critical role in pediatric burn rehabilitation, especially considering the extensive muscle loss that characterizes the recovery process in severely burned children.

B. Cardiorespiratory Fitness

In addition to its effects on muscle mass, aerobic training has been shown to significantly improve cardiorespiratory fitness in pediatric burn survivors, which is crucial for improving their endurance and overall physical capacity. Aerobic conditioning helps mitigate the adverse effects of prolonged immobilization and the heightened metabolic demands of burn recovery.

Suman et al. (3) examined the impact of a 12-week aerobic exercise program on children with large burns, finding substantial improvements in peak oxygen uptake (VO₂ max), a key indicator of cardiorespiratory fitness. Children who participated in the exercise program experienced a 15-20% improvement in VO₂ max compared to those who did not engage in structured exercise. This increase in aerobic capacity enabled the children to perform daily activities with greater ease, enhancing their functional independence and quality of life. Moreover, these improvements in cardiorespiratory fitness were associated with faster recovery and reduced reliance on assistive devices.

The findings underscore the importance of incorporating aerobic training into rehabilitation programs to improve pulmonary function and overall endurance, allowing pediatric burn patients to regain their physical capabilities more quickly.

C. Psychological and Quality of Life Improvements

Exercise not only improves physical function but also has a profound impact on psychological well-being and quality of life, particularly in children recovering from traumatic injuries like severe burns. Several studies documented the secondary benefits of exercise on mental health, with significant reductions in anxiety, depression, and social isolation.

For instance, Paratz et al. (5) found that children who participated in structured exercise programs, which included both aerobic and resistance components, reported lower levels of anxiety and depression compared to their peers who received standard care. These psychological improvements were attributed to the children's enhanced physical capabilities, which contributed to greater independence, confidence, and social engagement. The study also noted that children in the exercise group required fewer corrective surgeries, further supporting the idea that early physical activity not only restores physical function but also promotes emotional resilience and reduces the need for additional medical interventions.

These findings emphasize the holistic nature of exercise in rehabilitation, demonstrating that improving physical health can have ripple effects on mental and emotional recovery.

D. Pulmonary Function

Structured aerobic training programs have also been found to significantly enhance pulmonary recovery in pediatric burn survivors. Due to the nature of severe burns and the potential for smoke inhalation injuries, many children suffer from compromised lung function, which can impede their ability to participate in physical activities and prolong recovery.

Suman et al. (3) observed significant improvements in lung capacity and function in children who participated in aerobic exercises such as treadmill running and cycling. These children showed improved forced expiratory volume (FEV1) and maximal voluntary ventilation (MVV), which are critical measures of pulmonary function. The improvements in lung function were essential in restoring the children's ability to engage in normal physical activities and reducing their dependence on ventilatory support.

Given that pulmonary dysfunction can severely limit recovery in pediatric burn patients, the role of aerobic exercise in enhancing lung function is especially important for accelerating overall rehabilitation and helping children regain their physical independence.

E. Long-Term Benefits

One of the most encouraging findings from the review of pediatric studies is the evidence suggesting that the benefits of structured rehabilitative exercise extend well beyond the immediate intervention period. Long-term follow-up data indicate that improvements in muscle mass, strength, and aerobic capacity are often sustained for months, if not years, after the initial exercise program. In some cases, children who participated in rehabilitative exercise were able to achieve levels of physical function comparable to those of their uninjured peers.

This highlights the potential of early and sustained exercise interventions to mitigate the long-term consequences of severe burns, including muscle atrophy, pulmonary dysfunction, and impaired mobility. The ability to maintain these gains over time suggests that exercise not only accelerates recovery but also provides a foundation for ongoing health and functional independence as pediatric burn survivors continue to grow and develop.

These findings strongly support the inclusion of structured exercise programs in standard pediatric burn care to ensure long-term recovery and improved quality of life for children affected by severe burns.

CONCLUSIONS

The body of evidence reviewed underscores the transformative potential of structured rehabilitative exercise in the recovery of pediatric burn survivors. Severe burn injuries in children present a unique set of challenges, not only due to the significant physical damage but also because of the prolonged metabolic and physiological stress responses that follow the initial trauma. These responses result in extensive muscle catabolism, leading to severe muscle wasting, decreased cardiorespiratory function, and impaired mobility.

Traditional rehabilitation approaches, which focus primarily on wound healing, nutritional support, and physical therapy, have been effective in addressing acute recovery but fall short in fully reversing the long-term physical deficits that persist well beyond the initial phase of care.

Rehabilitative exercise, particularly when introduced as part of a comprehensive post-acute care plan, plays a pivotal role in restoring physical function. Resistance training has been shown to rebuild lean muscle mass, which is critical for improving strength and endurance. Aerobic exercises, meanwhile, enhance cardiorespiratory fitness, allowing children to regain their stamina and capacity for daily activities. These improvements not only help to expedite physical recovery but also provide a foundation for long-term health, reducing the risk of further complications that could arise from prolonged inactivity or muscle atrophy.

Importantly, the benefits of exercise extend beyond the physical domain; children who engage in structured exercise report improvements in their psychological well-being, including reductions in anxiety, depression, and feelings of social isolation. This holistic improvement in both physical and emotional health is essential for burn survivors, who often face significant psychological challenges as they cope with the trauma and visible scars of their injuries.

Another critical outcome of structured rehabilitative exercise is its ability to reduce the need for additional corrective surgeries. Burn patients, particularly those with large burns affecting key joints or limbs, often require multiple surgical interventions to address contractures and mobility issues. Studies indicate that children who participate in structured exercise programs experience fewer contractures and require fewer surgical interventions compared to those who do not engage in such programs. This not only enhances the quality of life for these patients but also reduces the overall burden on healthcare systems and families, lowering costs and improving long-term outcomes.

Despite these documented benefits, the implementation of structured rehabilitative exercise in pediatric burn care remains limited. Several barriers may contribute to this, including the lack of standardized exercise protocols, the need for specialized equipment and staff, and the logistical challenges of integrating exercise programs into outpatient care settings.

Moreover, there remains uncertainty about the optimal timing, intensity, and duration of exercise interventions, especially for children whose recovery trajectories can vary widely based on the severity of their injuries, their age, and other co-morbid conditions.

The findings from this review highlight the pressing need to overcome these barriers and integrate exercise more fully into pediatric burn rehabilitation. Exercise should not be viewed as a supplemental or optional component of recovery, but rather as an essential part of a multidisciplinary approach to burn care.

Early introduction of rehabilitative exercise, ideally within the first few months post-injury, has the potential to dramatically improve both short- and long-term outcomes for pediatric burn survivors. To achieve this, it is imperative that healthcare providers, rehabilitation specialists, and policymakers work together to develop accessible, evidence-based exercise programs tailored to the unique needs of burn patients.

In conclusion, rehabilitative exercise offers a comprehensive solution to the complex challenges faced by pediatric burn survivors. By addressing both the physical and psychological aspects of recovery, exercise plays a critical role in restoring functional capacity, improving quality of life, and reducing the need for additional medical interventions.

As more research continues to confirm the benefits of exercise, it is essential that burn rehabilitation programs evolve to include structured, individualized exercise regimens as a standard component of care. Doing so will not only improve the lives of pediatric burn survivors but will also set a new standard for rehabilitation practices, ensuring that future generations of burn patients receive the comprehensive care they need to recover fully and thrive.

Future Research Directions

While the reviewed literature strongly supports the role of exercise in pediatric burn rehabilitation, several areas warrant further investigation to optimize its application and efficacy:

- 1. Optimal Timing of Exercise Intervention*

The timing of introducing exercise during the rehabilitation process remains an open question. Many studies initiate exercise programs several months post-injury, but earlier interventions may provide more significant benefits.

Future research should investigate whether starting exercise earlier in the recovery process — potentially even during acute care — could lead to faster improvements in muscle mass and functional capacity without compromising safety.

2. Long-Term Outcomes and Sustainability

While short-term benefits of rehabilitative exercise are well documented, less is known about the long-term sustainability of these gains. Studies that track children several years post-injury are needed to determine whether the benefits of exercise persist and whether continued physical activity is necessary to maintain improvements in muscle strength, endurance, and overall function.

Additionally, examining how exercise impacts children's growth and development over time would provide insights into the unique needs of pediatric burn survivors as they transition through adolescence.

3. Individualized Exercise Programs

Given the variability in burn severity, body composition, and recovery rates among pediatric patients, a one-size-fits-all approach to exercise rehabilitation may not be optimal.

Research should focus on developing individualized exercise protocols tailored to each patient's specific needs, accounting for factors such as burn size, location, and the presence of other complications (e.g., inhalation injury or infection).

Personalizing exercise programs could lead to more effective recovery and better long-term outcomes.

4. Combination Therapies

Future studies should explore the combined effects of exercise with other therapeutic interventions, such as pharmacotherapy (e.g., propranolol or oxandrolone) and nutritional support.

Research indicates that pharmacological agents can enhance muscle mass retention and reduce hypermetabolism in pediatric burn patients, but it is unclear whether combining these treatments with structured exercise produces additive or synergistic effects.

Understanding how to best integrate exercise with other therapies could further optimize recovery protocols for severely burned children.

5. *Psychosocial Impacts of Exercise*

While physical recovery is the primary focus of most rehabilitation studies, the psychosocial benefits of exercise warrant further exploration. Exercise has been shown to reduce anxiety, depression, and social isolation in children recovering from burns. However, more comprehensive research is needed to quantify these effects and assess whether different types of exercise (e.g., group-based vs. individual exercise) offer specific psychological benefits.

Identifying strategies to maximize the psychosocial impact of exercise could contribute to improved overall well-being and faster reintegration into daily life for pediatric burn survivors.

6. *Exercise in Low-Resource Settings*

Many pediatric burn patients come from regions or families with limited access to specialized rehabilitation services.

Future research should investigate the feasibility of implementing rehabilitative exercise programs in low-resource settings, including home-based or community-based exercise regimens.

Developing cost-effective and accessible exercise programs could broaden the reach of this critical intervention, ensuring that more children benefit from structured physical activity regardless of their socioeconomic circumstances.

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