Published in final edited form as:

Phys Med Rehabil Clin N Am. 2023 November ; 34(4): 811–824. doi:10.1016/j.pmr.2023.05.003.

Key Exercise Concepts in the Rehabilitation from Severe Burns

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Keywords

Burns; Exercise; Aerobic; Resistance; Thermoregulation; Heat; Scar; Contracture

ESSENTIALS OF EXERCISE REHABILITATION TRAINING DURING THE IN-PATIENT STAGE

Numerous studies have demonstrated the benefits of exercise in counteracting the detrimental effects of bed rest, and post-discharge exercise is crucial for maintaining physical function, lean body mass, and metabolic recovery after major burn injuries.[1–3] Bed rest is known to have negative effects on a patient’s well-being,[4] cardiorespiratory capacity,[5] lean body mass (LBM),[6] and bone and whole-body metabolism.[6,7] A recent study showed that sedated adults on mechanical ventilation who received exercise and mobilization had better outcomes than those who received only sedation.[8] The managing physician must consider the patient’s current medical condition, medical comorbidities, premorbid functional level, and cardiovascular and respiratory reserves. External factors, such as timing after a skin graft, the presence of lines, and staffing, must also be considered. While the issue of staffing is critical, future studies should investigate how mobilization can decrease complications and justify the necessary staffing for physical and occupational therapists.

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DISCLOSURE
The authors have no relationship with a commercial company that has a direct financial interest in the subject matter or materials discussed in this article or with a company making a competing product.

Exercise during the in-patient stage may offer important benefits that may improve recovery and prevent long-term complications. The patient should have clearance by the attending medical doctor for exercising. Factors such as respiratory reserve, oxygen saturation, hemoglobin level, platelet count, a stable white blood cell count, infection status, and blood glucose levels, febrile status, mental alertness and neurologic status, as well as orthopedic limitations such as unstable spine or fracture, severe osteoporosis, or unstable bone metastasis should all be also considered.[9] Another factor to consider is the timing for getting up and exercising after a skin graft. Although numerous studies have shown that ambulation is safe on the day of grafting for lower leg burns in otherwise healthy patients with smaller burns, the risk of losing precious skin graft in a patient with a large burn should be considered against the potential trade-off of additional ventilator days and a poorer outcome at hospital discharge. This area of research is not well developed and requires more understanding.

Essentials of Rehabilitation Exercise Training During Outpatient Stage

With advancements in acute burn care in recent decades, survival rates for patients with severe burns (up to 90% of total body surface area) have greatly increased. However, the accompanying metabolic and cardiovascular complications may persist for up to 3 years post-injury.[10] As a result, there is now a growing recognition of the importance of implementing strategies to promote faster recovery and decrease long-term morbidity following a severe burn. Rehabilitation exercise training (RET) has been shown to effectively restore lean body mass, glucose and protein metabolism, cardiorespiratory fitness, and muscle strength in burn survivors.[1,11–14] RET has been reported to control for edema, decreases tendon adherence, joint stiffness, capsular shortening and muscle atrophy, burn scar contractures and improves physical conditioning in burned patients[13] .[15,16] Despite its proven safety and efficacy, RET is not commonly incorporated into rehabilitation programs for outpatients with severe burns. It is highly recommended is that all patients with severe burns should receive a long-term progressive resistance exercise training (PRET) prescription plan, as metabolic, endocrine, and cardiovascular complications persist.[17–21] Therefore, we recommend that a long-term exercise prescription plan be considered for all patients with severe burns as a means of restoring function and reducing post-burn morbidity.

Pediatric burn patients experience elevated muscle breakdown for up to 1 year after discharge.[22] The importance of RET such as resistance exercise is highlighted by work from Chang and colleagues[23] that reported a 10% loss of lean body mass (LBM) can negatively impact immune function, while a 20% loss can impair wound healing, and a 30% loss of LBM is associated with increased mortality. In addition, a 30% loss of LBM increases the likelihood of developing pneumonia and pressure sores, which further increases the risk of mortality by 50%. Burn survivors often face challenges when attempting to resume normal activities and reintegrate into society due to the loss of lean body mass (LBM), resulting in muscle weakness and other related health issues. However, progressive resistance exercise training (PRET) can help enhance LBM and strength, ultimately reversing the negative effects of burn injury on body composition and metabolism. It is worth noting that in all cases studied, a 40% loss of LBM resulted in death.[23] Other studies that utilized

RET have reported positive results. For example, the use of resistance exercise training (RET), including concurrent aerobic and resistance exercise, can increase lean body mass (LBM) in burned children by approximately 5% over a period of 6 to 12 weeks.[2,3,12,24–29] Long-term effects of RET were also evaluated by Wurzer and colleagues[26] in children who started the program at the time of hospital discharge and continued for approximately 2 years post-burn. Results indicated that RET improved muscle strength and cardiopulmonary fitness compared to standard of care at discharge, and these benefits persisted at 12 to 24 months post-injury. Similar results were observed in adult patients following a 6-week RET program that included both aerobic and resistance exercise.[30] Both boys and men showed similar increases in lean and fat mass by approximately 4% and 7%, respectively, after a 6 to 12-week RET program performed after hospital discharge.[31] RET has also been shown to improve skeletal muscle strength and increase total LBM in children with large burns (>50% TBSA) compared to SoC, without worsening hypermetabolism.[3] Furthermore, other studies have reported that 6 to 12 weeks of RET does not exacerbate hypermetabolism post-burn.[25,32]

Cardiovascular complications are reported after severe burn trauma. The cardiovascular system responds acutely to burn trauma by elevating resting cardiac output and heart rate, which is associated with myocardial degeneration and ventricular hypertrophy.[17,18,33] Chronic hyper-sympathetic innervation can cause cardiac deficiency and local myocardial hypoxia.[17,18] Pulmonary function is also affected by major burn trauma, with impaired spirometry function lasting several months postburn, leading to reduced cardiorespiratory fitness. Cardiorespiratory fitness (CRF), a standard health measure, reflects the integrative capacity of cardiac, pulmonary, circulatory, and skeletal muscle systems. Studies have demonstrated that CRF remains lower than normative values for years post-injury, highlighting the need for long-term rehabilitation exercise training.[18] Notably, the decrease in burn-injured children and adults' CRF-the measure of the body's ability to supply and use oxygen during maximal exercise.[34] Lower CRF values were reported by Willis and colleagues, Ganio and colleagues,[35] and Cambiaso-Daniel and co-workers[36] reported in burned patients, both adults and children, up to several years after their injury.

In summary, immediately following hospital discharge, RET can restore LBM and exercise capacity, while also improving quality of life.[2,3,12,37] Notably, 6- to 12-week RET programs that include concurrent aerobic and resistance training have been shown to improve CRF (+19%), strength (+37%), and LBM (+11%) in patients post-discharge.[13,38–40] Similar concepts have been applied in several studies of adult burn survivors, with a 12-week rehabilitative exercise program resulting in improvements in aerobic capacity, occupational performance,[41] muscle strength, LBM,[38,42] and quality of life.[43] This highlights the need for long-term rehabilitation exercise training.

Prior to an RET program, patients should be evaluated from baseline fitness levels utilizing standards in exercise prescription. The patient's physical and mental abilities are also assessed by the appropriate qualified ehabilitation provider, who then uses the results of this evaluation to tailor the training program in terms of frequency, intensity, time, type, volume, and progression. Muscle strength can be evaluated through isokinetic dynamometry testing, and the Three Repetition Maximum Test or 10 to 12 Repetition Maximal Test can determine a safe and effective weight load for resistance training. For a complete description of these standard tests refer to.[44] The measured maximal heart rate during the progressive exercise test and the maximal value for the three-repetition maximum can then be used to prescribe exercise as a percentage of cardiovascular and resistive exercise shown in Table 1.

Severely burned children and adults can benefit from RET that positively impacts their cardiorespiratory system, musculoskeletal system, and body composition. Several studies have shown the benefits of a 6 to 12-week combined aerobic and resistance training program. See Table 1 for general prescriptive guidelines that have been used successfully in population with severe burn injuries. For a complete description of the previous Shiners Hospitals for Children-Galveston RET program see reference.[44]

Burn Injuries and Long-Term Cardiovascular Health

While research aimed at improving immediate outcomes after severe burn injuries is essential, the long-term consequences are often overlooked, resulting in a lack of clarity regarding the health-related effects years after the injury. Studies utilizing epidemiological analyses sought to address this gap by examining all-cause mortality and various measures of morbidity burden in burn survivors years after the injury. These studies indicate that burn survivors have mortality rates 1.3 to 1.8 times higher than non-burned groups.[21,45,46] Consistent with this observation, individuals who previously sustained severe burn injuries have 1.5-fold more hospital admissions and 2.9-fold more hospitalization days for “circulatory diseases” years after the burn injury.[21] From that same set of studies, the burned cohort had higher admission rates for ischemic heart disease, heart failure, cerebrovascular disease, as well as a greater incidence of stroke. Furthermore, burn survivors have a higher risk of developing diabetes, hypertension, coronary artery disease, and heart failure for up to 8 years after the injury.[47] Although the underlying mechanisms responsible for these adverse outcomes in burn survivors remain unclear, similar negative effects are observed in sedentary non-burned individuals.

Long-term consequences of severe burn injuries include challenges associated with impaired temperature regulation, hypertrophic scars, hyperpigmentation, psychosocial barriers, decreased cutaneous sensation, and a lower quality of life.[48–53] Fatigue and muscle weakness are also prevalent, affecting over 50% of individuals a decade or more after the injury, with fatigue being a major barrier to returning to work and performing daily activities.[54] Importantly, burn survivors have profoundly reduced aerobic capacity many years after the injury. Specifically, one study found that ~75% of subjects who sustained major burn injuries at least 2 years prior had a peak oxygen uptake (VO2peak; a measure of aerobic fitness) in the lowest 20th percentile rankings, relative to sex and age adjusted non-burned individuals.[35] Similar observations are found when the obtained data were compared with normative VO2peak values from the American Heart Association, with 88% of the burned cohort being below age-adjusted normative VO2peak values[55] and the Aspenes and colleagues dataset, with 80% of the burned cohort have a VO2peak in the lowest quartile.[56] It is important to emphasize that in non-burned individuals, such low VO2peak values are associated with increased cardiovascular-specific and all cause morbidity and mortality.[35,56–60] Moreover, drawing from data relating percentile rankings of VO2peak with mortality,[57] ~75% of severely burned individuals have a 3 to 5 fold greater mortality risk, values consistent with the aforementioned epidemiological findings.

A lower aerobic capacity is associated with elevated cardiovascular risk factors, reduced quality of life, reduced ability to perform functions of daily living, and a greater reliance on dependent care as they age. Importantly, well-healed burn survivors can improve their aerobic capacity through an aggressive exercise training regimen.[30,43] For example, it was recently demonstrated that well-healed burn survivors can appropriately improve their aerobic capacity through an aggressive 6-month community-based exercise training regimen,[30] or after a supervised 12-week exercise training regimen.[43] Such a training regimen also improves blood pressure and ventilatory responses to exercise.[61,62] These findings strongly suggest that the primary etiology for a low VO2peak in well-healed burn survivors is likely related to reduced physical activity in this population, while bed rest associated with length of ICU stay in the acute phase of the injury may also contribute.[63] In summary, severe burn injuries can have a host of long-term consequences that impact a survivor's quality of life. Fatigue and muscle weakness are prevalent issues, while reduced aerobic capacity can lead to an increased risk of several health conditions and a greater reliance on dependent care. However, through an aggressive exercise training regimen, well-healed burn survivors can improve their aerobic capacity, potentially reducing their risk of developing further health complications.

Burn Injuries and Thermoregulation

Proper regulation of body temperature during physical activity is an important factor that can influence exercise tolerance. High body temperatures place an additional demand on the cardiovascular system that culminates in an elevated cardiovascular strain and an accompanying increased perception of effort.[64] Furthermore, high internal/core or skin temperatures can decrease thermal comfort, which likely decreases one's willingness to engage in physical activity. Body temperature homeostasis is maintained via a balance between heat accumulation (from internal and/or external sources) and heat dissipation.[65] Consequently, core body temperature will increase if the rate of heat accumulation is greater than that of heat dissipation. Typically, heat stroke is associated with a core temperature of greater than 40 °C, yet core temperatures of only 38 °C (ie, a 1 °C elevation from rest) can induce a significant increase in heart rate and sweat loss, even in resting subjects.[66–68] Sweating and elevations in skin blood flow are the primary mechanisms by which humans dissipate heat. For example, for each 1 g of sweat that evaporates from the skin surface, ~2400 J of heat energy is removed from the body.[69] The physical process of evaporative cooling also reduces blood temperature at the skin surface, such that cooler blood returns to the body core from the skin. However, if these heat-dissipating responses are insufficient relative to heat gain from metabolism and the environment, core body temperature will continually rise during physical activity, reducing one's desire to perform that physical activity, and potentially culminating in heat stroke.

The capacity for grafted skin to increase skin blood flow and sweating during heat stress is effectively absent, with these limitations persisting throughout the individual's life.[70] Such responses result in excessive elevations in core body and skin temperatures during physical activity, the extent of which is dictated by the size of the area of burned versus non-injured skin.[63,71,72] Furthermore, a heightened perception of heat stress that accompanies these elevated core body and skin temperatures has been documented in burn survivors.[71] Consistent with these laboratory observations, 72% of burn survivors report “problems in hot temperature” ~17 years post-injury. It is important to note that the risk of overheating in burn survivors may be specific to activity in hot ambient environments. A previous study examined the core body temperature responses in burn survivors to 1-h moderate-intensity exercise in a hot (40 °C) and neutral (25 °C) environment and observed differing responses.[73] During exercise at 40 °C, the magnitude of the increase in core temperature was proportional with the size of the burn injury, and heart rate was ~25 b/min greater in those with burns greater than 40% body surface area. However, there were no differences in core temperature during exercise in the 25 °C environment between non-burned individuals and burn survivors, regardless of the size of their injuries. These findings demonstrate that it is safe for burn survivors to perform moderate-intensity exercise if the air temperature is ≤ 25 °C. It is also worth noting that the extent to which burn injuries increase core temperature during activity in the heat is dependent on the activity level/intensity.[74] At a low activity level of ~ 4 METS, there were no differences in core temperature at 60 min of exercise in the heat between control and high burn surface areas of 60%. However, at a moderate intensity of ~ 6 METS in the same heated condition, a burn size of 40% and 60% resulted in greater core temperatures compared with non-burned control individuals.

Cooling Methods for Burn Survivors

Investigations have pursued several methods to help curtail excessive core temperature rises in burn survivors during physical activity in the heat. In non-burned subjects, physiological adaptation (acclimatization) to the heat occurs after 1 to 3 weeks of daily exposure to a hot environment.[75] The primary adaptation to heat acclimation is an increase in the sweating responses; that is, in heat acclimated subjects, sweating is activated at a lower core temperature threshold, sweat output is elevated for a given core temperature, maximum sweat output per gland is elevated, and the sweat becomes more dilute, such that less electrolytes are lost.[75–79] Interestingly, 7 days of heat acclimation induced favorable sweating adaptations in the non-injured skin of burn survivors (burn surface area ranging from 17% to 75%), such that core temperature and heart rate were significantly reduced during exercise in the heat after acclimation.[72] Importantly, sweating from grafted skin remained almost completely absent regardless of heat acclimation status, such that those with very high surface area burns (ie, approximately > 60%) may not realize the full benefits heat acclimation.

An effective and practical method to mitigate rises in core temperature in burn survivors may be to intermittently spritz the grafted skin with water using a spray bottle. Such water spray applied to grafted skin will replicate the effect of sweating, in that the water will evaporate from the skin surface and provide a cooling effect. In lab studies, water spray is typically applied every 5 minutes, or when the grafted skin is no longer wet. It is also beneficial to apply warm, instead of cold, water since warm water is generally better tolerated from a subjective perspective, and warm water will evaporate more efficiently from the skin surface compared with cold water. In environments at or below 33 °C air temperature, increasing the air speed with an electric fan can also have profound heat loss effects, especially if humidity is high.[80] Increasing the air speed increases convective heat loss while also improving the rate of sweat evaporation. In air temperatures above 33 °C, electric fans will have, at-best, a negligible effect on core temperature responses. However, in a similar manner to a convective oven, fans are likely to increase the core temperature if used in a hot environment (ie, ≥ 40 °C). Finally, wetted clothing also decreases physiological strain during heat exposure, though this observation has not be verified in burn survivors.[81]

Application to Exercise Rehabilitation

The data presented above have important implications for rehabilitation practices post-burn injury. Overall, the greater incidence of mortality in burn survivors up to 30 years post-injury is largely due to low aerobic capacity secondary to a sedentary lifestyle, given that low aerobic capacity is linked to greater morbidity and mortality. Therefore, improving aerobic capacity with exercise training, as previously discussed, should improve health-related quality of life in burn survivors years after the injury. Importantly, similar benefits of a community based (ie, outpatient) exercise training program were reported in the pediatric population.[3,82] Finally, a combined aerobic and resistance exercise training program increased psychological domains on the burn-specific health scale, but only after 12-weeks training.[83] Overall, physical activity appears to be an important and beneficial aspect of rehabilitation in burn survivors.

Knowledge Gaps in Thermoregulation

Currently, there is an absence of research investigating the impact of burn injury on core temperature in outdoor environments. The main difference outdoors is the potential for substantial additional heat gain from solar radiation.[84] While activity at low to moderate intensities is safe for burn survivors at 25 °C indoors, it is likely these thresholds will be reduced with direct sun exposure (ie, higher solar radiation). Moreover, further studies are required to determine how the interaction between different air temperatures and humidity may alter core temperature responses, that is, is exercise at 25 °C safe in burn survivors only at low to moderate humidity levels. If activity is undertaken outdoors in the sun, wearing white, loose-fitting clothing is the most effective method to reduce the effect of solar radiation on the thermal and cardiovascular strain. However, exercising indoors (ie, in a gym environment) should be initially recommended to avoid potential complications with high humidity and/or solar radiation. With regard to exercise training programs, more work is needed to determine to psychological benefits of training, since these responses are typically underreported in comparison to the physiological/functional benefits. Finally, studies are needed to determine if regular physical activity negates the epidemiological reports of increased morbidity and mortality in burn survivors decades following the initial injury. To date, no studies have evaluated the potential benefit of consistent physical activity on morbidity and/or mortality risks in burn survivors.

The Role of Exercise Movement in Scarring and Contractures

Following a burn, scars and contractures can limit motion, be a source of pain and itch, create dissatisfaction with appearance, and negatively impact quality of life.[85,86] Scarring is one of the most problematic sequelae for burn survivors, with 55% of survivors more than

10 years post injury reporting continued difficulty.[87,88] Conservative, non-invasive strategies for managing burn scars include massage, splinting and positioning, stretching, and exercise/ mobilization.[39,40,89]Although rehabilitation regimens may include movement (passive and active), strength training, and aerobic workouts to build endurance, improve lean body mass, and improve range of motion,[40] the influence of exercise on scar-related outcomes is rarely evaluated.[39,90–94] The few studies reporting scarring-related outcomes, however, suggest that exercise programs can reduce scar severity and the need for subsequent surgical interventions.[13,95,96] The need for scar release surgeries was reduced in pediatric burn survivors participating in a 12- week supervised, in-hospital exercise program with concurrent physical and occupational therapy compared to a cohort that did not exercise.[96] Similarly, comparison of pediatric burn survivors participating in an intensive physical exercise program to those who did not revealed that although the severity of initial injuries were comparable, exercise was associated with an approximate 60% reduction in contracture releasing surgeries.[96] In a study comparing conventional scar management to exercise and physiotherapy in adult burn survivors, range of motion improved and severity of post burn hypertrophic scarring was reduced with exercise.[95]

Knowledge Gaps in Exercise-Induced Effects on Contractures

Scar development and maturation are modulated by myriad factors, including mechano-physiological conditions, the presence of contractile myofibroblasts, and the influence of inflammatory cells and molecules.[97] Throughout the rehabilitative period, a combination of reconstructive surgeries, laser resurfacing, silicone sheets, and/or compression garments may be used to decrease tension within the wound/scar, reduce perfusion and vascularization, and control inflammation, thereby improving wound healing and decreasing scar formation.[97] Early movement, stretching, and exercise (resistance and aerobic) likely influence these processes as well, although the mechanisms underlying the improvement in scarring outcomes with exercise are unknown. In light of these findings, the need for additional well-designed studies designed to elucidate the effects of resistance and aerobic exercise on scar severity, range of motion, social participation and reintegration, and patient quality of life in larger groups of burn survivors is warranted. Studies that link the effects of exercise at the molecular or cellular level with whole-body physiology or function would advance the field by allowing the identification of pharmacologic targets or biomarkers of recovery. In addition, the determination of the mechanisms underlying the positive effects of exercise on burn recovery and rehabilitation is an unmet need.

FUTURE DIRECTIONS

The benefits of exercise for the burn survivor are numerous, but should be extended beyond current knowledge, especially with respect to determining underlying mechanisms. With improvements in clinical care over the past 50 years,[87] more patients now survive burns, necessitating increased focus on ameliorating long-term function and quality of life (QoL).[98] Large longitudinal studies revealed poorer long-term outcomes for burn survivors compared to age-matched non-burn cohorts, including significant increases in morbidity and mortality beginning as soon as a year after injury and continuing for decades.[21,45,46,98–101] Incidence of long-term organ damage (eg, musculoskeletal, cardiac)[45,46,102] and mortality (all-cause,[45,46,102] disease-specific,[21] and premature[103]) increases while QoL remains poor.[98] In comparison to the general US population, adult burn survivors are disproportionately less fit.[104] Survivors 3–30 years after injury continue to report weak hands, arms, legs, and feet, and difficulty walking or running.[104] Survivors engage in infrequent exercise (eg, walking one time per week or less), and compliance with stretching and strengthening programs is low.[104] Finally, there is evidence that nutritional and exercise strategies benefit pediatric and young adult burn survivors.[105] Thus, a multidisciplinary approach or study to incorporate wellness strategies and lifestyle changes may improve long-term outcomes and QoL for the burn survivor. Such studies should be sought.

FUNDING

NIH: R01GM068865; R01 HD049471; P50 GM060338DOD: W81XWH-15-1-0647; W81XWH-14-2-0160; W81XWH-09-2-0194.

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KEY POINTS

- An exercise training program for whole-body rehabilitation can be beneficial during the inpatient and outpatient stage of burn care. These benefits are physical, as well as psychosocial.
- Related to thermoregulation, burn survivors can have severely impaired thermoregulation which is related to the size of the burn injury.
- If the environmental conditions are temperate, and the workload is mild to moderate, a burn survivor can safely perform physical activity. In hot climates if the duration of activity is longer than ~30 minutes or less. If the environmental conditions are warm/hot and/or the workload is hard, physical activity for longer than ~30 min can cause excessive elevations in core temperature.
- Some studies have reported that exercise programs can reduce scar severity and the need for subsequent surgical interventions.

CLINICS CARE POINTS

- Participation in an exercise training program as an outpatient with severe burns is beneficial in counteracting burn-induced effects.
- Exercising indoor is recommended to avoid excessive strain on the thermoregulatory and cardiovascular system.
- In the heat an effective and practical method to mitigate rises in core temperature in burn survivors may be to intermittently spritz the grafted skin with lukewarm (not cold, not hot) water using a spray bottle.
- Participation in an exercise program alongside physical/occupational therapy may reduce the need for subsequent surgeries.
- Scar severity may be reduced as a result of participating in an exercise program.

Table 1

Exercise rehabilitation training prescription guidelines

RET Program Prescription	Cardiovascular Fitness	Resistive Fitness
Frequency	3–5 sessions/wk	At least 2 times/wk
Intensity	Moderate intensity between 70% and 85% HR peak or Vo_2 peak. High-intensity exercise can be prescribed at >90% Vo_2 peak	20% of total body mass for the upper body and 40% of total body mass for the lower body, with 3 sets and 8–15 repetitions per set.
Time	Continuous moderate intensity 20–40 min; High-intensity intervals, lasting 1–2 min, with 3–4 min recovery and 4–5 repetitions.	No time limit
Volume	Time volume is 150 min/wk, physical activity ambulation >5000–12000 steps/d	No established volume
Progression	Should start with what they can accomplish and an individualize progressive increase over time.	
Major considerations	Safety is the highest priority, so progress should be slow, techniques should be taught properly, and exercise prescription should be individualized based on the severity of burns and physical limitations.	