Rehabilitative Exercise Training for Burn Injury

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Abstract

Due to improvements in acute burn care over the last few decades, most patients with severe burns (up to 90% of the total body surface) survive. However, the metabolic and cardiovascular complications that accompany a severe burn can persist for up to three years post injury. Accordingly, there is now a greater appreciation of the need for strategies that can hasten recovery and reduce long-term morbidity post burn. Rehabilitation exercise training (RET) is a proven effective treatment to restore lean body mass, glucose and protein metabolism, cardiorespiratory fitness, and muscle strength in burn survivors. Despite this, very few hospitals incorporate RET in programs to aid the rehabilitation of patients with severe burns. Given that RET is a safe and efficacious treatment that restores function and reduces post burn morbidity, we propose that a long-term exercise prescription plan should be considered for all patients with severe burns. In this
literature review, we discuss the current understanding of burn trauma on major organ systems, and the positive benefits of incorporating RET as a part of the long-term rehabilitation of severely burned individuals. We also provide burn-specific exercise prescription guidelines for clinical exercise physiologists.

1 Introduction

According to the World Health Organization, the fourth leading cause of accidental injury is burn trauma, with about 11 million burn injuries occurring around the world annually resulting in approximately 180,000 deaths [1]. In the United States of America (USA) alone there are about half a million burn injuries yearly, which result in approximately 40,000 hospitalizations and 3,400 deaths. In 2016 approximately 75% (30,000) of patients with a burn in the USA were treated in one of 128 specialized burn centers [2]. In 2017 the American Burn Association (ABA) reported that flame burns were the most common cause for burn injuries (41%) in the USA, followed by scald burns (31%) [3]. The majority of burn injuries occur in children (1–16 years of age) and in people of working age (20–65 years of age), displaying a bimodal age distribution. Young children (under 5 years of age) tend to be injured by scalds, while flame burns are more common in adolescents and adults [4]. In regard to sex, burn injuries are equally distributed between boys and girls in toddlers, however with increasing age, boys and men are twice as likely to be injured by burns than girls and women due to behavioral factors [5]. Men also have a higher incident of burn injury in the workplace due to fire, scalds, chemical and electrical burns [1].

Severe burns are one of the most devastating forms of trauma. Beyond skin wounds, severe burns bring about a pathophysiological stress response, which can impact all of the body organ systems. Accordingly, restoration of homeostasis and ultimately physical function post burn is not readily achievable. Major burns are defined by the ABA as injuries involving greater than 20–30% total body surface area (TBSA). Severe burns also result in a prolonged pathophysiological stress response [6]. This stress response to burns has been well described, eliciting a chronic increase in total energy expenditure (hypermetabolism) that may persist for many years after the initial burn injury [7, 8]. The hypermetabolic response is mediated by persistent increases in circulating levels of catecholamines, cortisol, and proinflammatory factors that drive an increase in multiple oxygen-dependent processes post-injury [7–9]. In addition, muscle wasting, cardiac dysfunction, growth retardation in children, impaired insulin sensitivity, and hormonal dysfunction are all hallmarks of the stress response to major burns [9]. As a consequence, severe burn injuries affect the functional capacity and quality of life [7].

Interventions such as surgery, pharmacologic therapy, and nutritional support play important roles in aiding recovery and improving clinical outcomes following a severe burn [5, 8]. Rehabilitive exercise training (RET) represents an additional strategy that is both safe and effective in mitigating the pathophysiological responses and improving outcomes post burn. However, RET is an under-utilized treatment modality in burn patients [10]. In this literature review, we describe the current understanding of the impact of burn trauma from the point of hospital discharge and during the first three years post burn, on major organ systems and
discuss the benefits of RET in the long-term rehabilitation in severely burned individuals. We also provide exercise prescription guidelines for exercise trainers and clinical exercise physiologists.

2 Exercise Rehabilitation

Due to improvements in burn care, patients with significant burns (up to 90% TBSA) stand a reasonable chance of surviving their injuries. One major advancement in recovery is RET. However, despite clear data on its efficacy, very few hospitals have cardiopulmonary endurance and strength exercise programs in place to support the recovery of burn survivors [11]. From the point of hospital discharge, outpatient RET restores lean body mass (LBM), improves cardiopulmonary fitness and muscle strength, [12–15] while also increasing habitual physical activity (as determined by walking distance) [14, 15]. In addition, RET improves metabolic function in burned children [16]. RET also controls edema, decreases tendon adherence, joint stiffness, capsular shortening and muscle atrophy, and improves physical conditioning in burned patients [17, 18]. Furthermore, RET decreases the need for release of burn scar contractures [14]. Since metabolic, endocrine and cardiovascular complications can persist for up to three years post burn, we suggest that a long-term RET prescription plan should be considered for all patients with severe burns [7, 19–22].

2.1 Body Composition and Metabolism.

Burn trauma results in a persistent catabolic state, where the rate of muscle protein breakdown surpasses the rates of muscle protein synthesis, resulting in the loss of muscle protein [23]. Marked wasting of LBM and muscle weakness is often exacerbated by inactivity during prolonged intensive care unit (ICU) stays and after discharge [24]. Adrenergic stress is thought to contribute to altered glucose and lipid metabolism post burn, as well as driving a pronounced elevation of total energy expenditure (hypermetabolism). In summary, severe burns are associated with hypermetabolism, acute muscle catabolism, and deconditioning during enforced bed rest in the ICU. Collectively this results in a marked alteration of body composition, characterized by reduced LBM [25–29]. This state of chronic catabolism and loss of LBM is not readily reversible, and can persist for several years post burn [7, 12, 23, 30].

Little is known about the exact regional body composition changes (e.g., in terms of fat, muscle tissue and bone density, upper and lower extremities, etc.), particularly in the initial days and weeks post burn and during accompanying ICU stays. Body composition, including bone mineral density and content, as well as fat and lean mass, can be measured by dual-energy absorptiometry (DEXA). Cambiaso et. al. [29] reported decreased total LBM in both upper and lower extremities of burned children, where the magnitude of this response was greater in the upper limbs compared to lower limbs [29]. Furthermore, total fat mass increased in the truncal region by 23% [29]. At Shriners Hospital for Children® —Galveston, patients are typically fed 1.4–1.6 times their resting energy expenditure in addition to receiving about ~2–3 g/kg/day protein intake to prevent muscle loss [12]. Despite this treatment burn patients are often in a catabolic state, demonstrating that burn-induced muscle cachexia cannot be readily overcome by nutrition alone [31, 32]. Indeed, Cambiaso-
Daniel et al., reported a 17% reduction in lean mass and a 31% reduction in fat mass at one year post injury in children with severe burns [33]. Following discharge, muscle breakdown remains elevated in pediatric burn patients for up to one-year post burn [34]. Chang and colleagues suggest that a 10% loss of LBM may impair immune function, a 20% LBM loss may impair wound healing and a 30% LBM loss increases mortality. Further, a 30% loss of LBM results in increased incidence of pneumonia and pressure sores, which together increase chance of mortality by 50%. Notably, a 40% loss of LBM ultimately resulted in death in all cases [35]. Severe burn injury can also change bone metabolism. Longitudinal observational studies report bone loss changes occur soon after the injury are sustained [36]. Such an occurrence may increase the risk for post burn fractures due to stress, induced glucocorticoid production and resorptive cytokines resulting from the systemic inflammatory responses, which are likely aggravated by progressive vitamin D deficiency [37, 38]. Load-bearing exercise may mitigate these negative impacts of burns on bone integrity [39].

Due to loss of LBM, muscle weakness and accompanying morbidities, it can be a challenge for burn survivors to resume normal activities and reintegrate into society. Consequently, enhancing LBM and strength with RET can reverse the negative effects of burn injury on body composition and metabolism. Indeed, six to twelve weeks of RET, including concurrent aerobic and resistance exercise, increases LBM in burned children by about 5% [13, 40–47]. Further, Wurzer et al., [44] evaluated the long-term effects of a RET program in children starting at the time of hospital discharge and again at approximately two years post burn. They found that muscle strength and cardiopulmonary fitness improved with RET versus standard of care (SoC) at discharge, and these improvements persisted at 12–24 months post burn injury. Furthermore, after discharge, an increase in BMI was observed, and during the first year post burn, were significantly higher in the RET group than in the SoC group. Similar results were observed in adult patients after a 6 week RET program that included aerobic and resistance exercise [48]. Comparisons between boys and men show similar increases in both lean and fat mass by about 4% and 7%, respectively, following a 6–12 week RET performed after hospital discharge [49]. Suman et al., [40] found that 12 weeks of RET improved skeletal muscle strength and increased total LBM (trunk, leg, and arm) in children with large burns (>50% TBSA) compared to SoC. Notably, these children had impactful improvements in strength and muscle function, without worsening hypermetabolism. Indeed, other studies have reported that 6–12 weeks of RET does not exacerbate hypermetabolism post burn [50, 51].

The loss of LBM post-burn likely contributes to persistent insulin resistance, since skeletal muscle is responsible for 70–80% of whole body insulin-stimulated glucose uptake [52]. The impaired insulin sensitivity may last for up to three years post burn in children and adults [52]. Rontoyanni et al., reported that burn severity, sex and sepsis each influenced skeletal muscle mitochondrial function in burned children. Thus, glucose control and functional capacity are associated with altered muscle metabolic function in burn survivors [53]. Rivas et al., found that 6 weeks of RET with or without metformin (an insulin sensitizer) resulted in improvements in strength, an increase in LBM and cardiorespiratory fitness (CRF), reductions in fasting blood glucose concentrations, and reduced area under the curve for oral glucose tolerance tests [54]. Furthermore, mitochondrial respiration was likewise improved (i.e., with and without metformin) after RET [54]. For this study,
metformin had no additional benefit beyond exercise, which in turn had a clear positive benefit for restoring metabolism and exercise capacity of burn survivors.

2.2 Cardiorespiratory.

Burn trauma causes a profound stress on the cardiovascular system, which acutely elevates resting cardiac output and heart rate (HR) [7, 19, 55]. Elevated levels of catecholamines are associated with the cardiac response to burns, as well as increased myocardial oxygen delivery and consumption to support the elevated HR and cardiac output. This cardiac response may be associated with degeneration of the myocardium and ventricular hypertrophy that can cause derangements in cardiac physiology that persist for up three years post burn [19]. Chronic hyper-sympathetic activity in response to burn trauma can also cause cardiac deficiency, local myocardial hypoxia and cardiac death [7, 19]. Buk et al., utilized transesophageal echocardiography in adults with burns and identified markers that correlated with abnormalities of the wall of the heart and restrictive left ventricular diastolic function at 12, 24 and 36 h post burn [56]. Furthermore, both minor and severe burn injuries are associated with long-term musculoskeletal morbidity [57] that are thought to be risk factors for long-term cardiovascular disease [22].

Due to prolonged immobilization in the ICU, the possible need for mechanical ventilation and accompanying inhalation injuries, pulmonary function is also affected by major burn trauma [12]. An impaired spirometry pulmonary function represents a significant limitation for burned patients, which can last for several months post burn [58]. Other studies reported compromised pulmonary function in both burned adults [59] and children [46, 60], where combined obstructive and restrictive pulmonary defects may persist for several years post burn [59]. Such a compromised pulmonary function may contribute to a reduction in cardiorespiratory fitness. CRF (also quantified as VO$_2$max) refers to the capacity of the circulatory, respiratory, and skeletal muscle systems to supply and utilize oxygen by the skeletal muscle mitochondria for energy production needed during maximal exercise [61]. Therefore, CRF is a standard health measure that reflects the integrative capacity of cardiac, pulmonary, circulatory, and skeletal muscle systems. Willis et al., [59] demonstrated that CRF remained lower than normative values at approximately 5 years post injury. A study by Ganio and colleagues [62] demonstrated in a cohort of 25 severely burned adults that 80% of these patients had a CRF that was significantly lower than age-matched healthy nonburned adults. In children with burn injury, Cambiaso-Daniel and co-workers found that CRF was 25% lower than non-burned age/sex-matched children at discharge from hospital. Furthermore, these children were followed for several years post injury, where CRF was reported to be ~25% lower than the non-burned group four years post burn [33] (Figure 1). Thus, based on the cumulation of studies, CRF is diminished for years post injury, and this highlights the important need for long-term RET.

Several studies conducted at the Shriners Hospitals for Children®-Galveston, have shown the positive benefits of RET on CRF and pulmonary function [41, 44, 46, 47]. Suman and colleagues [41] reported that CRF at approximately 6 months post burn was significantly lower than in a nonburned healthy control group. In this study, a cohort of 31 severely burned children (aged 7–18 years, >50% TBSA) were divided into a combined 12-week
resistance and aerobic RET program, or a 12-week home-rehabilitation program that did not include RET. The RET group showed greater improvements in CRF and strength measurements compared to the control group. Recent studies evaluating the effect of exercising on well-healed adult burn patients have likewise shown positive benefits of exercise in a community-based setting [48, 63–65]. For example, in a cohort of well-healed burned adults, Romero et al., [48] demonstrated that a community based 6-month RET program improved CRF in burn survivors. In this study, CRF was measured in noninjured control subjects (n=11) and in individuals with well-healed burn injuries (n=13, 15–40% TBSA; n=20, >40% TBSA). RET similarly increased CRF in all groups (control 15±5%; moderate body surface area 11±3%; high body surface area 11±2%). Age may influence the negative effect of burn injury on adaptations of CRF. When directly comparing men and boys while controlling for burn size, men (n=39) had a greater increase in CRF by 19% compared to boys (n=40) who had a 10% increase in CRF after 6 to 12 weeks of the aerobic and resistance RET programs.

The aforementioned studies implicate a reduction in pulmonary function and reduced aerobic exercise capacity in burn survivors, which may last for several years post burn. A short term 12-week exercising program can improve CRF, though a long-term exercise training program may be needed to fully restore patients to pre-burn health.

2.3 Skin and Thermoregulation.

At the time of discharge from the hospital, acute thermal homeostasis post burn injury may differ than non-burned populations due to inadequate core-skin insulation and the hypermetabolic response to the severe burn. For example, burned patients have an elevated core temperature that is in part mediated by sympathetic and catecholamine activity, and this stimulates resting energy expenditure, metabolic heat production, and substrate mobilization [55, 66–68]. Indeed, greater energy expenditure post burn cannot be fully attributed to increased ATP turnover, indicating that mitochondrial proton leaks and thus non-shivering thermogenesis are recruited post burn [69, 70], possibly in an attempt to counter evaporative heat losses from burn wounds. The elevated internal body temperature commonly reported may also be from a reduced capacity of the skin to regulate body temperature during bouts of increased energy expenditure. In cool conditions, depending on the size of the burn injury, heat dissipation increases due to the burn injury and associated reduced epidermis, dermis, and subcutaneous tissue, which prompts an increase in energy expenditure to maintain internal body temperature. In adults with burn injuries, metabolic rates and catecholamine concentrations are found to be reduced in warm environmental (32–35°C) conditions, while being elevated in neutral cool environments (22°C) [55, 66–68]. Interestingly, in children with burns, blood flow to both burned and non-burned skin are elevated by 40–60% [71]. After discharged from the hospital, it has been reported that this profound increase in skin blood flow in both the burned and non-burned skin of injured children may be due to the continuous dissipation of heat and or inflammatory responses in conjunction with the hypermetabolic response to burns. Moreover, after hospital discharge, propranolol is often prescribed to reduce HR and stroke volume and to blunt energy expenditure after a severe burn, which may affect thermoregulation via circulation of heat from the core to the skin. However, Rivas et al., found that resting β-adrenergic blockade did not affect internal
body temperature of burned children exercising at similar relative intensities as non-burned children in the heat [71]. However, these responses may be different in adults and may be a function of the time of burn injury (e.g., at hospital discharge vs years post burn). Indeed, Davis et al., reported that cutaneous vasodilation and sweating in well-healed grafted skin during heat stress is severely impaired compared to adjacent undamaged skin in burned adults years postburn [72, 73].

The medical community has suggested that severely burned patients should avoid or limit strenuous physical activity or exercise, particularly outdoors or in the heat. This is due to disrupted thermal homeostasis evidenced by an inability of burned skin to facilitate heat loss [55, 66, 67, 74], including an attenuated or absent sweat rate response in grafted skin [73, 75, 76]. However, previous research has furthered the understanding of temperature regulation in burned adults and children during passive heating [67, 72, 73, 76–79] and exercise heat stress [76, 80–85]. Collectively, this literature does not support the recommendation to limit exercise in burn survivors. For example, in a case study, McEntire and colleagues found that the body temperature response to 30 min of moderate intensity exercise (75% of maximal capacity) in the heat (31°C, relative humidity 40%) in a 17 year old with a 99% TBSA burn was minimal, where only a slight increase in body temperature (Δ 0.69°C) was noted [74]. However, this individual’s response was highly dependent on exercise metabolic heat production that may have been low due to his low maximal aerobic capacity. Crandall and associates found that adults with up to 60% of their TBSA burned could exercise at a moderate intensity for 30 min, even in hot environmental conditions (39°C), without excessive elevations in body core temperature [86]. Most importantly, repeated exposure to heat can improve heat tolerance by acclimatization, which increases plasma volume and reduces cardiovascular strain. For example, Schlader et al., found that adult burn survivors with extensive skin grafts were able to complete a standard heat acclimation protocol (seven consecutive days involving 90 min of exercise at ~50% peak oxygen uptake in 40°C, 30% relative humidity). Importantly, burn survivors showed improvements in heat tolerance and dissipation post-acclimation, and the magnitude of improvements were not influenced by the extent of skin grafting [87].

Collectively, recent studies demonstrate that children and adults with burn injury can exercise in hot conditions for at least 30 min, though the well-being and hydration status of burn survivors should still be monitored during outdoor play or exercise. However, a prior burn injury should not discourage the medical community from promoting outdoor physical activity, especially given the proven role of exercise in restoring LBM, functional capacity, and quality of life in burn patients [13, 40–44, 46, 88, 89].

### 3 Exercise Rehabilitation Training Prescription

The standard physical and occupation therapy programs for burn injuries focus on restoring and maintaining range of motion, scar reduction, and prevention of contractures [90]. Several physical and functional limits post burn should also carefully be considered that may limit individuals with burn injuries from becoming independent. The limitations include home management, work duties, and leisure activities, as these are affected by limited range of motion, loss of mobility, intolerance to standing or walking, pain, and decreased strength.

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and endurance [91]. The exercise prescription described in this section is based primarily on the outpatient RET program that has been implemented at Shriners Hospitals for Children®-Galveston, Texas for rehabilitation of children and adults with severe burns. Over the last 30 years, Shriners Hospitals for Children®-Galveston has significantly contributed to filling knowledge gaps in burn patients and translated these findings into reducing suffering and improving recovery of burned children through research and education. Most significantly, in 1998, a single-institution-longitudinal cohort study compared SoC therapy with and without an adjunct RET program implemented after hospital discharge. The clinical trial proved the clear superiority of RET-supplemented SoC in restoring LBM, functional exercise capacity, and quality of life in severely burned children [12]. Since this initial trial, we have reported the benefits of a 12-week RET program at 6 months after burn injury [13, 40–46]. Furthermore, RET immediately after hospital discharge restores LBM and exercise capacity while improving quality of life [13, 42, 92, 93]. Notably, 6- to 12-week RET programs delivered to patients immediately after their hospital discharge and involving concurrent aerobic and resistive exercise training, improves CRF (+19%), strength (+37%) and LBM (+11%) [13, 40–44, 46]. Several studies have also shown benefits of aerobic and resistance exercising in adult burn survivors. The vast majority of the studies discussed in this review implemented a similar concept, relying on a 12-week exercise outpatient program. Collectively, they show that a 12-week rehabilitative exercising program improves the aerobic capacity [47, 48, 65], occupational [65], performance [65], muscle strength, LBM [94, 95], and quality of life [96].

3.1 Aerobic Exercise Training

Before patients can undergo aerobic training, they first should be tested in a standardized manner. For this purpose, there are several tests that can be performed to evaluate the CRF and observe systemic metabolic or cardiopulmonary responses. In Table 1, the different measures and tests for CRF are listed. The clinician and physiologists make sure to evaluate the patient’s physical and mental capability and adjust the training in terms of frequency, intensity, time, type, volume and progression based on the outcome of this tests (Table 2).

3.2 Aerobic Exercise Frequency

Training frequency is defined as how often one is exercising for a given time period (e.g., each week). The American College of Sports Medicine (ACSM) recommend that healthy adults participate in physical activity for 3 to 5 days per week for 20 to 60 minutes to improve physical fitness [97]. However, deconditioned patients can improve physical fitness with approximately 2 aerobic exercise sessions per week [61, 97]. A study reported [98] that only 41% of burn survivors participate in exercise programs once a week or less, which may not be enough to improve CRF. With regard to frequency, several studies conducted in the Shriners Hospitals for Children®-Galveston showed that 3–5 days a week of aerobic exercise improves cardiopulmonary fitness in severely burned children [12, 16, 47, 49, 95]. A study by de Lateur et al. reported a 12-week, 36-session, aerobic treadmill exercise program, which demonstrated significant improvements in aerobic capacity in severely burned adults [88]. This could also be confirmed in others studies with a 12-week exercise program consisting of 3 days a week of aerobic exercising or interval training [65, 111].
3.3 Aerobic Exercise Intensity

The intensity of an aerobic exercise is commonly described as a relative percentage of maximal aerobic capacity. There is a dose-response relationship between exercise intensity, and quality of life in clinical populations [99], and a dose-response relationship between both training intensity and volume for improving CRF in healthy populations [100]. In older adults, aerobic training at 66%–73% HR reserve (for 40–50 min per session for 3–4 day/week) is effective for improving CRF [101]. A study by Paratz et al. (22710771) reported a significant improvement in functional, physical, and psychologic measures with participants training with an intensity of 80% of VO2peak. A meta-analysis reported that intensity groups of 1: ~60–70%; 2: ~80–92.5%; or 3: ~100–250% VO2max had similar improvements in young healthy adults [102]. This suggest that exercise at an intensity of at least 60% of VO2max is needed for improvements in CRF. Another systematic review and meta-analysis found that aerobic training and high intensity interval training both resulted in large improvements in VO2max, however the gains were greater following high intensity interval training [103].

Because there is a linear relationship between relative oxygen consumption and HR, as exercise intensity increases, heart rate (HR) can be used as a simple cost effective tool to monitor and prescribe exercise. This approach will also require obtaining a maximal HR value during a VO2max test. It is also suggested that the utilizing a relative percentage of maximal HR (i.e., at an intensity between 65%–95% HR peak) should elicit positive improvements [61, 104]. If it is not feasible to carry out a maximal treadmill test, one can estimate the HR peak by using the formula (220-age) [61], however this formula is not accurate in severely burned children, as their HR peak is reported to be lower due to burn injury or drugs (i.e., propranolol) [47]. The rating of perceived exertion (RPE) scale [105] in adults and [106] for pediatric (Pictorial Children Effort Rating Table) populations could also be used during the CRF test, and prescription of exercise intensities. This is approach is important if obtaining a HR peak is not possible or if administered medications affect the HR-like β-blockers. The RPE scale runs from six to twenty, six being resting doing nothing at all and twenty being very, very heavy, and exhaustion. A moderate intensity (RPE=10) is recommended to improve aerobic capacity and for safety [88]. However, studies in severely burned children have shown that with a low intensive walking the children and adults reached 70–80% of their HR peak [33, 63, 64]. The relationship between relative oxygen uptake and relative HR peak in cohorts of children and adults with and without burns is shown in Figure 2. Prescribing exercise intensity for aerobic exercise for continuous exercise greater than 70% VO2peak correlated to about 85% HRpeak in burned children. High intensity interval exercise at 90% VO2peak correlate to greater than 95% HRpeak based off predictions of %VO2 and %HR. This relationship is similar in adults as shown in Figure 2. This observation suggests being cautious in prescribing exercise intensity in severely burned children and adults at the discharge time period when starting the prescription of exercise. For example, early exercise prescription can consist of light to moderate aerobic activities (>60% VO2 peak or >70% HR peak), to prevent any injury, muscle soreness, or pain. Such a workload may be low intensity walking even though the person with burn injury will be working at a high relative percentage of their aerobic capacity. The exercise intensity should increase slowly to ensure the safety of the patient. Shriners Hospitals for...
Children®—Galveston has implemented an exercise intensity of 70–85% of individual peak aerobic capacity (VO$_2$ peak) or 50–85% of HR reserve [47].

### 3.4 Aerobic Exercise Time

The duration of aerobic exercise should start with 5–20 minutes per session in the first week of the exercise program and increases over time depending on the individual patient in terms of safety and physical capability. The goal is to achieve an aerobic session with a duration of approximately 20–60 min in order to improve cardiopulmonary fitness. The exercises can be performed continually or in intervals. A recent study by Tapking et al., [107] utilized a high intensity interval training program at 85 to 90% of HR peak using either a treadmill (1- or 2-minute intervals) or cycle ergometer (2-minute intervals) for 20 minutes in burned children. Each interval was separated by a 2-minute active pause and slow walking or cycling recovery. This study showed that interval training significantly increased cardiopulmonary capacity in severely burned children up to 24 months post burn [107]. Interval training has also been implemented in adult burn survivors. In a study by Grisbrook et al. [65] interval training consisted of 30 min of walking/jogging performed on a treadmill. Participants were instructed to initially walk/jog at a high intensity workload that equated to 85% of their individual HR max (220-age), for 120 s, and then to reduce this intensity to a level that represented a low/moderate intensity workload (65–70% HR max) for 120s. They demonstrated that interval training improved VO2peak total work and functional ability.

An aerobic exercise session should consist of a warmup phase, having a duration of approximately 10 min easy walking or cycling, and an endurance phase with 20–40 minutes moderately fast walking or cycling (>75% HR peak). Nevertheless, the duration is linked to the intensity. High intensity exercising should last for 1 – 5 min intervals with 3 times that value for recovery (1 minute at 90% HR peak with 3 minutes recovery at 50% peakHR), whereas moderate intensity exercising should last for 10–20 minutes [97]. Following the endurance phase, a cool-down of 10 minutes consisting of slow walking is recommended. The aim is to return to a resting HR and blood pressure.

### 3.5 Aerobic Exercise Type

The type of exercise prescribed should consist of dynamic movements and involve large muscle groups. Treadmills, cycle ergometers, elliptical machines, arm ergometers, rowing machines and even sports such as soccer or basketball are appropriate modalities of aerobic exercises for burn patients. The goal is to improve the cardiopulmonary capacity; however, the safety of the patients should be the highest priority. The study by Baldwin et al., [98] demonstrated that walking was the most commonly used exercise type in patients with burn injury and therefore should also be considered as a good starting point, as it is practical and involves large muscle groups and can be performed continuously [61]. Furthermore, it is safe and easy to monitor. Walking speed as an aerobic exercise in burned children was described by our group [12, 16, 47, 49, 108]. It is important to keep the patients motivated and include sport activities in exercising programs to facilitate exercise variety and compliance.
3.6 Aerobic Exercise Volume and Progression

The American College of Sports Medicine (ACSM) recommend that healthy adults participate in physical activity for a total volume of 150 minutes per week of moderate to vigorous exercise to improve physical fitness [97]. In our RET guidelines at Shriners Hospitals for Children Galveston, we reported similar for children with burn injuries [47]. The exercise progression should be individualized to the patient’s capabilities and severity of burn injury. At the first 3–4 weeks of RET, the duration of an exercise regimen may begin with 10–15 min and progress slowly and consistently every 2 weeks, until participants are able to continuously exercise at a moderate to vigorous intensity for 20–30 min. We found that the average minutes of physical activity (steps) that included our RET program was lower in burned children (56 ± 25 minutes) compared to non-burned children (74 ± 28 minutes) and that percentage TBSA burned was inversely associated with steps (r = −0.54) and minutes of activity (r = −0.53) [109]. In adults, physical activity can be monitored with commercially available activity trackers that are a useful tool for prescribing activity goals [110]. Our data suggest in children with burn injuries that completed the rehabilitation exercise program, performed >5000–12000 steps per day over the 12 weeks [109]. An improvement of CRF and strength in a combined aerobic and resistive exercise program, with a frequency of 3 exercises/week, has also been demonstrated in adult burn survivors [65, 111].

3.7 Resistance Exercise Training

The benefits of resistive strength training in the healthy population are well known. The loss of LBM after severe burns is associated with reduced endurance and reduced upper and lower body function (47). Loss of LBM and strength after a severe burn and prolonged stay in the ICU can be significant enough to limit an individual’s ability to perform basic daily activities. Therefore, it is beneficial to include resistance and strength training into an exercise rehabilitation program in burn individuals. Several studies in children [13, 40–44, 46, 63], as well as in adults [112–114] with severe burns have shown the benefits of resistance training on muscle strength and LBM. However, it is important to teach the proper technique before starting a program, to prevent injuries. Different strength tests should be done before prescribing a program, which are visualized in Table 2. Similar to aerobic exercise the training, the frequency, intensity, time, type, volume and progression also apply to resistance training.

3.8 Resistance Exercise Frequency

Several studies report that resistance exercise should be performed 2–3 times per week. [12, 47, 95, 111, 115, 116]. Other studies recommend splitting the days of training between upper and lower body exercises and alternating with aerobic days (e.g. Concurrent exercise training) [47].

3.9 Resistance Exercise Intensity (Sets and Repetition)

In children, 1–3 sets with 8–15 repetitions of low-to-moderate weight are recommended [61]. In adults, 3 sets of 10–15 repetitions of moderate-to-high weight are recommended to improve strength and endurance [47, 65, 117]. We [47] and others [118] report that intensity...
can be prescribed as a volume load (reps × sets × weight). In children with burn injury, we have quantified our resistance exercise that utilized starting volume loads of ~135 kg (ex., 9 repetitions x 3 sets x 5 kg =135 kg) for the upper body and ~280 (ex., 9 repetitions x 3 sets x 10 kg = 270 kg) or as a relative percentage of total body mass (TBM) such as 20% of total body mass for the upper body exercise and 40% of TBM for the lower body exercise [47]. As previously mentioned, the prescription of exercise intensity should be individualized specific to the patient’s capabilities.

3.10 Resistance Exercise Type

A distinction is generally made between multi-joint, assistance and core exercises. Multi-joint exercises involve large muscle groups, like legs, chest and the back. Assistance exercises are single joint exercises involving smaller and isolated muscle groups like the biceps, triceps or the calf’s [61]. Core exercises stabilize the spine, the pelvis and support other muscle groups of the extremities [119]. The Shriners Hospital for Children-Galveston has implemented the following types of exercises into their RET: bench or chest press, leg press or squat, lat pulldown or row, leg extension, shoulder press, lunges, biceps curl, hamstring curl, triceps extension, and toe raises. Core strengthening exercises follow and may include exercises such as crunches, back extensions, pushups, plank exercises, bridging, bicycles, and hip and gluteus strength exercises. The exercises can be performed on machines, or with free weight, which was also reported in adult burn survivors [65, 117]. Type of exercises that can be done include bench press, leg press, shoulder press, triceps and biceps curl, seated row, resisted shoulder flexion or abduction and toe raises that have been reported in adult burn survivors [111].

3.11 Resistance Exercise Volume and Progression

During the first weeks, the patients should be familiarized with the right movements and the proper technique to avoid any injuries. For practice, a broomstick can be used to learn the movements. When the patients are confident with the technique, 50–60% of their 3 repetition maximum, and 12–15 repetitions should be performed for the first 2 weeks. The load can then be increased to 70–75% of their 3 repetition maximum for 8–10 repetitions for 4–5 weeks. At weeks 7–12, the load is increased to 75–85% of their 3 repetition maximum with 8–12 repetitions. [12, 41–43, 47, 120, 121]. In Grisbrook et al. [65,117], reported in their studies a 12-week combined exercise program a load of 50–60% of each individual’s assessed maximum. Paratz et al. [117] reported a load of 60% of the 3RM in the first week. Resisted exercise should then progress weekly by 5% to 10% by increasing the number of repetitions or the weights lifted.

4. Conclusion

Severely burned children and adults can benefit from RET, as this training has a positive impact on the cardiorespiratory system, the musculoskeletal system and body composition. Several studies have demonstrated the benefits of a 12-week combined aerobic and resistance training program in children and adult burn survivors immediately upon hospital discharge and years’ post-burn injury. The intensity of aerobic exercises should be between 70–85% HR peak that corresponds to 70–85% VO₂ peak, with a frequency of 3–5 sessions/
week, with each session lasting for 20–40 min. High intensity exercise can be prescribed at >90% VO₂ peak lasting for 1–2 min with 3–4 min recovery with 4–5 repetitions. Additional, physical activity can be prescribed up to >5000–12000 steps per day over 12 weeks or longer. For children, resistance training may be performed at a volume load of 20% of TBM for the upper body and 40% of TBM for the lower body, at least 2 times /week, with 3 sets and 8–15 repetitions per set. However, the highest priority is the safety of the patient, so it is important to progress slowly and teach the proper movements and techniques. With this in mind exercise prescription should be highly individualized with consideration to severity of burns, and physical limitations, to ensure the optimal outcome with regards to rehabilitation.

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Key points

- The metabolic and cardiovascular complications that accompany a severe burn can persist long term post injury that affect quality of life.
- Rehabilitation exercise training is a safe and efficacious treatment that restores lean body mass, glucose and protein metabolism, cardiorespiratory fitness, and muscle strength in burn survivors.
- We propose that a long-term exercise prescription plan should be considered for all patients with severe burns.
Cardiorespiratory fitness, as reflected by VO$_2$ peak, and strength as reflected by maximal average power (W) are reduced at the time of hospital discharge when compared to age-sex matched children, and show improvements to a 12 week rehabilitation exercise training program. However, both VO$_2$ peak and maximal average power are not fully restored four years postburn injury in children. Based on our data set analyzed from [33], VO$_2$, volume of oxygen consumption; DC, discharge; EX, exercise (†P ≤ .01 vs A/S matched group, *P ≤ .001 vs DC, ‡P ≤ .05 vs post-EX training; Mean values ± SD).

Figure 1.
Figure 2.
Relation between relative VO\textsubscript{2} peak and HR peak in children with and without severe burn injury. Based on data set analyzed from [33, 47, 63, 64]. VO\textsubscript{2}, volume of oxygen consumption; HR, heart rate. As mentioned previously, the intensity of exercise (e.g., walking) may seem low but as shown in Figure 3, both children and adults burn survivors are in fact exercising at a high percentage of their maximal capacities. This response is likely due to the prolonged adrenergic stress, the metabolic response to severe burn injuries, and/or prolonged bed-rest deconditioning.
Figure 3.
Relative differences in %HR peak and %VO$_2$ peak in children (A, B) and adults (C, D) with burn injury compared to nonburned. Children and adults with burns exercise are at a greater percentage of their HR peak and VO$_2$ peak throughout the modified Bruce protocol. These finding are shortly after hospital discharge and are based on data analyzed from [33, 63, 64]. VO$_2$, volume of oxygen consumption; HR, heart rate; Mean values ± SD.
Table 1.
Standard Measure and Tests before Aerobic and Strength Exercising Prescription

| Measurement/Test                              | Description                                                                 |
|-----------------------------------------------|-----------------------------------------------------------------------------|
| Modified Bruce treadmill protocol (MBT)       | Stage 1: 1.7 mph and 0% incline, 3 minutes                                  |
|                                               | Stage 2: 1.7 mph and 5% incline, 3 minutes                                  |
|                                               | Stage 3: 1.7 mph and 10% incline, 3 minutes                                |
|                                               | Stage 4: 2.5 mph and 12% incline, 3 minutes                                |
|                                               | Stage 5: 3.4 mph and 14% incline, 3 minutes                                |
|                                               | Stage 6: 4.2 mph and 16% incline, 3 minutes                                |
|                                               | Stage 7: 5.0 mph and 18% incline, 3 minutes                                |
|                                               | Stage 8: 5.5 mph and 20% incline, 3 minutes                                |
|                                               | Stage 9: 6.0 mph and 22% incline, 3 minutes                                |
| Heart rate                                    | Obtained with monitors (may be limited to 175–180 bpm in severely burned children). HR peak should be obtained at end of a maximal aerobic exercise test. |
| Rating of Perceived Exertion                  | Person’s subjective value from the 6–20 Borgs perceived exertion scale should be recorded at last minute of each stage. |
| Oxygen Consumption                            | Indirect calorimetry (entails continuous analysis of inspired and expired gasses, flow, and volume calibrated with known gas and volume.) |
| Peak Oxygen Consumption Estimation in absence of indirect calorimetry | \[7.63 + 2.16 \times \text{sex} (\text{females}=0, \text{males}=1) + 0.41 \times \text{age (years)} + 0.15 \times \text{maximal speed (m/min)} \] (\(R^2=0.6525\)) [122] |
| Isokinetic dynamometry strength testing       | To evaluate muscle strength and progress using Biodex Isokinetic dynamometer (on the dominant leg) |
| Three Repetition Maximum Test (3RM) or 1 repetition maximal test | To determine a safe and effective load: warm-up and then patient successfully lifts the weight for three repetitions, if the fourth repetition is not possible the test is terminated. The weight is the individual 3RM or 1 RM. |
Table 2.
Shriners Hospitals for Children®—Galveston exercise rehabilitation program workouts frequency, intensity, time, type volume and progression for patients with burns.

| Aerobic Workout | Specifications |
|-----------------|----------------|
| Frequency       | 3–5 days per week. |
| Intensity       | 70–85% of individual peak aerobic capacity (VO$_2$ peak) or greater than 80% HR peak. HR and rating of perceived exertion can be used at regular intervals. High intensity intervals training at 85 to 90% of HR peak using either a treadmill (1- or 2-minute intervals) or cycle ergometer (2-minute intervals) for 20 minutes. Each interval should be separated by a 2–3 minute active walking or cycling at 50–70% of maximal HR. |
| Time            | 20–40 minutes (excluding warm-up and cool-down); continuous or intervals of work to rest or easy to moderate. |
| Type            | Treadmills, cycle ergometers, elliptical machines, arm ergometers, rowing machines. Sports such as soccer, basketball, and kickball. |
| Volume and Progression | Physical activity of 5000–10,000 steps per day building up over 12 weeks, >150 minutes of aerobic exercise per week. Sessions may start from 10 min/day and progress up to 60 min/day over 12 weeks that includes warmup and cool down. |

| Resistance Workout | Specifications |
|-------------------|----------------|
| Frequency         | 2–3 days per week is recommended but may do every day if alternating upper and lower body workouts. Need to account for the type of aerobic workout. |
| Intensity, repetitions, and sets | Weeks 1–2: 50–60% of 3RM for 12–15 reps; Weeks 3–6: 70–75% of 3RM for 8–10 reps, Weeks 7–12: 75–85% of 3RM for 8–12 reps. 2–3 sets. |
| Type              | Exercise should start with the larger muscles first then move to the smaller muscles. 10 basic resistance exercises using variable resistance machines, free weights, or resistance bands: 5 for upper body, 5 for the lower body, plus 1–3 core exercises. |
| Rest period       | Approximately 1–2 minutes between sets. |
| Volume            | Children: Volume loads (reps × sets × weight) of 130 kg for the upper body and 280 kg for the lower body for 2–3 days/week. Adults may follow similar volume loads but should be individualized based on the capabilities. |