

# Quantification of an Exercise Rehabilitation Program for Severely Burned Children: The Standard of Care at Shriners Hospitals for Children<sup>®</sup>—Galveston

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Currently, there are no clear guidelines for the implementation of rehabilitative exercise training (RET) in burned individuals. Therefore, we quantified the training logs for exercise intensity, frequency, and duration of 6 weeks of this program to develop a basic framework for outpatient RET in patients recovering from severe burns. Thirty-three children (11 female, [mean  $\pm$  SD] 12  $\pm$  3 years, 145  $\pm$  18 cm, 40  $\pm$  11 kg, 49  $\pm$  31 BMI percentile) with severe burns (49  $\pm$  15% total body surface area burned, with 35  $\pm$  22% third-degree burns) completed our 6-week resistance and aerobic exercise training program. Cardiorespiratory fitness (peak  $\text{VO}_2$ ), strength, power, and lean body mass (LBM) were measured before and after RET. Outcome measures were analyzed as a relative percentage of values in age- and sex-matched nonburned children (11 female, 12  $\pm$  3 years, 154  $\pm$  20 cm, 49  $\pm$  22 kg, 56  $\pm$  25 BMI percentile). At discharge, burned children had lower LBM (77% of age-sex-matched nonburn values), peak torque (53%), power (62%), and cardiorespiratory fitness (56%). After 6 weeks of training, LBM increased by 5% (82% of nonburn values), peak torque by 18% (71%), power by 20% (81%), and cardiorespiratory fitness by 18% (74%;  $P < .0001$  for all). Quantification of data in exercise training logs suggested that physical capacity can be improved by aerobic exercise training performed at five metabolic equivalents ( $>70\%$  of peak  $\text{VO}_2$ ) at least 3 days/week and 150 minutes/week and by resistance training performed at volume loads (reps  $\times$  sets  $\times$  weight) of 131 kg for the upper body and 275 kg for the lower body for 2 days/week. We present for the first time the quantification of our RET and provide clear exercise prescription guidelines specific to children with severe burn injury. (*J Burn Care Res* 2018;39:889–896)

Burn trauma is the fourth leading cause of severe injury, and an estimated 11 million people around the world sought burn care in 2004 alone (1, 2). Approximately half a million Americans are affected by burn trauma, which leads to nearly 40,000 hospitalizations and 3400 deaths annually. Globally, about 265,000 deaths occur yearly (3).

Burn trauma causes a profound stress response that elevates cardiac output and induces a hypermetabolic response. In addition, elevated catecholamines cause dysregulation of glucose, lipid, and protein metabolism (4). The increase in energy expenditure and protein catabolism from burn trauma, coupled with deconditioning during bed rest in the ICU, causes loss of lean body mass (LBM) (5–8). Over the

past 30 years, Shriners Hospitals for Children<sup>®</sup>—Galveston has strived to reduce suffering and hasten recovery of burned children through research and education. In 1998, we undertook a single-institution, longitudinal, cohort study to compare the standard of care with and without an adjunct rehabilitative exercise training (RET) program implemented after hospital discharge. The trial ended in 2009 because of the clear superiority of exercise-supplemented standard of care in restoring LBM, functional exercise capacity, and quality of life (9). This finding led to the adoption of the program as the standard of care at our institution. Since this initial trial, we have reported benefits of a 12-week RET program at 6 months after burn injury (10–17). This program has consistently been shown to improve aerobic exercise capacity, strength, and LBM (Table 1). We are unaware of any other institution that has established a standard of care for RET programs in severely burned children or adults.

Both minor and severe burn injuries are associated with long-term musculoskeletal morbidity (18) and are thought to be risk factors for long-term cardiovascular disease (19). Because no current standard recommendations exist for exercise rehabilitation in children with severe burn injury, our aim was to develop specific guidelines by quantifying the exercise intensity, frequency, and duration of our RET program as well as associated improvements, as assessed by comparing burned and nonburned healthy children. Indeed, we have recently reported that children display signs of exercise intolerance and have an attenuated peak heart rate (HR) and cardiovascular response to submaximal exercise compared with age- and sex-matched nonburned children (20), underscoring the need for burn-specific guidelines for prescribing RET.

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**Table 1.** Exercise aerobic, strength, and lean body mass improvements from Shriners Hospitals for Children 12-week rehabilitation exercise training program

Author	n	Male (%)	Age (y)	TBSA (%)	PeakVO <sub>2</sub> (%Δ)	Strength (%Δ)	LBM (%Δ)
Suman et al. <sup>(10)</sup>	16	84	10.5 ± 1	60 ± 3	23	44	6
Suman et al. <sup>(11)</sup>	17	82	12.6 ± 1	60 ± 4	24	–	–
Suman et al. <sup>(12)</sup>	11	81	11.8 ± 2	61 ± 2	–	41	6
Clayton et al. <sup>(13)</sup>	18	82	12.3 ± 4	56 ± 13	22	40	22
Hardee et al. <sup>(14)</sup>	24	80	13.0 ± 1	60 ± 2	13	28	9
Wurzer et al. <sup>(15)</sup>	82	61	12.4 ± 4	56 ± 15	23	25	13
Przkora et al. <sup>(16)</sup>	51	80	11.6 ± 1	54 ± 4	23	41	8
Suman et al. <sup>(17)</sup>	13	70	10.5 ± 1	59 ± 3	–	43	5
Mean ± SD		77 ± 8	12.0 ± 1	58 ± 3	21 ± 4	37 ± 8	10 ± 6

TBSA, total burned surface area; VO<sub>2</sub>, oxygen uptake; LBM, lean body mass; Δ, change from pre- to post-training.

## METHODS

### Ethical Approval

All experiments were approved by the Institutional Review Board of the University of Texas Medical Branch and are in agreement with the Declaration of Helsinki. Before children's participation in the study, parents or legal guardians provided written informed consent. Child assent was obtained as applicable.

### Experimental Design

This was a retrospective study. Between 2005 and 2015, children with severe burn injury met the following criteria for analysis: no drug intervention and completion of 6 weeks of RET with recorded exercise training logs (33/325 patients qualified). The 6-week RET program began at hospital discharge. At discharge and after completion of 6 weeks of exercise training, cardiorespiratory fitness (also referred to as peak oxygen uptake or peak VO<sub>2</sub>), strength (torque and power), and body composition (LBM) were determined as described previously <sup>(14)</sup>. Exercise training consisted of resistance exercise 2 to 3 days/week and aerobic exercise (10–45 minutes) 3 to 5 days/week. Exercise logs were analyzed for frequency (days/week), duration (minutes/day and minutes/week), and intensity (metabolic equivalent [MET], percent total body mass [TBM], and volume load [VL, reps × sets × weight]).

### Participants

Thirty-three children (11 females, [mean ± SD] 11.9 ± 3.4 years, 144.8 ± 18.1 cm, 39.2 ± 11.2 kg, 48.5 ± 31.1 BMI percentile) with severe burns (49 ± 15% body surface area burned, with 35 ± 22% third-degree burn) qualified for analysis. Within 48 hours of admission to our institution, pediatric patients underwent the standard of care treatment involving total burn excision. Wounds were covered with available autograft, and remaining open wounds covered with homograft. Total fluid resuscitation was administered within 24 hours of admission and according to the Galveston formula (5000 ml/m<sup>2</sup> total body surface area burned plus 2000 ml/m<sup>2</sup> total body surface area lactated Ringer solution). During the first week, all patients received

the same nutritional support, which was calculated as 1500 kcal/m<sup>2</sup> body surface plus 1500 kcal/m<sup>2</sup> area burned and was administered via the enteral duodenal or nasogastric route <sup>(21)</sup>. During the remainder of the acute stay, intake was modified to 1.4 times the weekly measured resting energy expenditure. Total body surface area burned and with third-degree burns were calculated by nursing staff. At admission, total body surface area burned was documented in Lund and Browder charts and adjusted accordingly on demarcation of third-degree burns. Participants were discharged once wounds were 95% healed and were then enrolled in the 6-week RET program. A cohort of nonburned age- and sex-matched counterparts served as controls and did not complete the exercise training. Each burned child was matched to a control based on age and sex (controls: n = 33, 11 females, 12.2 ± 2.7 years, 154.0 ± 20.1 cm, 48.8 ± 22.1 kg, 55.6 ± 25.0 BMI percentile).

### Peak Aerobic Exercise Capacity Test

Peak VO<sub>2</sub> was determined by a modified Bruce protocol maximal treadmill exercise test to volitional exhaustion. Respiratory gases were analyzed using breath-by-breath data using an automated MedGraphics Cardi O<sub>2</sub> metabolic cart (St. Paul, MN) after O<sub>2</sub> and CO<sub>2</sub> gas and air flow were calibrated using known gases and a 3-l syringe. Initial speed was set at 1.7 mph and angle of elevation at 0%. These were then increased every 3 minutes. Participants were continually encouraged to complete 3-minute stages, and the test was ended once peak volitional effort was achieved. The test was deemed to be maximal once participants signaled to stop exercise and at least three of the following criteria were met: a respiratory exchange ratio ≥ 1.05, a leveling off in VO<sub>2</sub> with increasing workloads (< 2 ml kg<sup>-1</sup> min<sup>-1</sup>), volitional fatigue, a final exercise HR ≥ 190 bpm, or a final test time of 8 to 12 minutes. All participants met three of the aforementioned criteria. Values were normalized to LBM to account for differences from pre- to post-exercise training and from healthy nonburn controls.

### Peak Strength and Mean Power Assessment

Muscle strength was assessed using the Biodex System-3 Dynamometer (Shirley, NY). The isokinetic test was

performed at an angular velocity of  $150^{\circ}\cdot\text{s}^{-1}$  on the dominant leg extensors. Participants were familiarized with procedures before testing through visual and verbal explanations. Following three submaximal repetitions without load, 10 maximal voluntary muscle contractions (full extension and flexion) were performed consecutively without rest between repetitions. Values of peak torque and average power were calculated by the Biodex software system and normalized to kg of LBM to account for differences in fat mass from pre- to post-exercise training and from healthy nonburned controls.

### Body Morphology

Standard calibrated scales were used to determine weight and height. Dual-energy x-ray absorptiometry (DXA) was used to determine body composition (Hologic QDR 4500 densitometer, Hologic, Inc., Bedford, MA). DXA measurements were performed within 7 days of the exercise protocol during the participant's first visit to the laboratory. On the day of each test, the DXA instrument was calibrated using the procedures provided by the manufacturer, and DXA scans were performed and analyzed using pediatric software. Two mass indices were used: body mass index (BMI) and BMI percentile. BMI was calculated by weight in kilograms divided by the square of height in meters. BMI percentile was determined using the normative values provided by the Centers for Disease Control and Prevention (22).

### Statistical Analysis

For participant characteristics and each exercise training measure, a paired student's *t*-test was used to compare pre- and post-training values, and an independent *t*-test was used to compare each pre- and post-training time point to nonburn healthy data. For strength and cardiorespiratory measures, each burned child's value was converted to a percentage of value for their age- and sex-matched counterpart, and a paired *t*-test was used to compare pre- and post-exercise training values. A two-way factorial analysis of variance (ANOVA) was used to compare exercise

variable (relative percent peak HR and percent peak  $\text{VO}_2$ ) and work load (interaction and main effects of group  $\times$  work rate). Similarly, two-way ANOVA assessed interaction and main effects of time  $\times$  stage of the exercise stress test for absolute values (HR and  $\text{VO}_2$ ). If significance was found, the appropriate Holm-Sidak multiple comparison post hoc test was performed. The rate of external work was calculated from the treadmill grade and speed using the following standard formula: Watt (W) = body mass in kilograms  $\times$  9.81  $\times$  (speed in mph  $\times$  0.44704)  $\times$  (%Grade/100). To control for growth and body morphology variations between burned and nonburned children, we normalized  $\text{VO}_2$  to kg of TBM and LBM. Pearson correlations were used for relationships between percent  $\text{VO}_2$  and percent HR. Data were analyzed in GraphPad Prism (Version 7, La Jolla, CA), with significance set at  $P < .05$ . Data are reported as mean  $\pm$  SD or  $\pm 95\%$  confidence intervals were indicated.

## RESULTS

### Participants

Characteristics of burned and age- and sex-matched nonburned children are presented in Table 2. Nonburned children were significantly taller and had less fat mass and greater lean mass than burned children (each,  $P < .05$ ). The patients in this study were admitted for flame burns (65%), scald burns (29%), and combined electric/flame burns (1%). The average length of stay from admittance to discharge was  $29 \pm 20$  days.

### Quantification of the 6-Week Rehabilitative Exercise Program

The duration of exercise training was  $6.1 \pm 1.3$  weeks. Over this time, aerobic exercise performed at an intensity was  $5.9 \pm 2.5$  METs and a frequency of  $3.5 \pm 1.2$  days/week,  $41 \pm 25$  minutes/day, and about  $146 \pm 117$  minutes/week (Table 3). Aerobic activities included walking, running, cycling, rowing, and playing sports or games (sport games

**Table 2.** Participant characteristics

Characteristic <sup>†</sup>	Burned			Nonburned controls	P
	Pretraining	Post-training	P		
n (male/female)	33 (22/11)	33 (22/11)	–	33 (22/11)	–
Age (y)	11.8 $\pm$ 3.3	11.9 $\pm$ 3.3	–	12.2 $\pm$ 2.7	0.70
Height (cm)	144.8 $\pm$ 18.0 <sup>‡</sup>	144.9 $\pm$ 17.6 <sup>‡</sup>	0.49	154.0 $\pm$ 20.1	<b>0.04</b>
Weight (kg)	39.2 $\pm$ 11.2	41.7 $\pm$ 12.1	0.18	48.8 $\pm$ 22.1	0.10
BMI (%tile)	48.5 $\pm$ 31.1	57.1 $\pm$ 31.1	0.12	55.6 $\pm$ 25.0	0.82
Fat mass (kg)	11.6 $\pm$ 7.1	12.5 $\pm$ 9.5	0.32	11.7 $\pm$ 6.0	0.68
Fat mass (% total body)	26.8 $\pm$ 6.7 <sup>‡</sup>	26.7 $\pm$ 6.4 <sup>‡</sup>	0.46	23.2 $\pm$ 4.2	<b>&lt;0.01</b>
Lean mass (kg)	27.7 $\pm$ 8.4 <sup>‡</sup>	29.4 $\pm$ 8.9 <sup>‡</sup>	0.21	37.2 $\pm$ 17.1	<b>&lt;0.02</b>
TBSA burn (%)	49 $\pm$ 15	–	–	–	–
TBSA third-degree burn (%)	35 $\pm$ 22	–	–	–	–

BMI %ile, body mass index percentile for age; TBSA, total body surface area.

<sup>†</sup>Data reported as mean  $\pm$  SD.

<sup>‡</sup>Statistically different from nonburned healthy controls.

**Table 3.** Frequency, intensity, and duration of exercise in the 6-week aerobic and resistance exercise rehabilitation program

Week	Aerobic exercise					Resistance exercise				
	METs	Days per week	Minutes per day	Minutes Per week	Days of upper	Percent total body weight	Volume load (kg)	Days of lower	Percent total body weight	Volume load (kg)
1	3.7 ± 1.3	3.3 ± 1.4	34.2 ± 21.8	127.3 ± 118.9	1.7 ± 1.1	15 ± 10	91 ± 108	1.3 ± 0.5	28 ± 15	164 ± 141
2	5.0 ± 1.6	3.2 ± 1.3	33.5 ± 22.3	119.9 ± 102.3	1.7 ± 0.6	17 ± 9	110 ± 79	1.3 ± 0.5	36 ± 18	245 ± 175
3	6.0 ± 1.6	3.1 ± 1.2	44.9 ± 23.5	152.5 ± 113.6	1.6 ± 0.9	24 ± 25	161 ± 217	1.3 ± 0.8	45 ± 23	296 ± 203
4	5.8 ± 2.9	3.9 ± 1.1	52.9 ± 31.1	200.5 ± 142.9	1.6 ± 0.7	19 ± 13	123 ± 108	1.6 ± 0.7	49 ± 19	330 ± 184
5	6.0 ± 4.1	3.7 ± 1.0	43.6 ± 20.9	169.5 ± 108.1	1.7 ± 1.0	18 ± 12	129 ± 121	1.4 ± 0.6	46 ± 24	312 ± 208
6	6.8 ± 3.6	3.6 ± 1.2	36.0 ± 27.1	107.6 ± 116.2	1.4 ± 0.8	21 ± 16	171 ± 209	1.4 ± 0.8	45 ± 20	307 ± 210
Mean ± SD	5.9 ± 2.5	3.5 ± 1.2	41.0 ± 24.5	146.2 ± 117	1.6 ± 0.9	19 ± 14	131 ± 140	1.4 ± 0.7	42 ± 20	275 ± 186

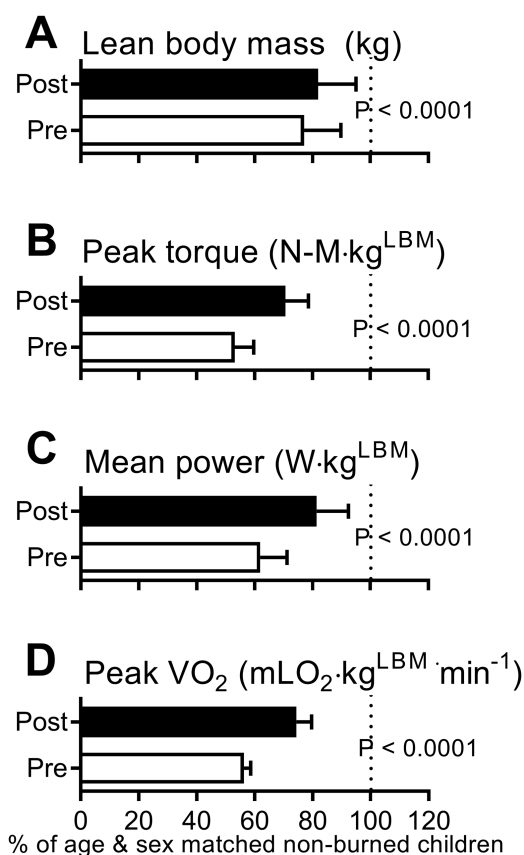
METs; metabolic equivalents.

Volume load (kg) = reps × sets × weight.

were excluded from the intensity quantification analysis as there was no way for quantifying them). For resistance exercise, the exercise intensity for the upper body was  $19 \pm 14\%$  of kg of TBM with a VL of  $131 \pm 140$  kg (Table 3). Intensity for lower body was  $42 \pm 20\%$  of kg of TBM and a VL of  $275 \pm 186$  kg. Upper body exercise was performed  $1.6 \pm 0.9$  days/week and lower body exercise  $1.4 \pm 0.7$  days/week. Children typically performed three sets of resistive upper and lower body exercises each session with a 2-minute rest between sets. Eight basic resistive exercise activities were used: bench press, squats, shoulder press, leg press, biceps curl, leg curl, triceps curl, and toe raise. A recovery day rest between each was followed.

### The 6-Week Aerobic and Resistance Training Program Improves LBM, Strength, and Cardiorespiratory Fitness in Severely Burned Children

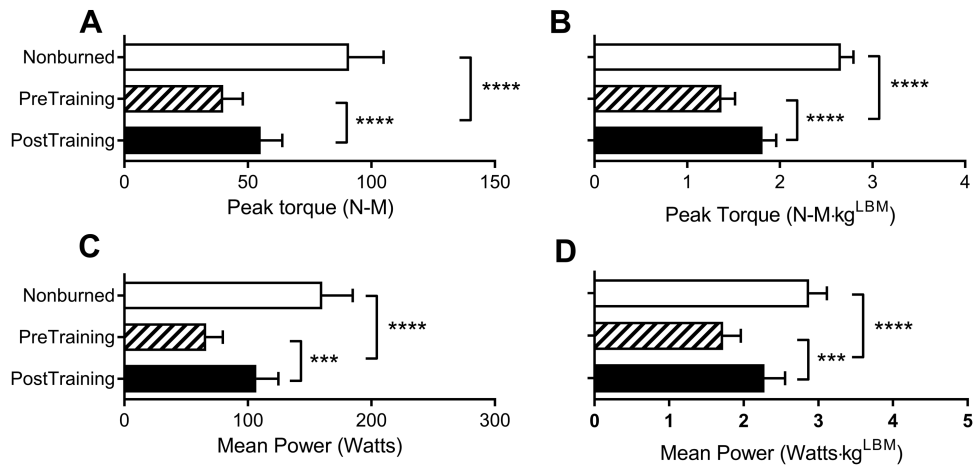
Figure 1 shows the improvements following the 6-week rehabilitative exercise program relative to age- and sex-matched healthy nonburned children. At discharge (before exercise training), burned children had reduced LBM (77% of age- and sex-matched nonburn value), peak torque (53%), mean power (62%), and cardiorespiratory fitness (56%). After 6 weeks of training, LBM was increased by 5% (82% of age- and sex-matched nonburn value), peak torque by 18% (71%), power by 20% (81%), and cardiorespiratory fitness by 18% (74%;  $P < .0001$  for all). Similarly, absolute and LBM-normalized strengths were low at discharge but increased significantly after the rehabilitative exercise program (Figure 2). At discharge, absolute values for peak  $\text{VO}_2$  and peak work rate were significantly lower than nonburn values, and these were partially restored to nonburn values after RET (Figure 3). Peak HR values were also lower than nonburn values ( $P < .01$ ), though they did not improve after exercise training. Indices of peak cardiovascular function (i.e., stroke volume, oxygen delivery, and cardiac muscle efficiency) were attenuated at discharge but improved after exercise training. An index of lung function did not differ between burned children and nonburned controls at discharge or after exercise training.



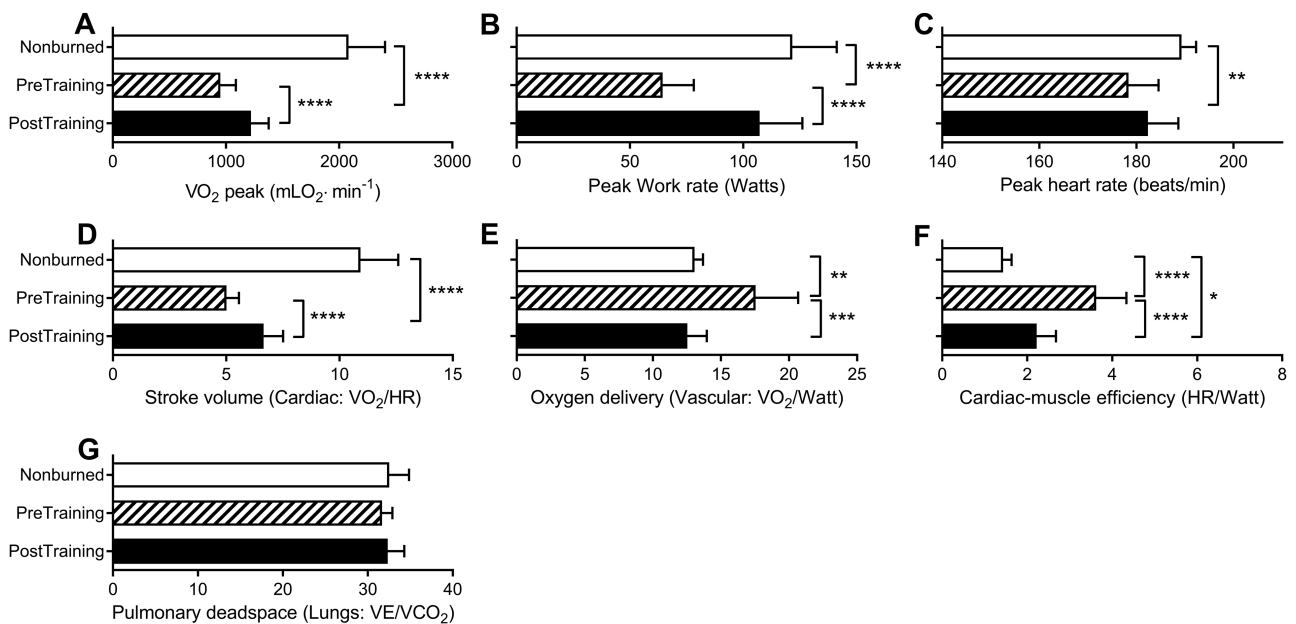
**Figure 1.** Effect of rehabilitative exercise training on lean body mass (LBM) (A), strength (peak torque, B; mean power, C), and cardiorespiratory fitness (peak  $\text{VO}_2$ , D) in burned children. All values are expressed relative to age- and sex-matched nonburn values and are reported as mean ± 95% CI.

### The 6-Week Aerobic and Resistance Training Program Improves the HR Response to Exercise But Not Submaximal Exercise Economy

Analysis of submaximal and peak LBM-normalized  $\text{VO}_2$  during the modified Bruce exercise test revealed that submaximal  $\text{VO}_2$  (exercise economy) did not change after exercise



**Figure 2.** Effect of rehabilitative exercise training on absolute strength (peak torque, A; mean power, C) and lean body mass (LBM)-normalized strength (B, D) in burned children. Healthy age- and sex-matched nonburned controls are shown for reference. All values are reported as mean  $\pm$  95% CI. \*\*\* $P < .001$ ; \*\*\*\* $P < .0001$ .



**Figure 3.** Effect of rehabilitative exercise training on peak cardiorespiratory fitness and indices of cardiovascular function. Absolute peak values are shown for VO<sub>2</sub> (A), work rate (B), and heart rate (C). Indices of peak cardiovascular function are stroke volume (D), oxygen delivery (E), cardiac muscle efficiency (F), and pulmonary dead space (G). Healthy age- and sex-matched nonburned controls are shown for reference. All values are reported as mean  $\pm$  95% CI. \* $P < .05$ ; \*\* $P < .01$ ; \*\*\* $P < .001$ ; \*\*\*\* $P < .0001$ .

training (Figure 4). However, burned children reached, on average, one stage higher in the exercise test and attained greater levels of LBM-normalized peak VO<sub>2</sub> during the final stage of the test. The HR response to each stage of exercise was better after exercise training (i.e., HR was reduced) than at discharge.

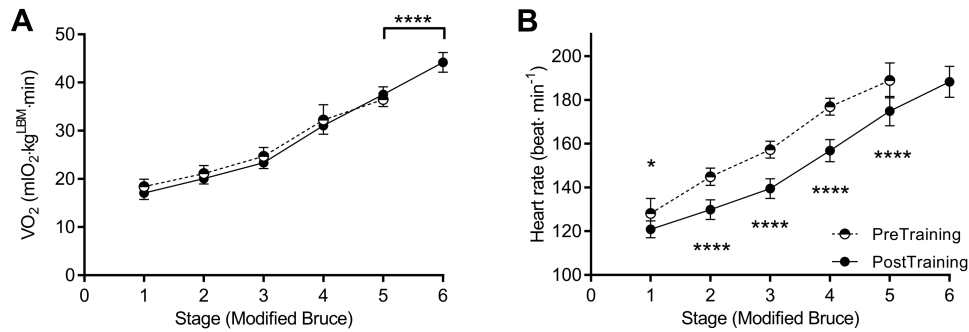
#### Burned Children Exercise at a Greater Intensity than Nonburned Children for a Given VO<sub>2</sub> and Peak HR During Submaximal Exercise

Peak VO<sub>2</sub> and peak HR expressed as a percentage of non-burn values were analyzed at all stages of exercise (Figure 5). During submaximal and maximal exercise, burned children

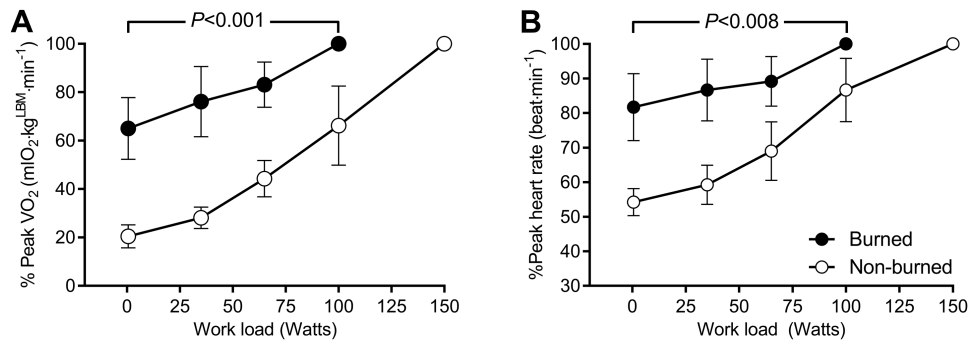
used ~30% to 40% more oxygen and required ~20% to 30% more cardiac work than nonburned children at similar work rates (0–100 W,  $P < .008$ ).

#### The Relationship Between Relative VO<sub>2</sub> and Relative HR Does Not Differ Between Burned and Nonburned Children

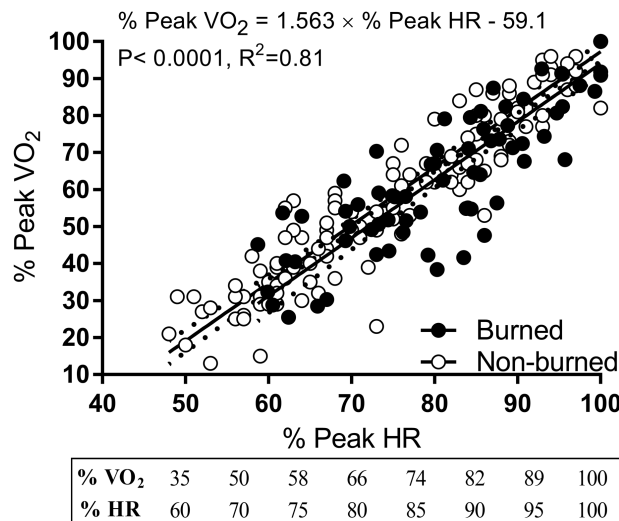
Figure 6 shows the relationships between the percentage of peak VO<sub>2</sub> and percentage of peak HR from submaximal to maximal exercise. The slopes and elevations did not differ between burned and nonburned children (slopes,  $P = .63$ ; elevations  $P = .39$ ). Both groups showed strong correlations between percent VO<sub>2</sub> and HR (burned,  $r = .77$ ; nonburned,



**Figure 4.** Submaximal to maximal changes in oxygen uptake ( $VO_2$ ) and heart rate during the modified Bruce exercise stress test for burned children at discharge (pretraining) and after 6 weeks of rehabilitative exercise training (post-training). All values are reported as mean  $\pm$  95% CI. \* $P < .05$  and \*\*\*\* $P < .0001$  indicate differences from pre- to post-training.



**Figure 5.** Comparison of relative peak oxygen uptake (% peak  $VO_2$ , A) and relative peak heart rate (% peak HR, B) at the indicated exercise work rate between burned children and healthy age- and sex-matched nonburned children. All values are reported as mean  $\pm$  95% CI.



**Figure 6.** Comparison of the relative relationship between percent peak oxygen uptake ( $VO_2$ ) and percent peak heart rate between burned children and healthy age- and sex-matched nonburned children.

$r = .86$ ; each  $P < .0001$ ) that accounted for 77% to 86% of variation ( $R^2$ ).

**DISCUSSION**

Because of advances in burn care, most patients with burns covering up to 90% of the total body surface area can now

survive. Therefore, mortality is no longer the endpoint of greatest interest, and rehabilitation has taken on greater significance. Burn injury is accompanied by long-term metabolic and cardiovascular complications that persist for up to 3 years postburn (19, 23–26). The increase in energy expenditure and protein catabolism arising from burn trauma and bed rest cause a loss of LBM and muscle wasting (5, 27).

Thus, exercise training immediately after discharge is an important component of the standard of care at our institution given its ability to restore LBM, exercise capacity<sup>(9, 14)</sup>, and metabolic function<sup>(28)</sup>. A survey about aerobic and resistance training exercise programs implemented by members of the American Burn Association, Occupational and Physical Therapist Special Interest Group found that for burn patients, 81% stated that no hospital-based cardiopulmonary endurance exercise programs were available<sup>(29)</sup>. In addition, the criteria characterizing physical function were infrequently determined with more subjective parameters used. This requires more objective characterization of exercise rehabilitation programs specific to burn patients. The objective of this study was to quantify our 6-week aerobic and resistance rehabilitation training program and report the benefits of this program, as assessed through a comparison of burned children to healthy age- and sex-matched controls, with the goal of developing specific guidelines for exercise intensity, frequency, and duration following severe burn trauma.

We found that this 6-week RET program improved LBM, strength (peak torque and mean power), and cardiorespiratory fitness (peak  $\text{VO}_2$ ) to a comparable extent as our 12-week RET program<sup>(10-17)</sup>. As previously reported, the 12-week program improved strength by  $37 \pm 8\%$  (as a relative change from before exercise), cardiorespiratory fitness by  $21 \pm 4\%$ , and LBM by  $10 \pm 6\%$  (Table 1). Similarly, the 6-week RET program improved strength by 32%, cardiorespiratory fitness by 23%, and LBM by 5%. These data show that, at 6 weeks, exercise capacity should be re-evaluated so that training intensity can be adjusted for continued improvement. Additionally, resistance exercise can be objectively measured as the weight lifted relative to TBM (19% for upper and 42% for lower body) or VL, as this approach captures all characteristics of resistance exercise and can improve prescription and monitoring of exercise intensity in burned children. Our findings suggest that physical capacity is improved by aerobic exercise training performed at five METs ( $>70\%$  of peak  $\text{VO}_2$ ) at least 3 days/week and 150 minutes/week and by resistance training performed at VLs of 131 kg (19% of TBM) for the upper body and 275 kg (42% TBM) for the lower body for 2 days/week. Our recommendation of 150 minutes/week spread out over 3 to 4 sessions, each lasting 30 to 40 minutes, is similar to guidelines for improving metabolic and cardiovascular profiles in other patient populations<sup>(30-33)</sup>.

Notably, whether adaptations to exercise training also involve improvements in cardiovascular function in burned populations is currently unknown. We found that RET improved indices of cardiac function during peak exercise, specifically stroke volume, oxygen delivery, and cardiac muscle efficiency, as well as HR during submaximal exercise. In addition, peak  $\text{VO}_2$  was improved after 6 weeks of the training program. Recently, Duke et al. reported that burn injury increases the risk for long-term cardiovascular disease<sup>(19)</sup>. Peak  $\text{VO}_2$  is a strong predictor of all-cause mortality<sup>(34)</sup>, suggesting that exercise training could be useful for preventing cardiovascular disease years after burn injury. We have recently reported that children display signs of exercise intolerance and have an attenuated peak HR and cardiovascular response to submaximal exercise compared with age- and sex-matched

nonburned children<sup>(20)</sup>. Therefore, burn-specific guidelines should be used for improving exercise capacity.

HR and  $\text{VO}_2$  (i.e., percent HR/ $\text{VO}_2$  peak) are commonly used to guide exercise prescription in clinical populations<sup>(35)</sup>. We found that relative exercise intensities at percent peak  $\text{VO}_2$  and percent peak HR differ between burned and nonburned children. During submaximal exercise, burned children require more oxygen usage and work at a greater HR than nonburned children exercising at similar work rates. This is an important consideration when prescribing exercise at an appropriate intensity for obtaining adaptations from a RET program. In adults, relative HR-based prescriptions are used for exercise training given the linear relationship between HR response and  $\text{VO}_2$  during exercise. However, we have shown that burned children have an attenuated peak HR compared with nonburned children, suggesting that formulas developed by others<sup>(36)</sup> to predict peak HR values for the purpose of estimating exercise intensity (percent peak HR) may not be a valid approach in burned populations. In support of this, we likewise show altered indices of stroke volume, oxygen delivery, and cardiac muscle efficiency (Figure 3). Therefore, in burned populations, an actual exercise stress test is needed for obtaining peak HR values for the estimation of exercise intensity for prescription purposes (i.e., percent Peak HR). Most importantly, no expensive indirect calorimetry equipment is needed. A modified Bruce protocol to exhaustion with a HR monitor should suffice. We found that the aerobic exercise intensity expressed as METs was consistently at  $\sim 6.0$  from week 1 to week 6. Further examination found this intensity to be at  $\sim 82\%$  peak  $\text{VO}_2$ . Using the regression equations (Figure 6), we calculated this exercise intensity to be 90% peak HR. After 6 weeks RET, this was reduced to  $\sim 70\%$  peak  $\text{VO}_2$  and 82% peak HR which was due to improvements in cardiorespiratory fitness. Based on our results, gauging intensity of exercise using HR monitoring should be between 70% and 80% peak HR that corresponds to 70%–80% peak  $\text{VO}_2$ . The regression equations provided here can be used to predict percent  $\text{VO}_2$  based on percent peak HR and will be useful for prescribing appropriate exercise intensity (i.e., percent peak  $\text{VO}_2$ ).

To summarize, the current findings support the following guidelines for RET in burned children. Aerobic exercise training should be performed at an intensity of five METs ( $>70\%$  of peak  $\text{VO}_2$ ), with a duration of at least 150 minutes/week and a frequency of at least 3 days/week. Resistance training should be performed at a volume load of 131 kg (19% of TBM) for the upper body and 275 kg (42% of TBM) for the lower body. Resistance exercise should be performed at least 2 days/week, with upper and lower body resistance exercise being performed on alternating days. Future research should build on this work, and exercise prescription should be individualized to optimize rehabilitation benefits in severely burned children.

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