Functional Exercise Capacity in Children With Electrical Burns

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Electrical burns are a severe form of thermal injury extending deep into tissue. Here, we investigated the effect of electrical burns on metabolic rate, body composition, and aerobic capacity. We prospectively studied a cohort of 24 severely burned children. Twelve patients had a combination of electrical and flame burns and 12 matched controls had only flame burns. Endpoints were cardiopulmonary fitness (maximal oxygen consumption [VO_2]), muscle strength (peak torque per body weight), body mass index, lean body mass index, and days of myoglobinemia (≥500 mg/dl). Demographics of both the groups were comparable. The electrical burn group had more days of myoglobinemia during acute hospitalization than the flame burn group (3.6 ± 1.8 days vs 0.3 ± 0.5 days, *P* < .0001). Maximal VO_2 was significantly lower in the electrical burn group than in the flame burn group at intensive care unit discharge (27 ± 6 ml/kg/min vs 34 ± 5 ml/kg/min, *P* < .0014). Electrical burns are associated with myoglobinemia and decreased cardiopulmonary fitness. (J Burn Care Res 2017;38:e647–e652)

Severe burn injuries covering more than 30% of the TBSA result in a unique pathophysiological stress response.[1] During the acute hospitalization, this hypermetabolic response is characterized by increased cardiac output, resting energy expenditure, and respiratory rate, as seen by increased resting oxygen consumption.[2,3] Recently published studies have shown that these hyperdynamic and hypermetabolic changes are sometimes present for up to 2 years post burn.[4] Prolonged bed rest, vast muscle protein breakdown, and loss of lean body mass (LBM) lead to a decreased functional exercise capacity following severe burns.[5–8]

Severe burn injuries include burns caused by flame, electric shock, chemicals, contact, scald, or a combination of these. However, electrical burns are considered the most severe type of thermal trauma and are generally associated with greater damage of functional structures, such as muscle and bone.[7] This type of burn leads to a longer hospitalization, more operations, and greater morbidity and mortality than other types of thermal injuries of the same size.[8] Nevertheless, how the combination of flame and electrical burns affects exercise capacity is unknown, particularly in children. Furthermore, whether exercise capacity is affected to a greater extent by this type of injury compared with a simple flame injury is unclear. Suman et al[5] had previously shown that in burn patients the maximal oxygen consumption (maximal VO_2) is decreased when comparing them with nonburn patients.

Here, we compared the functional exercise capacity in patients with a combination of flame and electrical burns and patients with flame burns. We hypothesized that exercise capacity would be lower in patients with electrical and flame burns.

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METHODS

Patients

Between 2010 and 2014, we prospectively enrolled severely burned children admitted to the burn hospital for this study, which was approved by the Institutional Review at University of Texas Medical Branch Galveston (Galveston, TX). Parents or legal guardians provided informed consent before enrollment. To be included in the study, all children must have been between 7 and 18 years of age, had thermal burns (flame alone or combination of flame and electrical) covering more than 30% of the TBSA, and been admitted to our burn unit within 3 days of injury. On arrival at the hospital, all patients received standard burn care until discharge from the acute burn unit.[9] Exclusion criteria were pregnancy and mental retardation, autism, or any other mental disorder making participation in exercise testing impossible.

Case–Control Study

We studied 24 severely burned children; 12 children had a combination of electrical and flame burns and a group of 12 matched controls suffered from only flame burns. Matching was performed according to sex, age, burn size, and year of admission. Primary endpoints were days of serum myoglobin above 500 mg/dl during the acute hospitalization, as well as muscle strength (peak torque per body weight [PT/BW] and maximal oxygen consumption (maximal VO_2) at discharge. Secondary endpoints were height, weight, body mass index (BMI), lean BMI (LBMI), and length of stay (LOS). None of the patients had smoke inhalation injury.

Body Composition

After intensive care unit (ICU) discharge, LBM and LBMI (kg/m^2) were measured using dual-energy x-ray absorptiometry (DEXA) and QDR 4500A software (Hologic, Waltham, MA). Whole-body analysis was performed with the patient in the supine position according to the manufacturer's instructions[10] and as described previously.[11] In brief, DEXA works by measuring attenuation of one high-energy and one low-energy x-ray beam, with bone and soft tissue mass being inferred from these measures based on standard models. Resulting soft tissue values were subsequently separated into LBM (g) and fat mass.

Strength Testing

Exercise assessments were conducted after ICU discharge. Height, BW, and isokinetic extensor strength were measured after patients sat quietly for ~15 minutes. Strength was determined using a Biodex dynamometer (Shirley, NY). Dominant leg extensors were tested at an angular velocity of 150°/s. The test procedure was explained and demonstrated for all patients. A band was then fastened midway on the thigh and on the pelvis and trunk to stabilize patients in a sitting position. Care was taken to ensure that knee joint axis was aligned with the mechanical axis of the dynamometer. Patients were allowed a warm-up period in which they performed only three submaximal repetitions without load to practice the movement. Patients were then asked to perform 10 consecutive maximal voluntary muscle contractions (full extension and flexion) without rest in between. A second trial was repeated after 3 minutes of rest to reduce fatigue. Biodex software was used to determine PT, total work, and average power. The highest values of these parameters obtained during the two trials were selected. PT was corrected as described previously.[12]

Maximal Oxygen Consumption Testing

Immediately after strength tests, exercise capacity was determined via Modified Bruce Treadmill test, which is part of the standard clinical outpatient evaluation.[13] Heart rate and VO_2 were measured as described elsewhere.[5] In brief, we used a Medgraphics CardiO_2 and a VO_2/ECG exercise system (St. Paul, MN) for respiratory gas analysis.

For the treadmill test, patients started walking at 1.7 mph at 0% grade for 3 minutes. The patient then walked 1.7 mph at 5% grade for 3 minutes and 10% grade for another 3 minutes. Every 3 minutes thereafter, speed was increased (2.5, 3.4, 4.2, 5.0, and 6.0 mph) along with grade (12, 14, 16, 18, 20, and 22%) until a maximal effort was reached.

Open-circuit expired gas analysis was used to determine maximal VO_2, as previously described.[5] Flow rates, expired gas, inspiratory capacity, and end-expiratory lung volume were determined throughout the final minute of each exercise stage.[11,12,14–19]

Other Measurements

We measured and recorded serum myoglobin values during the first 5 days after admission to the ICU. Blood was collected from a central venous catheter, with patients in the supine position. The blood was immediately centrifuged at 5800 rpm (3000*g*) for 6 minutes. The plasma was removed and analyzed. Serum myoglobin activity was determined in a spectrophotometer in duplicate using a commercially available kit. The reference range of normal serum myoglobin is 0 to 85 ng/ml. We also recorded the LOS from the admission date to the discharge date.

Statistical Analysis

Measurements were transferred to an encrypted spreadsheet, and statistical analyses were performed using Excel (Microsoft, Richmond, VA). Normally distributed measurements are presented as mean ± SD. Continuous measurements as age, TBSA burn, TBSA full-thickness burn, height, weight, LOS, days of myoglobinemia (≥500 mg/dl), maximal VO_2, PT/BW, BMI, and LBMI of both groups were compared using a Student's *t*-test for matched pair samples. Sex was compared using a χ^2 test. Significance was accepted at $P < .05$.

RESULTS

Patient Characteristics

As shown in Table 1, the groups did not significantly differ with respect to percent TBSA burned (40 ± 8% for flame vs 41 ± 11% for electrical/flame, $P = .577$) or percent TBSA full-thickness burn (24 ± 16% for flame vs 30 ± 12% for electrical/flame, $P = .068$). Both groups had male:female ratio of 10:2. Age was 14 ± 3 years for patients with flame burns and 15 ± 3 years for the patients with electrical and flame burns ($P = .127$).

Body Composition and Dual-Energy X-Ray Absorptiometry

The groups did not differ in height ($P = .237$), weight ($P = .780$), or BMI ($P = .253$, Table 2). Similarly, the groups did not differ in total LBM ($P = .281$), LBMI ($P = .619$), or right leg lean mass ($P = .236$). Accordingly, total fat mass ($P = .224$) and the total fat mass index ($P = .138$) were comparable between groups.

Isokinetic Strength

Analysis of PT revealed no difference between the flame group and the electrical/flame group ($P = .298$). In addition, no differences in PT/LBM were detected between patients with flame burns and those with electrical and flame burns ($P = .653$). Average power ($P = .291$) and maximal repetition total work ($P = .480$) were comparable between both groups.

Maximal Oxygen Consumption

Cardiopulmonary fitness, assessed as maximal VO_2 at discharge, was significantly lower in the electrical/flame group than the flame group ($P < .0014$, Table 3). Maximal VO_2/LBMI was 1.6 ± 1.2 for flame group and 1.4 ± 2.3 for the electrical/flame group ($P = .118$).

Myoglobin Levels and Length of Stay

Patients with a combination of flame and electrical burns had significantly more days of myoglobinemia (≥500 mg/dl) than patients in the flame group ($P < .0001$, Table 1). No differences were detected between both groups with respect to LOS ($P = .222$).

DISCUSSION

This cohort study revealed significant differences in the duration of myoglobinemia between flame and electrical/flame groups. Because patients with a combination of electrical and flame burns presented with higher levels of myoglobin in the blood, we postulate that the degree of the muscle destruction correlates directly with the serum level of myoglobin, and this destruction is present in all severe electrical burn injuries.[8,20] In addition, our results confirmed our hypothesis that patients with electrical burns have decreased exercise capacity related to cardiopulmonary fitness. To our knowledge, this is

Table 1. Patient characteristics and serum myoglobin levels

Characteristic	Flame Burns n = 12	Flame + Electrical Burns n = 12	P
Gender, male:female	10:2	10:2	
Age (yr)	14 ± 3	15 ± 3	0.127
Height (cm)	153.0 ± 11	159 ± 13	0.237
TBSA burn (%)	40 ± 8	41 ± 11	0.577
TBSA full-thickness burn (%)	24 ± 16	30 ± 12	0.068
Length of stay (d)	22 ± 7	27 ± 12	0.222
Increased myoglobinemia (≥500 mg/dl), days	0.3 ± 0.5	3.6 ± 1.8	<0.0001

Values are presented as mean ± SD.

Table 2. Aerobic capacity and body composition at ICU discharge

Assessment	Flame Burns n = 12	Flame + Electrical Burns n = 12	*P*
Total mass (kg)	49.2 ± 14.4	47.9 ± 9.5	0.780
Body mass index (kg/m^2)	20.4 ± 4.1	18.8. ± 2.7	0.253
Total lean body mass (kg)	35.1 ± 8.1	38.7 ± 8.8	0.187
Lean body mass index (kg/m^2)	15.7 ± 4.9	14.9 ± 3.5	0.619
Total fat mass (kg)	11.6 ± 4	14.7 ± 6	0.224
Total fat mass index (kg/m^2)	0.5 ± 0.1	0.8 ± 0.4	0.138

ICU, intensive care unit.
Values are presented as mean ± SD.

the first report to confirm that electrical burns not only severely damage muscle and bone but also decrease cardiopulmonary fitness when compared with patients with flame burns, probably because of the initial muscle destruction that accompanies electrical burns. This can be demonstrated by the higher serum myoglobin levels (myoglobinemia) in patients with electrical burns than in patients with only flame burns.

Clinical parameters, such as the mechanism of injury, voltage, burn size and depth, gross urine color, and myoglobinemia, can be easily used to predict and estimate the muscle damage. The serum myoglobin value is a marker of muscle damage. Besides myoglobinemia, myoglobinuria indicates significant muscle damage.[21] Myoglobin and hemoglobin pigments in the patients' urine present risk of acute renal failure and must be cleared promptly. While low levels are of less concern, grossly visible urinary pigmentation requires a rapid response to minimize tubular obstruction. Therefore, we will use myoglobin values in blood as appropriate predictor of muscle damage. Injured muscle may not provide adequate energy pathways.

To determine the extent of deep-tissue injury, other investigators have used multiple diagnostic modalities. Radionuclide scanning with Xenon-133[21] and technetium pyrophosphate[22,23] has been shown to be accurate predictors of tissue damage in research studies. Hammond and Ward[22] reported that scanning did not decrease hospital stay or number of operations required. In addition, gadolinium-enhanced magnetic resonance imaging has demonstrated potential viability in zones of tissue edema and had a good correlation with histopathology.[22,24,25] While very sensitive and specific, these diagnostic scans often add little to direct clinical evaluation and create logistical problems of their own. In practice, the uses of the herein mentioned techniques are expensive.

In contrast to serum myoglobin levels, the LBM (muscle mass) did not significantly differ between groups, as determined using the latest and most accurate technology (DEXA). Thus, we infer that part of the problem in the patients with electrical burns is not the quantity of the muscle per se, but the muscle itself, specifically its capacity for oxygen uptake, which was greater in patients with only flame burns. The finding that maximal VO_2 consumption was significantly lower in after electrical burns than after only flame burns suggests that muscle damage resulting from electrical burns directly affects functional exercise capacity and has direct repercussions on the quality of life.

Among burn injuries, electrical burns are the most damaging because they usually affect not

Table 3. Muscle strength and cardiopulmonary fitness assessments

Assessment	Flame Burns n = 12	Flame + Electrical Burns n = 12	*P*
Peak torque (N·m)	52.8 ± 22.5	61.5 ± 16.5	0.298
Peak torque/lean body mass (N·m/kg)	1.5 ± 0.4	1.5 ± 0.4	0.653
Average power (W)	65.3 ± 31.0	77.7 ± 23.8	0.291
Maximal repetition total work (J)	51.3 ± 28.6	60.0 ± 28.3	0.480
Maximal VO_2 (ml/kg/min)	34.0 ± 5	27.0 ± 6	<0.0014
Maximal VO_2/lean body mass index (ml/kg/min/m^2)	1.6 ± 1.2	1.4 ± 2.3	0.118

VO_2 max, maximal aerobic capacity.
Values are presented as mean ± SD.

only the skin but also deeper tissues. The severity of electrical burns is apparent in the longer hospitalization, greater number of operations, and greater morbidity seen with this type of injury than with other types covering a similar surface area.[8] According to Stergiou-Kita et al,[26] electrical burns trigger are associated with a variety of injuries and complications including orthopedic injuries, amputation, and sensory and neuropsychiatric disturbances. They also include respiratory impairments and cardiovascular dysfunction, as corroborated by the current findings showing decreased maximal VO_2 values in electrical burn patients. To our knowledge, no studies have attempted to assess the effect of electricity-induced muscle damage on VO_2.

Muscle damage can sufficiently compromise oxygen delivery as reflected by decreased maximal VO_2. Thus, electrical muscle damage may slow VO_2 kinetics. Slowed VO_2 kinetics are consistent with the notion that muscle damage caused by electrical affects all muscle fibers. Moreover, the influence of voltage on VO_2 kinetics might be intensity dependent. In experimental models where both convective and diffusive muscle oxygen uptake could be altered, VO_2 response kinetics during moderate muscle damage were not limited by oxygen availability. Although higher-order fibers are more susceptible to reduced tissue oxygenation, moderate muscle damage does not seem to compromise oxygen delivery sufficiently to cross the tipping point.[27]

There are a few limitations of this study. First, this study included a relatively small number of subjects. However, despite the small sample size, our findings were statistically significant and are expected to hold in larger scale studies. Second, it can be argued that we have not assessed levels of hemoglobinuria in our studied cohort. According to the literature, serum myoglobin levels do correlate well to urine myoglobin levels.[28] Because of this, we considered measurement of myoglobin levels in the blood sufficient.

Despite these limitations, the results from this study evidently indicate that electrical injuries reduce cardiopulmonary functional exercise capacity to a greater degree than flame injuries. This finding emphasizes the importance of implementing specific, focused exercise programs for patients with electrical burns and testing these exercise and rehabilitation protocols to ensure that they are effective.[25] With this in mind, future training protocols could focus on specialized and individualized aerobic programs and resistance training exercises that limit muscle damage (for example concentric-only).

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