Thermoregulation in Burn Patients During Exercise

K. G. Austin, MS, J. F. Hansbrough, MD, C. Dore, RN, J. Noordenbos, RN, M. J. Buono, PhD

The purpose of this study was to assess the ability of patients with burns on 30 to 40% and 60% or greater of their BSA to thermoregulate their core temperature during exercise in the heat. Two groups (n = 3 in each) of subjects with healed third-degree burns (34.0 ± 1.4% and 77.7 ± 12.4%, respectively) and a group of unburned subjects (n = 2) exercised for 1 hour on a cycle ergometer at 75 Watts in an environmental chamber set at 35°C and 60% relative humidity. Subjects were monitored for rectal and skin temperatures, heart rate, whole body sweat rate, skin blood flow, and active sweat gland density (number per cm^2) in unburned, burned, and harvested skin. The results demonstrated that patients with burns on 60% or greater BSA did not show an intolerance to moderate exercise in the heat, as evidenced by only a moderate rise in rectal temperature and heart rate. Furthermore, the responses were similar to those of the unburned subjects. (J Burn Care Rehabil 2003;24: 9–14)

The body's ability to regulate core temperature during exercise is highly dependent on the dissipation of heat via the evaporation of sweat. For there to be efficient heat dissipation, it is imperative that the full integrity of the dermis and epidermis be intact, including the sweat glands, nerves, and blood vessels.[1,2] In third-degree burns, normal skin and its appendages are replaced with split-thickness skin grafts with absence of the complete dermal layer. It is generally believed that because of the extensive damage to the skin and appendages after thermal injury, thermoregulatory function during exercise is impaired. Because the evaporation of sweat is the body's primary mechanism for heat loss, it is generally believed that hyperthermia would be a problem for most burn patients. Previous studies have shown that although unburned areas of the patient's body attempt to compensate by excessive sweating, heat was produced faster than could be dissipated, resulting in hyperthermia in patients with burns of 40 to 55% BSA.[3–6]

The purpose of this study was to describe the ability of burn patients to regulate their body temperature before and after exercise in the heat. Furthermore, whole body sweat rate and skin blood flow were measured before and after exercise in patients that had burns on 30 to 40% and 60% or greater TBSA.

From the Department of Exercise and Nutritional Sciences, San Diego State University, and the UCSD Burn Center, University of California, San Diego, San Diego, California.
Address correspondence to Michael J. Buono, PhD, San Diego State University, MC: 7251, San Diego, California 92182.

0273-8481/2003

DOI: 10.1097/01.BCR.0000045643.41890.15

METHODS

Subjects

Six patients with third-degree healed burns and two unburned subjects volunteered to participate in the study. The methods and procedures used in this investigation were reviewed and approved by the Committee on the Protection of Human Subjects at San Diego State University before data collection. Written informed consent was obtained from all subjects. Values are presented as means ± SD. The subject's were divided into three groups: (A) three patients with burns of ≥60% BSA (77.7 ± 12.4), (B) three patients with burns of 30 to 40% BSA (34.0 ± 1.4), and (C) two nonburned volunteers of similar age to those of the study groups. All burned subjects were assessed for total BSA burn using the rule of nines protocol.[7] TBSA burn refers to the percentage of grafted third-degree burn in which there is an absence of the dermis and epidermis.

Protocol

Participants were asked to perform an exercise trial on a Lode cycle ergometer (Excaliber Sport; Groningen, The Netherlands) wearing shorts and a T-shirt. Lung function, heart rate, skin and rectal body temperatures, skin blood flow, whole body sweat rate, and the number of active sweat glands were assessed before and at the end of the exercise bout. Subjects were asked to cycle for 1 hour at 75 watts in an environmental chamber set at 35°C and 60% relative humidity with a wind speed of 0 meters per second.

Pulmonary function was measured by dry spirometry for forced expiratory volume (FEV_1) and forced vital capacity using a Micro Medical spirometer (Vacu Med, Ventura, CA). After two to three normal breaths, the subject completed a maximal inhalation followed by a maximal exhalation. Forced expiratory volume expressed as a percentage of forced vital capacity was calculated (FEV_1%). Residual volume was measured by the oxygen dilution method.[8] Subjects took a maximal inhalation and exhalation followed by seven deep breaths of 100% oxygen.

Heart rate was measured using a Polar pulse monitor (Polar Electro, Woodbury, NJ), which was attached transsternally. Skin temperature was recorded on burned, unburned, and harvested skin in burn subjects and on the arm and thigh in control subjects using skin thermistors (YSI-401, YSI, Yellow Springs, OH). Core body temperature was monitored every 10 minutes throughout the exercise session and immediately upon cessation of exercise using rectal thermistors, which were inserted 10 cm past the anal sphincter. Skin blood flow was measured using a laser Doppler. A probe leading from the 403A TSI Laserflo blood perfusion monitor (TSI, St. Paul, MN) was used for monitoring of blood flow in unburned, burned, and harvested skin.

Whole body sweat rate was measured by the difference of the subject's dry weight pre- and postexercise with corrections for water intake and urine output. The number of active sweat glands (number per cm^2) in unburned, burned, and harvested skin was measured with iodine paper.[9,10] The criteria for terminating testing was a rectal temperature above 39°C and/or a heart rate of 170 bpm, dizziness, nausea, anhidrosis, or cessation of the exercise session by the subject.

Data Analysis

Because of the small sample size, all data for burn participants were reported as individual case studies rather than in aggregate form. Mean data for the control participants was used as a comparison with the burn participants.

RESULTS

Group A

The results for group A are presented below, and their subject characteristics can be found in Table 1.

Subject 1. The subject was a 43-year-old Hispanic male who was 177 cm tall, weighed 79 kg, and was burned 2 years previously. The subject had suffered third-degree burns to 35% of his TBSA, which included the chest, stomach, upper arms, and parts of the back and head. Skin was harvested from 27% of his body, including the thighs, legs, and unburned portion of the back, and used as skin grafts to the burned areas. The subject walked twice a day and occasionally swam or biked for physical activity. The subject had been an active participant in soccer and running before being burned.

Forced vital capacity was 4.29 L with an FEV_1% of 76% and a residual volume of 2.01 L. The exercise trial lasted 35 minutes with cessation of exercise because of irritated skin on the subject's chest. The subject's initial rectal temperature was 37.4°C and increased by 0.2°C after exercise. Skin temperatures for unburned, burned, and harvested skin showed initial values of 34.2, 34.3, and 33.2°C and increased after exercise by 0.9, 1.9, and 2.5°C, respectively. Resting heart rate was 72 bpm, which increased to 117 bpm

Table 1. Subject characteristics

Subject	Age (Years)	Height (cm)	Weight (kg)	%TBSA Burn (3rd Degree)	Harvested Skin (%)	Postburn (Years)
Group A						
1	43	177	79	35	27	2
2	53	180	108	32	20	8
3	50	170	69	35	30	42
Group B						
1	21	168	70	60	11	6
2	19	183	91	90	9	2
3	33	174	76	80	19	10

after exercise. Blood flow in unburned, burned, and harvested skin was 0.5, 0.8, and 0.8 ml per 100 ml/min after exercise, respectively. Whole body sweat rate was 12.1 ml/min, and active sweat gland density in unburned, burned, and harvested skin was 84, 9, and 27, respectively.

Subject 2. The subject was a 53-year-old white male who was 180 cm tall, weighed 108 kg, and was burned 8 years previously. The subject had suffered third-degree burns to 32% of his TBSA, which included the chest, stomach, upper and lower arms, and neck. Skin was harvested from 20% of his body, including the thighs and back, and used as skin grafts to the burned areas. The subject participated regularly in walking 20 minutes a day. The subject had been an active Boy Scout Leader before being burned, which required much physical activity in various climates.

Forced vital capacity was 4.15 L with an FEV_1% of 84% and a residual volume of 2.15 L. The exercise trial lasted 32 minutes with cessation of exercise because of exhaustion. The subject's resting rectal temperature was 37.8°C and increased by 0.3°C after exercise. Skin temperatures for unburned, burned, and harvested skin showed initial values of 32.9, 33.0, and 33.7°C and increased by 2.9, 4.0, and 1.8°C, respectively after exercise. Resting heart rate was 87 bpm, which increased to 125 bpm after exercise. Blood flow in unburned, burned, and harvested skin was 1.5, 1.3, and 6.5 ml per 100 ml/min after exercise, respectively. Whole body sweat rate was 15.0 ml/min and active sweat gland density in unburned, burned, and harvested skin was 117, 0, and 54, respectively.

Subject 3. The subject was a 50-year-old Caucasian female who was 170 cm tall, weighed 69 kg, and was burned 42 years ago. The subject had suffered third-degree burns to 35% of her TBSA, which included the posterior thighs, legs, arms, and buttock. Skin was harvested from 30% of her body, including the stomach, back, and chest. The subject participated regularly in running, biking, and swimming to train for triathlons. The subject had been an active participant in many sports over the years.

Forced vital capacity was 3.49 L with an FEV_1% of 70% and a residual volume of 2.01 L. The exercise trial lasted the full 60 minutes. The subject's resting rectal temperature was 37.5°C and increased by 0.9°C after exercise. Skin temperatures for unburned, burned, and harvested skin showed initial values of 33.8, 32.9, and 32.2°C and increased by 2.5, 2.8, and 3.2°C after exercise, respectively. Resting heart rate was 98 bpm, which increased to 137 bpm after exercise. Blood flow in unburned, burned, and harvested skin was 2.5, 2.5, and 2.0 ml per 100 ml/min after exercise, respectively. Whole body sweat rate was 8.0 ml/min and active sweat gland density in unburned, burned, and harvested skin was 132, 0, and 27 respectively.

Group B

Group B results are presented below, and their subject characteristics can be found in Table 1.

Subject 1. The subject was a 21-year-old Caucasian male who was 168 cm tall, weighed 70 kg, and was burned 6 years previously. The subject had suffered third-degree burns to 60% of his TBSA, which included the chest, stomach, upper and lower arms, and parts of the back, buttock, and thighs. Skin was harvested from 11% of his body, including the legs and unburned portion of the back, and used as skin grafts to the burned areas. The subject participated regularly in basketball, racquetball, rollerblading, surfing, soccer, volleyball, and weight lifting. The subject had been active in all the same sports before being burned.

Forced vital capacity was 4.52 L with an FEV_1% of 88% and a residual volume of 1.12 L. The exercise trial lasted the full 60 minutes. The subject's resting rectal temperature was 37.2°C and increased by 0.9°C after exercise. Skin temperatures for unburned, burned, and harvested skin showed initial values of 34.5, 34.2, and 33.6°C and increased by 2.6, 2.9, and 2.6 after exercise, respectively. Resting heart rate was 86 bpm, which increased to 143 bpm after exercise. Blood flow in unburned, burned, and harvested skin was 2.8, 1.5, and 4.5 ml per 100 ml/min after exercise, respectively. Whole body sweat rate was 13.0 ml/min and active sweat gland density in unburned, burned, and harvested skin was 108, 0, and 63, respectively.

Subject 2. The subject was a 19-year-old Caucasian male who was 183 cm tall, weighed 91 kg, and was burned 2 years previously. The subject had suffered third-degree burns to 90% of his TBSA, which included most of his body except for a leg and portions of his right lower arm, left upper arm, and right anterior thigh. Skin was harvested from 9% of his body, including the unburned leg, right anterior thigh and arm, and used as skin grafts to the burned areas. The subject participated regularly in jogging his dog twice a day for 45 minutes, swimming, and weight lifting. The subject had been physically active in the same way before being burned.

Forced vital capacity was 5.58 L with an FEV_1% of 68% and a residual volume of 1.45 L. The exercise trial lasted the full 60 minutes. The subject's resting rectal temperature was 37.5°C and increased by 1.0°C after exercise. Skin temperatures for unburned,

burned, and harvested skin showed initial values of 33.0, 33.3, and 32.8°C and increased by 3.4, 4.0, and 4.2 after exercise, respectively. Resting heart rate was 72 bpm, which increased to 166 bpm after exercise. Blood flow in unburned, burned, and harvested skin was 2.0, 5.0, and 4.0 ml per 100 ml/min after exercise, respectively. Whole body sweat rate was 20.0 ml/min and active sweat gland density in unburned, burned and harvested skin was 78, 0, and 63, respectively.

Subject 3. The subject was a 33-year-old white female who was 174 cm tall, weighed 76 kg, and was burned 10 years ago. The subject had suffered third-degree burns to 80% of her TBSA, which included the thighs, legs, arms, back, face, and buttock. Skin was harvested from 19% of her body, including the stomach and chest. The subject participated regularly in walking her dog two to three times per day and staying active with five children. The subject had been physically active in the same way before being burned.

Forced vital capacity was 2.16 L, which is less than 50% of the expected value.[10] She had a normal FEV_1% of 74% and a residual volume of 1.21 L. The exercise trial lasted 14 minutes with cessation of exercise because of an accelerated heart rate that led to panting and a flushed appearance. The subject's resting rectal temperature was 37.5°C and increased by 0.6°C after exercise. Skin temperatures for unburned, burned, and harvested skin showed initial values of 30.5, 34.0, and 32.9°C and increased by 3.0, 0.8, and 2.5°C after exercise, respectively. Resting heart rate was 84 bpm, which increased to 161 bpm after exercise. Blood flow in unburned, burned, and harvested skin was 6.5, 4.5, and 6.5 ml per 100 ml/min after exercise, respectively. Whole body sweat rate was 13.0 ml/min and active sweat gland density in unburned, burned, and harvested skin was 72, 0, and 45, respectively.

Group C

Mean data of the two control subjects (one male and one female) was used to represent the response of unburned participants to the testing protocol. Both subjects were Caucasian with a mean age of 34 years, height of 174 cm, and weight of 77 kg. Subjects participated in aerobic exercise four times per week for at least 45 minutes.

Forced vital capacity was 4.23 L with an FEV_1% of 84% and a residual volume of 1.32 L. The exercise trials lasted the full 60 minutes. The mean resting rectal temperature was 37.9°C and increased by 0.5°C after exercise. Skin temperatures for unburned skin at the thigh and arm showed initial values of 32.6 and 35.2°C and increased by 3.9 and 1.3°C after exercise, respectively. Resting heart rate was 99 bpm, which increased to 146 bpm after exercise. Blood flow in unburned skin was 2.2 ml per 100 ml/min after exercise, respectively. Whole body sweat rate was 12.4 ml/min and active sweat gland density in unburned skin was 86.

DISCUSSION

Previous studies have demonstrated that patients with healed third-degree burns covering 40 to 55% of their BSA and ectodermal dysplasia patients both have a significant decrease in heat tolerance.[3–6] The current study examined whether patients with third-degree burns of 30 to 40% and ≥60% of TBSA demonstrate a significant intolerance to the heat. Testing was conducted during the winter so that all subjects were unacclimatized to heat at the time of testing.

The results of group A and B demonstrate that patients with burns of 30 to 40% and ≥60% of their BSA do not show a significant intolerance to the heat, as was evidenced by only a moderate rise in rectal temperature and heart rate after exercise. Furthermore, the responses were similar to those of unburned subjects. This indicates that the cessation of exercise in the heat by some patients (before 60 minutes) was not the result of hyperthermia or intense cardiovascular demand but caused by other factors. Previous studies[3–6] have also concluded that after exercise in hot climates, there is no impairment in thermoregulation for burn patients with burns on less than 40% of their BSA.

It has been documented that after exercise in hot climates, there is a significant impairment in physical function in patients with burns on 40 to 55% of their BSA and by subjects with ectodermal dysplasia.[3–6] Patients in these studies were found to have significantly higher rectal and skin temperatures and heart rates than unburned subjects and those with burns on less than 40% of their BSA. Although the current study did not see the marked differences, it may be hypothesized that had the subjects exercised longer or at a greater intensity, larger differences may have been seen. The studies conducted by Ben-Simchon et al.[3] and Shapiro et al.[6] are noted to have been longer in duration than the current study, and may explain the differences reported. Additionally, the present study examined heat tolerance during exercise in an environment where the subjects were exposed to a moderate heat load (35°C). This allowed for greater heat loss through means of radiation since skin temperature was able to exceed the ambient temperature. The studies by Ben-Simchon et al[3] and Shapiro et al[6] examined heat tolerance at 40°C, which placed a severe heat load on the body. This allowed for greater heat storage because heat loss by radiation was not possible; therefore, the only means for cooling the body was through evaporation. The heat gained by radiation from the environment exceeded the rate of heat dissipation from the body that was possible by evaporative means.

Furthermore, whole body sweat rate data in burn patients did not demonstrate a decreased efficiency to dissipate heat but rather an overcompensation in healthy skin areas to maintain thermoregulation during exercise. This is evidenced by the similar whole body sweat rate seen in groups A, B, and C, yet the sweat volume produced by groups A and B was over a reduced unburned skin surface area. Other studies have reported positive correlations between sweat rate and burned skin surface area.[3–6] Therefore, the greater the TBSA burn, the greater the sweat rate in unburned and harvested skin.

Previous studies have also reported a significantly higher sweat rate in burn patients with 20 to 55% BSA burn. Ben-Simchon et al[3] claim that this is caused by a greater rise in rectal temperature in burned patients and therefore an increased stimulus to sweat. It is expected that the similar responses in rectal temperature of all three groups in the current study could explain the similar response in whole body sweat rate. The greater sweat rate in burn patients seen in previous studies can be attributed to the higher rectal temperatures seen in those subjects.

Examination of the number of active sweat glands in the burned skin for groups A and B revealed complete inactivity. When comparing unburned skin and harvested skin, it was noted that there was a decrement in the number of active sweat glands for harvested skin. This suggests an even greater decrement in the capacity for maintaining thermoequilibrium through evaporation in these groups. However, whole body sweat rate was essentially equal between groups, indicating an increased efficiency and compensation by the remaining active sweat glands for those subjects in groups A and B.

Comparison of burned, unburned, and harvested skin temperatures after exercise suggest that the increased skin temperature in the burned surface area is a legitimate thermoregulatory difference between the damaged skin and the unburned and harvested skin areas. This is in agreement with findings of earlier studies, which reported similar differences in burned and unburned skin temperatures after exercise in hot climates.[3-4,6]

Ben-Simchon et al[3] and McGibbon et al[4] proposed that there is a reduced vascularization in burned tissue, which could explain why skin temperature was lower in burned skin at rest in a temperate climate. Ben-Simchon et al[3] also proposed that during exercise in a hot climate, the excess sweat that covered the burned area was ineffective for cooling the body because of an isolation effect of the hypovascularized cicatrix. The findings of the current study do not support differences in vascularization but rather an equalized skin blood flow in unburned, burned, and harvested skin.

Lung capacity was assessed in burn patients because of the potential for smoke inhalation injury, which often occurs during the fires and can often limit the lung's mechanical function, which is a necessary component for gas exchange during exercise. When gas exchange is hindered, exercise capacity is reduced, and the energy cost of ventilation is greatly increased, which in turn increases the cardiovascular demands on the body.[11] Five of six subjects for groups A and B displayed normal forced vital capacities, indicating that lung mechanics was not a limitation. Furthermore, FEV_1% was normal and did not indicate any severe obstructive lung disease. It is therefore concluded that lung capacity was not a limitation to exercise in the heat for these subjects.

Lung capacity appeared to be the cause for cessation of exercise for one subject in group B. Although FEV_1% does not indicate obstructive pulmonary disease, the subject had a forced vital capacity that was only 50% of the predicted value, or 4.3 L.[12] Limitation of the lung's mechanical function, which is a necessary component for gas exchange during exercise, can increase the cost of breathing by up to 40%.[11] When gas exchange is hindered, exercise capacity is reduced and the energy cost of ventilation is greatly increased,[11,13,14] which in turn increases the cardiovascular demands on the body.[11,13,14] This was reflected by the subject's accelerated heart rate after only 10 minutes of exercise. The subject did not display a rapid rise in rectal temperature, supporting that cessation of the test was not because of hyperthermia. At the cessation of exercise, the subject was panting profusely and identified respiratory distress as a limitation to exercise and voluntarily terminated the session.

After reviewing the physical activity records of all the participants, it appears that a major factor in determining the burn patient's ability to maintain thermoequilibrium during exercise in hot, humid conditions is the cardiovascular fitness level of the subject. This suggests that it might be possible for burn patients to adapt to their decreased TBSA for dissipation of heat via training. Edlich[15] reported that once the burn patient has achieved complete rehabilitation of their burn injury and has been cleared by their attending physician, that physical activity should include regular aerobic exercise at 70 to 85% maximal capacity, three times per week.

CONCLUSIONS

Previously, Ben-Simchon et al,[3] McGibbon et al,[4] Roskind et al,[5] and Shapiro et al[6] had indicated that those with burns on >40% of their BSA would have an impaired response to thermoregulate their body's temperature. This was not found in the current study, as evidenced by ending rectal temperature, ending heart rate, and whole body sweat rate responses. The differences seen in this study and the above mentioned studies could largely be caused by the level of heat tolerance that was tested. The current study demonstrates that mild exercise in an environment that places a moderate heat load on the body is possible for burn patients, whereas the studies by Ben-Simchon et al[3] and Shapiro et al[6] demonstrate that exercise in conditions of severe heat exposure should be avoided. Therefore, physicians should promote regular physical activity in burn patients after rehabilitation of their injury. Future studies should examine the benefits of chronic exercise in burn patients.

REFERENCES

1. Sawka MN, Wenger CB, Pandolf KB. Thermoregulatory responses to acute exercise-heat stress and heat acclimation. In: Fregly MJ, Blatteis CM, editors. Handbook of physiology, section 4: environmental physiology. Vol 1. New York: Oxford University Press; 1996. p. 157–85.
2. Rhaodes R, Pflanzer R. Regulation of body temperature. In: Alexander J, Brady E, editors. Human physiology, sect. 27: normal body temperature. Vol 1. New York: Harcourt College Publishers; 1996. p. 812–7.
3. Ben-Simchon C, Tsur H, Keren G, Epstein Y, Shapiro Y. Heat tolerance in patients with extensive healed burns. Plast Reconstr Surg 1981;67:499–504.
4. McGibbon B, Beaumont W, Strand J, Paletta F. Thermal regulation in patients after the healing of large deep burns. Plast Reconstr Surg 1973;52:164–70.
5. Roskind J, Petrofsky J, Lind A, Paletta E. Quantitation of thermoregulatory impairment. in patients with healed burns. Ann Plastic Surg 1978;1:172–6.
6. Shapiro Y, Epstein Y, Ben-Simchon C, Tsur H. Thermoregulatory response of patients. with extensive healed burns. J Appl Physiol 1982;53:1019–22.
7. Demling R, DeSanti L, Orquill D. The Rule of Nines In: Initial. assessment and management of the burn injured patient. Available from http://www.burnsurgery.org; Internet, accessed 31 Oct. 2002.
8. Wilmore J, Vodak P, Parr R, Girandola R, Billing J. Further simplification of a method for determination of residual long volume. Med Sci Sports Exerc 1980;12:216–218.
9. Dubois D, Dubois E. A formula to estimate the approximate surface area if height and weight are known. Arch Environ Med 1916;17:863–71.
10. Sato K, Dobson DL. Regional and individual variations in the function of the human eccrine sweat gland. J Invest Dermatol 1970;54:443–9.
11. Levison H, Cherwiack R. Ventilatory cost of exercise in chronic obstructive pulmonary disease. J Appl Physiol 1968; 25:21.
12. Ruppel G. Manual of pulmonary function testing. Vol. 1. St. Louis: The CV Mosby; 1975. p. 100.
13. Carter R, Coast J, Idell S. Exercise training in patients with chronic obstructive pulmonary disease. Med Sci Sports Exerc 1992;24:281–91.
14. Coast J, Rasmussen S, Krause K, O'Kroy J, Loy R, Rhodes J. Ventilatory work and oxygen consumption during exercise and hyperventilation. J Appl Physiol 1993;74:793.
15. Edlich R. Cardiovascular rehabilitation of patients with burns. J Burn Care Rehabil 1990;11:246–255.