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HEAT ACCLIMATION OF AN ADULT FEMALE WITH A LARGE SURFACE AREA OF GRAFTED SKIN

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ABSTRACT

Grafted skin has impaired blood flow and sweating responses necessary for heat dissipation. Heat acclimation improves temperature regulation in healthy individuals, but it is unknown whether heat acclimation improves temperature regulation of individuals with large areas of grafted skin. **Objective:** Case report of the effects of heat acclimation on thermoregulatory and cardiovascular responses to exercise in a hot environment. **Methods:** A 33-year-old female with 75% TBSA grafted skin 14 years post-injury/grafting performed upright cycling exercise at 45% peak oxygen uptake (50 W) for 7 consecutive days in a climatic chamber set to 40 °C and 30% relative humidity. The daily goal was for this patient to exercise 90 minutes (with a 5-min break at min 45); however, exercise was stopped when an internal temperature (T_c) limit of 39.5 °C was reached. **Results:** The T_c limit was reached during min 46 of exercise on day 1 of acclimation, but not until min 65 of exercise on day 7 of acclimation. The increases in T_c and heart rate during the first 45 min of exercise (the minimum duration completed for all acclimation bouts) were progressively mitigated with successive days of heat acclimation. Sweat sensitivity (the increase in sweat rate per 1 °C increase in T_c) in an area of uninjured skin increased by ~30% on acclimation day 7 relative to day 1. **Conclusions:** Heat acclimation improved thermal tolerance of this patient with a large area of grafted skin, which could increase safety and comfort during thermal stress and/or exercise.

Keywords: thermoregulation; exercise; sweat rate; cycle ergometry; heat stress

INTRODUCTION

In humans, typical heat loss mechanisms include sweating and increased skin blood flow (1). In burn victims, full thickness excision of damaged skin leaves no dermal layer. Since this cutaneous layer houses sweat glands and a vascular network that are both crucial for thermoregulation, heat dissipation, via elevations in skin blood flow and sweating, is impaired. Despite skin grafting over the damaged area, thermoregulatory responses of that skin remain impaired because grafted skin has attenuated reflex cutaneous vasodilation and sweating responses to heat stress (2, 3). Consequently, individuals with a large proportion of total body surface area (TBSA) of grafted skin may be at an increased risk for heat injury during exercise and/or hyperthermic exposure, although the percent TBSA of grafted/damaged skin necessary to impair whole-body temperature regulation remains unclear.

One way in which individuals with a large percent TBSA of grafted skin may counter thermal intolerance is via heat acclimation. Heat acclimation is the physiological adaptations that occur upon repeated moderate to heavy exercise in a hot environment (4). It has been shown to be beneficial in individuals with uninjured skin by lowering cardiovascular and thermal strain during heat exposure following the acclimation regimen (5-7). It is unknown, however, whether heat acclimation is effective in improving temperature regulation of individuals with skin grafting over large portions of their body.

CASE DESCRIPTION

A self-reported recreationally active 33-year-old female (height = 173 cm; mass = 82.7 kg; body mass index = 27.6 kg/m^2, $\dot{V}O_{2peak}$ = 32.4 mL·kg^{-1}·min^{-1}) with an 88% TBSA burn (~75% TBSA grafted skin) voluntarily consented to undergo a 7-day heat acclimation regimen. The patient's injury and subsequent grafting procedures occurred 14 years prior to this investigation. Before beginning heat acclimation, peak oxygen uptake ($\dot{V}O_{2peak}$; used to identify the exercise intensity for subsequent visits) was measured using an incremental cycle ergometry test to volitional fatigue in a normothermic environment (25 °C). The next 7 consecutive visits consisted of the heat acclimation regimen. On each occasion, the patient exercised on a cycle ergometer at 45% $\dot{V}O_{2peak}$ (50 watts) in a climatic chamber set to 40 °C and 30% relative humidity. The daily objective was to exercise for 90 min (two 45-min bouts separated by 5 min of seated rest). The patient was instructed to consume adequate fluids during the 24 hours between exercise sessions to maintain hydration. Euhydration was confirmed by measuring urine specific gravity prior to each bout. Additionally, the patient drank 300 mL of warm (i.e., climatic chamber temperature) fluid (Gatorade™) at min 20 of exercise and again during the break. Heart rate and core temperature (T_c; ingestible telemetry pill; HTI Technologies) were measured continuously and ratings of perceived exertion (RPE; Borg scale) (8) and thermal sensation (9) were obtained at 10-min intervals throughout all acclimation sessions. Whole-body sweat rate and local sweat rate from uninjured and grafted skin were measured on days 1, 4, and 7. Additionally, carbon monoxide rebreathe derived blood volumes (10) were measured 1 week prior to and 1 day after completion of the 7-day heat acclimation regimen.

RESULTS

The T_c limit (i.e., 39.5 °C) was achieved during the 46th min of exercise on the first day of acclimation (i.e., 1 min into the second exercise period), but not until the 65th min of exercise on the final day of acclimation (i.e., 20 min into the second exercise period). Pre-exercise T_c for each of these days was within 0.02 °C. Since exercise durations differed across days of the heat acclimation regimen, data are presented for the first 45 minutes of exercise which was the minimum duration achieved for each acclimation day.

The increase in heart rate and T_c by the 45^{th} min of exercise was attenuated over the course of the acclimation regimen (Figure 1). This indicates the acclimation program was successful in progressively mitigating cardiovascular and thermal strain. Additionally, sweating sensitivity (i.e., the increase in sweat rate per 1 °C increase in T_c) increased at healthy, uninjured skin (Figure 2), while no measurable sweating was observed in grafted skin regardless of the acclimation day. Improved sweating responses from healthy, uninjured skin were not sufficient to increase whole-body sweat rate (data not shown), which was not different over the course of the acclimation regimen.

In non-grafted individuals, heat acclimation can result in elevations in plasma volume (11-13). Consistent with this finding, this patient experienced a 7.5% increase in blood (4984 to 5359 mL) and plasma volumes (3199 to 3439 mL) after heat acclimation.

In addition to the physiological measures described above, it is important to note the decrease in perceptual responses to exercise over the course of the acclimation regimen. RPE at 45 min decreased 4 units from day 1 (18 units) compared to day 7 (14 units) of acclimation. Furthermore, the rating of thermal sensation decreased from 7.5 to 6.5 between acclimation day 1 and day 7, respectively.

DISCUSSION

Heat acclimation responses of this patient demonstrate improved thermal tolerance. The difference between T_c at the 45^{th} min of exercise on day 1 vs. day 7 was relatively small (0.35 °C), although this may be all that can be achieved in an individual with such a large percent TBSA of skin with impaired thermoregulation. In non-grafted individuals, acclimation regimens extending to 14 days have been utilized (14). Perhaps a longer acclimation protocol would have elicited even greater responses in this patient, although T_c and heart rate responses to acclimation typically begin to plateau around day 7 (5). The attenuation of the increase in T_c during exercise at the end of the acclimation regimen is comparable in magnitude to that observed by others (15, 16) investigating heat acclimation in women. Furthermore, the change we observed is greater than that seen after the 6th day of an 11-day heat acclimation regimen involving an exercise protocol comparable to that of the current study and utilizing a hotter environment (45 °C) (17). On-the-other-hand, some studies have observed a greater attenuation of the increase in T_c (~0.7 °C) after heat acclimation in non-grafted women (18). Differences among studies are likely attributable to: 1) the highly variable responses to heat acclimation widely documented in the research literature on this topic, 2) differences in protocols utilized, and 3) differences in the subjects studied. .

The lack of improvement in whole-body sweat rate in this skin graft patient is inconsistent with observations in non-grafted women (16). For instance, Avellini et al. (16) found a 15-18% improvement in sweat rate in women during the pre- and post-ovulatory periods, respectively, after 10 days of treadmill walking for 2 h/day in 36 °C, 80% relative humidity. The most likely reason for this difference is the smaller area of non-grafted skin of the present subject relative to that in non-burned individuals in the cited study (16). Assuming the TBSA of our patient was 1.96 m^2 based on the Dubois formula for body surface area (19), she would only have approximately 0.23 m^2 available for appropriate sweat secretion since sweating is impaired in grafted and scarred skin (2). That said, differences in the heat acclimation protocols between these studies may, in part, have contributed to these differences.

Of particular importance in the present case is the fact that in addition to the physiological changes that occurred in conjunction with heat acclimation (e.g., lower heart rate and T_c at the same time point over the course of acclimation days), this patient perceived the exercise as easier and more comfortable based upon lower RPE and thermal sensation ratings at the end of the acclimation regimen. Thus, following heat acclimation, exercise or activity in hot conditions would be better tolerated and therefore may be performed more frequently, which would have positive health benefits for the patient.

Despite improvements in thermal tolerance, this patient remains at a severe disadvantage in terms of an ability to withstand heat stress. The large percent TBSA of grafted skin, with its inability to appropriately dissipate heat, renders this individual susceptible to development of a heat illness upon excessive hyperthermic exposure. Consequently, even with improved thermal tolerance associated with heat acclimation, patients such as this one must still use caution when performing activities in hot conditions.

An interesting observation from this patient was that her pre-exercise T_c averaged 38.1 ± 0.15 °C, which is higher than the typical T_c of non-skin grafted individuals. To further investigate this, we tracked T_c for ~22 hours between the end of acclimation day 1 and the beginning of acclimation day 2. This patient's T_c remained around 38 °C, with the exception of when she went to sleep, at which time her T_c decreased to approximately 37.1 °C (Figure 3). The patient's baseline oxygen uptake (determined just before the peak oxygen uptake test) was not elevated (~ 300 – 400 mL/min), so it is unlikely she experienced increased basal metabolic heat production. Instead, a likely rationale for this T_c response may be that during daily activity heat dissipation is inadequate relative to metabolic heat generation such that T_c is elevated. Upon sleeping, metabolism associated with activities of daily living is reduced and thus T_c is reduced. These responses would occur in the background of typical circadian-induced changes in T_c. Regardless of the mechanism resulting in elevated pre-exercise T_c, this individual, and presumably others with a similar extent of injured skin, begins activity and/or heat stress at an elevated T_c, so each would have a reduced reserve to increase T_c prior to reaching a critical threshold at which performance suffers and/or heat injury results.

This case study confirms that heat acclimation is successful in improving tolerance to heat stress, even in an individual with ~75% TBSA of grafted skin, so that activities can be performed with greater safety and less physiological strain. However, sweating remains absent in areas of grafted skin while improvements in sweat sensitivity are observed from non-grafted skin. Thus, this individual remains at a high risk for the development of a heat injury because of compromised heat dissipation capability. These findings raise the question of whether similar, or perhaps greater, improvements in heat acclimation responses would occur in individuals with a lower percent TBSA of grafted skin. It also remains unclear what minimum percentage TBSA of grafted skin is necessary before whole-body thermoregulation is compromised.

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FIGURE LEGENDS

Figure 1. A: Increase in core temperature (T_c) during the first 45 min of exercise across acclimation days. B: Average heart rate during min 45 of exercise across acclimation days.

Figure 2. Sweat sensitivity, defined as the increase in sweat rate per 1 °C increase in T_c, from non-grafted skin on days 1, 4, and 7 of acclimation. Units of sweat sensitivity are milligrams of sweat per square centimeter of skin surface area per minute relative to internal temperature ($[mg\cdot cm^{-2}\cdot min^{-1}]/°C$).

Figure 3. Continuous core temperature tracking for ~22 h during the period between the first and second acclimation bouts. Notice the large decrease in core temperature around the time the patient slept.

Figure 1

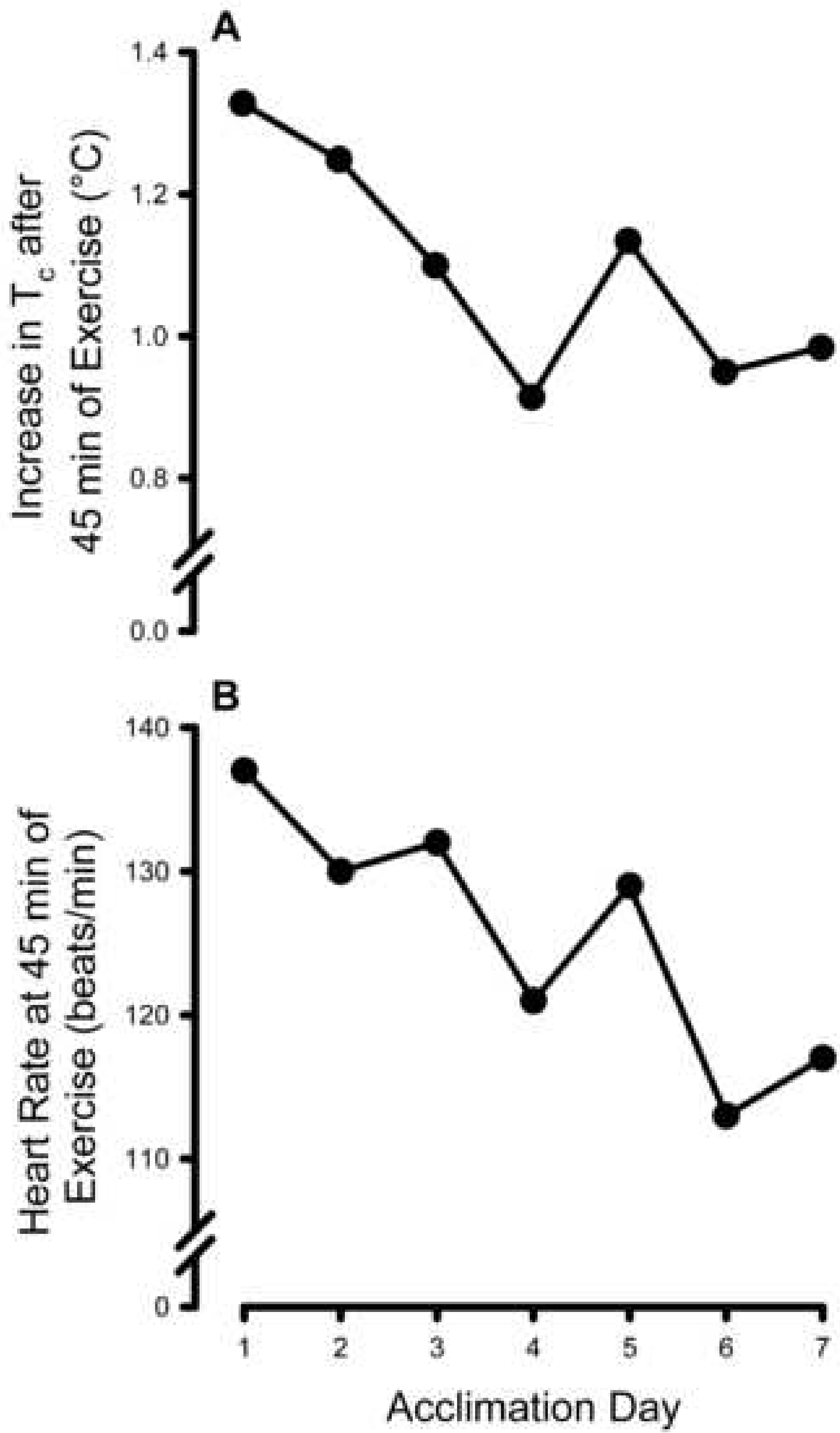

Figure 1

Figure 2
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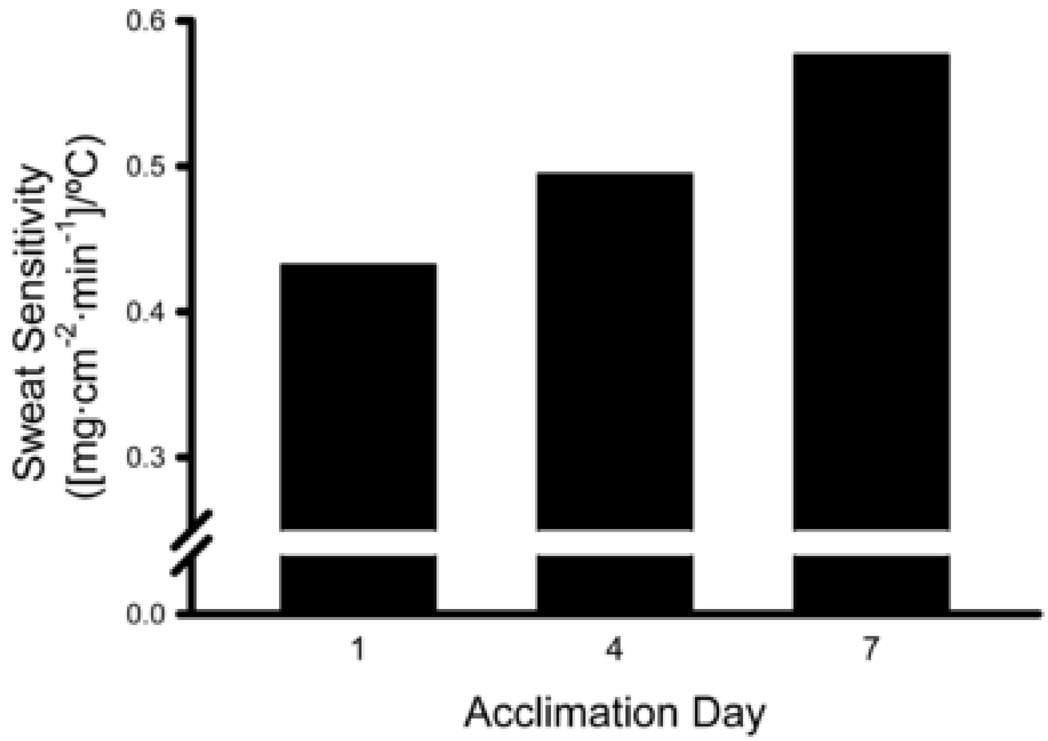

Figure 2

Figure 3
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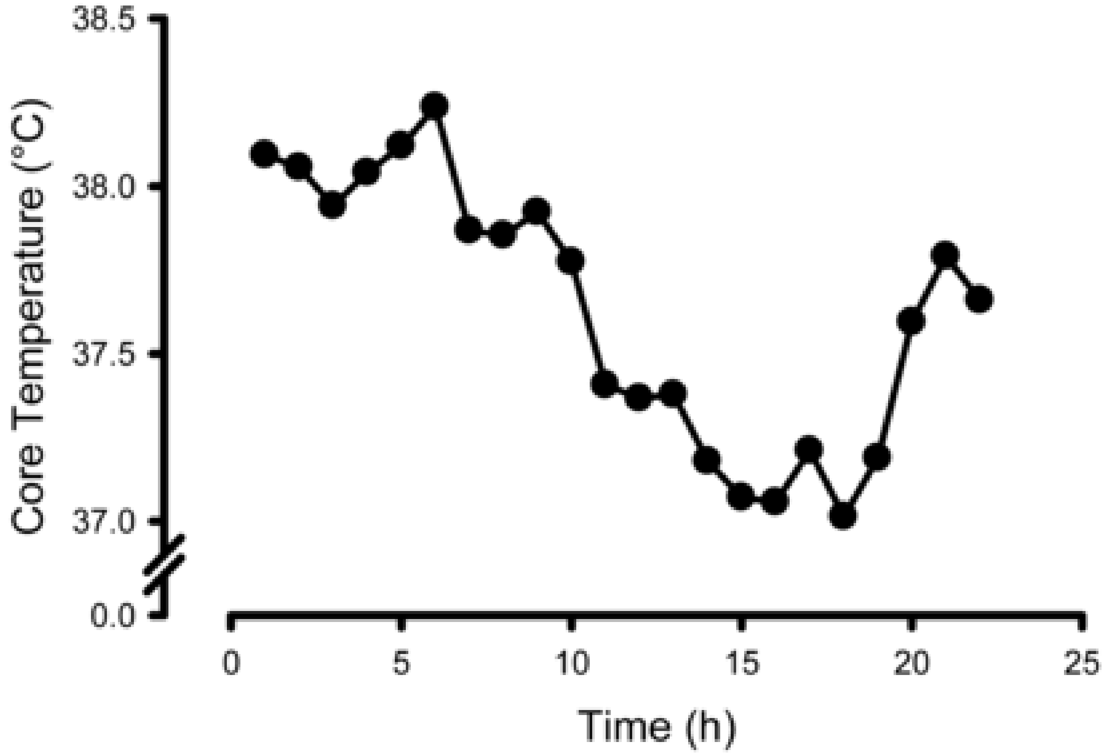

Figure 3