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ORIGINAL ARTICLE

Leg skin temperature with body-weight-supported treadmill and tilt-table standing training after spinal cord injury

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Study design: Randomized crossover.
Objectives: Effects of body-weight-supported treadmill (BWST) and tilt-table standing (TTS) training on skin temperature and blood flow after spinal cord injury (SCI).
Setting: McMaster University, Canada.
Methods: Seven individuals with SCI participated in BWST and TTS training (3 times per week for 4 weeks, 4-week detraining between protocols). Skin temperature was measured before and after a single session of BWST or TTS, pre- and post-training. Leg blood flow was measured at rest pre- and post-training.
Results: Resting skin temperature decreased at four sites after 4 weeks of BWST training in comparison with the pre-training. Four weeks of TTS training resulted in resting skin temperature decreases post-training at the right thigh only. Both BWST and TTS training resulted in altered reactivity of skin temperature at all sites except the right calf in response to a single session of BWST and TTS. Post-BWST training, a single session of BWST stimulated increased temperature at all sites, whereas after TTS training a single session of TTS resulted in temperature decreases at two of the six sites. No changes were observed in resting blood flow with either BWST or TTS training.
Conclusion: Increased resting skin temperature and decreased skin temperature reactivity have been linked to the development of pressure sores. BWST and TTS may stimulate different skin temperature responses and the impact on pressure sore development warrants further investigation.
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Keywords: skin temperature; blood flow; body-weight-supported treadmill; tilt table; spinal cord injury

Introduction

Individuals with spinal cord injury (SCI) have altered vascular structure and function in the paralyzed limbs and are also at risk of experiencing secondary complications after their injury.[1–3] It has not been determined how changes in blood flow to the paralyzed limbs impact the development and progression of some secondary complications or how these factors are affected with different physical rehabilitation techniques. Pressure sores are a secondary complication of SCI, in which an area of skin or underlying tissue is dead or dying due to lack of blood flow. A relationship between increased body temperature and the development of pressure sores exists.[4]

Research indicates that both the resting skin temperature and the reactivity (magnitude of change in response) of skin temperature to a stimulus are indicative of the susceptibility to pressure sore development.[5–10] An increase of 1 °C in resting skin temperature causes a 10% increase in tissue metabolism, thus increasing tissue susceptibility to ischemic injury.[5] Ek *et al.*[6] compared healthy individuals with in-patients in a long-term care facility, and patients had a higher incidence of pressure sore development and smaller increases in skin blood flow after exposure to a mild heat stimulus. They concluded that impairment in the ability to increase skin blood flow in response to a thermal stimulus might be a factor in the development of pressure sores.

The physical rehabilitation of individuals with SCI is often focused on regaining functional ability, decreasing spasticity, maintaining muscle mass and improving cardiovascular function. Body-weight-supported treadmill (BWST) training is a form of physical rehabilitation that allows individuals who have deficits in independent walking ability to participate in upright treadmill ambulation. BWST training involves assisted walking while supported over a treadmill by a harness mechanism and overhead pulley system that can support a percentage of the participant's body weight. It has been shown to improve ambulation,[11,12] partially

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reverse muscle atrophy,[13] improve whole body lean mass[14] and muscle morphology,[15] improve heart rate and blood pressure variability, and increase femoral artery compliance[16,17] after SCI. Tilt-table standing (TTS) is an alternative weight-bearing training technique, which is less labor intensive than BWST training. Tilt-table standing allows for prolonged passive 'standing'. Compared with a seated position, TTS places load on the lower limbs and imposes stretch on the skeletal muscles that cross the hip, knee and ankle joints. To date the short- and long-term effects of BWST and TTS on leg blood flow and skin temperature have not been investigated.

The purpose of this study was to determine the effects of short-term (one session) and long-term (4 weeks of three times per week) BWST and TTS on resting leg skin temperature, skin temperature reactivity (change because of one session of BWST or TTS) and resting blood flow in individuals with chronic SCI.

Materials and methods

All applicable institutional and governmental regulations regarding the ethical use of human volunteers were followed and the Hamilton Health Sciences Research Ethics Board approved this study. All participants were required to complete written, informed consent before involvement in the study. Seven participants (six male) were recruited from the Hamilton Health Sciences outpatient SCI rehabilitation program. All participants had chronic (>1 year) SCI and relied on a wheelchair as their primary method of mobility. Participant characteristics are summarized in Table 1. Exclusion criteria for participation in the study included participation in any BWST training during the 6-month period before commencement of the study and cardiovascular disease or conditions, which may have prevented exercise.

Before the first testing session, each participant had an introductory session in which they were familiarized with the equipment and testing protocols. Participants were then randomized into exercise groups, to determine whether BWST or TTS would be their first mode of training.

Testing methods

Participants emptied their bladders immediately before testing and were asked to refrain from caffeine, nicotine, marijuana and physical activity 24 h before each testing day. All testing was conducted with participants seated in their wheelchair, with their legs free from clothing, in a temperature-controlled room ($23.5 \pm 0.9\,^{\circ}$C) adjacent to the location used for the training sessions.

Before and immediately after the first training (BWST or TTS) session, skin temperature was assessed to determine both resting skin temperature and skin temperature reactivity (post session minus rest). Leg blood flow was also assessed before the training session at this time point. Each training block consisted of 4 weeks of BWST or TTS three times per week for a total of 12 training sessions. Each training session included 30 min of the specified training stimulus. On the day of the last training session of each 4-week training period, resting skin temperature and blood flow data were assessed before the training session and skin temperature was assessed immediately after the training session. Each participant therefore completed 4 weeks of BWSTT, 4 weeks of detraining and 4 weeks of TTS training in a randomized order, with testing at the start and end of each block. To ensure consistency, each participant's training sessions were held on the same days of the week and within 1 h of the initial testing session. To ensure training compliance, missed sessions were re-scheduled for a total of 12 training session for each type of training.

Table 1 Participant characteristics

Participant ID	*Sex*	*Age (years)*	*ASIA Severity Scale*	*Level*	*Post-injury (years)*
1	M	40	C	T2	2
2	M	37	A	C6	14
3	M	32	B	T5	7
4	F	24	C	C5	5
5	M	39	A	T5	3
6	M	49	C	T10	3
7	M	39	C	T2	1

Abbreviations: F, female; M, male.

Skin temperature was measured on the anterior aspect of the thigh and shin and posterior calf of both legs, using the DermaTemp Infrared Surface Skin Scanner, using surface ceramic chip thermistors (MA-100, Thermometrics, Edison, NJ, USA). Skin temperature was recorded at 8-s intervals using a data logger (Smartreader 8 Plus, ACR, Vancouver, British Columbia, Canada), and saved on a computer for offline analysis. The average value at the third minute after the onset of data collection was used for all analyses.

Blood flow was assessed at the common femoral artery using Doppler ultrasound (GE Vingmed System Five, Horten, Norway) as previously described to provide measures of average leg blood flow at each time point.[18]

Training methods

The BWST training was performed using a Woodway Locosystem (Woodway USA Inc., Foster, CT, USA) with a harness and overhead pulley capable of supporting a percentage of the participant's body weight. The initial body-weight support and speed of the treadmill were chosen to enable appropriate gait with full knee extension during stance. Modifications of these parameters were made according to the training protocol, described previously.[12]

Tilt-table standing was performed on a motorized tilt table (Midland Manufacturing Co., Inc., Columbia, SC, USA) at the greatest tolerated tilt angle, up to a table maximum of 80°. Velcro straps were used at the knees, hips and torso, if necessary, to support the individual in an upright position. Participants were allowed to increase gradually to their maximum tilt angle and reduce their tilt angle during the session if requested because of lightheadedness.

Two-way analyses of variance (time $\times$ type) with repeated measures were used to analyze the short-term (skin temperature reactivity due to a single training session) and long-term (resting skin temperature and resting blood flow pre versus post 4 weeks of training) effects of BWST or TTS training. When significance was observed, *post hoc* analysis consisted of paired *t*-tests of group means with a Bonferroni correction. Statistical analyses were performed using SigmaStat for Windows 3.1 (Systat Software Inc., San Jose, CA, USA). All data are presented as mean ± s.d., unless otherwise specified. A *P*-value of $\leqslant 0.05$ was considered significant.

Results

Body-weight support treadmill

Resting skin temperature. Four weeks of BWST resulted in a significant decrease in resting leg skin temperature at the right thigh and shin, and the left shin and the calf as compared with resting skin temperature before any training. Significant changes were not observed in the left thigh or right calf (Figure 1).

Skin temperature reactivity. After 4 weeks of BWST training, the reactivity of skin temperature due to one session of BWST was altered at all sites except for the right calf (Figure 2). Before BWST training, the leg was cooler at the left and right thigh, immediately after a single session of BWST compared with that before the session. Before training, the leg was relatively warmer at all other sites in the leg immediately after a single session of BWST compared with the resting skin temperature. After 4 weeks of BWST training, a single session of BWST resulted in elevated skin temperature at all sites measured. This change in skin temperature in response to a single session of BWST was greater post-training at all sites except the right calf.

Tilt-table standing

Resting skin temperature. Four weeks of TTS training did not result in any significant changes in resting skin temperature of the leg, except decreases post-training in the right thigh (Figure 3).

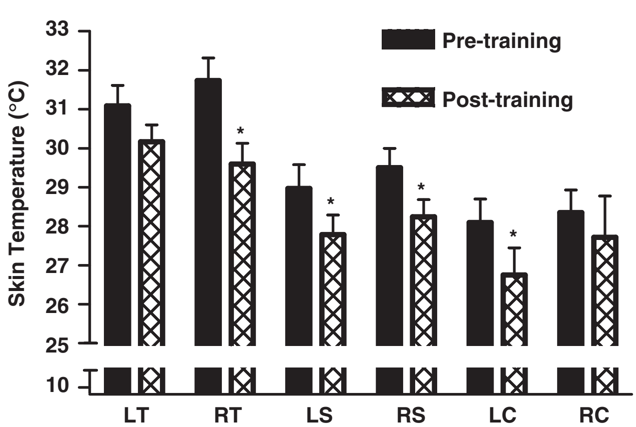

Figure 1 Pre-BWST training resting skin temperature (°C) versus post-BWST training resting skin temperature (°C). *Represents post-training resting values that are significantly lower than the pre-training resting values. Abbreviations: LC, left calf; LS, left shin; LT, left thigh; RC, right calf; RS, right shin; RT, right thigh.

Skin temperature reactivity. After 4 weeks of TTS training the skin temperature reactivity in response to one session of TTS was altered at all sites except the right calf (Figure 4). Both pre- and post-training the leg was cooler at the left and right thigh immediately after a single session of TTS compared with that before the session; however, the magnitude of the temperature decrease was reduced post-training. At all other sites a single session of TTS resulted in increases in skin temperature both pre- and post-training, and showed greater reactivity at all sites except the right calf.

Blood flow. There were no significant changes observed in resting blood flow measures as a result of either BWST or TTS training (Table 2).

Discussion

The most significant finding from the current study is that BWST training resulted in decreases in resting leg skin temperature at four of the six sites examined, whereas TTS training only resulted in decreases in resting skin temperature at one of the six sites. These decreases in resting skin temperature after training may indicate improvements in skin temperature regulation and therefore reduction in risk of secondary complications of SCI. Braden and Bergstrom[5] identified that one factor affecting the tolerance of tissue to pressure sores is skin temperature. An increase in skin temperature of 1 °C was estimated to cause a 10% increase in tissue metabolism, and tissue susceptibility to ischemic injury.[7] Schubert *et al*.[8] found increased skin microcirculation at the area of an early-stage pressure sore versus undamaged skin in an elderly population of men and women. Schubert and Fagrell[9] suggested that increased resting skin temperature elevates the risk of developing a pressure sore, as an increase in blood flow may not elevate the flow in nutritional capillaries of the skin while concomitantly increasing the nutritional demands of the

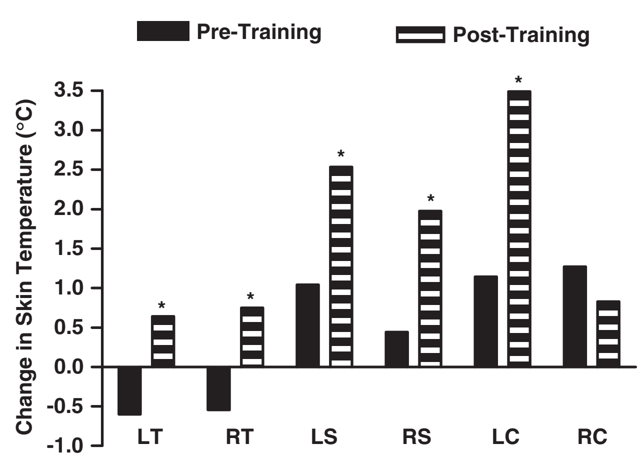

Figure 2 Pre-training change in skin temperature (°C) after a single session of BWST versus post-training change in skin temperature (°C) after a single session of BWST. *Represents post-training delta values that are significantly different from the pre-training delta values. Abbreviations: LC, left calf; LS, left shin; LT, left thigh; RC, right calf; RS, right shin; RT, right thigh.

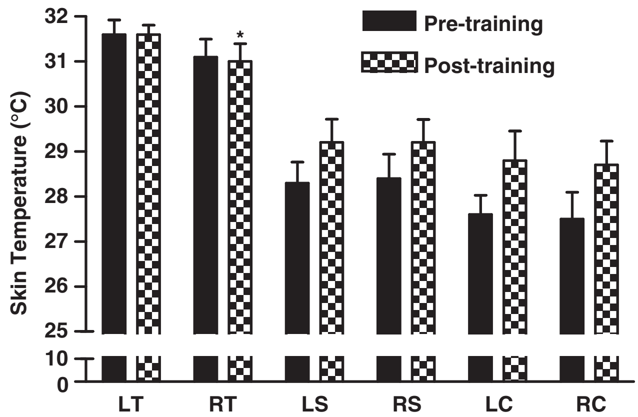

Figure 3 Pre-TTS training resting skin temperature (°C) versus post-TTS training resting skin temperature (°C). *Represents post-training resting values that are significantly lower than the pre-training resting values. Abbreviations: LC, left calf; LS, left shin; LT, left thigh; RC, right calf; RS, right shin; RT, right thigh.

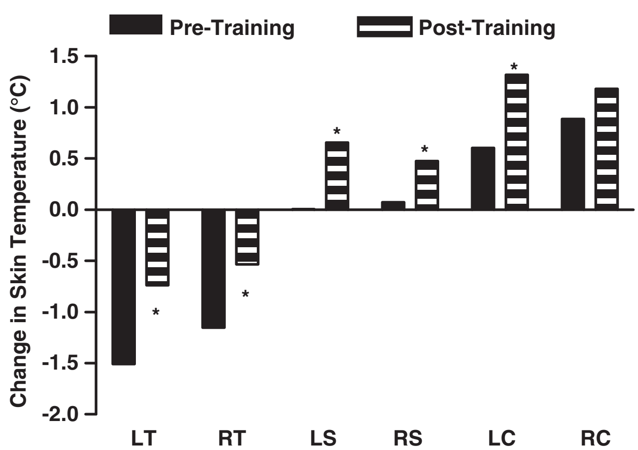

Figure 4 Pre-training change in skin temperature (°C) after a single session of TTS versus post-training change in skin temperature (°C) after a single session of TTS. * Represents post-training delta values that are significantly different from the pre-training delta values. Abbreviations: LC, left calf; LS, left shin; LT, left thigh; RC, right calf; RS, right shin; RT, right thigh.

skin cells. In the current study the decreased resting skin temperature at four sites after BWST and at one site after TTS training were all $>1\,^{\circ}C$. In the long term, these resting temperature changes may result in decreased risk of ischemic injury and therefore pressure sore development.

Although the resting skin temperature may provide useful information about the metabolic demands of skin, the response of the skin temperature to a physiological challenge (reactivity), such as heating or exercise, can also provide information about the regulatory capacity of the microcirculation. The skin temperature reactivity to a single training session was different between training methods (BWST versus TTS) and this response was also altered by 4 weeks of training to a different degree depending on the training method. After 4 weeks of BWST training, a single session of BWST resulted in uniform warming of the leg at all

Table 2 Blood flow results

Condition	*Pre-training blood flow (ml min^{-1})*	*Post-training blood flow (ml min^{-1})*	P-*value*
Left femoral artery baseline			
BWST	77.29	79.97	0.912
TTS	84.08	85.54	0.943
Right femoral artery baseline			
BWST	89.96	66.28	0.260
TTS	91.33	68.05	0.069

Abbreviations: BWST, body-weight-supported treadmill; TTS, tilt-table standing.

sites measured, whereas before training, a single session of BWST resulted in decreases in skin temperature at two of the six sites. Although 4 weeks of TTS training also resulted in altered changes in skin temperature in response to a single TTS session, uniform warming was not observed at all sites. Ek *et al.*[6] found larger increases in skin blood flow in response to a local heat stimulus in healthy individuals compared with the in-patients with pressure sores, in a long-term care facility. They concluded that impairment in the ability to increase skin blood flow in response to thermal stimuli might be a factor in the development of pressure sores. Sanada *et al.*[10] examined the relationship between skin blood flow and pressure sore development during surgery. Patients who did not develop pressure sores after their surgery had an increase in blood flow of 500% compared with pre-surgery values, whereas blood flow levels during surgery decreased in the patients who developed pressure sores. They concluded that impairments in skin temperature reactivity might be factors in the development of pressure sores.

Despite the observed changes in resting leg skin temperature at several sites with the training methods used here, we did not observe any changes in resting leg blood flow, as a result of either training method. These results may suggest that measuring bulk blood flow from conduit vessels, such as the femoral artery, may not be sensitive enough to reflect changes in blood flow distribution and potential impacts on skin blood flow and temperature, within the leg. This highlights the need for assessments of microvascular blood flow in combination with assessments of conduit blood flow, to determine adaptations in blood flow distribution after various interventions, such as BWST or TTS training.

Limitations

Limitations to the current study include issues related to data collection and interpretation. Although skin temperature was measured at six sites (three in each leg), none of the temperature sensors were placed at locations of highest incidence of pressure sores in SCI (gluteal and posterior thigh regions). Measurement at these sites would have required participants to transfer from their chair and lie in the prone position, which would have added considerably to the participant's discomfort and extended the time between the end of a training session and the time of the post-training measurement. It is possible that the observed alterations in skin temperature reactivity because of a single session of BWST after 4 weeks of training may be interpreted as an increase in blood flow benefiting the area; however, this was not reflected in the blood flow measures used for this study. Measurement of bulk blood flow may not be sensitive enough to detect changes that may have occurred at a microcirculatory level. Finally, although we feel the investigation of skin temperature changes provides useful mechanistic information to clinicians when considering physical rehabilitation options, we acknowledge that pressure sore development was not an outcome measure examined in this study, and therefore further research is required to determine whether the observed changes in temperature translate to reduced risk of secondary complications.

This study shows that 4 weeks of BWST training results in decreases in resting skin temperature and increases in skin temperature reactivity at more sites in the legs of individuals with SCI compared with TTS training. As increased resting skin temperature and decreased skin temperature reactivity to a physical challenge have been directly linked to the development of pressure sores, the results of this study suggest that BWST may be a useful tool to decrease the risk of developing pressure sores. Despite the fact that BWST is labor intensive compared with TTS, the outcomes observed in skin temperature show its potential in decreasing secondary complication risk.

Conflict of interest

The authors declare no conflict of interest.

Acknowledgements

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