



ARTICLE

Development of a skin temperature map for dermatomes in individuals with spinal cord injury: a cross-sectional study

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Abstract

Study design Cross-sectional study.

Objective The aim of this study was to map the skin temperature (Tsk) of individuals with SCI and compare able-bodied individuals, and among the groups to demonstrate the effects of differences in the levels of injury (paraplegia and tetraplegia with high and low injuries).

Setting Outpatient clinic, Brazil.

Methods Individuals with tetraplegia ($n = 20$), paraplegia ($n = 21$), and able-bodied ($n = 11$) individuals were recruited. A noncontact infrared thermometer (IRT) was used to measure three times the Tsk at the forehead, and at the C2 to S2 dermatomes. Core body temperature was measured at the axilla using the IRT and three other clinical thermometers.

Results Autonomic regulation is impaired by the injury. A Tsk map was constructed for the three groups. Significant differences in the Tsk of dermatomes were observed when comparing individuals with SCI and the able-bodied at the following dermatomes: C3, C7, T2, T3, T8, T9, L1, L2, L4, and S2. When comparing individuals with tetraplegia and able-bodied individuals, the dermatomes that showed significant differences were C5, C6, C8, T1, T10, L3, and S1. Dermatomes C5–C7, and T5 showed significant differences between individuals with tetraplegia and those with paraplegia. For L5 and S1 in paraplegia significant differences were found when comparing high with low injury.

Conclusion A Tsk map on dermatomes in individuals with SCI was implemented, and showed a significant difference between able-bodied. As temperature is a parameter for analyzing autonomic function, the study could benefit rehabilitation by providing baseline values when constructing clinical protocols.

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Introduction

In individuals with spinal cord injury (SCI), autonomic regulation of body temperature could be impaired below the injury level, and the hypothalamus is unable to control the cutaneous blood flow. A loss of sweating capacity and vasomotor control has also been reported [1]. The skin temperature (Tsk) varies with the ambient temperature and is influenced by skin blood flow and microcirculation, presenting different temperatures in the tendons, ligaments, muscles, adipose tissue, and bones [2–4]. Individuals with SCI often show vascular changes such as decreased arterial diameter, capillarization, changes in the resistance of vessels, and impaired microcirculation and, consequently, blood flow [2, 3, 5–10].

One instrument that could be used to measure the Tsk is the infrared thermometer (IRT). It detects the radiation emitted by a hot surface and provides an estimate of the surface temperature [4]. Currently, it is widely used as it

offers considerable advantages such as hygiene, rapid measurement, noninvasiveness, and comfort compared with other thermometers [3, 11–14].

As the Tsk of individuals with SCI is subject to change with the changes in blood flow and microcirculation, the aim of this study was to map the Tsk of individuals with SCI and compare it with that of able-bodied controls. We hypothesized that the Tsk of individuals with SCI is lower below the lesion level than individuals in the control group. The various changes that occur in blood flow in individuals with SCI, especially in the microcirculation of lower limbs, may be one of the factors that lead to decreases in Tsk in these individuals. Furthermore, clinical rehabilitation protocols might lead to increases in Tsk below the injury level due to improvements such as muscle contraction, which could increase the individual's metabolism and quality of life.

Methods

Study design

Cross-sectional study.

Participants and setting

Forty-one male individuals with SCI were enrolled and were divided into two groups: 21 individuals with paraplegia and 20 individuals with tetraplegia; and 11 able-bodied controls were recruited. According to the International Standards for Neurological Classification of Spinal Cord Injury, the level of injury (neurological level) was classified by using ASIA impairment scale [15]; the score ranged from C4 to T12, where C4 [A ($n = 7$), B ($n = 1$)], C5 [A ($n = 3$), B ($n = 2$)], C6 [A ($n = 2$), B ($n = 4$)], C7 [A ($n = 1$)], T3 [A ($n = 5$)], T4 [A ($n = 3$), B ($n = 3$)], T5 [A ($n = 1$), B ($n = 1$)], T6 [A ($n = 1$)], T7 [A ($n = 2$), B ($n = 1$)], T8 [A ($n = 3$)], and T12 [B ($n = 1$)]. In addition, individuals with SCI were further subdivided into paraplegia: high (T1–T6) and low (T7–T12) injuries, and for tetraplegia: high (C1–C4) and low (C5–C8) injuries. The inclusion criteria were individuals with SCI for more than a year and hemodynamically stable. The following individuals were excluded, based on restrictions in the measurements of Tsk: those with fever or ingestion of antipyretics up to 2 h before the test; those exposed to sun before the test; those who consumed alcohol, who performed strenuous activity on the previous day, who smoked, who consumed caffeine or chocolate up to 1 h before the test; those who presented with autonomic dysreflexia during the test or any type of infection including active urinary tract infection, skin disease, inflammation, or skin lesions; in pain, especially severe neuropathic pain, and with fractures of the lower limb.

The study was approved by the local ethics committee (CCAE: 19458313.1.0000.54.04). Prior to the test, all individuals provided written informed consent. In Individuals who could not write due to the involvement in the lesion, fingerprints were used or a family member signed the informed consent, being similarly aware. We certify that all applicable institutional and government regulations concerning the ethical use of human volunteers were followed during the course of this research. All evaluations were performed in the same room by the same researcher, in the Spinal Cord Injury Rehabilitation Outpatient Clinic of the Department of Orthopedics and Traumatology. This paper has included all parameters included in the STROBE guidelines [16].

Material

Instrumentation

The noncontact IRT, FLIR TG 165 (FLIR Systems Inc., Orlando, FL, USA), was used for the Tsk measurements. The IRT, featuring a FLIR Lepton[®] micro-thermal sensor, was imported by the FLIR Systems, Brazil. The measurement accuracy of the IRT is ± 1.5 °C, with a measuring range of -25 to 380 °C. The emissivity of the apparatus was adjusted to that of the skin (0.98). This device has been approved by the United States Food and Drug Administration and is furnished with the appropriate certification document (Fig. 1a) [2, 17–20].

The room temperature and humidity were controlled using a thermo-hygrometer device (MT-240, Minipa Electronics Inc., Houston, TX, USA), imported by Minipa Ltd of Brazil. The device has an internal sensor (range 0 to $+60$ °C) and an accuracy of ± 1 °C (range 0–40 °C), and it measures humidity (20–90%) with an accuracy of $\pm 5\%$ (Fig. 1b).

A reliability test was performed using the IRT and three digital thermometers, and the temperature was measured at the axilla of a staff member and/or of an individual in the



Fig. 1 Devices for the Tsk Measurements. **a** Noncontact infrared thermometer FLIR TG 165, and **b** MT-240 hygrometer/thermometer.

study using three consecutive measurements. The digital thermometers were the MC-245 (Omron Healthcare Dalian, China), TH 400 (G-Tech, Hangzhou, China), and the mercury thermometer BR-P136 (Incoterms, Brazil).

Measurement points

The measurement points (baseline) for mapping of the Tsk were the center of the forehead and the dermatomes (C2 to S2) on the right side of the body. The parameters points used were the same used by ASIA level [15]. The core body temperature measurement was done at the axilla.

Experimental procedure

The room temperature was artificially adjusted with air conditioning to 24 °C. Data were collected from 10 a.m. to 4 p.m. On the day of data collection, the first step was the reliability of the IRT with three digital thermometers in the axilla. Then, the Tsk measurement was performed for each individual, with three measurements for each dermatome. The time for each test was 40 min.

All individuals were assessed in the same room in a sitting position. The control group individuals were seated in chairs with armrests, and the individuals with SCI were seated in their own wheelchairs. All individuals were asked to wear shorts to facilitate the exposure of the skin to the ambient temperature of the room. Prior to data collection, all individuals were asked to remain at rest for 20 min to accommodate to the room temperature. The distance between the thermometer and the skin was 60.9 cm. All measurements were performed three times under the same condition by the same researcher.

Data analysis

The mean and standard deviation for all measurements were calculated for further analysis. The Shapiro–Wilk test was used to verify normal distribution. The Student's *t* test for independent samples was used to determine the influence of the level of SCI, such as for paraplegia: high (T1–T6) and

low (T7–T12) injuries, and for tetraplegia: high (C1–C4) and low (C5–C8) injuries. Comparisons among groups (able-bodied controls, individuals with paraplegia, and individuals with tetraplegia) were performed using the analysis of variance tests (p value ≤ 0.05). If significant differences were detected, post hoc with the Tukey's test were performed (three per variable) with corrected p of 0.01666 ($0.05/3 = 0.01666$). The data were analyzed using IBM SPSS software version 21 for Windows.

Results

Participants

In total, 52 males were evaluated. Table 1 shows the demographic variables for the individuals in the control, paraplegia, and tetraplegia groups.

Instrumentation

The mean (SD) value of room temperature was 23.59 (0.22) °C and that of relative humidity was 60.27 (7.19)%. The IRT accuracy compared with the three conventional thermometers used was not statistically different (Table 2).

The results for Tsk mapping and for the comparison of Tsk values in the paraplegia group—high and low injuries and in the tetraplegia group—high and low injuries are presented in Tables 3 and 4. In the paraplegia group, statistically significant differences were observed between high and low injuries at L5 ($p < 0.01$) and S1 ($p = 0.03$). In the tetraplegia group, no significant differences were observed in any dermatome, regardless of the level of injury.

The values of Tsk mapping and the comparisons among the three groups are shown in Table 5 (Supplementary information). Significant differences between the control and the SCI groups and between the SCI groups were found in many dermatomes. Significant differences were observed between the tetraplegia and the control groups at C5 ($p < 0.01$), C6 ($p < 0.01$), T1 ($p < 0.01$), T10 ($p = 0.01$), L3 ($p < 0.01$), and S1 ($p = 0.01$) dermatomes. The dermatomes that

Table 1 Characteristics of the individuals studied ($n = 52$).

	Control ($n = 11$)	Individuals with paraplegia ($n = 21$)	Value p (control \times para)	Individuals with tetraplegia ($n = 20$)	Value p (control \times tetra)
Age (years)	44 \pm 12.3	42.81 \pm 12.5	0.95	40.55 \pm 8.98	0.69
Mass (Kg)	88 \pm 10.9	76.56 \pm 10.8	0.01	70.89 \pm 9.38	0.00
Height (m)	1.80 \pm 0.1	1.76 \pm 0.07	0.54	1.77 \pm 0.05	0.78
Body mass index (kg/m ²)	27.8 \pm 4.2	24.78 \pm 2.85	0.04	22.73 \pm 3.03	0.00

Significant difference ($p \leq 0.05$) among the control group and the group with individuals with paraplegic and tetraplegic. Values: means (SD).

Table 2 Values of the three clinical thermometers and the IRT in all groups.

Thermometer temp (°C)	Control (n = 11)	Individuals with paraplegia (n = 21)	Individuals with tetraplegia (n = 20)
OMRON	36.08 ± 0.60	36.18 ± 0.35	35.68 ± 0.74
G-Tech	35.69 ± 0.58	35.68 ± 0.48	35.30 ± 0.71
Mercury	36.34 ± 0.58	36.31 ± 0.35	35.76 ± 0.61
IRT	35.5 ± 0.76	35.59 ± 0.60	35.23 ± 0.92

Temperature in Celsius degree (°C). Values: means (SD).

showed significant differences between the SCI groups were: C5–C7 ($p < 0.01$) and T5 ($p < 0.01$).

Discussion

Despite not finding statistical differences in all dermatomes between individuals with SCI and able-bodied individuals, Tsk is lower in SCI, especially in individuals with tetraplegics. The principal objective of this study was the development of a Tsk map to compare the differences in Tsk between individuals with SCI and able-bodied individuals. Our study aimed to fill this gap in knowledge about the difference in Tsk between able-bodied and SCI individuals and to provide a new tool to use in clinical and research practice, which can be used in the analysis of care and/or treatment of SCI individuals, comparing the values with the values found in our study.

SCI has numerous deleterious effects on the human body, such as respiratory complications, pressure sores, heterotopic ossification, bladder dysfunction, spasticity, pain, musculoskeletal and metabolic complications, including dysfunction of thermoregulation and cardiovascular changes, such as increased risk of atherosclerosis [21, 22]. In addition, remodeling of the peripheral arteries in the paralyzed limbs, which could lead to a decrease in the systemic blood flow in as little as a few weeks after acute SCI. Therefore, the results suggest that there may be some change in blood flow, such as a decrease in blood flow in both upper and lower limbs after SCI.

Heat production from organ function or muscular work is transferred from the central compartment (core) to the skin (periphery) through the bloodstream in order to dissipate heat. This compartmental transfer is controlled by vasoconstriction and vasodilatation of the arteriovenous arterioles and anastomoses. This mechanism is under the control of the hypothalamic modulation of the sympathetic nervous system [23]. Therefore, individuals with SCI show a decrease in blood circulation (in the lower limbs, blood flow decreases by 50–67%) and, consequently, an increase in atherosclerotic risk factors due to inactivity, decreased

Table 3 Comparison of Tsk in dermatomes between high (T1–T6) and low (T7–T12) injury in the group—individuals with paraplegia.

	Para—high Injury—T1–T6 (n = 14)	Para—low Injury—T7–T12 (n = 7)	95% CI
Forehead	34.1 ± 0.73	34.3 ± 0.63	(−0.88; 0.48)
C2	34.1 ± 0.61	34.1 ± 0.59	(−0.58; 0.58)
C3	33.9 ± 0.59	34.2 ± 0.38	(−0.82; 0.22)
C4	33.7 ± 0.75	33.3 ± 0.73	(−0.32; 1.12)
C5	31.8 ± 0.77	32.1 ± 0.92	(−1.09; 0.49)
C6	33.5 ± 0.85	32.6 ± 1.1	(−0.01; 1.81)
C7	33.1 ± 0.63	32.5 ± 1.1	(−0.18; 1.38)
C8	32.5 ± 0.75	31.6 ± 1.61	(−0.16; 1.96)
T1	32.7 ± 0.64	33.1 ± 0.78	(−1.07; 0.27)
T2	34.0 ± 0.59	34.4 ± 0.88	(−1.07; 0.27)
T3	32.2 ± 0.79	32.4 ± 0.72	(−0.94; 0.54)
T4	32.3 ± 1.43	32.5 ± 0.67	(−1.40; 1.00)
T5	33.8 ± 0.66	33.4 ± 0.50	(−0.19; 0.99)
T6	33 ± 0.93	33.2 ± 0.44	(−0.98; 0.58)
T7	32.6 ± 0.84	32.2 ± 0.67	(−0.37; 1.17)
T8	31.7 ± 0.89	31.7 ± 0.75	(−0.82; 0.82)
T9	31.4 ± 0.91	31.9 ± 0.39	(−1.26; 0.26)
T10	31.0 ± 0.98	31.4 ± 0.69	(−1.27; 0.47)
T11	31.0 ± 1.0	31.4 ± 0.81	(−1.31; 0.51)
T12	31.2 ± 0.77	31.5 ± 0.98	(−1.12; 0.52)
L1	31.1 ± 0.66	30.7 ± 0.35	(−0.16; 0.96)
L2	30.5 ± 0.57	30.6 ± 0.59	(−0.66; 0.46)
L3	28.3 ± 0.96	28.5 ± 1.44	(−1.30; 0.90)
L4	29.1 ± 1.1	28.6 ± 1.54	(−0.72; 1.72)
L5	29.6 ± 1.38*	29.1 ± 2.6	(−1.30; 2.30)
S1	29.6 ± 1.44*	28.9 ± 3.13	(−1.36; 2.76)
S2	28.9 ± 0.78	28.2 ± 1.14	(−0.18; 1.58)

Temperature in Celsius degree (°C). Values: means (SD) and 95% CI.

*Statistical difference $p \leq 0.05$.

insulin sensitivity, and body composition [24]. In this study, we found that Tsk has a variation of value depending on the characteristics of the measured area, for example, the temperature is higher in a more vascularized area. Individuals with paraplegia suffer from vasomotor disorders and show reduced venous distensibility [25, 26].

Krassioukov et al. [27] reported that body temperature and Tsk could be used to evaluate autonomic function above or below the injury and concluded that in the acute phase of injury, temperature is a valid parameter to determine the autonomic function in such individuals.

The values found in this study showed that individuals with SCI have lower Tsk in most dermatomes than individuals in the control group. Significant differences were found in dermatomes L5 and S1 for individuals with paraplegia between high injury (T1–T6) and low injury (T7–T12). Being regions of extremities, there is generally

Table 4 Tsk value according to dermatomes and comparison between high (C1–C4) and low (C5–C8) injury in the group—individuals with tetraplegia.

	Tetra—high Injury —C1–C4 (<i>n</i> = 8)	Tetra—low Injury —C5–C8 (<i>n</i> = 12)	95% CI
Forehead	33.7 ± 0.73	34.0 ± 0.94	(−0.13; 0.53)
C2	33.8 ± 0.65	33.8 ± 0.59	(−0.59; 0.59)
C3	33.7 ± 0.95	33.4 ± 0.9	(−0.58; 1.18)
C4	33.2 ± 0.94	33.1 ± 0.82	(−0.73; 0.93)
C5	30.8 ± 1.21	31.1 ± 1.33	(−1.53; 0.93)
C6	32.3 ± 0.73	31.5 ± 2.04	(−0.79; 2.39)
C7	32.0 ± 1.04	31.2 ± 1.51	(−0.49; 2.09)
C8	32.0 ± 1.39	31.4 ± 1.57	(−0.84; 2.04)
T1	32.0 ± 1.27	32.3 ± 1.0	(−1.37; 0.77)
T2	33.9 ± 0.46	34.4 ± 1.11	(−1.38; 0.38)
T3	32.1 ± 0.6	32.5 ± 0.55	(−0.95; 0.15)
T4	32.4 ± 0.67	32.0 ± 0.60	(−0.20; 1.00)
T5	32.5 ± 0.64	32.8 ± 0.85	(−1.04; 0.44)
T6	32.9 ± 0.91	32.7 ± 0.57	(−0.49; 0.89)
T7	32.5 ± 0.72	32.3 ± 0.6	(−0.42; 0.82)
T8	31.9 ± 1.1	31.7 ± 0.44	(−0.54; 0.94)
T9	31.7 ± 0.92	31.0 ± 0.71	(−0.07; 1.47)
T10	30.9 ± 0.76	30.7 ± 0.78	(−0.54; 0.94)
T11	30.6 ± 1.11	30.7 ± 1.11	(−1.16; 0.96)
T12	31 ± 1.0	31 ± 1.0	(−0.96; 0.96)
L1	30.5 ± 0.47	30.5 ± 0.71	(−0.60; 0.60)
L2	30.4 ± 0.37	29.9 ± 0.75	(−0.10; 1.10)
L3	28.6 ± 0.93	27.6 ± 0.72	(0.23; 1.77)
L4	28.8 ± 1.18	28.1 ± 1.47	(−0.61; 2.01)
L5	29.5 ± 2.02	28.1 ± 2.1	(−0.58; 3.38)
S1	28.7 ± 1.5	27.6 ± 1.92	(−0.60; 2.80)
S2	29.4 ± 0.85	28.3 ± 1.0	(0.19; 2.01)

Temperature in Celsius degree (°C). Values: means (SD) and 95% CI.

oscillation of Tsk values between individuals. This could be attributed to the small sample size of our study. Therefore, it would be interesting and necessary in the future, a study with a larger sample, as well as a more detailed investigation of each dermatome, to perhaps explain this behavior.

Another important observation was that dermatomes L3 and S1 presented with lower temperatures compared with the most dermatomes (Tables 3 and 4, Table 5 (Supplementary information)). This showed that location and anatomy could influence Tsk. Dermatome L3, due to its location (anterior part of the middle part of the knee joint), does not have much musculature, as it is located primarily in a bony area. The values for L3 in all groups were determined to be low. The dermatome S1 (lateral part of the calcaneus), being a part of the extremity (peripheral), favors greater temperature fluctuations and temperature exchange between individuals. Considering these observations

pertaining to changes in Tsk in some body dermatomes, a detailed investigation analyzing a larger sample would be interesting in the future.

Therefore, we conclude that there is a difference observed in Tsk between individuals with SCI and the able-bodied controls. However, significant differences were observed only in certain dermatomes while comparing individuals with tetraplegia and paraplegia. We speculate that these findings are probably the result of changes in blood flow and the tendency for cardiovascular changes common in individuals with SCI. An important benefit of our study by mapping Tsk in individuals with SCI and able-bodied individuals is that changes in Tsk in some body dermatomes would imply further investigation, assisting in the diagnosis, clinical rehabilitation protocols, and/or prevention complications such as hyperthermia, hypothermia, injuries, and clinical rehabilitation protocols that might yield increase in Tsk below the injury.

A limitation of this study was that it was performed in a hospital with few female individuals with SCI. Hence, the study was performed only in men. Another limitation was the difficulty in recruiting a large and homogeneous sample. Further studies, including males and females with SCI, performed at the same time of the day and to determine if rehabilitation protocols can increase Tsk, thus improving the metabolism of such individuals.

In conclusion, we showed a significant difference in Tsk in some dermatomes between individuals with SCI and able-bodied individuals. The Tsk map proposed in this study is a new and interesting tool that could help future rehabilitation research such as clinical practice daily assessments in clinics or hospitals, and could analyze autonomic function in different protocols used in rehabilitation. It could serve as a simple and quick method for analyzing a specific dermatome above or below the level of injury in individuals with SCI in any clinical setting.

Data availability

The support to this study is available from the corresponding author upon reasonable request.

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Author contributions JRT was the principal researcher of this research, who performed data collection, analyzed the results and discussion of the data. RAT was the co-author and assistant researcher, who assisted in the elaboration of the proposed method, in the interpretation and discussion of the data, and in data collection. MB performed the statistical analyses. CAF was the co-author, who assisted in the preparation of the manuscript, statistical analyses, discussion of data, and proofreading of the manuscript. ACJ was the academic advisor, who proposed the initial concept of this paper and provided

guidance and assistance in the development and execution of the research. Each author has contributed substantially to the research, preparation, and production of the paper and approves of its submission to the Journal.

Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest

Ethics statement We certify that all applicable institutional and government regulations concerning the ethical use of human volunteers were followed during the course of this research. This work has been approved by the Ethics Committee and consent forms have been signed by all participants.

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