Determination of Localized Skin Temperature of the Transtibial Residual Limb

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Research

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Abstract

Background: Interventions to resolve thermal discomfort as a common complaint in amputees, are usually chosen based on the residual limb skin temperature while wearing prosthesis; whereas, less attention was paid to residual limb skin temperature while outside of the prosthesis. The objective of this study was to explore the localized and regional skin temperature over the transtibial residual limb (TRL) while outside of the prosthesis.

Methods: Eight unilateral transtibial amputees were enrolled in this cross sectional study. Participants sat on a chair and rested for 30 minutes while their prosthesis was removed. Twelve sites were marked in four columns (anterolateral, anteromedial, posteromedial, and posterolateral) and three rows (proximal, middle, and distal) over the residual limb and used for attachment of analog thermistors. Skin temperature was recorded and compared during 11 minutes. Furthermore, the relationship of skin temperature with participants' demographic and clinical characteristics were explored.

Results: The middle and distal zones of the anteromedial column had the highest and lowest skin temperatures (29.8 and 26.3°C, $p<0.05$), respectively. The average temperature of the TRL was 27.73±0.83°C and had no significant relationships ($p>0.05$) with participants' demographic and clinical characteristics.

Conclusions: An unequal distribution of temperature over the TRL was found with significantly higher and lower temperatures at its anterior column and distal row, respectively. This temperature pattern should be considered for thermoregulation strategies. Further investigation of the residual limb temperature while considering muscles thickness and blood perfusion rate are warranted with and without prosthesis.

Background

Key factors in successful use of a prosthesis include skin integrity of the residual limb, its health and hygiene [1, 2]. Skin irritation, ulceration, dermatitis, and excessive sweating are common complaints of amputees who use prostheses for their daily activities [3, 4]. Heat and moisture that becomes trapped inside the socket leads to a jeopardizing, unpleasant, and infectious environment for amputees which greatly decreases the quality of life, satisfaction and use of the prosthesis, and social participation [3, 5, 6]. In dysvascular and/or neuropathic patients, any area of the skin with 2ºC or more increased temperature compared to adjacent areas has increased risk of ulceration [7]; therefore, localized skin temperature is an indicator of a potential skin breakdown.

Understanding the temperature distribution over the transtibial residual limb (TRL) may facilitate prosthetic socket design and fit by preventing possible thermal hazards and improving amputee comfort [5]. Investigation of TRL skin temperature has been performed using temperature sensors, thermography cameras, and virtual methods (i.e. mathematical modeling of the residual limb) during rest and activity [5, 8–12]. In order to resolve thermal discomfort in people with TRL through prosthetic development, a comprehensive knowledge of temperature distribution over the residual limb [13–16] is required.

The TRL skin temperature measurements with the prosthesis applied, demonstrate unequal heat build-up over different anatomical locations [8, 9]. The TRL has a heterogeneous structure consisting of different underlying tissues with different thicknesses, blood perfusion rates, metabolic activities, and thermal characteristics [9]. There are few studies that have measured TRL skin temperature without a prosthesis [12, 17, 18]; however, due to difficulties in skin temperature measurements using thermistors and thermography cameras, the sample size is usually small. Different study designs and unique characteristics of the amputee population make it difficult to compare the results between studies; therefore, further investigation is needed. The present study aimed to measure TRL skin temperature while prosthesis was removed to describe surface temperature distribution. In addition, relationships among some demographic and clinical characteristics with residual limb temperature were explored.

Methods

Participants

Eight male veterans were enrolled in this study based on a purposive sampling method. A list of all potential veterans with transtibial amputation who were living in the Hamadan province of Iran was excerpted and provided by the Veterans and Martyrs Affair Foundation (VMAF) from their comprehensive national database of about 500 thousands Iranian veterans and martyrs [19]. Thereafter, all veterans who met the study inclusion criteria, were invited by phone call to participate in this study. Twenty eight veterans were volunteered to participate and attended for a pre-screening of their adaptability with the inclusion/exclusion criteria. Finally, twenty veterans were excluded from study and all tests were done with eight veterans. The inclusion criteria were: (1) unilateral TRL with at least 25 cm length from knee axis, (2) traumatic amputation, (3) age between 18–60 years, (4) at least 2 years experience of prosthesis use, (5) existence of intact skin of the residual limb without any ulceration based on medical examination. The exclusion criteria were (1) existence of any medical comorbidities that may alter sensation/thermoregulation (e.g. neurological, cardiovascular, and endocrine), (2) smoking for at least 30 minutes before starting experiment [20], (3) alcohol drinking and medication use on experiment day, (4) impaired thermal sense in the residual limb based on clinical examination [21], (5) use of antiperspirant sprays, powder, and lotions on skin of the residual limb on experiment day. A written informed consent was obtained from participants after a full description of the study aims and procedures before their enrollment. All aspects of the study were approved by the ethics committee of the Hamadan University of Medical Sciences (IR.UMSHA.REC.1394.333).

Temperature measurement over the transtibial residual limb

Twelve sites from four columns (anteromedial, anterolateral, posteromedial, and posterolateral) and three circumferential rows (proximal, middle, and distal) were marked over the residual limb to provide attachment sites of thermistors [8]. Attachment sites were labeled Z1 to Z3 from proximal to distal and were marked at a constant distance to each other (Fig. 1). A portable thermoregulatory system that was designed, fabricated and tested in a previous study was used for data collection [22]. Twelve analog NTC (negative temperature coefficient - NXFT15XH103, Murata Manufacturing Co. Ltd., Japan) thermistors were calibrated and then attached to the skin using adhesive tape [22]. Each thermistor was wired to a small amplifier board and attached to the input port of an Arduino Duemilanove (Arduino, Italy) microcontroller board. A 7V and 2A lithium-ion battery with nominal capacity of 2.2 Ah was used to supply the required power for thermistors and microcontroller.

Experimental set up

Participants sat on a chair to remove their prosthesis and rested for 30 minutes to become familiar with the laboratory environment and become adapted to its ambient temperature. Demographic and clinical characteristics of participants were surveyed using a questionnaire and inclusion/exclusion criteria were verified. Thermistors were then attached to the marked sites over the residual limb. During one session, localized skin temperature of the residual limb was recorded during 11 minutes at the ambient temperature of 23 °C. Temperature distribution over the TRL was determined by comparing temperature at different sites. The average of the recorded temperature at different sites over of the TRL was determined and its potential relationship with demographic and clinical characteristics of participants was explored.

Data and statistical analysis

Statistical analyses were computed using IBM SPSS software (Version 22.0, IBM Corp, New York, NY). The mean temperature of the residual limb was calculated at each zone and compared to the gran mean of the whole residual limb using one-sample t test. Furthermore, localized skin temperature over the residual limb was compared to each other based on their column and circumferential row grouping using one-way analysis of variance (ANOVA). Tukey post hoc analysis was used to identify differences among columns, as well as circumferential rows. Pearson's correlation coefficient and partial eta squared were calculated to explore potential relationship of average temperature of the residual limb with quantitative and nominal characteristics of participants. Significance for all data was defined as $p < 0.05$ and all data are reported as mean ± SD (standard deviation).

Results

Demographic and clinical characteristics of participants

The demographic and clinical characteristics of participants are presented in Table 1. Participants had a mean ± SD age of 40.3 ± 8.4 years. With respect to employment status, fifty percent of participants were employed and had a job; the remaining participants were retired or unemployed and received compensation and pension from VMAF based on their disability rating. The average time after amputation and experience of using a prosthesis were 19.3 ± 9.6 and 18.9 ± 9.8 years, respectively. Exoskeletal prosthesis use was the same as endoskeletal prosthesis among participants; however, polyfoam liner was more popular than silicon/gel liners. Average daily prosthesis use was 10 ± 3.5 hours.

Table 1
the demographic characteristics of participant veterans (N = 8)

Variable	Data Range	Mean	Standard Deviation (SD)
Age	23–51	40.3	8.4
Weight (kg)	60–92	75.8	8.8
Height (cm)	165–178	170.6	4.3
BMI (kgm^{-2})	19.6–31.8	26.1	3.5
Time after Amputation (y)	4–30	19.3	9.6
Years of Prosthesis Use (y)	3–30	18.9	9.8
Daily Prosthesis Use (h)	7.5–18	10	3.5
Employment Status	E: n = 4		
	*Un-E: n = 4		
Amputation Side	R: n = 5		
	L: n = 3		
Type of Prosthesis	Ex-P: n = 4		
	En-P: n = 3		
	En-S: n = 1		

SD: Standard deviation; E: Employed; *Un-E: Unemployed (Retired or unemployed veterans and veterans who received compensation and pension from Veterans and Martyrs Affair Foundation (VMAF) based on their disability rating considered unemployed); R: Right side; L: Left side; Ex-P: Exoskeletal with polyfoam liner; En-P: Endoskeletal with polyfoam liner; En-S: Endoskeletal with silicone/gel liner.

Temperature measurement over the transtibial residual limb

The mean, SD, and SE (standard error) of the skin temperature recorded by the thermistors for each zone, as well as the grand mean for the whole residual limbs (i.e. 27.7 °C) are presented in Table 2.

Table 2
Recorded temperature and its comparison with the grand mean of the residual limbs

Case ID	Regional residual limb temperature												Mean ± SD residual limb temperature
	Anterolateral			Anteromedial			Posteromedial			Posterolateral			
	Z1	Z2	Z3	Z1	Z2	Z3	Z1	Z2	Z3	Z1	Z2	Z3	
1	27.8	27.7	26.4	28.4	28.8	24.8	27.4	27.6	24.8	27.1	26.1	24.8	26.8 ± 1.3
2	28	27.9	26.6	27.7	29.6	26.5	29.2	26.5	24.8	27.5	24.4	24.3	26.9 ± 1.7
3	30.6	26.6	28.5	31.1	29.6	28	24.7	25.7	28	27.7	26.8	27.1	27.9 ± 1.8
4	29.2	29.3	26.7	28.2	29	25.5	27	24.4	26.5	28.4	25.8	25.2	27.1 ± 1.6
5	30	29.3	27.9	30	29.8	25.9	24.1	27.8	26.4	29.8	28.5	27.7	28.1 ± 1.8
6	29.7	28.8	28.7	28.8	29.8	26.8	29	26.8	27.1	28.6	27.6	27.3	28.2 ± 1
7	27.8	29.4	27.2	28.4	30.2	25.8	26.5	27.2	26.3	26.3	26.8	26.9	27.4 ± 1.3
8	29.7	28.5	30.5	31.1	31.9	27.1	26.7	29.4	31.4	28.2	28.9	30.4	29.5 ± 1.6
Mean	29.1	28.4	27.8	29.2	29.8	26.3	26.8	27	26.9	27.9	26.9	26.7	27.7 ± 0.8
SD	0.1	0.9	1.3	1.3	0.9	0.9	1.7	1.4	2	1	1.4	1.8	
SE	0.4	0.3	0.5	0.5	0.3	0.4	0.6	0.5	0.7	0.4	0.5	0.7	
t	3.6	2.1	0.2	3.2	6.4	-4	-1.4	-1.4	-1.1	0.6	-1.6	-1.4	
P	0.01*	0.08	0.85	0.02*	0.00*	0.01*	0.21	0.20	0.33	0.54	0.15	0.20	

Z: zone; SD: standard deviation; SE: standard error; t: one sample t statistics for comparison to the grand mean of the whole residual limbs temperature (i.e. 27.7); P: P-value; *: difference is statistically significant ($p < 0.05$).

One sample t test between grand mean of the whole residual limb temperature with mean temperature at each zone indicated significant difference at four zones (Fig. 2). The highest temperature was recorded at the middle portion of the anteromedial region of the TRL. The lowest temperature was recorded at the distal end of the anteromedial region of TRL (Fig. 2).

The Levene's test for homogeneity of variances showed that temperature distribution in columns and circumferential rows had equal variances; therefore, parametric one-way analysis of variance was used to explore the variability of temperature over the TRL. The results revealed there were significant differences among mean values of temperature among four columns ($F_{(3,92)} = 6.09, p = 0.001$) as well as among three rows ($F_{(2,93)} = 5.69, p = 0.005$). The Tukey post hoc analysis showed that the columns and rows can be categorized into 2 and 1 distinct temperature regions, respectively (Table 3).

Table 3
The recorded temperature (Mean ± SD) at each region over the residual limb

Columns	**Anteromedial**	**Anterolateral**	**Posteromedial**	**Posterolateral**	***F(3,92)***	***P***
	28.4 ± 1.5	**28.4 ± 0.5**	**26.9 ± 0.1**	**27.2 ± 0.5**	**6.1**	**0.001**
Rows	Proximal	Middle		Distal	*F(2,93)*	*P*
	28.3 ± 1.6	28.0 ± 1.7		26.9 ± 1.7	5.7	0.005
Classification of temperature sites based on their column and row (Note: sites under each class have no significant difference with each other, however there is significant difference (*p < 0.05*) between classes)						
Temperature in Columns				Temperature in Rows		
Class 1	Class 2			Class 1	Class 2	
Anteromedial	Posteromedial			Zone 1: Proximal	Zone 3: Distal	
Anterolateral	Posterolateral			Zone 2: Middle		
P: P-value.						

Relationship of average residual limb temperature with clinical and demographic characteristics of participants

Table 4 presents the correlation data between average residual limb skin temperature with participant demographic and clinical characteristics. There was no significant relationship between average residual limb temperature and participants' demographic or clinical characteristics.

Discussion

Similar to other studies [8–10, 17], the present study focused on temperature measurement of the TRL while it was outside of prosthetic socket. On average, lower residual limb temperature was found compared to previous studies [5, 8, 10, 17]. Uneven temperature distribution over the TRL was found, which followed a specific thermal gradient pattern that probably was related to residual limb tissue characteristics rather than amputee's demographic and clinical characteristics.

Temperature measurement over the transtibial residual limb

In line with previous studies [5, 8, 10, 17], uneven temperature distribution over TRL was found. In this study, the highest temperature was recorded at middle part of the anteromedial (Z2) location of TRL. The lowest temperature was recorded at the distal part of the anteromedial (Z3) location of TRL. Contrary to the intact limb [23], the locations of the highest and lowest temperature sites over the TRL are close probably due to shortened length of the limb (decreased surface area) and compromised muscular and vascular tissues after amputation. Previous research with small sample sizes and diverse study designs on TRL skin temperature is conflicting. Peery et al. evaluated skin temperature of five TRLs and reported that proximal anterior region of the residual limb was the coldest site and the posterior region of the residual limb was the warmest site [8]. Klute et al. examined residual limb skin temperature of nine transtibial amputees and found that skin over the tibialis anterior, i.e. anterolateral location of the residual limb, at the middle level between the proximal and distal ends had the warmest temperature while the posteromedial location at the distal level of the residual limb had the coldest temperature [5]. Ghoseiri and collegues measured residual limb skin temperature in a single transtibial amputee and found that the middle part of the anterolateral region of the TRL showed the highest skin temperature, whereas the distal part of the posterior region of the residual limb showed the lowest skin temperature [17]. Therefore, in spite of some common findings regarding the warmest and coldest regions of the TRL, there is no general consensus, which indicate the need for further research.

It was reported that spotted higher skin temperature compared to the adjacent parts is a predictor of skin damage [24]. Therefore, provision of a constant temperature, thermoregulation, by keeping a relatively constant temperature as well as heating or cooling mechanisms could ensure optimal physiological health and function [25]. Thermoregulation can be induced internally (e.g. by changes in the blood flow during vasodilation or vasoconstriction) [26] or externally (e.g. thermoregulatory systems and exercise maneuvers) [22]. With respect to the external thermoregulation, the pattern of temperature distribution over the TRL may be useful for selecting appropriate thermoregulatory strategies both in and out of the prosthesis. Challenges in developing a thermoregulatory system include management of the size, weight, cost, and required power of the system to work efficiently when applied as a prosthetic component [5, 22]. Therefore, for both in and out of prosthesis approaches, the distinct skin temperature measurements based on column and row could help in the selection of the best attachment sites of thermoregulatory systems. Our findings revealed that the anteromedial and posteromedial columns of the residual limb were the warmest and coldest regions, respectively, while the anterior part of the TRL had higher temperature compared to the posterior part. Furthermore, the proximal and middle circumferential rows had higher temperature compared to the distal row. Therefore, to provide a thermal equilibrium out of the prosthesis, a cooling mechanism may be required for the proximal and middle rows of the anterior part of the residual limb, while a heating mechanism may be necessary for the distal and posterior parts of the residual limb.

In this study, the skin temperature of the TRL averaged 27.7 ± 0.8 °C, ranging from 27 to 31 °C. However, the reported average temperature of the TRL was 29.1 ± 0.6 °C [17], 29.5 ± 0.9 °C [10], 31.0 ± 1.5 °C [5] and 31.4 ± 1.3 °C [8]. These variations could be related to differences in study designs and recording methods. Thermal standards in non-amputees are based on both environmental (e.g. air temperature, air velocity, radiant temperature, and relative humidity) and personal factors (e.g. activity level, metabolic rate, weighted average of skin temperature, and clothing insulation) [26, 27]. In people with amputation the residual limb skin temperature is generally greater than in non-amputees because of the decreased surface area of the body and changes in blood circulation, as well as the volume and shape of the residual muscles [18, 28]. Interestingly, the distal residual limb temperature in unilateral amputees is cooler than the corresponding site on the contralateral intact side [18]. Therefore, all personal factors differ from non-amputee people and thermal standards available for intact persons cannot be used for people with amputation.

Relationship of the average residual limb temperature with demographic and clinical characteristics of participants

Statistical analysis indicated small non-significant relationships between the average residual limb temperature and participants' demographic and clinical characteristics. This finding was promising as we recorded temperature without prosthesis at the rest condition, which excludes the potential heating effects of prosthetic socket on the skin temperature and thermal discomfort [11]. We found that the middle part of the anteromedial region of the residual limb had over 2 °C temperature difference with the mean temperature of the residual limb; therefore, this site may have higher vulnerability to thermal discomfort and skin irritation. With increasing age, thermal sense may be decreased and some older persons may not detect up to 4 °C of temperature change [29]. However, thermal sense quantification differs from skin temperature recording and was beyond the scope of the present study. Although the present study had no focus on participants thermal comfort, Klute et al. reported an increase of 2 °C can cause thermal discomfort in people with amputation [5]. In contrast, Diment and colleagues noted that thermal discomfort in lower limb prosthetic users is not directly related to the skin temperature [30]. Similar to localized TRL skin temperature, there is no consensus about thermal comfort in people with amputation. The interaction of residual limb temperature with demographic and clinical characteristics has direct effect of quality of life of amputees and needs further investigation probably around residual limb tissue characteristics.

Study Limitations

Several aspects may threaten then internal and external vailidity of this study. Evaluating residual limb temperature is difficult because the thermistors are connected to a computer or microcontroller using small and breakable wires, likely leading to small sample sizes in the previous temperature measurement studies in amputees [5, 8, 10, 17]. The small sample size and purposive sampling of male veteran amputees may limit generalizability to other amputees. Future studies may assess thermoregulatory mechanisms such as skin perfusion or thermal receptor activation. Skin and tissue thickness was not assessed in this study, which may influence results. Future research may use muscluloskeletal ultrasound to quantify soft tissue thickness of the residual limb.

Conclusions

This study may provide important information to develop thermoregulatory strategies for the residual limb in transtibial amputees.ranging from prosthetic socket design, component manufacturing, and material selection, to potential therapeutic exercises [31]. The TRL had unequal skin temperature distribution while outside of the prosthetic socket. The highest and lowest skin temperatures were recorded at the middle and distal zones of the anteromedial region of TRL, respectively. Skin temperature recording showed that anterior part of the residual limb had significantly higher skin temperature compared to its posterior part. Similarly, the distal part of the residual limb had a significantly lower temperature compared to its middle and proximal parts. Further thermoregulatory investigations (both in and out of the socket) with larger sample sizes are warranted; these studies should consider the volume and thickness of the residual muscles and blood perfusion rate at different regions of the residual limb.

List Of Abbreviations

ANOVA
Analysis of Variance
NTC
Negative Temperature Coefficient
SD

Standard Deviation
SE
Sstandard Error
TRL
Transtibial Residual Limb
VMAF
Veterans and Martyrs Affair Foundation

Declarations

- ### Ethics approval and consent to participate

All aspects of the study were approved by the ethics committee of the Hamadan University of Medical Sciences (IR.UMSHA.REC.1394.333).

- ### Consent for publication

Not applicable

- ### Availability of data and material

The datasets used and/or analysed during the current study are available from the corresponding author on reasonable request.

- ### Competing interests

The authors declare that they have no competing interests

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- ### Authors' contributions

KG, MA, and DCB contributed in study concept and design. KG, MA participated in data gathering. KG and JRM, PP, DCB analyzed and interpreted data. All authors contributed to drafting of the manusctipt and read and approved the final manuscript.

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Figures

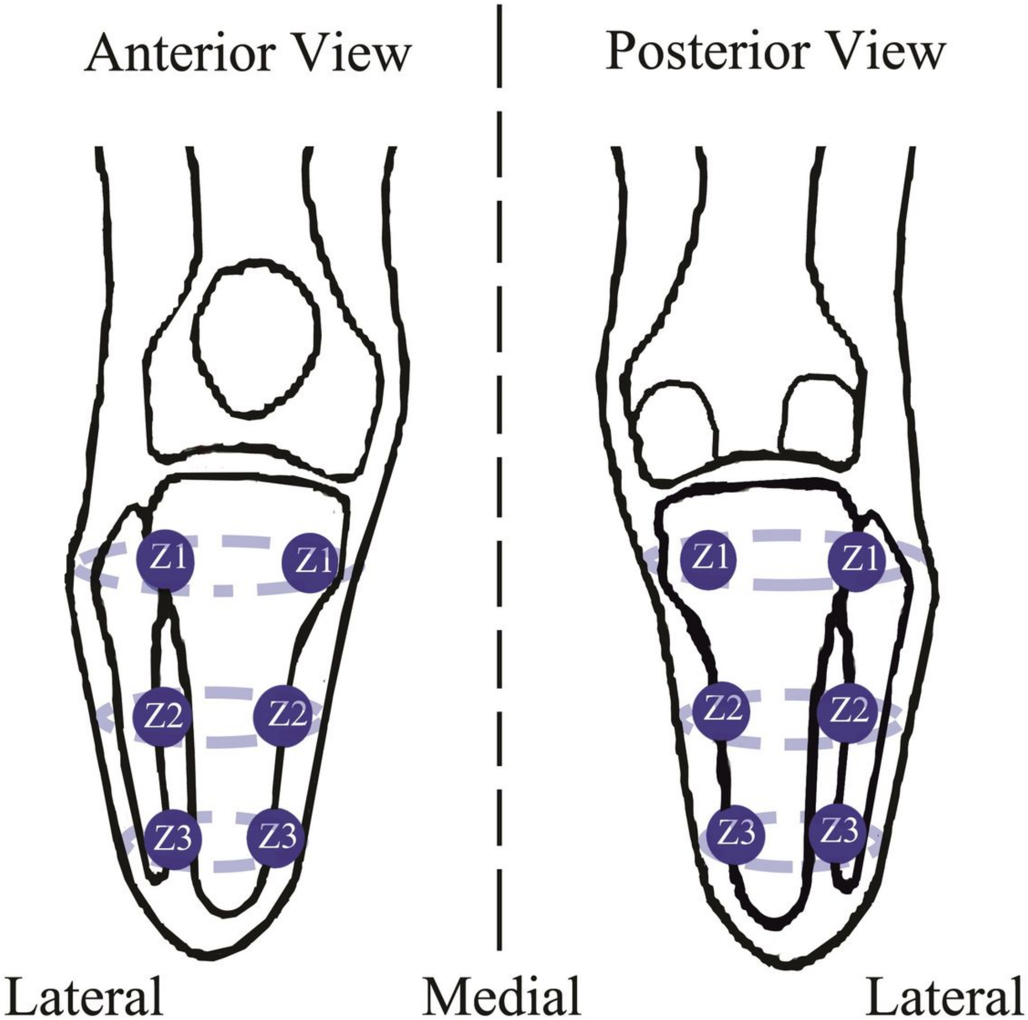

Figure 1

Temperature measurement sites over transtibial residual limb

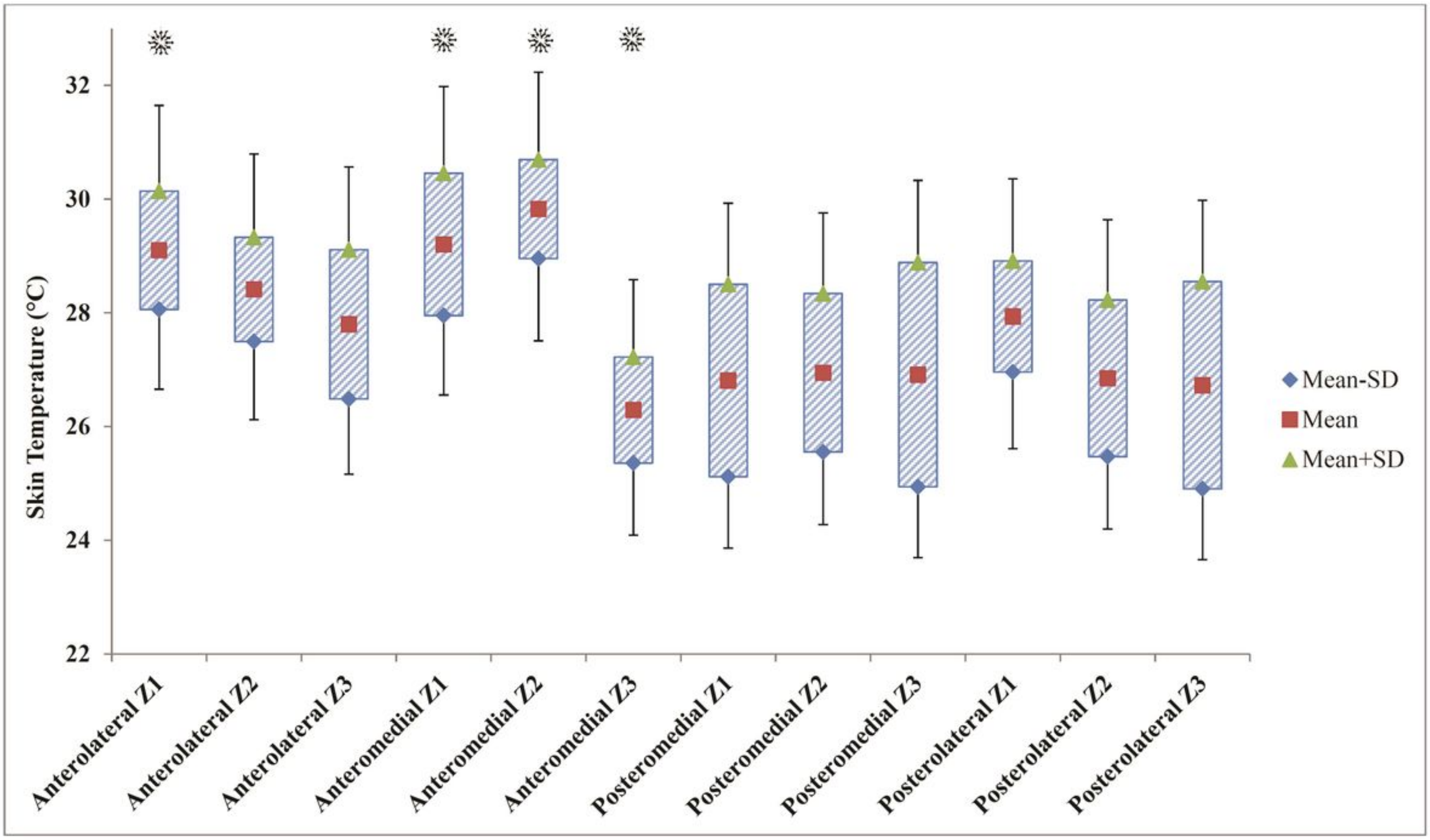

Figure 2

Mean value of the recorded temperature at each zone around the residual limb difference is statistically significant ($p<0.05$) based on one sample t test in comparison of grand mean of the whole residual limb temperature and temperature at each zone.

Table 4
Correlation of average residual limb temperature with clinical & demographic characteristics of participants

	Statistics Value	Clinical & Demographic Characteristics								
		Quantitative¥						Nominal		
		Age (y)	Mass (kg)	Height (cm)	Time after Amputation (y)	Years of Prosthesis Use (y)	Daily Prosthesis Use (h)	Prosthesis Type	Employment Status	Amputation Side
Residual Limb Temperature	Correlation	0.45	0.33	-0.07	0.56	0.55	0.30	0.15	0.28	0.16
	p	0.27	0.42	0.88	0.15	0.16	0.48	0.66	0.18	0.32

¥: Pearson’s r

: Partial Eta Square