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Relationship between skin temperature and soft tissue hardness in diabetic patients: an exploratory study

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Abstract

Objective: The role of skin temperature and soft tissue hardness in the development of plantar ulcers is still in debate. However, the relationship between skin temperature and soft tissue hardness has not been explored. This study intends to analyse an eventual association between skin temperature and soft tissue hardness in the foot of diabetic patients *Approach*: Twenty diabetic patients enrolled for this study. The analysis was done at the foot level, therefore, skin temperature and soft tissue hardness data of the plantar surface of 40 feet were obtained in eight regions of the foot, two in the heel, two in the midfoot, three in the forefoot and one in the hallux. Information regarding glycaemic control (HbA1c levels) was retrieved from the clinical records of the patients. *Main results*: After averaging skin temperature and soft tissue hardness in the calcaneum (medial and lateral), in the midfoot (medial and lateral) and in the metatarsal head (1st, 2nd–3rd and 4th–5th), a negative, moderate and significant association was found between skin temperature and soft tissue hardness in the metatarsal head (rho $= -0.553$; $p < 0.001$), a positive, low and significant association was found in the midfoot (rho $= 0.333$; $p = 0.036$), but no association was found in the heel. The multiple linear regression models with skin temperature as dependent variable and soft tissue hardness as predictor were statistically significant in the metatarsal heads and midfoot, and explained 28.8% ($R^2 = 0.288$, $F_{(1,38)} = 15.37, p < 0.001$) and 11.9% ($R^2 = 0.119, F_{(1,38)} = 5.151, p = 0.029$) of the variance in skin temperature, respectively. *Significance*: Skin temperature is negatively associated with soft tissue hardness in the metatarsal head region and positively associated with soft tissue hardness in the midfoot. These findings imply that soft tissue hardness should be considered in the assessment of diabetic foot patients and that this variable should be controlled in studies assessing the determinants of foot skin temperature.

1. Introduction

The prevalence of diabetes is increasing worldwide. Diabetes is a chronic condition that occurs when high levels of glucose are present in the blood and is often associated with disabling and life-threatening complications (International Diabetes Federation 2017), such as foot ulcers. The yearly incidence of foot ulcers is around 2%–4% in developed countries (Boulton *et al* 2005) and the recurrence rate may reach 40% (Pound *et al* 2005), illustrating the elevated burden to the patients, health care systems and society. Sensory loss, foot deformities, inability to coordinate movements and impairments in sweat and sebaceous glands functioning increase the vulnerability of the foot to infection and ulcer formation (Frykberg *et al* 2006, Noor *et al* 2015). Altered pressure distribution throughout the sole of the foot due to soft tissue changes, might also contribute to foot ulceration

(Frykberg *et al* 2006). These soft tissue changes include limited joint mobility, callus formation and increased hardness of plantar tissues (Pavicic and Korting 2006, Chao *et al* 2011, Periyasamy *et al* 2012a).

Regarding soft tissue hardness, the balance between proliferation, differentiation and cell death of keratinocytes sustains the thickness of the epidermis (Truong and Khavari 2007). Previous research has evidenced that an increase in proliferation is related to the accumulation of advanced glycation products induced by hyperglycaemia in patients with diabetes (Kennedy and Baynes 1984, Sternberg *et al* 1985, Chao *et al* 2011), which in turn increase skin stiffness through increase in cross-linking of collagen (Nikkels-Tassoudji *et al* 1996). This is even more evident in patients with diabetes and foot complications such as neuropathy and ulceration (Chao *et al* 2011). Soft tissue hardness has a small but significant influence on the ability to perceive light touch in healthy feet (Strzalkowski *et al* 2015) and it is logical to assume that it may worsen this already impaired ability in diabetic patients with foot complications. Moreover, patients with neuropathy have higher soft tissue hardness than diabetic patients without neuropathy and nondiabetic subjects (Piaggesi *et al* 1999), and the severity of neuropathy is strongly correlated with the increase in hardness. Another study has evidenced that patients with diabetes, neuropathy and a history of ulcers had higher stiffness than age, gender and BMI matched controls (Klaesner *et al* 2002). Previous research has suggested that soft tissue stiffness may be related to peak plantar pressure (Zheng *et al* 2000, Klaesner *et al* 2002, Charanya *et al* 2004), therefore it may contribute to foot ulcer occurrence.

Clinical abnormalities related to changes in blood flow and inflammation may affect skin temperature (Ring and Ammer 2012), and its relevance in the study of diabetes is well established (Armstrong *et al* 2007, Ring 2010). Increments in skin temperature, when compared to the contralateral side, can predict the occurrence of foot ulcers (Houghton *et al* 2013) and the International Working Group on the Diabetic Foot has suggested that monitoring skin temperature can reduce the recurrence of plantar ulcers (van Netten *et al* 2016). Neuropathy, a common feature in diabetic patients has been associated with higher values of skin temperature (Papanas *et al* 2009, Bagavathiappan *et al* 2010).

Autonomic dysfunction is a feature associated with the increase in soft tissue hardness and skin temperature in diabetic patients. Sudomotor dysfunction, a consequence of impaired innervation of sweat glands (Vinik *et al* 2015, Castro *et al* 2016) is associated with dry skin, callus formation and increased skin temperature (Goodman 1966, Fealey *et al* 1989, Boulton 2004, Sun *et al* 2006, Papanas *et al* 2010) and has been reported to be correlated with glycated haemoglobin (HbA1c) levels, a measure of glycaemic control (Chahal *et al* 2017). Regardless the relevance of studying soft tissue hardness and skin temperature in patients with diabetes and their common features, the relationship between both parameters has not been investigated. Therefore, the aim of this study was to explore whether an association between skin temperature and soft tissue hardness exists in the foot of diabetic patients.

2. Methodology

This study was conducted with data from a larger prospective cohort study (ClinicalTrials.gov Identifier: NCT03254095), approved by the ethical committee of Centro Hospitalar do Porto.

2.1. Participants

Considering the association between skin temperature and soft tissue hardness reported in a conference paper by Seixas *et al* (2018b), an $\alpha = 0.05$ and a statistical power of 80%, a minimum sample size of 27 feet was required (Lachin 1981). Twenty adults with diabetes, recruited from a specialized foot surveillance centre (mean age: 67.3 years; mean BMI: 26.1 kg m^{-2}; mean diabetes duration: 17.8 years), volunteered to participate in this study. Risk categories for ulceration, according to the International Working Group on the Diabetic Foot, ranged between 1 and 3. Glycaemic control information was assessed retrieving HbA1c levels from the clinical registry of the patients (mean HbA1c: 60 mmol mol^{-1}; minimum HbA1c: 37 mmol mol^{-1}; maximum HbA1c: 104 mmol mol^{-1}). Considering that study variables are relevant at the foot level and not at the patient level, data was collected for both feet and all analysis were done at the foot level, therefore, 40 feet were analysed.

2.2. Soft tissue assessment

Soft tissue hardness (STH) was assessed in eight regions using a Shore-A PCE-DDA 10 durometer (PCE Instruments, Meschede, Germany), with a resolution of 0.1 and a repeatability $<\pm 1$ Shore units. Measurements were made at the heel (medial and lateral), midfoot (medial and lateral), first metatarsal head, between the second and third metatarsal head, between the fourth and fifth metatarsal head, and at the hallux. The durometer consists of a spring-loaded truncated cone-tipped indenter and is an instrument frequently used in research to assess soft tissue hardness in patients with diabetes (Piaggesi *et al* 1999, Periyasamy *et al* 2012a). For this assessment the patients were seated, with the knees extended and toes pointing upwards. The durometer was pressed against the surface of both feet at the selected locations. Three measurements were recorded at each location and averaged.

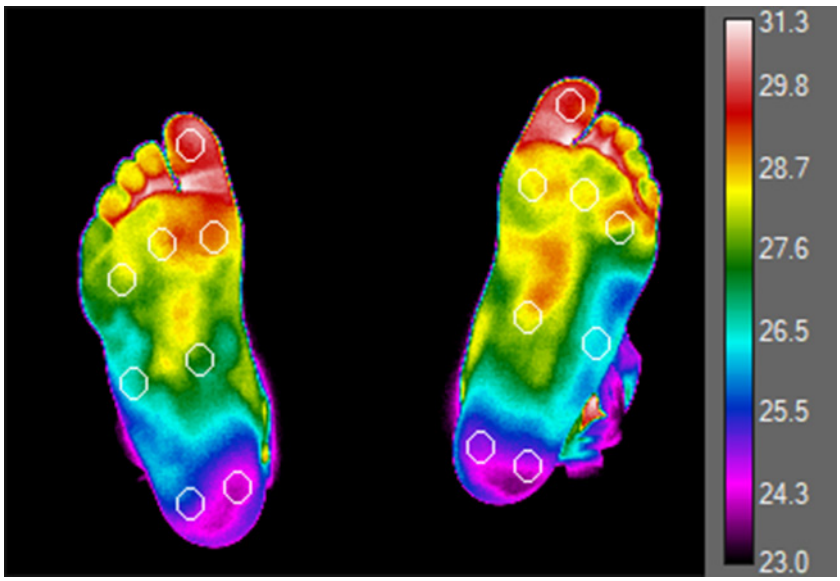

Figure 1. Regions of interest (ROI) on the foot, both for thermal and hardness assessment.

The durometer quantifies the relative degree of soft tissue hardness in Shore units (S), in a scale from 0–100 units. Soft materials, such as skin, evidence lower Shore values and hard materials evidence higher Shore values (Periyasamy *et al* 2012b).

2.3. Skin temperature assessment

Skin temperature (TSk) data was collected between 9 a.m. and 1 p.m., away from airflow and infrared radiation sources. After a 10 min acclimation period, thermal images were recorded in a room with controlled ambient temperature (23.2 °C ± 0.5 °C) and relative humidity (53.2% ± 5.1%). Plantar foot thermograms were recorded with an infrared camera FLIR E60 (FLIR Systems, Wilsonville, OR, USA) with a sensor array size of 320 × 240 and ± 2% of measurement uncertainty of the overall reading and with emissivity set to 0.98. The camera was always turned on at least 40 min before the first assessment, allowing sensor stabilization. For image acquisition, the camera was positioned perpendicular to the feet, at 1 m distance. The patients were seated, with legs supported by a chair. Patients were instructed to keep their foot in zero degrees dorsiflexion while acquiring the thermograms. All thermograms were acquired by the same researcher.

Thermal images were analysed with FLIR ResearchIR Max software (FLIR Systems, version 4.30.0.69). Circular regions of interest (ROI) were defined in the same areas where soft tissue hardness was assessed (figure 1), and mean temperature values were extracted and further analysed. The ROI were always the same, with a size of 96 pixels.

The assessment of STH and TSk was performed in the same session, with feet in the same position.

2.4. Data analysis

Data analysis was performed using Statistical Package for the Social Sciences (SPSS Statistics version 25, IBM Corp., Armonk, NY, USA). Data distribution was assessed with the Shapiro–Wilk test and through histogram visual inspection. The related samples Friedman's two-way analysis of variance test was used to compare TSk and STH between the areas of the foot and pairwise comparisons were made, adjusting the significance values using the Bonferroni correction. Non-parametric correlation (Spearman's rho) was selected to analyse the association between the measures of TSk and STH of selected regions and to analyse the association between the measurements of TSk and STH in each selected region. The areas in the heel (medial and lateral aspects), in the midfoot (medial and lateral aspects) and in the metatarsal head (1st, 2nd–3rd and 4th–5th metatarsal head) were averaged and the association between TSk and STH in these 3 regions was assessed with the same method. Confidence intervals for the correlation were obtained through a bootstrapping approach. Considering the results of the assessment of the association between TSk and STH, two multiple linear regression model (method enter) was tested, considering TSk as the dependent variable and STH, adjusting for glycaemic control as independent variables, for the region of the metatarsal head and midfoot. Glycaemic control was included in the model because sudomotor dysfunction, which is in the origin of dry skin and increased hardness, has been shown to be associated with HbA1c values (Chahal *et al* 2017). The assumptions of the models for the metatarsal head region and midfoot were assessed graphically (residual distribution and homoscedasticity) and through the Durbin–Watson statistic ($d = 1.457$ and $d = 1.781$, respectively). Multicollinearity between the

Table 1. TSk and STH values, presented as median values (interquartile range) in the regions of the foot and significance values (Friedman's test) for the comparison across regions.

Foot regions	TSk (°C)	STH (S)
Heel medial	27.8 (3.1)	12.6 (5.9)
Heel lateral	27.5 (3.0)	12.2 (6.0)
Midfoot medial	28.7 (1.3)	6.7 (4.4)
Midfoot lateral	27.1 (2.1)	12.1 (4.6)
1st metatarsal head	27.7 (3.7)	13.7 (15.6)
2nd–3rd metatarsal head	27.5 (2.3)	11.9 (4.9)
4th–5th metatarsal head	27.3 (2.8)	13.8 (7.5)
Hallux	26.0 (4.6)	6.8 (3.9)
P	<0.001	<0.001

independent variables in the metatarsal head region and midfoot was assessed through the variance inflation factor ($VIF = 1.000$ and $VIF = 1.139$, respectively). The assumptions and multicollinearity analysis have not revealed relevant issues. A post-hoc analysis has been conducted using G ∗ Power (Faul *et al* 2007) to determine the statistical power of the correlation and regression analysis. Statistical significance was admitted if $p \leqslant 0.05$.

3. Results

3.1. Skin temperature and soft tissue hardness

The results of TSk and STH measurements are presented in table 1.

The region with highest TSK was the medial aspect of the midfoot and the region with lower TSk was the hallux. TSk in the medial aspect of the midfoot was significantly higher than TSk in the hallux ($p < 0.001$), in the 4th–5th metatarsal head ($p < 0.001$), in the 1st metatarsal head ($p = 0.004$), in the lateral aspect of the midfoot ($p < 0.001$), in th medial aspect of the heel (p = 0.002) and in the lateral aspect of the heel ($p < 0.001$). TSk in the hallux was lower than TSk in the medial aspect of the heel ($p < 0.001$), in the 1st metatarsal head ($p = 0.010$), in the 2nd–3rd metatarsal head ($p < 0.001$) and the medial aspect of the midfoot ($p < 0.001$). Concerning STH, the region with highest values was the 4th–5th metatarsal head and the region with lower values was the medial aspect of the midfoot. STH in the 4th–5th metatarsal head was significantly higher than STH in the hallux ($p < 0.001$) and in the medial aspect of the midfoot ($p < 0.001$). STH in the medial aspect of the midfoot was lower than STH in the 1st metatarsal head ($p < 0.001$), in the 2nd–3rd metatarsal head ($p = 0.006$), in the 4th–5th metatarsal head ($p < 0.001$), in the lateral aspect of the midfoot ($p < 0.001$), in the lateral aspect of the heel ($p < 0.001$) and in the medial aspect of the heel ($p < 0.001$).

3.2. Association between skin temperature and soft tissue hardness

The association between TSk and HST in the selected regions of the foot is represented in table 2.

Considering TSk, a positive and significant association was observed between all the ROI. Regarding STH, significant correlations were observed between the regions in the heel and the midfoot and the other regions (with exception of the 1st metatarsal head), between the 2nd–3rd metatarsal head and the 4th–5th metatarsal head and between the hallux and the regions in the heel and midfoot.

A negative, moderate and significant correlation was observed between TSk and STH in the 1st metatarsal head region. No significant correlations were observed between TSk and STH in the other regions of the foot.

Considering the heel, midfoot and metatarsal head in the foot, after averaging the TSk and STH measurements in each region as detailed in the data analysis section, a moderate, negative and significant correlation was observed in the metatarsal head (rho $= -0.553, p < 0.001$) with 30.6% of the variance in TSk being predicted by STH, and a low positive and significant correlation was observed in the midfoot (rho $= 0.333, p = 0.036$) with 11% of the variance in TSk being predicted by STH (table 3 and figure 2).

3.3. Regression analysis

In the metatarsal head region, multiple linear regression identified STH ($\beta = -0.155$; $t = -3.868$; $p < 0.001$) as significant predictor of TSk, but not HbA1c ($\beta = 0.008$; $t = 0.056$; $p = 0.956$), therefore, HbA1c was not included in the final model. A significant regression equation was found ($F_{(1,38)} = 15.37$, $p < 0.001$), with an R^2 of 0.288 ($1 - \beta = 0.975$), explaining 28.8% of the variance of TSk. Participants predicted TSk is equal to 29.715–0.155 (STH) °C when STH is measured in Shore units.

In the midfoot region, multiple linear regression identified STH ($\beta = 0.155$; $t = 2.698$; $p < 0.001$) as significant predictor of TSk, but not HbA1c ($\beta = -0.163$; $t = -1.530$; $p = 0.134$), therefore, HbA1c was not included in the final model. A significant regression equation was found ($F_{(1,38)} = 5.151$, $p = 0.029$), with an R^2 of 0.119

Table 2. Correlation matrix for TSk and STH. Correlation between TSk and STH in each foot region in bold (diagonal), correlation between TSk in the different foot regions below the diagonal and correlation between STH in the different foot regions above the diagonal.

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
(1) Heel medial	**− 0.207**	.0.754[c]	0.454[b]	0.514[b]	0.184	0.329[a]	0.350[a]	0.368[a]
(2) Heel lateral	0.959[c]	**0.028**	0.541[c]	0.620[c]	0.091	0.341[a]	0.494[b]	0.535[b]
(3) Midfoot medial	0.699[c]	0.700[c]	**0.045**	0.376[a]	0.308	0.141	0.343[a]	0.507[b]
(4) Midfoot lateral	0.661[c]	0.672[c]	0.925[c]	**0.296**	0.115	0.236	0.310	0.577[c]
(5) 1st metatarsal head	0.529[c]	0.517[b]	0.633[c]	0.670[c]	**− 0.450**[b]	0.238	0.232	− 0.077
(6) 2nd–3rd metatarsal head	0.545[c]	0.576[c]	0.719[c]	0.805[c]	0.853[c]	**− 0.157**	0.534[b]	0.073
(7) 4th–5th metatarsal head	0.583[c]	0.615[c]	0.755[c]	0.865[c]	0.735[c]	0.905[c]	**− 0.078**	0.092
(8) Hallux	0.513[b]	0.510[b]	0.520[b]	0.536[b]	0.796[c]	0.810[c]	0.685[c]	**0.084**

[a] $p < 0.05$.
[b] $p < 0.01$.
[c] $p < 0.001$.

Table 3. Correlation between TSk and STH in the heel, midfoot and metatarsal head: correlation coefficient (Spearman's rho), 95% confidence interval (CI), significance (p), determination coefficient (rho^2) and power ($1 - \beta$).

Foot regions	Spearman's rho	95% CI	p-value	rho^2	$(1 - \beta)$
Heel	−0.192	[−0.475;0.134]	0.255	0.036	0.222
Midfoot	0.333	[0.023;0.584]	0.036[a]	0.110	0.586
Metatarsal head	−0.553	[−0.742; −0.257]	<0.001[b]	0.306	0.969

[a] $p < 0.05$.
[b] $p < 0.001$.

$(1 - \beta = 0.620)$, explaining 11.9% of the variance of TSk. Participants predicted TSk is equal to 26.944 + 0.124 (STH) °C when STH is measured in Shore units.

4. Discussion

The goal of this study was to analyse whether an association between TSk and STH is present in the foot of diabetic patients. To the best of our knowledge, this has not been reported in the literature, although the relevance of studying these variables in diabetic patients has been already demonstrated. The main finding of this research is that TSk and STH are significantly correlated in the metatarsal head region and midfoot. In the region of the metatarsal head, one of the areas at high risk to develop foot ulcers given the exposure to high pressure (Boulton 2018), TSk and STH are negatively correlated and in the midfoot TSk and STH are positively correlated.

There is a lack of research regarding the association of TSk and STH. Soft tissue hardness has been assessed in diabetic patients before (Piaggesi *et al* 1999, Thomas *et al* 2003, Periyasamy *et al* 2012b) but no association with TSk has been attempted. Ammer *et al* (2001) have assessed the association between the presence of hotspots, defined as any area at least 0.5 °C warmer than the surroundings, and callus formation and reported no significant association. However, although not significant, the association was negative in half of the analysed sites. Increased skin thickness and callus formation are not the only reasons for increased STH. Small-muscle wasting, a common feature in diabetic foot patients (Boulton 2018), is also a possible cause, leading to metatarsophalangeal joint deformity (Cheuy *et al* 2016), which increases STH measurements.

The findings of the present study suggest a negative association between TSk and STH in the metatarsal head region, with STH explaining 28.8% of the variance in TSk. It is possible that increased skin thickness, might act as an insulator, affecting heat dissipation, similarly to how fat tissue affects skin temperature (Chudecka and Lubkowska 2015). Considering that muscle activity is a source of heat output (Kuht and Farmery 2018), the small-muscle wasting in the foot, which leads to lower muscle activity, may also have contributed to lower skin temperature. Previous research has demonstrated that TSk in feet with paralysed muscles is significantly lower than TSk in the healthy contralateral limb (Zurek *et al* 2008). However, not being the focus of this study, these factors were not assessed and should be addressed in future research.

In the midfoot, the results suggest an opposite relation between TSk and STH. Although week, the correlation between these variables is positive and significant. However, the small variance of TSk explained by STH and the low statistical power in the analysis warrant further investigation. This area of the foot is less prone to STH increments and is the area of the foot with lower hardness, decreasing the eventual role of skin thickness as an insulator. Moreover, the midfoot is the area of the foot with higher TSk, being the entrance of vascular structures in the plantar foot. This conjugation of factors may be related to the differences in the association between TSk

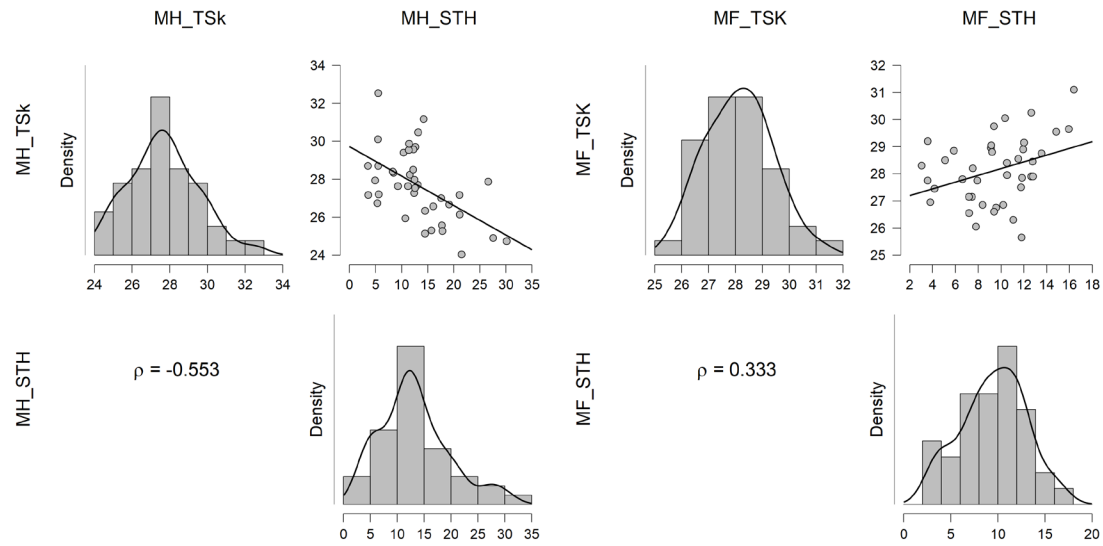

Figure 2. Correlation plots between TSk and STH in the metatarsal head and midfoot regions, and density plots for each variable.

and STH in the midfoot and in the metatarsal heads. Further research is needed to clarify these differences in the association between TSk and STH in different areas of the foot.

Regarding glycaemic control, the present results suggest the absence of association between HbA1c and TSk, however glycaemic control through HbA1c only reflects the glycaemic control over the previous three months. Sudomotor dysfunction has been shown to be associated with higher HbA1c levels (Chahal *et al* 2017) and higher TSk (Sun *et al* 2006, Papanas *et al* 2010). Sivanandam *et al* (2013), contrary to the present findings, reported a negative association between TSk and HbA1c measurements in all analysed body regions, but the feet were not included in the analysis. A recent study (Chatchawan *et al* 2018) has evidenced a positive correlation between TSk and ankle brachial index, suggesting an association between TSk and blood perfusion and Ding *et al* (2018) have reported a strong association between HbA1c and incident peripheral artery disease, which leads to a decrease in TSk (Seixas *et al* 2018a). Foot blood flow impairment can have both atherosclerotic occlusive disease affecting medium-sized arteries and microcirculatory dysfunction, which is not fully understood (Deery and Guzman 2018), affecting blood flow at the arteriolar and capillary levels (Akbari and LoGerfo 1999), contributing to lower skin temperature as disease progresses. These evidences were not supported by the results of the present study.

Few studies have reported TSk in various regions of the feet in diabetic patients, especially in the midfoot, which limits the ability to compare the present results with other studies. A recent study has reported lower TSk in the hallux than in the 1st and 5th metatarsal regions and heel (Astasio-Picado *et al* 2018), and similar TSk in the region of the metatarsal head (Astasio-Picado *et al* 2018, Silva *et al* 2018) which is in line with our findings. However, these authors have not reported the size of the ROI and considering the available information, point measurements may have been performed, which, in addition to the variability in foot temperature, could explain why temperature values are globally lower in the study of Astasio-Picado *et al* (2018) than those in the present study, and higher in the study of Silva *et al* (2018). In the present study, the medial aspect of the midfoot was the ROI with highest TSk, in line with the findings of Bharara *et al* (2014). Other authors, although only providing a qualitative analysis of thermograms (Mori *et al* 2013), also support these findings since the most frequent typologies of foot thermograms had the medial aspect of the midfoot identified as possible area of higher temperature values.

Concerning STH, previous research has reported highest STH in the region of the first metatarsal, and lowest values of STH in the region of the second metatarsal in patients with diabetes (Periyasamy *et al* 2012b). The present results are partially in line with these findings since higher STH was found in the fourth-fifth and first metatarsal heads regions but the lowest STH values were found in the medial aspect of the midfoot and hallux, which was the second area with highest STH in the study of Periyasamy *et al* (2012b). Although not the focus of this study, these differences might be related to differences in the mobility of the hallux of the assessed patients. Patients with lower mobility of the hallux will evidence higher values of STH because, during the assessment, more pressure is exerted in the indenter of the durometer. Another study has assessed STH in the heel, in the midpoint of the line connecting the centre of the heel and the base of the first toe and in the midpoint of the line connecting the centre of the heel and the base of the fifth toe, and reported the lowest values in the medial aspect of the midfoot and similar values in the heel and lateral aspect of the midfoot (Piaggesi *et al* 1999), which is in line with the present results. Considering the foot anatomy, it is expectable to find higher STH values in the metatarsal head and lower STH in the medial aspect of the foot, except in patients with foot deformities (e.g. Charcot foot).

This study has some limitations, the most important being the relatively small sample size. However, the post-hoc analysis of the statistical power gives confidence to the results. Moreover, given the exploratory nature of the study, we have not explored variables such as active ankle and hallux mobility, foot deformities and peripheral artery disease, which would provide information regarding muscle function and blood flow, possible skin temperature determinants influencing the study results. We have not assessed core temperature, mean body skin temperature, resting blood pressure or heart rate to confirm the thermal status or hemodynamic stability. We have also not assessed physical activity levels, but patient characteristics (age and risk of ulceration) suggest that this is unlikely to have influenced the study results. Moreover, not having included healthy controls, the relevance of these findings in the management of diabetic patients needs further analysis.

5. Conclusion

The findings of this exploratory study suggest a negative association between skin temperature and soft tissue hardness in the metatarsal head region and a positive association between these variables in the midfoot. Soft tissue hardness (but not glycaemic control) is a significant predictor of skin temperature in these areas of the foot. Notwithstanding the relatively small sample size, that limit the study findings to this sample only, this work offers valuable insights into the relationship between two important variables in diabetic foot research. Considering the evidence relating skin temperature to the risk of ulceration, these findings suggest that soft tissue hardness should be considered in the assessment of diabetic foot patients. Moreover, studies analysing the determinants of skin temperature should control for soft tissue hardness.

Future research should be conducted in a larger sample to confirm, or refute, these findings and to analyse additional determinants of foot skin temperature, such as active range of motion, the existence of peripheral artery disease and plantar pressure. Their role in the development of foot ulcers should also be addressed in future studies.

Disclosure statement

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