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Evaluation of the surface temperature distribution in the feet of patients with type 2 diabetes using the thermovision method

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Abstract

Introduction. Diabetic foot syndrome (DFS) is one of the most common complications of diabetes. The purpose of the study was to evaluate the distribution of superficial temperature and microcirculation in the feet of patients with type 2 diabetes.
Methods. 52 patients (the study group) with type 2 diabetes participated in the study, diagnosed by a physician while treated at "Centrum Medyczne" Provincial Specialist Healthcare Centre as part of the Diabetic Foot Syndrome Prevention Programme. The control group included 33 patients without diabetes. Superficial dorsal and plantar temperature of both feet was measured in all participants. The measurements were taken using a ThermoVision FLIR SYSTEM T335.
Results. In both study groups, the temperature of the dorsal side of the foot was higher than the temperature of the plantar side. The observed difference in the control group was clearly larger than in the group of diabetic patients, and amounted to 1.7°C and 1.0°C. In the patients with diabetes the plantar temperature was higher by an average of 2.2°C, and the dorsal temperature was higher by an average of 1.5°C compared to the control group.
Conclusions. Thermal imaging can be used as a supplement to DFS diagnostics. Recommending daily self-monitoring of surface temperature with thermography for diabetic patients can help reduce the risk of neurotrophic changes in the foot.
Key words: diabetes, thermal imaging, microcirculation, diabetic foot

Introduction

The issue and incidence of diabetes are considered a global epidemic of the 21st century. An inadequately treated, chronic pathologic process, caused by genetic and environmental factors, can lead to multiple complications, of which one of the most serious is diabetic foot syndrome (DFS) [1, 2]. It is characterised by the presence of infection, ulceration or destruction of the deep tissues of the foot, accompanied by neurological disorders. It deforms the passive motor system of the foot and causes various degrees of dysfunction of the peripheral blood vessels in the lower extremities. The key factor is uncontrolled hyperglycaemia, which causes nerve damage as well as exacerbation and acceleration of lower extremity atherosclerosis in patients with DFS [3].

The lifetime risk for developing ulceration in the distal sections of the lower extremities is 12–25% in diabetic patients, and the likelihood of amputation is 30 to 40 times higher than in non-diabetic patients. Scientific reports reveal that the diabetic foot syndrome is the most common cause of non-traumatic limb loss [3, 4].

The diagnosis of the diabetic food syndrome is an extensive process, since the causes of this condition include nerve damage, vascular damage, and mechanical trauma. Therefore, frequent and thorough monitoring of a diabetic patient's feet is extremely important. If the early symptoms are detected, such as the impaired perception of temperature or vibration and the compromised neurotrophy of the skin and blood vessels, appropriate measures can be implemented in order to prevent progression of the condition [5, 6].

Specialist examinations in the diagnosis of the diabetic foot syndrome include the neurological assessment of the perception of touch and sensations using the Semmes-Weinstein Monofilament Test, the perception of vibratory sensations using the Rydel-Seiffer tuning fork, the perception of pain (using a needle) and temperature using a thip-therm device. The neurological assessment also includes the examination of muscle reflexes using a reflex hammer. DFS diagnosis also includes the examination of the heart rate in the arteries of the lower extremities by way of determination of ABI (ankle-brachial index, which is the systolic pressure at the ankle divided by the systolic pressure at the arm) and using Doppler ultrasonography, mini-Doppler, or magnetic resonance angiography, an advanced imaging technique which allows the practitioner to examine the blood vessels and other tissues of the extremity [4, 6].

The literature on this subject mentions that the diagnosis can be complemented by a podographic analysis, which shows the areas of the foot put under the greatest pressure. Those areas are the most susceptible to ulceration. This examination allows the practitioner to precisely determine the right type of footwear and therapeutic insoles for the patient, so that the pressure placed on the foot is distributed evenly [4].

In recent years, the monitoring of diabetic foot syndrome has been complemented by thermal imaging [6]. This method

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is non-invasive for the human body and involves the imaging of physiological and metabolic changes based on the emissivity of infrared radiation of the examined area. By observing the gradient of the dynamics involved in the changes in superficial temperature, the practitioner is able to analyse the patient's microcirculation. As a result, it is possible to visualise and monitor inflammation and ischemia during the progression of a chronic condition [6–8].

The purpose of the study was to assess the applicability of thermal imaging in the diagnosis of DFS and to analyse superficial foot microcirculation in patients with type 2 diabetes in order to undertake preventive measures before neurotrophic foot lesions develop.

During the initial stages of the condition, the finer structures, such as the capillaries and thin nerve fibres, are the most susceptible to damage. As a result, the first signs of damage are very rarely noticed by the patient. The most common symptoms include occasional pain and numbness in the lower extremities, which may be easily ignored and confused with the symptoms observed after remaining seated for a long period of time or symptoms generally related to compression.

In the research project described in this article, it was assumed that the temperature of the superficial tissues relates to the lesions of the feet, their severity, inflammation, ischemia or infection. Therefore, thermal imaging can be used to detect dysfunctions at an early stage and to complement the diagnostic methods and treatment.

Subjects and methods

Study groups

A total of 52 patients (the study group) participated in the study, diagnosed by a physician as having type 2 diabetes, and treated at "Centrum Medyczne" Provincial Specialist Healthcare Centre as part of the Diabetic Foot Syndrome Prevention Programme.

The control group included 33 patients without diabetes who had a rehabilitation stay at Státní Léčebné Lázně Janské Lázně due to various dysfunctions of their motor organs, none involving the feet or ankles. Participation in the research project was voluntary and each participant gave their informed consent in writing. The characteristics of the study groups are presented in Table 1.

Research methods

Statistical analysis

The Shapiro–Wilk test was used to confirm the normality of distribution of all the variables measured. The descriptive statistics were calculated. The arithmetic mean was used as a measure of central tendency and the standard deviation was used as a measure of dispersion.

The independent samples *T*-test was used to verify the significance of the differences between the study group and the control group. The paired-samples *T*-test was used to verify the significance of the differences between the dorsal and plantar aspects of the foot. The significance of the differences between the groups for qualitative variables was verified using the chi-squared test. The analysis was carried out using Statistica 13.3 (TIBCO Software, USA).

Cohen's *d*, calculated using online statistical calculators (http://www.psychometrica.de/effect_size.html) (accessed on 2 June 2022) was used as the effect size [9]. The level of significance for all tests used was determined at $p < 0.05$.

Measurement of superficial temperature using thermal imaging

The superficial foot temperature was recorded using a ThermoVision FLIR SYSTEM T335 (FLIR SYSTEM AB, country of manufacture: Sweden) thermal imaging camera and Therma CAM Researcher Pro 2.10 software for thermal image analysis. Prior to the taking of measurements, the participants waited 10 minutes without socks or footwear in order to balance their body temperature.

The FLIR T335 has a resolution of 320 × 240 pixels and a built-in auto-calibration system, ensuring the appropriate homogeneity of the image characteristics. The system is activated 20–30 minutes before each session in order to prepare the camera for thermal imaging, ensuring the electronics do not cause fluctuations or changes in the recorded image.

The software settings are the same and each measurement session is validated before the target recording is made.

The measurements for all the participants were taken under the same conditions. The thermal images were recorded in identical research conditions, in a room with an ambient temperature of 21–22°C and relative humidity of 34–35%.

Table 1. Characteristics of the sample groups

	Study group (N = 52)		Control group (N = 33)		$p\ \chi^2$
Diabetes	YES		NO		
Sex (female/male)	34/18		23/10		0.6802
	Mean	*SD*	Mean	*SD*	*p T*-test
Age (years)	67.17	8.89	63.52	8.82	0.0688
Height (cm)	168.57	7.45	170.53	9.58	0.1870
Body weight (kg)	80.31	15.38	81.60	17.89	0.7491
BMI (kg/m²)	26.98	5.52	27.67	5.99	0.0892
Diabetes (years)	11.75	8.92	–	–	–
Skin lesions on the feet YES/NO (*n*)	45/7		–	–	–
Medications YES/NO (*n*)	52/0		–	–	–

$p < 0.05$

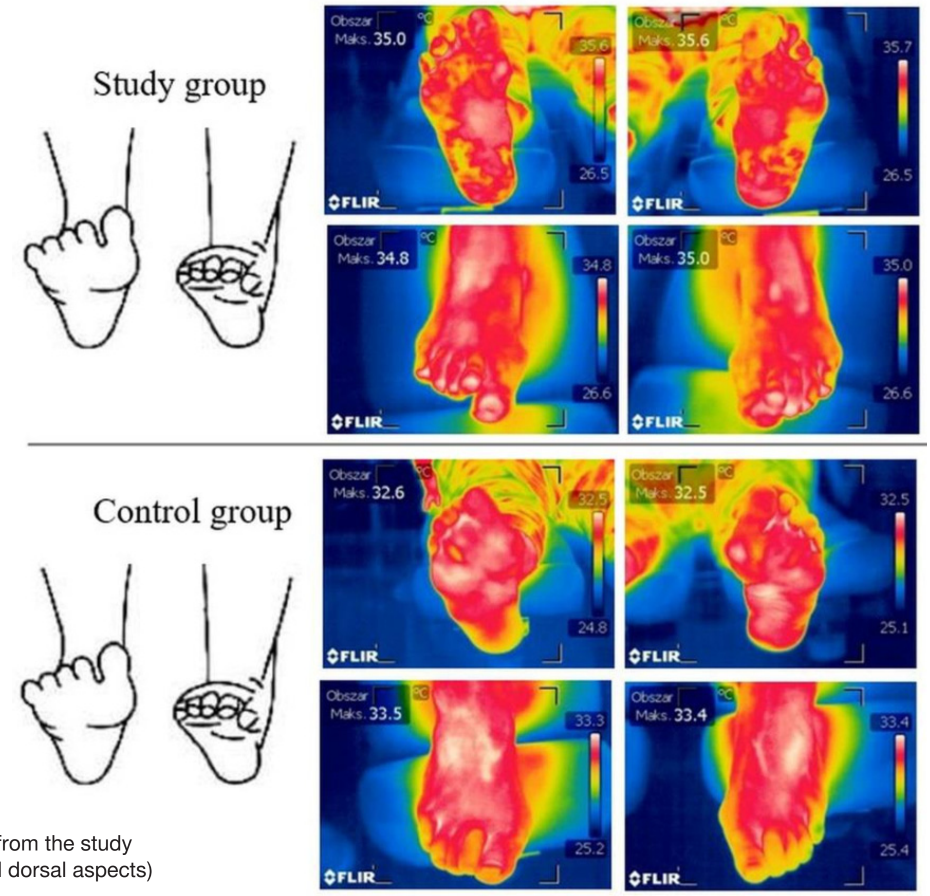

Figure 1. Foot thermograms from the study and control groups (plantar and dorsal aspects)

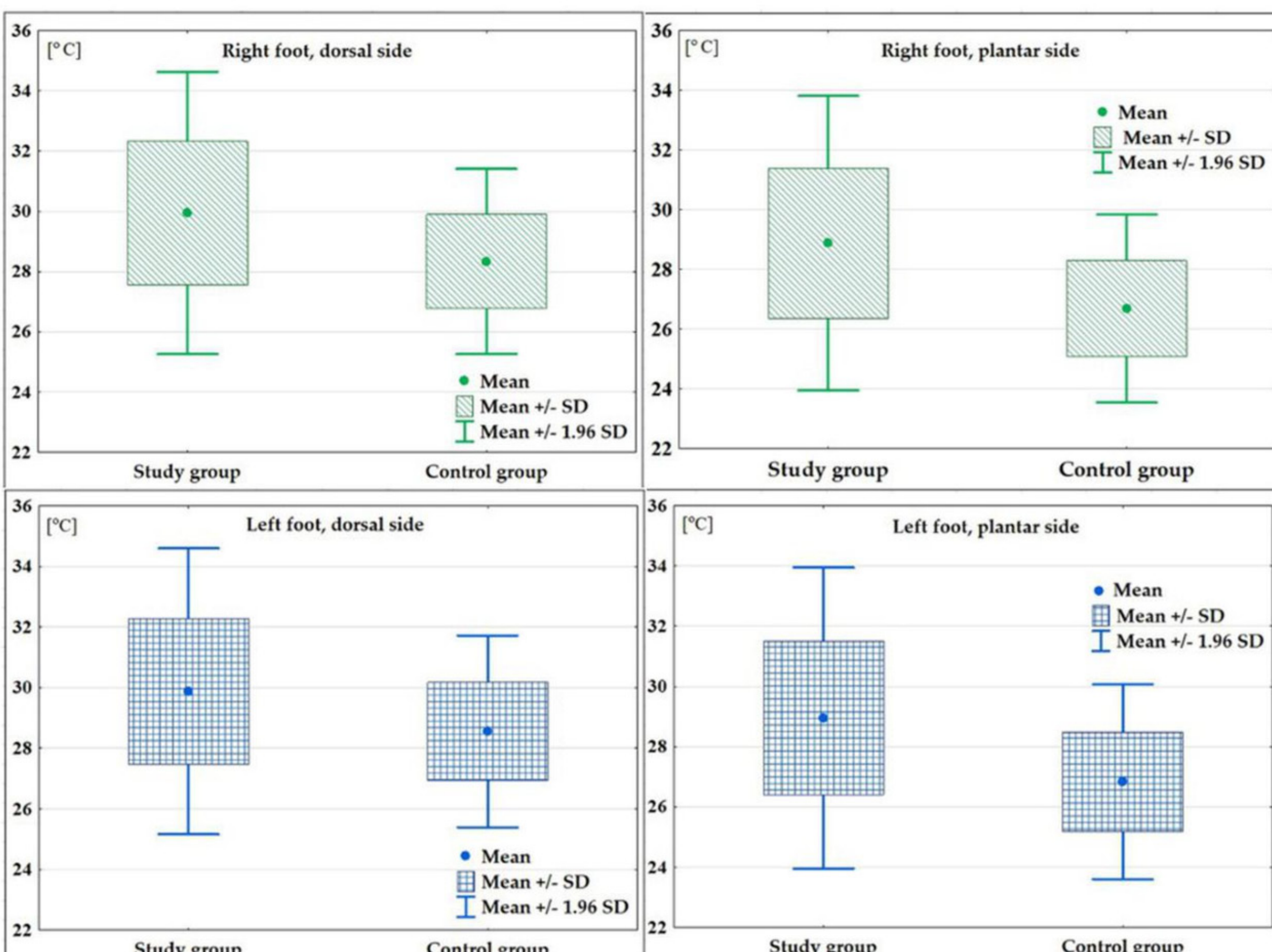

Figure 2. Average superficial temperatures of the study and control groups (plantar and dorsal aspects)

All participants were examined in the supine position. The superficial plantar and dorsal temperature of both feet was measured at a distance of 1.5 m. Each participant had four thermograms taken, which were then used to determine the average temperatures of the dorsal and plantar aspects of the right and left foot (Figure 1).

Ethical approval

The research related to human use has complied with all the relevant national regulations and institutional policies, has followed the tenets of the Declaration of Helsinki, and has been approved by the Senate Committee on Ethics of Scientific Research at the Wrocław University of Health and Sport Sciences (28 June 2007, approval No.: 3/2019).

Informed consent

Informed consent has been obtained from all individuals included in this study.

Results

The analysis of the dorsal and plantar thermograms revealed differences between the average superficial temperatures registered in the study and control groups. In both groups, the dorsal temperature was higher than the plantar temperature. The differences observed in the control group were markedly greater than in the diabetic group, and amounted to 1.7°C and 1.0°C, respectively.

While comparing the average foot temperature for the study group and the control group, it was observed that in the patients with type 2 diabetes, the plantar temperature was higher by an average of 2.2°C and the dorsal temperature was higher by an average of 1.5°C as compared to the control group (Figures 2). Furthermore, the statistical significance of all the observed differences was confirmed (Table 2).

Table 2. Statistical significance of the average differences in the average superficial temperature measured in the study and control groups

Group	Foot	*T*-test	*p*	Cohen's *d*
Dorsal vs plantar aspect				
Study group	right	13.36	< 0.0001*	0.48
	left	10.47	< 0.0001*	0.39
Control group	right	5.07	< 0.0001*	0.99
	left	4.53	0.0001*	0.98
Study group vs control group				
Plantar aspect	right	4.91	< 0.0001*	1.09
	left	4.59	< 0.0001*	1.02
Dorsal aspect	right	3.69	0.0004*	0.82
	left	2.97	0.0040*	0.66

* $p < 0.05$

Discussion

Diabetes is a social and civilization disease, and its incidence is defined as a global epidemic. The disease affects the quality of life of the patients, and their ability to function independently. The number of patients is approaching half a billion and continues to grow every year. Most cases are type 2 diabetes, which causes many long-term pathologies [1].

DFS is one of the most serious and cost-generating health issues experienced by patients with type 2 diabetes [10]. Impaired homeostasis of the entire body, caused by the etiopathogenesis of diabetes, also triggers complications in the lower extremities. Due to the spectrum of neurotrophic, circulatory, neurological and biomechanical changes in the motor system of the feet, it is necessary to implement effective measures aimed at preventing the development of DFS [11]. In the research literature, DFS prevention is based on the key elements related to the monitoring and examination of feet at risk of deficits, and the identification of the type of DFS. It is also necessary to educate the patient, their family and the multidisciplinary team, select appropriate footwear and carry out a swift treatment process in order to prevent the development of ulceration [4].

Due to the compromised immunity and limited blood supply to the skin (impaired microcirculation and peripheral circulation) in the distal sections of the lower extremities in the course of diabetes, soft tissue damage often develops, which as a result of decreased oxygenation of the tissues and the number of neutrophils promote the growth of bacteria, particularly anaerobic organisms, which in turn lead to ulceration [2, 12].

Our own research included an analysis of superficial foot temperature in patients using DFS (without visible neurotrophic skin changes), as well as of the patients with motor organ dysfunctions in order to monitor and assess microcirculatory impairment.

In the results, the analysis of the thermograms of the plantar and dorsal aspects of feet showed differences in the average superficial temperatures for both groups. Dorsal temperatures were higher than the plantar temperatures, in both the study and control groups. The differences between the aspects of the feet in the control group was markedly greater than in the group of patients with type 2 diabetes, amounting to 1.7°C and 1.0°C, respectively. In all the cases where significant difference average values of the surface temperature between the study group and the control group were demonstrated, Cohen's *d* effect size value was greater than 0.8. A value > 0.8 indicates a high correlation of results.

The difference in infrared emissivity in the examined areas of the feet may be associated with the multi-layered structure of the skin, which includes the epidermis, dermis and subcutaneous tissue [13]. The thickness of individual layers varies depending on the anatomical areas of the body. For instance, the epidermis on the eyelids is the thinnest and measures less than 0.1 mm, while the epidermis on the palms of the hands and the plantar aspect of the feet is the thickest and measures approximately 1.5 mm. Dermis is the thickest on the palmar and plantar aspects of the hands and feet, and is also 30–40 times thicker than the epidermis in the same areas [14, 15].

Higher infrared emissivity in the dorsal aspects of the feet in the control group confirms healthy microcirculation in those areas. Microcirculation consists of two vascular plexuses: superficial, located at the depth of 400–500 μm, and deep, located at the depth of 1.9 mm underneath the skin's surface. Both plexuses are connected by ascending arterioles and descending venules, with arteriovenous anastomoses between them, which are the most numerous in the fingers, nose, lips and ears. They are involved in thermoregulation by way of rapid changes in the blood flow. The majority of the microvasculature in the skin (85–90%) participates in thermoregulation; only 10–15% of those vessels are capillaries, which are responsible for delivering nutrition [16, 17].

While comparing the average superficial foot temperature recorded in the study group and the control group, it was observed that in the patients with type 2 diabetes, the plantar temperature was higher by an average of 2.2°C and the dorsal temperature was higher by an average of 1.5°C, compared to the control group. This may be a characteristic image of infrared emissivity in distal polyneuropathy with visible microcirculatory impairment. The visible difference in emissivity is caused by the dysfunction of the peripheral nerves. Damaged nerve fibres are inflamed and cannot secure an adequate reaction in the cardiovascular system. The issue consists of both the inability to accurately perceive any changes in the external conditions and the impaired control of the nervous system over the blood vessels [18, 19].

Elevated temperature in the patients at increased risk of developing DFS was observed by Armstrong et al. [20]. In this study the authors examined 225 patients with diabetes at a high risk of ulceration. They were divided into two groups. One was assigned to standard therapy (Standard Therapy Group), the other to dermal thermometry (Dermal Thermometry Group). Both groups received therapeutic footwear, diabetic foot education, regular foot care, and performed a structured foot inspection daily. Dermal Thermometry Group subjects used an infrared skin thermometer to measure temperatures on 6-foot sites, twice daily. Observed temperature differences between corresponding sites on the left and right feet triggered patients to contact the study nurse and reduce activity until the temperatures normalized [20].

Also Lavery et al. [21] demonstrated in his research that patients suffering from skin lesions were characterised by significantly higher plantar and dorsal foot temperature. The differences between the foot temperature in those patients without complications were lower by an average of 2.75°C than in the patients with complications. The incidence of neurotrophic changes depending on the patient's sex was varied (30% of male patients and only 6% of female patients suffered from ulceration or wounds); however, in all patients the examined parameter's values were elevated [21].

The general awareness of complications related to diabetes in Poland is very low. Diabetic patients have no access to equipment that would allow them to record temperature changes in their feet. Daily self-examination by the patients can significantly reduce the incidence of the DFS thanks to the use of liquid crystal thermography or infrared equipment [22].

Lavery et al. [22] in their research projects paid particular attention to prevention. Therefore, participants were recruited from among diabetic patients at high risk of DFS. Lavery et al. [22] found that the most objective examination methods which could prevent the development of skin lesions, ulceration and open wounds were thermal imaging and thermographic analyses. Together with his co-authors, he concluded that a difference in the temperature between the right and left feet of approximately 2.2°C was a warning sign and an indication of active inflammation. If ignored, it could lead to complications in the form of DFS, which means that the systematic evaluation of temperature distribution is the most effective method for mitigating the risk of adverse consequences of chronic diabetes. In their observations, Lavery et al. [22] noticed that DFS occurred in 20% of the patients who did not undergo thermographic examinations and in only 2% of the patients who were using a thermal imaging camera. The team expanded their research and launched another project, which confirmed the results obtained earlier. In 2007, they divided 173 diabetic patients into 3 groups, which differed in terms of the scope of preventive measures. The first group was required to exercise regularly; the second group was additionally required to systematically evaluate the skin of their feet visually and by palpation. The third group performed all of the above tasks, as well as recording their superficial foot temperature every day at 6 sites – great toe, heads of the 1st, 3rd and 5th metatarsal bones, metatarsus, and heel. Only 8.5% of the participants from the last group developed DFS over the course of 15 months, as compared to 29.3% of participants from the first group and 30.4% of participants from the second group [22]. These results clearly demonstrate that the use of infrared emissivity evaluation reduces the risk of DFS.

Considerable temperature variability between the feet can be interpreted as the onset of neuropathic foot ulceration. Simple measurements based on infrared emissivity can be beneficial for all patients and allow effective self-monitoring [5, 19, 20].

It has been demonstrated that DFS can be caused by peripheral neuropathy secondary to diabetes. In their study, Papanas et al. [23] analysed superficial foot temperatures in diabetic patients. The participants were divided into 2 groups of 30 members, the majority of whom (55%) were male. The differentiating factor was the diagnosis of neuropathy. Temperature was measured using an infrared thermometer. Dorsal and plantar temperature measurements demonstrated statistically significant differences, amounting to 1°C on average. The group of patients with peripheral neuropathy were characterised by a higher foot temperature than the group of patients without neuropathic lesions. This confirms that it is necessary to implement preventive measures at earlier stages of potential complications, not only in order to prevent ulceration, but also to protect the patients against progressive neuropathic or ischemic changes [23].

In the DFS, thermal imaging can be successfully used to evaluate the healing process of wounds and ulcers. High sensitivity of the built-in detector allows the visualisation of very subtle vascular and neurological changes in the lower extremities long before the development of symptoms perceived by the patient [19, 24, 25].

It is necessary to implement broader preventive measures aimed at improving the quality of life of diabetic patients. The use of multiple objective diagnostic methods, including thermal imaging, can reduce the risk for dangerous micro- and macroangiopathies. The search for more factors which affect the incidence of the DFS should be the basis for further research into the preventive measures in this case.

Conclusions

Increases in the superficial foot temperature in patients with type 2 diabetes may be a sign of impaired microcirculation in the dorsal and plantar aspects of the feet.

Thermal imaging can be used to complement the diagnostics of DFS.

Recommending thermography to diabetic patients can help mitigate the risk for neurotrophic foot lesions.

The study was conducted among patients with type 2 diabetes, who have not developed any neurotrophic foot lesions. Further continuous research among patients at various stages of the condition should provide information on the dynamics of superficial temperature changes depending on the phase of the illness. During the treatment and physiotherapeutic management, the use of thermal imaging can create the basis for the analysis of the body's response to the stimuli used and the effectiveness of the therapy.

Bulleted novelty statement

The paper presents the application of the thermographic imaging method, which is helpful in complementing the diagnosis of patients with type II diabetes. This should allow for non-invasive monitoring of disease complications using the thermal imaging method. There are many diagnostic methods that allow the detection of various factors of tissue trophic disorders, foot ulceration, bone inflammatory processes, polyneurarthropathy or soft tissue ischemia, but the use of thermovision recording can help patients in the prediction, prevention and faster response to the treatment processes.

Disclosure statement

No author has any financial interest or received any financial benefit from this research.

Conflict of interest

The authors state no conflict of interest.

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