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Original Research Article

The influence of ambient temperature on foot temperature in patients with diabetic foot ulceration

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ABSTRACT

Background: Patients with diabetic neuropathy exhibit a higher foot temperature than those without neuropathy and they are at risk for foot ulceration. Ambient temperature and foot ulceration additionally influence foot temperature in such patients. The aim of the study was to assess the influence of ambient temperature on foot temperature in patients with an ulcer on one of the feet.

Methods: Miniature temperature data loggers were used for the monitoring of foot skin and ambient temperature. Twenty patients with diabetic neuropathy and ten healthy subjects were monitored for about 24 h each.

Results: The temperature of the foot with an ulcer correlates significantly with ambient temperature, with the slope of the regression line of 0.09. The temperature of the non-ulcerated foot also correlates significantly with ambient temperature, with the slope of 0.31, however the correlation coefficient and the slope are significantly higher than in the case of the foot with an ulcer. The difference of temperature of the foot with an ulcer and temperature of the foot without an ulcer correlates well with ambient temperature with the slope of −0.219. The temperatures of left and right feet were studied as a function of ambient temperature in healthy individuals and there were no statistically significant differences between correlation coefficients and slopes.

Conclusions: It is apparent that ambient temperature influences foot temperature even during foot ulceration. Thus ambient temperature should be taken into consideration in any application when foot temperatures are important, especially in the prediction of diabetic foot ulceration.

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1. Background

Uncontrolled diabetes with high blood glucose levels causes pathology in the microcirculation [1]. The nerve tissue is very sensitive to the insufficient blood supply and that leads to its degradation. Damage begins in small fibers and the first symptoms may be such as a loss of pain and temperature sensing and impaired sudomotor function, resulting in the diminished sweating of the foot [2,3]. Patients with a nerve dysfunction in the foot (peripheral neuropathy) exhibit a higher foot skin temperature than those with diabetes only [4,5], and it was shown that the higher the ambient temperature, the higher the foot skin temperature, too [6,7]. That means that body thermoregulation exists in patients with diabetes and neuropathy, although the foot temperature is higher in those who have neuropathy than in those without neuropathy. Diabetic neuropathy is very common in type 2 diabetes (even more than 50% of cases) and it is thought to be the main risk factor for developing foot ulcers. Up to 15% of diabetic ulcers lead to lower-limb amputation [8]. The presence of an ulcer on the foot increases foot temperature, but whether such a foot remains sensitive to the changes in ambient temperature has not been, to the authors' knowledge, studied before.

There are a few methods of skin temperature monitoring in ambulatory subjects [8]. For the continuous or semi-continuous skin temperature monitoring the most appropriate tools are the systems with a miniature data logger placed on the subject's body and storing the measured temperature with the measurement date and time. Kang et al. [6] used a temperature measurement system with thermocouples connected to a data logger via wires. The data logger was relatively large and the thermocouple wire connection failed sometimes. More advanced temperature measurement systems based on a DS1921 Thermochron iButton temperature data logger were used later [9]. Such a system was small and could be placed on the skin on the measurement site. Recently, a temperature data logger based on an ultra-low-power microcontroller (MSP430F149, Texas Instruments Inc., USA) was used for skin temperature monitoring [10,11]. Its advantages over the Thermochron iButton data logger are the wireless communication with the computer, a larger memory and its being waterproof. Such temperature data loggers (sensors) were used in the current study.

The aim of the current study was to evaluate the influence of ambient temperature on foot skin temperature in patients with a foot ulcer on one of the feet.

2. Materials and methods

2.1. *Temperature sensors*

The temperature sensor is based on an ultra-low-power microcontroller [12] with a wireless RFID (Radio Frequency IDentification) interface. The sensor may store 57 thousand measurement data pieces that can be downloaded to a PC. Before application in foot temperature measurements, the temperature sensors were encapsulated with epoxy resin to secure them from the environmental conditions and to protect the human skin from possible injuries that could be caused by the sharp edges of the mechanical parts and electronic components of a sensor (Fig. 1). The thickness and the diameter of the sensors after encapsulation were 6.0 ± 0.5 mm and 15.0 ± 0.5 mm, respectively. All the sensors were programmed to perform temperature measurements in the period of 5 min and at the beginning they were calibrated in a water bath. The temperature registered by a sensor was compared with the temperature in the water bath at 5 temperature points within the range from 22.5 to 39.2 °C. When the temperature in the water bath was plot, as a function of the temperature registered by the sensor, it was possible to determine the calibration equation for each sensor and the temperatures registered by the sensor could be recalculated for true temperatures. A strong linear relationship with the Pearson's correlation coefficient equal to 0.9998 or greater was found for all sensors. The resolution of the temperature measurement by the sensor was about 0.2 °C. The temperature in the water bath was measured using a calibrated and certified mercury thermometer. The calibration procedure is necessary to be performed only once for a sensor.

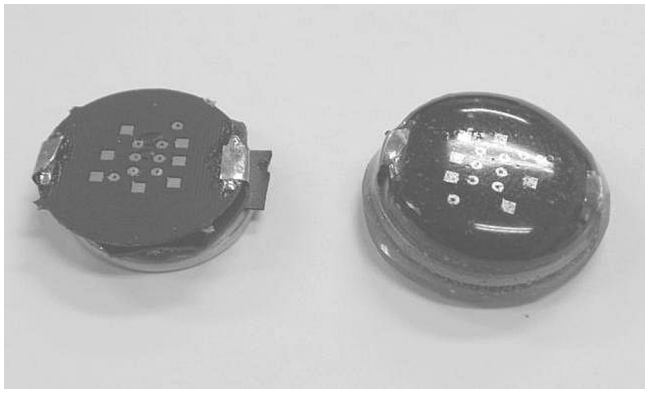

Fig. 1 – The temperature sensor before (left) and after (right) encapsulation.

2.2. *Subjects*

The study group consisted of 20 patients (9 women and 11 men) from outpatient and inpatient clinics. There were 16 patients with diabetes type 2 and four with type 1. The mean age of the patients and the mean diabetes duration were 56.4 ± 6.9 and 16.6 ± 12.9 years, respectively. Each patient had foot neuropathy and an ulcer on one foot. Neuropathy was diagnosed using monofilament and a tuning fork. The presence of ulcers on both feet was the exclusion criterion for a patient. The etiology of foot ulcers was neuropathic in the character in 50% of patients and neuro-ischemic in the remaining 50%. Most of the foot ulcers ($n = 17$) caused an inflammation state with a necessity of antibiotic treatment, but in the case of 3 patients (6%) inflammation was not diagnosed. The dimensions of foot ulcers ranged from 0.5 cm × 0.3 cm to 6.7 cm × 3.5 cm (maximal length and perpendicular maximal width) and the phases of foot ulcers healing were diverse.