Continuous Monitoring of Feet Temperature Using a Data Logger with Wireless Communication

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The aim of the present study was to verify a system for continuous monitoring of feet temperature. The temperature measurement system developed in cooperation of the Center for Biomedical Technology (Krems, Austria) and Digilog Inc. (Perg, Austria) company was used for monitoring of the skin temperature on foot. The temperature monitoring devices are wirelessly controlled and they could be encapsulated in order to achieve waterproofing and facilitate disinfection with liquid disinfectant. The skin temperature measurements were performed every 1 or 5 minutes. Two healthy subjects were monitored for 7–9 days. The preliminary system application showed its usefulness in continuous temperature monitoring of feet.

Keywords: continuous temperature monitoring, foot temperature

1. Introduction

Neuropathy, retinopathy, arteriosclerosis, and nephropathy are complications of a chronic disease called diabetes. Peripheral neuropathy and arteriosclerosis are responsible for development the diabetic foot syndrome (DFS), in which slow-healing wounds at feet and tissues destruction are very common. The DFS patients may need hospitalization and good medical care extended to their homes [1, 2]. Neuropathy influence the thermoregulation of the lower extremity and therefore diabetic patients with feet neuropathy have higher temperature of foot compared to temperature of foot.
in individuals without neuropathy [3, 4]. Monitoring of the foot skin temperature in diabetics may be a useful tool for preventing foot ulceration [5, 6] that in serious cases may result in foot amputation. Kang et al. [7] showed that the higher the ambient temperature the higher is foot temperature in diabetic patient with feet neuropathy.

There are some methods of temperature monitoring in diabetic patients [8]. Infrared thermometry and liquid crystal thermography are used in this field the most frequently. There are also methods based on thermocouples [9], semiconductor devices [8], and infrared thermography [10]. Continuous temperature measurement of feet and ambient temperature is a very useful tool in thermoregulation studies of the lower extremity. A system with data logger and ability of registering ambient and skin temperature based on thermocouple was showed by Kang et al. [7], but much more comfortable system was used by Rutkove et al. [9] based on a DS1921 Thermochron iButton temperature datalogger (Maxim Integrated Products, Inc., USA). The device is able to store 2048 temperature measurements and is based on the 1-Wire interface and therefore it is not submersible and its disinfection should be done with caution.

The goal of our study was to evaluate a novel temperature measurement and registration system in the monitoring of foot skin temperature.

2. Materials and Methods

The temperature measurement system [11] developed in cooperation of the Center for Biomedical Technology (Krems, Austria) and Digilog Inc, (Perg, Austria) company was used for monitoring the skin temperature on feet. One part of the system is a measurement device based on the ultra-low-power microcontroller (MSP430F149, Texas Instruments Inc, USA) and the RFID (Radio Frequency IDentification) interface. Another part of the system is a base station connected to a computer (PC). The temperature measurement by the microcontroller (μC) is based on the measurement of voltage drop over a silicone diode integrated in the μC. The μC is able to store about 57 thousand measurement data that can be downloaded to the PC via the wireless RFID interface. The temperature measurements are performed by the μC in the period programmed during sensor activation, and it was 1 minute in case of patients 1, 2, 3 and 5 minutes in the healthy subjects and patients 4 and 5. The battery capacity enables active state of a device for 2–3 years.

The electronics and the battery of the measurement device were encapsulated in order to secure them from the environmental conditions and to protect the human skin from injury caused by sharp edges of the printed circuit board and the electronic components. Two-component epoxy resin (Libella Sp. z o.o., Poland) was used as the encapsulation material. Dimensions of the encapsulated sensor were: thickness 6.0±0.5 mm, and diameter 15.0±0.5 mm.

The temperature sensors were calibrated in a water bath at the temperatures: 27.8±0.1, 29.9±0.1, 31.9±0.1, 34.0±0.1, 36.0±0.1°C. Temperature in the water
bath was measured using a calibrated and certified mercury thermometer. Constant
temperature of the water bath at each level was maintained for at least 30 minutes.
When the temperature in the water bath was plotted as the function of mean temperature
registered by the sensor, it was possible to determine the calibration equation for the
sensor. A linear relationship was found for the sensors and the registered temperature
could be recalculated to the true temperatures.

The sensor activation and memory readout was possible using a USB base station
and Dentagent software. Both were developed by the Centre of Biomedical Tech-
nology, Danube University, Krems and Digilog Inc., Perg, Austria. The base station
powered from the computer USB port and equipped with a RFID antenna enables
wireless communication from the PC to the sensor µC. During the sensor activation
the software starts the sensor software for the temperature measurements and sets
the interval between the measurements and current date and time as well. From that
moment the sensor performs the temperature measurements until full memory. It is
possible to download the measurement data stored in the sensor memory at any time
after the sensor activation and even after filling up the sensor memory and cessation
of the temperature measurements.

The temperature measurements were performed on two healthy males aged 45
and 46 years. Two sensors were used on both feet. They were attached to an adhesive
dressing with double-sided tape and then placed at the dorsal part of the foot. The
place of sensor attachment was above the shoe level (Fig. 1), so the sensors were
neither pressed nor covered by the shoe material. The subjects were wearing socks all
the time during the trial, except the time of taking a shower or a bath. The sensors
were also removed for that moment, and the temperature measurements from that
time were deleted from the data set. The skin areas which were in contact with the
sensor were checked for signs of the skin irritation. The temperature registration,
in case of the healthy subjects, was during their usual daily activities in the winter period with outside temperature varied from –12 to 10°C, unfortunately the ambient temperature was not registered.

3. Results

The first healthy subject was monitored for 9 days and the second one – for 7 days. The feet temperatures registered on the healthy volunteer is shown in Fig. 2.

Figure 3 shows the mean temperature differences between feet registered healthy subjects in 1-hour periods of a day starting from 0:00. The temperature data were averaged for all days of the monitoring.

The skin observation for irritation due to contact with the sensor encapsulation material gave negative result.

![Fig. 2. The feet temperatures registered in 46-year healthy male subject. Grey area between two graphs underline the temperature difference between feet](image)

![Fig. 3. Temperature difference of feet in two subjects](image)
4. Discussion

The system for foot temperature monitoring based on Thermochron iButton temperature monitors used by Rutkove et al. [9] is similar to that used in our research. The main difference concerns the way of communication with the sensor. In case of our sensors the communication is wireless. Thermochron needs an electrical contact to communicate and therefore it cannot be permanently encapsulated. When a waterproof capsule (DS9107) for Thermochron is used, the dimensions of the entire device rise to 25mm of diameter and 16mm of thickness. Thermochron is able to store 2048 temperature measurements whereas our device has about 27-fold larger memory. Our sensors need calibration prior the measurements, but the calibration procedure is not complicated and can be done in a few hours using a water bath. Measurement data need to be recalculated using the equation received during calibration.

The large temperature changes (28–36°C) in the healthy subject (Fig. 2) may result from large differences in ambient temperature: room temperature was 22–25 °C, whereas mean outside temperature was –0.6°C in region where subjects lived (data from Institute of Meteorology and Water Management, Warsaw, Poland). The temperatures of left and right foot did not differ very much and its maximal mean value was 1.42 ±0.93°C. This result was achieved in the time between 2:00 and 3:00 in the night during sleep and may be associated with one foot not covered by a blanket. Kang et al. [7] showed foot temperature in healthy subjects to be independent of ambient temperature, however, the range of ambient temperature was 12–34°C in their study.

Strong point of the presented system for temperature measurement is the wireless communication with the sensors and therefore possibility of the hermetic sensor encapsulation as well as large data memory enabling the run of a sensor for 6 months if the period between readings is 5 minutes. Another advantage of the system is lack of skin irritation by the epoxy resin used for encapsulation. The developed system for skin temperature monitoring seems to be promising in medical applications.

5. Conclusion

The feasibility study of the system of temperature monitoring based on the datalogger with wireless communication revealed its usefulness in skin temperature monitoring in humans.

References


