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Body Core Temperature Sensing: Challenges and new Sensor Technologies

Marc-Florian Uth*, Jochim Koch, Frank Sattler

Technology & IP, Drägerwerk AG & Co. KGaA, 23558 Lübeck, Germany

Abstract

Core temperature measurements have gained a growing interest as the development of this value can be used to estimate the mental and physical performance of workers or athletes. It can also be used to plan the application of warming of perioperative patients to reduce risks during or due to surgery. While invasiveness and accuracy was correlated up to know, several sensor principles are known today, that can measure with the sensor attached to the skin. Some of these are presented here, while for one solution, the results of clinical studies are presented that prove the competitiveness with invasive methods of this sensor. Offering a simple method for core temperature sensing could increase the acceptance to monitor this and achieve the mentioned effects.

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Keywords: Core temperature; heat-flux; perioperative; neonates

1. Introduction

The temperature distribution in a human body can reach broad ranges. While local peripheral skin temperatures can be close to 0° Celsius in extreme conditions, the human's thermoregulation system manages to keep its core temperature at the nominal value of around 37°C. The core comprises all inner organs of the corpus and the brain, where a narrow temperature range has to be maintained to reach a maximum efficiency of the body and to optimize the supply of all organs, respectively. While peripheral temperatures are tolerated in a broad range of temperatures, the body reacts to deviations of the core temperature heavily. An increased core temperature leads to a strong decrease

* Corresponding author. Tel.: +49-451-882-6843
E-mail address: marc-florian.uth@draeger.com

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in mental and physical performance. This is the case, when athletes are performing in hot weather or when workers are dressed with protective clothing, which inhibits the natural cooling mechanisms of the human body. Especially the effect of evaporation, which is the most effective one, is nearly decreased to zero, because the humidity in the protective suit rapidly reaches values near 100%.

On the other hand, a decreased core temperature (Hypothermia) can lead to impaired consciousness or in extreme cases to circulatory collapse. Corresponding mechanisms like vasoconstriction or shivering can reduce Hypothermia up to a certain level. In perioperative conditions, these mechanisms are weakened resulting in drop in core temperature. Studies have shown that this leads to an increased risk of prolonged hospital stay and impedes wound healing postoperatively [1–3].

Thus, the monitoring and control of the core temperature in such situations can lead to a better performance of workers or, in perioperative conditions, an increased outcome for patients. However, the reason why this is used very rarely, can be found in the very complex application of measurement techniques with high accuracy. Most of them have a high level of invasiveness, such as a measurement in the arteria pulmonalis or the esophagus. Other more commonly known means, like axillar, sublingual or tympanic measurements do not reach the desired accuracy and reliability.

In this paper we will show new non-invasive sensor technologies and their principles that combine with a high accuracy, amongst which the Double-Sensor (Dräger Tcore) has shown to be one of the best.

Nomenclature

SD	Standard deviation	k_T	heat-transfer coefficient of the tissue
CCC	Concordance correlation coefficient	T_C	Core temperature
r	correlation coefficient	BMI	Body Mass Index

2. Non-Invasive Core temperature sensor technologies

2.1. Heart Rate Variability

The first sensor suitable for core temperature determination does not measure any temperatures at all. In a recent publication [4] an algorithm is presented that estimates the current core temperature from non-invasive heart rate measurements for first responders in protective suits. For this method it could be shown, that the observed bias and variance are on the same level as oesophageal and rectal measurements. The used equations in this study were presented in [5]. There data from ten studies with a total of 100 testimonials were compared and good agreement to reference temperatures were shown. The good results were achieved in different environmental conditions. A closer look on the candidates in the studies shows that only young and well-trained persons with a similar fitness level were investigated. It is still an open question, if the algorithm also works for a broader range of people. Thus, this technique can not be seen as ready for a general use for fire fighter because it is not proven in a broader range of applications.

2.2. Zero-Heat-flux thermometry

Another idea to measure core temperature is based on the principle, that an actively heated sensor, that is attached to the skin will adopt the core temperature, if the heating is controlled in such a way that the heat-flux inside the sensor is zero (see Figure 1 middle). Tests with such a core temperature thermometer were already done in the seventies [6]. A commercial thermometer for perioperative applications is available. As muscles or even fat produce heat themselves, such a thermometer can only be applied at spots where only little of such tissue is located between the sensor and the core to be measured. At the human body such a spot can be found at the forehead which is a suitable position for perioperative applications. The advantage of this principle is that no information about the heat transfer properties of the underlying tissue must be known. However, it does not work for higher environmental temperatures near the core temperature level or above. Additionally there is no experience with such a device when attached for longer time. Especially for neonates with very sensitive skin a heated sensor could become a problem.