USE OF THERMAL IMAGING IN THE EVALUATION OF BODY SURFACE TEMPERATURE IN VARIOUS PHYSIOLOGICAL STATES IN PATIENTS WITH DIFFERENT BODY COMPOSITIONS AND VARYING LEVELS OF PHYSICAL ACTIVITY

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Abstract. This is a review of thermal imaging methods used for the measurement of body surface temperatures, including the most important medical applications, papers on thermal maps of people with various body compositions, and the applicability of thermal imaging in sport training.

Key words: thermal imaging, body composition, physical activity

Temperature inside and on the surface of the human body

Physiologically, homeothermia in the human body relates solely to body cavities and blood. Skin and extremities are poikilothermic (Rajewski et al. 2001). Therefore, human body can be divided into the homeothermic core and heterothermic shell. The average temperature inside the body is 37°C and 33°C on the surface (depending on individual characteristics), and it is a function of the temperature of an internal organ and the thermal properties of the tissues that separate the organ from body surface. For instance, the content of fat and muscle tissue, as well as the volume of the blood flow and its temperature, skin moisture and amount of energy produced in homeostatically regulated metabolic processes (Aarts 1975; Broniarczyk-Dyla 1974; Kuzariski 1993; Davidovits 2001).

Individual human tissues and organs differ in their temperature. The highest temperature can be found in the heart, liver and brown adipose tissue. The most constant temperature prevails in the right ventricle of the heart and in the brain. In certain thermal conditions, the temperature inside the body may exceed the temperature of the surface of the skin by up to 20°C; a difference of 4°C is usually considered normal (Kozlowski and Nazar 1999).
The thermoregulatory mechanism is based on the mutual feedback between body temperature and the reactions that modify the production and removal of heat. The heat balance of the body is maintained by thermogenic and thermolytic reactions.

The use of thermal imaging in research

Thermal imaging is a technique capable to map the temperature distribution on the human skin. In healthy subjects, skin temperature is highly symmetrically distributed, related to the symmetry axis situated in the median plane of the human body. It is assumed that the temperature difference between symmetrical areas should not exceed 0.5°C (Freitas 1999).

The visualization of temperature distribution on the surface of the human body can provide valuable diagnostic information, and is mostly a reflection of the processes inside the body. Altered temperature is often the first sign of tissue lesions, before structural or functional changes can be observed.

Any disturbance of normal temperature patterns may be detected either as a hyperthermic or hypothermic area. Hyperthermic areas within medical thermal images may be caused by inflammation, increased blood flow, growing tumor, or other tissue lesions. They may also result from heat generation induced by muscle contraction during physical effort, or ambient temperature being higher than the thermal comfort limits. Hypothermic skin changes may be caused by decreased blood flow, loss of muscle contraction, sympathetic hyperactivity induced by partial nerve lesion, lymphedema or low ambient temperature. Owing to the aforementioned regularities, thermal imaging has numerous medical applications presented in many reviews (Ring and Ammer 2012; Jiang et al. 2005; Anbar 1990; Plassmann et al. 2006; Ring 1984; Ring 1990; Merla and Romani 2007; Merla and Romani 2005; Merla and Romani 2006; Mikulska 2006; Jones 1998; Bronzino and Diakides 2007).

In the available literature, there are few studies on the thermal maps of the body surface of healthy people and the range of normal temperatures, based on a representative sample of population. However, such studies could be used as a handy reference in medical and physiological diagnostics. Based on previous studies carried out on small groups of subjects, it is known that in the extremities, higher temperatures are normally observed at the proximal end of the limb rather than on the tips of fingers or toes (Ammer et al. 2002). Given that the range of these temperatures varies with age, the body surface temperature of the elderly is slightly lower, particularly in the distal parts of the body (Niu et al. 2001; Arens and Zhang 2006; Uematsu et al. 1988; Ammer et al. 2002; Du Bois 1951; Dębiec-Bąk and Skrzek 2012). This area of research needs to be completed, and the healthy body thermal map of men and women of normal weight created, taking factors such as age into account.

Another group of studies concerns the body surface temperature of people with various body compositions, especially obese individuals, in which the processes of heat exchange with the environment may be affected by a considerable thickness of fat – an insulator that impedes heat transfer to the surface.

With obesity, weight increases without a proportional increase in height, resulting in a lower ratio of surface area to body mass (Verbraecken et al. 2006) and, because cutaneous heat loss is relatively proportional to skin surface area (Sessler et al. 1991), obese individuals may lose their metabolic heat more slowly than those with normal body weight (Kurz et al. 1995). Thus, obesity itself reduces the ratio of heat loss to heat production and should lead to the retention of body heat. However, because the core temperature in obese individuals is homeostatically regulated, thermoregulatory reflexes must compensate and be biased toward heat dissipation in those with excessive adiposity. Several physiological changes that accompany the development of obesity tend...
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...to increase heat production or impede heat loss. First, resting metabolic heat production is significantly greater in obese than in lean individuals. This greater heat production is primarily due to the larger fat-free mass (FFM), i.e. muscle, that accompanies excessive adiposity. Second, adipose tissue, because of its reduced thermal conductivity and increased insulator capacity, provides an insulating barrier to conductive heat flow and reduces the body’s ability to respond to changes in the core temperature (Havenith 2001; Landsberg et al. 2009; Landsberg 2012; Hoffmann et al. 2012; Heikens et al. 2011; Savastano et al. 2009).

The surface temperature distribution in significantly malnourished individuals or people with eating disorders, such as anorexia nervosa or bulimia, is little known, but could provide additional valuable diagnostic information. Somatic symptoms of anorexia are the result of starvation, during which the body adapts to the reduced quantity of nutrients and dehydration, using reserves and slowing down metabolic processes and leaving the body in a state of hypothermia (body temperature remaining at a level below 36°C). The hypothermia among anorexics is also influenced by hormonal imbalance (in particular the reduction in the level of thyroid hormones), the disorder of the circulatory system, the heart rate (reduced blood flow, circulation problems especially in the distal parts of the body, bradycardia, low blood pressure), a significant loss of body fat that serves as an insulator in the body, and muscle (heat generator due to the contraction of muscles) (Smith et al. 1983; Wakeling and Russell 1970; Faje and Kilbanski 2012; Luck and Wakeling 1980; Bock 1993).

The use of thermal imaging in physical activity and sport

In competitive sports, scientists are looking for new research and diagnostic methods, particularly non-invasive ones, that could help achieve higher training efficiency and success in sport. Among other things, physical fitness and adaptation to exercise depends on efficient thermoregulation, which, as shown by Afanacewa et al. (1985), can be evaluated based not only on the temperature inside the body, but also surface temperatures. Thermal imaging provides a quantitative and therefore objective assessment of changes in the surface temperature of the body, and may give an insight into factors affecting the removal of endogenous heat during exercise. For example, thanks to thermal imaging, it is known that the surface temperature of the body during physical activity increases, and stabilizes at a level higher in proportion to the intensity of exercise (Smorawiński et al. 1990; Coh and Sirok 2007). Pascoe et al. (2002) argues that the use of thermal imaging to monitor skin temperature, which is crucial for the control of heat dissipation, will allow for a better understanding of thermoregulation. It is also known that the effective removal of heat, generated during exercise, is influenced by physiological and morphological factors. (Chudecka et al. 2008; Chudecka and Lubkowska 2010; Chudecka et al. 2010; Chudecka and Lubkowska 2011; Chudecka and Lubkowska 2012).

Thermal imaging method can therefore be used as a tool for coaches to evaluate the dynamics of the body surface temperature of athletes, thereby monitoring the efficiency of thermoregulation. Any form of physical activity increases the metabolism, speeds up the delivery of oxygen through increased blood flow, and leads to an increase in body temperature due to the heat generation by the working muscles. An important physiological advantage of training, especially in competitive sports, is an increase in the ability to remove heat from the body (acceleration of response and dynamics of perspiration, and reducing the internal temperature increase), which allows the continuation of effort. Changes in the body surface temperature may therefore indicate the loading of the locomotor system, provide information on the efficiency of endogenous heat removal systems during exercise and metabolic changes associated with the return to homeostasis after exercise, and hence the usefulness of thermal imaging as a method of monitoring these phenomena.
References


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