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

Monika Chudecka

Department of Human Functional Anatomy and Biometry, Institute of Physical Culture and Health Promotion of Szczecin University

Address for correspondence:
Monika Chudecka
Department of Human Functional Anatomy and Biometry,
Institute of Physical Culture and Health Promotion of Szczecin University,
al. Piastow 40b, 71-065 Szczecin, Poland
E-mail: monikachudecka@wp.pl

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; Kuzański 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 (Kozłowski 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 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 Klibanski 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

Aarts N. Presidential address: First European Congress on Thermography. Bibl. Radiol., Basel 1975; 6.

Afanaceva R., Basargina L., Załugujewa O. Estimation average temperature of human body during physical effort. Gig. Sanitaria. 1985; 9: 32–35.

Ammer K., Ring E. The Thermal Image in Medicine and Biology, Wien: Uhlen 2002.

Ammer K., Ring E., Plassman P., Jones B. A database of normal thermal images of healthy subjects (abstract). Thermol. intern. 2002; 12: 77.

Anbar M. Recent technological developments in thermology and their impact on clinical applications Biomed. Thermol. 1990; 10: 270–276.

Anwajler J., Dudek K. Evaluation of activity of a chosen group of muscles on the basis of temperature changes on the skin's surface. Inżyn. Biomed. 2009; 15: 20–22.

Arens E., Zhang H. The Skin's Role in Human Thermoregulation and Comfort . University of California, Berkeley 2006.

Bock L. Body temperature in persons with anorexia nervosa. J Am Diet Assoc. 1993, 93 (9): 976–979.

Broniarczyk-Dyla G. Several Remarks on Skin Thermometry. Dermatol Rev. 1974, 61: 89–93.

Bronzino, J., Diakides, N. Medical Infrared Imaging. Boca Raton, FL: CRC Press 2007.

Chudecka M., Lubkowska A. Evaluation of the body surface temperature changes in the basketball players' after training. Inż. Biomed. 2011; 17 (4): 271–274.

Chudecka M., Lubkowska A. Temperature changes of selected body's surfaces of handball players in the course of training estimated by thermovision, and the study of the impact of physiolgical and morphological factors on the skin temperature. J. Ther. Biol. 2010; 35 (8): 379–385.

Chudecka M., Lubkowska A. The use of thermal imaging to evaluate body temperature changes of athletes during training and a study on the impact of physiological and morphological factors on skin temperature. Human Movement. 2012; 13 (1): 3–39.

Chudecka M., Lubkowska A., Kempińska A. Evaluation of temperature changes in upper extremities of waterpolo players by thermovision. Inż. Biomed. 2010; 4 (16): 334–338.

Chudecka M., Szczepanowska E. Kempińska A. Changes of thermoemission of upper extremities in female handball players-the preliminary study. Med. Sportiva 2008; 12: 99–102.

Clark R.P., Mullan B.J., Pugh L.G. Skin temperature during running – a study using infra-red colour thermography. J. Psysiol. 1977; 267: 53–62.

Coh M., Sirok B. Use of the thermovision method in sport training. Facta Universitatas: Series Physical Education and Sport. 2007; 5: 85–94.

Davidovits P. Physics in Biology & Medicine Ed: Academic Press 2001.

Dębiec-Bąk A., Skrzek A. The comparison of surface body temperature distribution between men and women by means of thermovision. Inż. Biomed. 2012; 18: 25–29.

Du Bois E. The Many Different Temperatures of the Human Body and Its Parts. Western J. Surg. 1951; 59: 476–490.

Faje A., Klibanski T. Body composition and skeletal health: too heavy? Too thin?. A Curr. Osteoporos. Rep. 2012; 10 (3): 208–216.

Formenti D., Ludwig N., Gargano M., Gondola M., Dellerma N., Caumo A., Alberti G. Thermal Imaging of Exercise-Associated Skin Temperature Changes in Trained and Untrained Female Subjects. Biomed. Engin. 2013; 41 (4): 863–871.

Freitas R. Nanomedicine Vol. I: Basic Capabilities. Landes Bioscience, Georgetown 1999.

Havenith G. Human surface to mass ratio and body core temperature in exercise heat stress – a concept revisited. Journal of Thermal Biology. 2001; 26: 387–393.

Heikens M., Gorbach A., Eden H., Savastano D., Chen K., Skarulis M., Yanovski J. Core body temperature in obesity. Am. J. Clin. Nutr. 2011; 93 (5): 963–967.

Hoffmann M., Rodriguez S., Zeiss D., Wachsberg K., Kushner R., Landsberg L., Linsenmeier R. 24-h core temperature in obese and lean men and women. Obesity (Silver Spring). 2012; 20 (8): 1585–1590.

Hunold S., Mietzsc E., Werner J. Thermographic studies on patterns of skin temperature after exercise. Eur. J. Appl. Physiol. 1992; 65: 550–554.

Jiang L., Ng E., Yeo A., Wu S., Pan F., Yau W., Chen J., Yang Y. A perspective on medical infrared imaging. J. Med. Engin. & Tech. 2005; 29 (6): 257–267.

Jones B. A reappraisal of the use of infrared thermal image analysis in medicine. EEE Trans Med Imaging. 1998; 17 (6): 1019–1027.

Kozłowski S., Domaniecki J. Thermoregulation during physical exercise in men of diverse physical performance capacity. Acta Physiol. Polonica. 1972; 23 (5): 761–772.

Kozłowski S., Nazar K. Introduction to Clinical Physiology. Medical Publisher PZWL, Warszawa 1999: 3.

Kruk B., Kaciuba-Uściłko H., Nazar K., Opaszowsk B., Szczypaczewska M., Bicz B., Nazar K. Metabolic, body temperature and hormonal responses to repeated periods of prolonged cycle-ergometer exercise in men. Eur. J. Appl. Physiol. 1992; 64: 26–31.

Kurz A., Sessler D.I., Narzt E., Lenhardt R., Lackner F. Morphometric influences on intraoperative core temperature changes. Anesth Analg 1995; 80 (3): 562–567 [PubMed].

Kuzański W. The Application of Thermography as an Imaging Diagnostic Method in Medicine. Pediat. Rev. 1993; 1: 135–141.

Landsberg L. Core temperature: a forgotten variable in energy expenditure and obesity? Obes. Rev. 2012 Dec.; 13 Suppl. 2: 97–104.

Landsberg L., Young J., Leonard W., Linsenmeier R., Turek F. Is obesity associated with lower body temperatures? Core temperature: a forgotten variable in energy balance. Med. Clin. Exp. 2009; 58: 871–876.

Luck P., Wakeling A. Altered thresholds for thermoregulatory sweating and vasodilatation in anorexia nervosa. Br. Med. J. 1980; 4; 281 (6245): 906–908.

Lund D., Gisolfi C. Estimated of mean skin temperature during exercise. J. Appl. Physiol. 1974; 36 (5): 625–628.

Merla A., Di Donato L., Romani G.L. Infrared Functional Imaging: Analysis of skin temperature during exercise. Conf. Proc IEEE Eng. Med. Biol. Soc. 2002; 7.

Merla A., Mattei P., Donato L., Romani G. Thermal Imagining of Cutaneous temperature Modification in Runners During Graded Exercise. Biomed Engin. 2010; 38 (1): 158–163.

Merla A., Romani G. Biomedical Applications of Functional Infrared. In: J. Bronzino, N. Diakides (eds). Medical Infrared Imaging, CRC Press. 2007; 15: 1–20.

Merla A., Romani G. Biomedical Applications of Functional Infrared Imaging. Conf. Proc IEEE Eng. Med. Biol. Soc. 2005; 1 (1): 690–693.

Merla A., Romani G. Functional Infrared Imaging in Clinical Applications. In: J.D. Bronzino (ed.). The Biomedical Engineering Handbook, CRC Press. 2006; 32: 1–13.

Merla A., Romani G. Functional infrared imaging in medicine: a quantitative diagnostic approach. Conf. Proc IEEE Eng. Med. Biol. Soc. 2006; 1: 224–227.

Mikulska D. Contemporary applications of infrared imaging in medical diagnostics. Ann. Acad. Med. Stetin. 2006; 52 (1): 35–39.

Niu H.H., Lui P.W., Hu J.S., Ting C.K., Yin Y.C., Lo Y.L., Liu L., Lee T.Y. Thermal Symmetry of Skin Temperature: Normative Data of Normal Subjects in Taiwan Chinese Medical Journal (Taipei) 2001; 64: 459–468.

Pascoe D., Molloy J., Smith J., Purohit R. Historical Perspectives of Thermal Physiology and Thermography. 30th Annual Meeting of American Academy of Thermology in Orlando. Abstract 2002.

Plassmann P., Ring E., Jones C. Quality assurance of thermal imaging systems in medicine. Thermol. Int. 2006; 16: 10–5.

Rajewski M., Łazowski J., Pisula A. The temperature distribution in the body cryotherapy treatments. Fizjoterapia. 2001; 9: 20–25.

Ring E., Ammer K. Infrared thermal imaging in medicine. Physiol. Meas. 2012; 33: 33–46.

Ring E. Quality control in infrared thermography Recent Advances in Medical Thermology. E. Ring, B. Phillips (eds). New York: Plenum 1984: 185–194.

Ring E. Quantitative thermal imaging. Clin. Phys. Physiol. Meas. (Suppl. A). 1990; 11: 87–95.

Savastano D., Gorbach A., Eden H., Brady S., Reynolds J., Yanovski J. Adiposity and human regional body temperature. Am. J. Clin. Nutr. 2009; 90 (5): 1124–1131.

Schlader Z., Stannard S., Mündel T. Human thermoregulatory behavior during rest and exercise – a prospective review. Physiol. Behav. 2010; 99 (3): 269–275.

Sessler D.I., McGuire J., Sessler A.M. Perioperative thermal insulation. Anesthesiology. 1991; 74 (5), 875–879 [PubMed].

Smith D., Ovesen L., Chu R., Sackel S., Howard L. Hypothermia in a patient with anorexia nervosa. Metabolism. 1983; 32 (12): 1151–1154.

Smorawiński J., Grucza R., Kozlowski S. Thermoregulatory adaptation to exercise in the course of endurance training. International perspectives in Exercise Physiology, Human Kinetics Books. Champaign, Illinois 1990: 188–191.

Tori M., Yamasaki M., Sasaki T., Nakayama H. Fall in skin temperature of exercising man. Br. J. Sp. Med. 1992; 26 (1): 29–32.

Uematsu S., Edwin D., Jankel W., Kozikowski J., Trattner M. Quantification of thermal asymmetry Part 1: Normal values and reproducibility. J. Neurosurg. 1988; 69: 552–555.

Veghte J.H., Adams W.C., Bernauer E.M. Temperature changes during exercise measured by thermography. Aviat. Space Environ. Med. 1979; 50 (7): 708–713.

Verbraecken J., Van de Heyning P., De Backer W., Van Gaal L. Body surface area in normal-weight, overweight, and obese adults. A comparison study. Metabolism. 2006; 55 (4): 515–524. [PubMed].

Wakeling A., Russell G. Disturbances in the regulation of body temperature in anorexia nervosa. Psychol. Med. 1970; 1 (1): 30–39.

Zaidi H., Taiar R., Fohanno S., Polidori G. The influence of swimming type on the skin-temperature maps of a competitive swimmer from infrared thermography. Acta of Bioengin. Biomech. 2007; 9 (1): 47–51.

Zontak A., Sideman S., Vertsky O., Beyer R. Dynamic Thermography: Analysis of Hand Temperature During Exercise. Annals. of Biomedical Enineering. 1998; 26: 998–993.

Cite this article as: Chudecka M. 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. Centr Eur J Sport Sci Med. 2013; 2: 15–20.