REVIEW ARTICLE

APPLICATION OF THERMOGRAPHY IN MEDICINE. PART I

Zastosowanie termografii w medycynie. Część I

Małgorzata Chochowska[1], Dagmara Porada[1], Krzysztof Rujna[1,2], Leszek Kubisz[2]

1. *Department of Physiotherapy, University School of Physical Education in Poznan, Faculty of Physical Culture in Gorzów Wielkopolski, Poland*
2. *Chair of Biophysics, Department of Biophysics, Karol Marcinkowski University of Medical Sciences, Poland*

Małgorzata Chochowska – 0000-0002-7391-647X

Abstract

Infrared thermography is an imaging technique that utilizes the distribution of infrared radiation emitted by an object. Any body with a temperature higher than 0 K emits electromagnetic radiation, the spectrum of which depends on its temperature and emissivity. A thermal imaging device (thermal imaging camera/infrared radiation detector) detects infrared radiation emitted by the examined body, based on thermal or quantum effects. The result of infrared thermography measurement is referred to as a thermogram, or thermal image, where different temperatures are represented in different colours or shades of grey. Infrared thermography can detect changes in the temperatures of different parts of the body. Increased warmth is usually associated with enhanced vascular perfusion and inflammation (autoimmune diseases, endocrine disorders, orthopedic injuries). At the same time, infrared thermography can also locate areas characterized by reduced blood flow. The first part of the article presents the basics of infrared thermography and describes the possibilities of its use in angiology, internal diseases, aesthetic and reconstructive surgery, dermatology, as well as physiotherapy and rehabilitation.

Streszczenie

Termografia to technika obrazowania wykorzystująca rozkład promieniowania cieplnego emitowanego przez dany obiekt. Każde ciało o temperaturze wyższej niż 0 K emituje promieniowanie elektromagnetyczne, którego widmo jest zależne od temperatury i zdolności emisyjnej. Urządzenie termowizyjne (tzw. kamera termowizyjna/detektor promieniowania cieplnego) wykrywa promieniowanie cieplne emitowane przez badane ciało w oparciu o efekty termiczne lub kwantowe. Wynikiem termografii jest termogram, czyli obraz termiczny, w którym różne temperatury są przedstawione w różnych kolorach lub odcieniach szarości. Termografia pozwala wykryć zmiany temperatur różnych części ciała. Zwiększone ucieplenie zwykle jest powiązane z nasiloną perfuzją naczyniową oraz stanem zapalnym (choroby autoimmunologiczne, zaburzenia hormonalne, urazy ortopedyczne). Jednocześnie termografia pozwala wykryć obszary cechujące się zmniejszonym przepływem krwi. W pierwszej części artykułu przedstawiono podstawy termografii oraz opisano możliwości jej wykorzystania w angiologii, chorobach wewnętrznych, chirurgii estetycznej i rekonstrukcyjnej, dermatologii oraz fizjoterapii i rehabilitacji.

Keywords: thermography, angiology, internal diseases, dermatology, physiotherapy and rehabilitation

Słowa kluczowe: termografia, angiologia, choroby wewnętrzne, dermatologia, fizjoterapia i rehabilitacja

DOI 10.53301/lw/175039

Received: 11.10.2023

Accepted: 09.11.2023

Corresponding author:
Małgorzata Chochowska
Department of Physiotherapy, Poznań University of Physical Education, Branch Faculty of Physical Culture in Gorzów Wielkopolski
13 Estkowskiego St., 66-400 Gorzów Wielkopolski
e-mail: chochowska.malgorzata@gmail.com

Introduction

Infrared thermography (IRT) is an imaging technique that utilizes the distribution of infrared radiation (IR) emitted by an object. Any body with a temperature greater than 0 kelvin (K) emits electromagnetic radiation, the spectrum of which depends on the temperature and its specific properties (emissivity). Bodies below 700°C emit radiation mainly in the infrared and microwave ranges [1, 2].

According to Stefan-Boltzmann law, the total amount of radiation generated by an object per unit area is directly related to its emissivity and the fourth power of its absolute temperature. Thus, when the emissivity and the total amount of radiation emitted by an object are known, its temperature can be estimated, which is used in IRT.

A thermal imaging device (the so-called thermal camera/IR detector) detects thermal radiation emitted by the investigated body based on thermal or quantum effects. ITR result is presented in the form of a thermogram, or thermal image, where different temperatures are represented by different colours or shades of grey [2]. Modern thermographs designed to radiometrically (quantitatively) reproduce the temperature fields of investigated objects operate in the 2–5 micrometre (μm) (medium-wave infrared, MWIR) or 8–12 μm (long-wave infrared, LWIR) bands. The sensor in a thermal camera can be made of different materials. Microbolometer matrices, consisting of hundreds of thousands of pixels, capture IR and transmit the signal to a processor, which converts the signal into a thermogram. Cooled matrices, on the other hand, use nitrogen or helium cooling systems, which allows for higher sensitivity and resolution [3]. The thermal camera must be properly calibrated so that the image displayed reflects the actual temperatures. Additionally, it is worth following the principles of image optimisation and considering factors that may affect the final temperature range readout. A calibration source with a known temperature (reference) is used for this purpose. Lens, which allows for focusing the IR on the detectors, is also an important component of a thermal camera. Thermal lenses are made of materials that are permeable to IR, such as germanium, silica or polyamide [4].

Aim

The aim of this study was to present the current state of knowledge on the applicability of thermography in various medical departments.

Review methods

Polish, German and English-language articles (n = 86) from PubMed and Google Scholar electronic databases, all with abstracts in English, were included in the review. The following keywords were used as search criteria: thermography, followed by thermography in combination with: *angiology*, *internal medicine*, *aesthetic surgery*, *reconstructive surgery*, *dermatology*, *physiotherapy*, *rehabilitation*, *gynaecology*, *obstetrics*, *cardiology*, *cardiac surgery*, *oncology*, *orthopaedics*, *paediatrics*, *rheumatology*, *dentistry*, *urology*.

Medical applications of thermography

The link between raised human body temperature and disease has been known since the dawn of medicine (Hippocrates devoted much space to fever and classified it as malignant, mild and acute) [1]. The first simple instrument for assessing temperature ("thermoscope") was built by Galileo Galilei in 1595. Later, in 1871, Wunderlich constructed a clinical thermometer and postulated that body temperature should be measured in every patient.

The history of IRT dates back to Herschel (detection of IR and obtaining a thermal image of solar radiation - a "thermogram"). In 1959, IRT was first used in medicine to assess the increased heat of arthritic joints (the "Pyroskan" device, developed in 1942, and its successor "Pyroskan Mark2"). It took 3–4 minutes to obtain each thermogram, and its interpretation was highly challenging. Further improvements in imaging conditions allowed for obtaining better-quality thermograms, which are now a valuable complement to other imaging studies (US, MRI, CT) [1].

IRT detects temperature changes in various parts of the human body. A local rise in temperature is usually associated with increased vascular perfusion and inflammation [2]. This may be seen in autoimmune and endocrine disorders accompanied by thermoregulatory disorders (e.g., thyroid diseases), as well as in orthopaedic injuries (fractures and sprains, muscle and tendon injuries), in which case temperature changes near the site of the injury are a prognostic factor in determining its severity and further development or the healing process [5]. IRT can also detect areas characterized by reduced blood flow (e.g., renal flow in patients with diabetes or heart disease [6, 7]). For this reason, IRT is used as a diagnostic tool (currently as an additional/supplementary tool) in many fields of medicine, the most important of which are presented below.

Thermography in angiology

In angiology, IRT has a high potential for use in screening for carotid artery stenosis (since the skin surface temperature is higher in healthy subjects and lower in patients with stenosis) [8]. Active dynamic thermography (ADT), during which a slower return of normal temperature on the stenotic side is recorded after an external cold stimulus, is also used for this purpose [9].

IRT is also highly effective in assessing vascular function after allografts (e.g. limbs), monitoring the effectiveness of revascularisation in patients with diabetes or peripheral artery disease [10], imaging peripheral vascular malformations (PVM) and assessing their progression, detecting abdominal aortic aneurysms (earlier than other techniques) by assessing the increase in temperature on the abdominal skin during the systolic phase compared to a healthy aorta [11], as well as in predicting the stage of venous ulcer (a complication of chronic venous disease of the lower extremities), where non-healing wounds with poorer prognosis show a greater temperature difference compared to normal skin than shallow, healing ulcers [12].

Thermography in internal medicine

IRT is increasingly used to quickly and conveniently detect fever and thus possible infections. A breakthrough in such use of this method occurred during the COVID-19 pandemic, when it became necessary to maximize non-contact diagnosis. Combining thermography with advanced algorithms may allow for simple, non-invasive, automated and non-contact real-time monitoring of vital signs (skin temperature and respiratory rate) in ICU patients; however, it is burdened with an absolute error, which may generate false results [13].

IRT is also used to:

- assess treatment efficacy in the form of reduced local inflammation in viral and bacterial infections (by detecting a decrease in temperature) [14];
- monitor temperature in patients with hyperthyroidism or hypothyroidism to assess treatment efficacy and the metabolic activity of brown adipose tissue (responsible for heat production) [15];
- confirm and automatically classify allergic reactions (which reduces the risk of physician's subjectivity when making a diagnosis) [16];
- assess neural function in neuropathic pain (resulting from altered microcirculatory flow) [17];
- detect and control diabetic complications: retinopathy, vascular disorders in the diabetic foot, polyneuropathy [18, 19] and hypoglycaemia in patients with type 1 diabetes mellitus (a drop in skin temperature) [20].

Thermography also offers hope for an accurate diagnosis (as an imaging modality) of metabolic syndrome (inflammation of adipose tissue is detected by the camera and presented on the monitor in the form of a higher temperature compared to healthy individuals) and monitoring of treatment efficacy [21].

Thermography in aesthetic and reconstructive surgery

IRT is used in aesthetic surgery to map the course of skin perforators during preparation for surgery (usually on the anterolateral thigh and abdominal wall) [22]. This increases surgical safety and contributes to the final outcome, which is crucial in this specialty, especially in breast reconstruction [23].

Thermography in dermatology

Dermatology represents one of the key medical fields that make use of IRT. Thermography helps effectively diagnose, classify and treat many skin diseases [24], including:

- frontal fibrosing alopecia (FFA), by detecting inflammation and quick implementation of pharmacotherapy [25];
- acne inversa, hidradenitis suppurativa [26];
- decubitus ulcers (lower temperature at the edge of the wound compared to its centre or the surrounding skin indicates better healing prognosis) [27].

IRT also offers the possibility of detecting fungal infections in patients with subungual hyperkeratosis (the temperature of the affected toes is lower than that of healthy toes) [28], and obtaining a complete picture of herpes zoster skin lesions, which allows for the implementation of appropriate treatment (or its intensification) and minimization of the risk of complications [29].

Thermography in physiotherapy and rehabilitation

In physiotherapy, IRT is used to control the patient's body temperature when applying thermal stimuli (e.g., high-energy laser therapy, microwave therapy and electrotherapy) [30], thus avoiding the risk of burns and other complications associated with elevating local tissue temperature [31]. In sports physiotherapy, IRT is used for preventing muscle and tendon damage (e.g., in football players), to evaluate the effectiveness of physiotherapy and its programming in the post-traumatic period, as well as during preparation for physical exercise and sports training [32] (it allows identification of areas that require further or intensified treatment [33]). This method is helpful in the screening diagnosis of idiopathic scoliosis (increased warmth of the paraspinal tissues on the convex side of the curvature [34]), as well as in paediatric physiotherapy, for example, to evaluate the efficacy of new therapeutic methods in children with cerebral palsy [35].

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