Thermography in the diagnosis of musculo-skeletal disorders

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Abstract

This paper is a systematic review on the use thermography as a diagnostic tool in musculoskeletal disorders. Thermal imaging cameras record skin surface temperature. As many musculoskeletal disorders impair cutaneous circulation, with thermography we can observe circulatory abnormalities in inflammation, ischemia or sympathetic system dysfunction. Based on literature data a number of uses for thermography in musculoskeletal medicine can be found. In orthopedics in the diagnosis and evaluation of joint disorders, vertebral column pathologies or to monitor the effects of physical rehabilitation. In rheumatology to diagnose soft tissue inflammatory disorders. In surgery and neurology to assess nerve damage. In sports medicine to select appropriate training intensity or as a diagnostic tool to detect injuries. Available literature shows that thermography, although unspecific, is a very sensitive method and can be a valuable complementary diagnostic or screening test.

Key words: thermography, musculoskeletal disorders

Streszczenie

W pracy przedstawiono systematyczny przegląd piśmiennictwa dotyczący zastosowania termografii w schorzeniach układu mięśniowo-szkieletowego. Kamery termiczne wykorzystują temperaturę skóry do oceny niektórych schorzeń poprzez rejestrację zmian krążenia krwi i ucieplenia w stanach chorobowych takich jak zapalenia, niedokrwienie i uszkodzenie układu współczulnego. Według dostępnych piśmiennictwa metoda znajduje zastosowanie w ortopedii do oceny schorzeń stawów, patologii kręgosłupa lub w monitorowaniu efektów fizjoterapii. Zastosowanie w reumatologii polega na diagnozowaniu schorzeń zapalnych tkanki miękkiej. W chirurgii i neurologii do oceny uszkodzeń nerwów, w medycynie sportowej do wykrywania urazów tkanki miękkiej. Metoda ta, chociaż niespecyficzna odznacza się dużą czułością i może być cennym badaniem uzupełniającym diagnozy schorzeń narządu ruchu jako test przesiewowy.

Słowa kluczowe: termografia, schorzenia narządu ruchu
Introduction

Thermography is an imaging technique which measures surface temperature of a given area. It is widely used in many aspects of science and everyday life, such as in the military, police, fire departments or security to evaluate or detect objects, or in industry to control manufacturing processes. In architectural engineering thermography helps assess the quality of isolation [1]. In recent years numerous attempts had been made to bring thermography into medicine to diagnose diseases, monitor treatment and rehabilitation or into different fields of medical research [2].

Historic background

Earliest reports of recording skin temperature differences come from the ancient history. Hippocrates was the first to assess body surface temperature by smearing his patient with a thin layer of mud and marking the spot where mud dried out quicker. This area of increased temperature indicated pathology [3]. First studies on thermography in medicine were conducted in 1956, however an absence of standardised measurement technique, lack of studies on large groups and imprecise equipment led to a loss of interest in this diagnostic method [4].

Principles

The principle of infrared [IR] thermography is visualization of surface temperature distribution of a given object. Such an image is created with thermographic cameras, which register thermal radiation from various objects. These cameras are detectors operating in mid-infrared wavelength, i.e. 0.9 to 14 micrometres, and converting the received signal to images [5,6]. Humans are homeothermic and their physiologic temperature is relatively constant at 36,6°C±0,7°C. Only distal body parts have a higher temperature variability. Moreover, the distribution among contralateral areas is symmetrical. This symmetry was a topic of numerous papers. Many authors tried to devise a thermal equation to predict the minimal temperature difference, above which a pathology could be suspected. Depending on a researcher this number ranged from 0,3°C to 0,8°C [7,8,9]. By measuring the temperature on a surface area we indirectly assess the blood supply to that area. Many factors impair skin circulation, but most causes fall into one of the following groups
- inflammation
- ischaemia
- sympathetic system disorders

Owing to infrared thermography we can indirectly suspect such pathologies in examined areas.

Skeletal system

Joint inflammation was diagnosed for centuries using the fundamental symptoms of inflammation (pain, oedema, redness, loss of function). A temperature rise around an affected joint indicates an exacerbation of inflammation, whereas a decrease of temperature suggests the opposite [10,11]. It has been proven that an increase of temperature near a joint in patients affected by rheumatoid arthritis (RA) correlates directly with an elevation of biochemical and cellular inflammatory factors inside it. Cosh conducted a study analysing joint circulation in patients with RA by an intravenous Technetium-99m injection followed by a scintigraphy. During this study patients received intra-articular glucocorticoids, while having their joint circulation monitored with thermographic cameras. In case of active RA an increase in radioisotope uptake was observed, which indicated increased blood flow in that area. This effect was counteracted with an intra-articular steroid injection. Thermographic images correlated strongly with scintigraphy results [12]. A similar study was published by Brenner and Braun in 2006. An experiment had been planned on 3 types or rats. The researchers created a joint inflammation through an injection of a specific agent and then monitored the extent of inflammatory response by the size of oedema, activity of inflammatory mediators, thermal images and pathology examination. Thermography correlated positively with the degree of joint inflammation. Based on these, and a number of other reports, a conclusion can be drawn that thermography is a promising method and could be utilized in the diagnosis and monitoring of joint inflammation or to evaluate the effectiveness of treatment, especially following intra-articular injections. Interestingly, Brenner and Braun in their study assessed the usefulness of infrared thermography in the diagnosis of early stages of synovitis (before clinical symptoms are present) - thermography did not prove useful in that phase of inflammation [13].

Denede and Hall tested infrared thermography as a diagnostic tool in osteoarthritis (OA) in a group of 30 females. Based on the Kellgren and Lawrence radiological clasification they divided patients depending on the severity of OA. A thermographic evaluation of joints had been performed in 6-month intervals. A correlation between thermographic images and the severity of degenerative changes was observed [14]. Varju and Pieper in their study evaluated the correlation between thermography, X-ray images and OA severity. Study group included 91 patients, whose proximal interphalangeal (PIP), distal interphalangeal (DIP) and metacarpophalangeal (MCP) joints were assessed on both hands (2198 joints in total). Temperature was measured at different stages of the disease. Statistical significance was set at p<0,05. The highest temperature was observed in stage I of degenerative changes, i.e. at the time when radiological assessment reveals no abnormalities. As the disease progresses, joint tem-
perature drops and radiological features become more evident. The authors observed that as temperature decreases, so does the severity of symptoms reported by patients. Infrared thermography could be, therefore, used as a complimentary examination method, especially in early disease stages. Radiography is used to obtain static images to evaluate joint anatomy, while thermography can give information about dynamic pathophysiological processes within the joints [15]. Thermographic joint assessment is also performed in sports medicine, where the trauma affects most frequently the skeletal system. Professional athletes often marginalize pain, however even mild discomfort could indicate an ongoing pathology. This is why a simple and quick screening test should be available to diagnose musculoskeletal disorders as early as possible. Many reports confirm the effectiveness of thermography in early diagnostics of sports injury [16,17]. Devereaux and Parr examined 30 runners with patellofemoral pain (‘runner’s knee’). The results have been compared with a group of 30 patients suffering from osteoarthrosis and 30 patients with other joint pathologies. A statistically significant difference has been observed between these groups. Sportsmen with patellofemoral pain had a decrease of temperature around the medial aspect of knee joints. The sensitivity was estimated at 93%, specificity at 100%. The cause of this asymmetry was connected to an unequal quadriceps force exerted on the knee joint. No evident cause for such a temperature distribution could be found, however [18].

Muscular system

The second most frequent type of injuries are ones affecting the muscular system.

Schmitt and Guillot assessed the usefulness of thermography in muscular trauma in athletes. They examined 200 athletes from different disciplines with varying lower extremity soft-tissue trauma using a thermal imaging camera. The examination was repeated weekly until temperatures returned to normal. 3 thermal patterns were observed:

- a normal pattern, where temperatures on both extremities were equal and patients could resume training after 1-2 weeks;
- hyperthermia associated with over-stretching, rupture or hematoma formation. Hy-perthermia confirmed the severity of trauma, despite a lack of symptoms in some patients. Elevated temperatures returned to normal over 3-4 weeks after symptom relief and only then were the patients allowed to return to training;
- hypothermia was observed after damage to non-extensible tissue (tendons, aponeuroses), in chronic pain syndromes or in areas previously affected by trauma where local calcification or fibrosis was present [19].

According to the authors, thermography may be a useful tool in diagnosing and evaluating injury, however a normal thermogram of a healthy area should be previously obtained for reference. Thermal images help in assessing the severity of trauma in the acute phase, in monitoring the evolution and estimating healing and recovery time. In chronic, overlooked or misdiagnosed injuries thermography is a promising supplementary diagnostic and monitoring tool.

Mela and Matteo recorded with thermography a group of professional runners while they were gradually increasing training intensity. Based on the observations they concluded that thermal imaging could be useful to plan the type, duration, intensity and load of training for different athletes. What is more, thermography might be used to measure the effectiveness of thermoregulatory mechanisms [20,21].

Local temperature distribution imbalances could be caused by tendon pathology. Park and Hyun showed a correlation between clinical, intraoperative and thermal image in 100 patients with supraspinatus tendinitis. 73% of patients had an abnormal thermal image, which according to authors, shows the potential usefulness of thermography in shoulder stiffness and pain in that area. They observed that supraspinatus tendinitis is associated with decreased temperature [22]. A different condition in which thermography has proved useful is lateral epicondylitis, also called the “tennis elbow” [23]. Another study conducted in 2005 in Wrocław, Poland, evaluated different techniques of Achilles tendon reconstruction with thermography. The results showed that thermography is a good supplementary method of extremity function evaluation and treatment effect monitoring. Furthermore, thermal image can determine the least traumatic operative technique [24].

Nervous system

One of thermoregulatory mechanisms is the constriction and dilation of small dermal blood vessels. Skin microcirculation is regulated by the sympathetic system. When this part of the autonomous system is stimulated, skin circulation decreases and so does body surface temperature. When the stimulus is stopped, an opposite reaction occurs. Spinal disc herniation or degenerative changes compress the nervous trunks and limit, among others, sympathetic transduction. This causes secondary vascular disorders, the severity of which is proportional to sympathetic nerve fiber damage. The following phases of sympathetic nerve injury can be observed:

- primary pathologic irritation, which leads to increased sympathetic response i.e. vasoconstriction and lower surface temperature,
- denervation – prolonged compression of nerve fibers damages them, which stops sympathetic nerve conduction and leads to an elevation of surface temperature,
The potential use of thermography in diagnosis of spinal pathologies associated with chronic pain [26]. In the ‘80s Pochaczewsky and Wexler confirmed it on a study group of 101 patients. They compared clinical symptoms, myelography and intraoperative image with thermography in the diagnosis of chronic spinal pain resulting from spinal herniation. Liquid crystal thermography (an older and less accurate method than thermographic cameras) did, according to the authors, correlate with symptoms better than myelography. In that study typical thermal patterns were observed in some nerve trunk compression syndromes. This paper was one of the first attempts to objectify patients’ complaints. [27]. In the following years many researches were aimed at evaluating thermography in spinal nerve compression diagnosis. A major study was published by Uematsu and Jankel in 1988. The authors evaluated 144 patients with unilateral chronic back pain and compared the results of thermography with myelography. Positive predictive value of thermography was 94.7%, specificity 87.5%. Interestingly, some patients with normal myelography despite chronic pain have presented abnormal thermal images. As proved later, their symptoms were caused by other truncal pathologies, such as malignant growth near lumbar plexus, previous sympathectomy or early herniation, which could not be detected with myelography alone. According to the authors, qualification for spine surgery should not be based on assessing structural abnormality alone.

To give a final diagnosis, an evaluation of nerve trunk function should be conducted using a technique which could assess not only the morphology, but also the activity of nerves. Thermography has the potential of becoming such a test [28]. In a study conducted by Thomas et. al, thermal images were compared with MRI, CT, myelography, the severity of symptoms and simple spinal mobility tests. They have shown that abnormalities in thermography correlated well with other imaging methods. Moreover, it has been observed that temperature variations on the sole of the feet may be connected to the intensity of pain [29].

Another study confirming the usefulness of thermography in spinal pathologies was conducted in 2014 by Zhang et. al. 137 patients with varying spinal cord tumours were included. The results of computed tomography, magnetic resonance imaging, patients’ complaints and thermography were compared. The authors concluded that thermography may be a valuable supplementary tool in the diagnosis and differentiation of spinal tumours [30].

Complex Regional Pain Syndrome (CRPS) or Reflex Sympathetic Dystrophy (RSD) is a rare disorder characterised by pain and swelling of a previously injured extremity. Dysfunction of circulation, skin changes and degenerative changes to the musculoskeletal system are observed. This syndrome is mostly affecting one arm or leg with a history of trauma without visible nerve damage. In this syndrome blood vessels lose the ability to constrict and dilate and a typical image of swelling and hyperthermia develops.

Thermoregulatory disorders in CRPS and the potential use of thermography for diagnostics were brought up in many papers. Aside from varying resting temperatures of two extremities, Niehof and Huygen observed a different vascular response to stimuli in dynamic thermography. The hand with CRPS needed significantly more time to return to normal temperature after being cooled down. Such imbalances were described as sympathetic system disorders [32]. Similar conclusions were reached by others, e.g. Connwel and Hobins in 2010, who confirmed high specificity and sensitivity of dynamic thermography in CRPS diagnostics [33, 34, 35].

Owing to the fact that most peripheral nerves include sympathetic nerve fibers, it can be assumed that damaging them could induce regional blood supply. This assumption was tested by Pulst and Haller, who used thermography to diagnose skin circulation and vascular activity in patients with peripheral nervous system pathologies at different stages of their disease. That study included 23 patients with unilateral nerve damage assessed with medical history, neurological examination and additional tests – X-ray, electromyography and myelography. Thermography was used to evaluate vascular response. Patients’ hands were first cooled down and then the return to normal temperature was recorded with a thermal imaging camera. The extent of autonomous nervous system disorders was also measured with Minor starch-iodine sweat tests. All patients with autonomous dysfunction showed a significant difference temperature difference between the healthy and affected hand. It was shown, that during the first 4-5 months of disease hyperthermia and quicker return of temperature occurred. After that time hypothermia developed and the return to normal temperature after cold stimulus was slower. The authors underlined the usefulness of thermography in assessing sympathetic nerve fiber or trunk damage [25].

Conclusions

Rapid technology advancement over the last decades allowed for newer, more precise temperature measurement devices to be produced. This has shifted the attention of researchers towards potentially very wide diagnostic applications of thermography in the field of medicine. Modern thermal imaging cameras are capable of not only taking static pictures, but also recording dynamic temperature changes in time. This dynamic thermography is further expanding the capability and usefulness of this method.

As literature shows, an undeniable advantage of thermographic assessment is the possibility of diagnosing pa-
thologies in preclinical stage, a fact that may justify its use in screening. In comparison with other imaging tests thermography is inexpensive, simple, non-invasive and relatively easy to interpret.

It is now, however, without flaws. Thermal imaging camera can only record skin surface temperature, which depends on various internal and external factors. It is im-portant to take them into account when interpreting a result of thermographic evaluation. Moreover, there are no commonly accepted guidelines for performing thermography in medicine. Limited consensus statements have been published by European Association of Thermology (EAT) and International Electrotechnical Commission [5].

In orthopedics in the diagnosis and evaluation of joint disorders, vertebral column pathologies or to monitor the effects of physical rehabilitation [36, 37]. In rheumatology to diagnose soft tissue inflammatory diseases or circulatory dysfunction. In sports medicine in early trauma diagnosis or to select an appropriate training type and intensity. In occupational medicine to objectify symptoms referred by patients. It should be underlined that in the majority of studies thermography was not the ex-clusive or primary diagnostic test. Most of modern imaging and laboratory tests as-sess only morphology; methods evaluating function are less common.

Available literature shows that thermography, albeit un-spe-cific, is a very sensitive method and can be a valuable supplement-ary diagnostic or screening test. An inter-pretation of results has to be made in correlation with clinical symptoms, laboratory and imaging results.

**References**

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