Mini Review

Danielle Fokam* and Christian Lehmann

Clinical assessment of arthritic knee pain by infrared thermography

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Abstract

Background: Infrared thermography (IRT) provides accurate measurements of surface temperatures. In inflammatory conditions such as arthritis, tissue temperature is elevated, which can be measured on the periarticular skin surface by IRT. The aim of this review is to evaluate the evidence for the relationship between skin temperature (measured by IRT) and arthritic knee pain and discuss the limitations of IRT in clinical settings of arthritis.
Method: To reach this goal, a mini-review of all the relevant papers indexed in PubMed was conducted.
Results: Several studies suggest a significant correlation between skin temperature assessed by IRT and the severity of arthritic knee pain (especially in osteoarthritis and rheumatoid arthritis).
Conclusion: IRT is a reliable technique to assess inflammatory arthritis pain.

Keywords: infrared thermography; osteoarthritis; pain; rheumatoid arthritis; temperature.

Introduction

Arthritis represents several painful joint pathologies. The two most common pathologies are osteoarthritis (OA), a degenerative joint disease with loss of cartilage in synovial joints as a main characteristic [1], and rheumatoid arthritis (RA), a systemic autoimmune disorder. According to a World Health Organisation (WHO) report in 2015, arthritis affects millions of people worldwide. In Canada, more than 4.4 million people are living with OA, and it is anticipated that more than 10 million people will show this pathology over the next 30 years [2].

Despite considerable progress in the clinical and radiological characterization of arthritis, it remains cumbersome to study arthritis-associated pain. Pain scales are influenced by gender, race, age, and even culture [3]. OA and RA have in common an underlying inflammatory process responsible for pain, redness, heat, swelling, and joint stiffness [4]. Therefore, it is intriguing to include biochemical, physiological, and inflammation-related parameters in the study of arthritic knee pain.

In arthritis, the chemical mediators of inflammation (histamine, serotonin, bradykinin, prostaglandins, and cytokines) are released into the joint by nerves, immune cells, synovial cells, and the vascular endothelium. Inflammation is characterized by four major signs: redness, heat, swelling, and pain. Swelling results from the accumulation of fluid outside the dilated and permeable blood vessels and infiltration of cells into the damaged area. Pain is due to the direct effects of the chemical mediators of inflammation, which increase the excitability of peripheral nociceptive sensory fibers. During the inflammatory process, there is a dilation of the blood vessels, leading to an increase in blood flow. This will cause redness and heat. The heat can be measured on the skin covering the sick joint by infrared thermography (IRT).

History of infrared thermography

The first report on body heat originated from Hippocrates (460–377 BC), who used a cloth soaked in clay to compare the temperatures between healthy and diseased parts of the body based on the drying time of the clay [5]. In the 1800s, the German astronomer William Herschel discovered infrared radiation. Molecules of every object emit infrared radiation (electromagnetic waves) as a result of their rotational-vibrational movements. That radiation is reflected and refracted like light and can be detected. IRT is a method to capture this radiation and quantify the signal, i.e. temperature [6, 7]. Thus, the first electronic sensors for the detection of infrared radiation were

***Corresponding author: Danielle Fokam,** Dalhousie University Halifax, Department of Pharmacology, 5850 College Street, B3H 4R2, Halifax, Nova Scotia, Canada, E-mail: danielle.fokam@gmail.com
Christian Lehmann: Dalhousie University Halifax, Department of Pharmacology, Halifax, Nova Scotia, Canada

designed by the army and used as night vision systems. At that time, IRT technology was large and expensive, and the quality of the images was mediocre [8]. The past few years have witnessed the evolution of IRT, which has been extended to several scientific and commercial areas, including medicine.

The first IRT instrument for medical use was based on contact thermography. The device was kept in contact with the skin, separated only by a sheet with liquid crystals of black cholesterol, which changed its color depending on the temperature of the skin with which it was in contact. Then arrived remote sensing thermography, which captured the infrared emission at a distance and produced an image of the temperature distribution in real time. Today, IRT uses computers and cameras that process pictures quickly and provide high-resolution thermal images. Furthermore, those devices are small and inexpensive compared to those using other techniques (e.g. radiography) and provide high-resolution images. Unlike radiography, scintigraphy, or magnetic resonance imaging, IRT provides noncontact, noninvasive, radiation-free, and dynamic measurement of joint inflammation.

Thermal data are acquired and interpreted using a camera and a thermal evaluation software. In 1974, Collins et al. [9] developed an index to quantify infrared imaging, namely the thermographic index (TI). It represents the difference between the measured temperature of several regions of interest and a predefined isotherm constant, divided by the total area measured. The isotherm constant is calculated from data from healthy subjects. In a very simplified way, TI represents the difference between the measured values and "normal" values. After realizing that the heat is not distributed in the same way depending on whether the joint is sick or healthy, Salisbury et al. [10] created few years later the heat distribution index (HDI). This index is more complex than TI and allows evaluation of the measured temperature while minimizing the influence of the environment. Accordingly, Salisbury et al. demonstrated in their study that HDI is more accurate than IT.

Presenting evidence of the relationship between skin temperature (measured by IRT) and arthritic knee pain and discussing the limitations of IRT in the clinical settings of arthritis are the objectives of this review. To achieve these goals, we performed a literature search using the following keywords on PubMed: infrared, thermography, arthritis. Among the 58 articles found, only 10 were relevant.

Infrared thermography in arthritis

IRT has been evaluated under several musculoskeletal conditions, such as complex regional pain syndrome [11], juvenile polyarthritis, rheumatoid arthritis, and osteoarthritis [12–20]. Bhowmik et al. studied inflammation in human knees with OA and RA by IR [15]. They found that patients with RA showed bilateral temperature increases, while in OA a unilateral temperature increase was observed (Figure 1).

Another study by Lerkvaleekul et al. evaluated the use of IRT and ultrasonography in the diagnosis of wrist arthritis [19]. Three groups of patients with different degrees of arthritis were separated following physical examination: healthy controls, those with inactive arthritis, and those with active arthritis (including mild and severe arthritis as subgroups). The mean and maximum temperatures assessed by IRT in the region of interest were significantly higher in the active arthritis group than in the inactive group and healthy controls. Furthermore, temperatures in the severe arthritis subgroup were significantly higher than in the mild arthritis subgroup. HDI followed the same trend: in the moderate to severe arthritis group, this index was significantly higher than in healthy controls. The results clearly suggested a

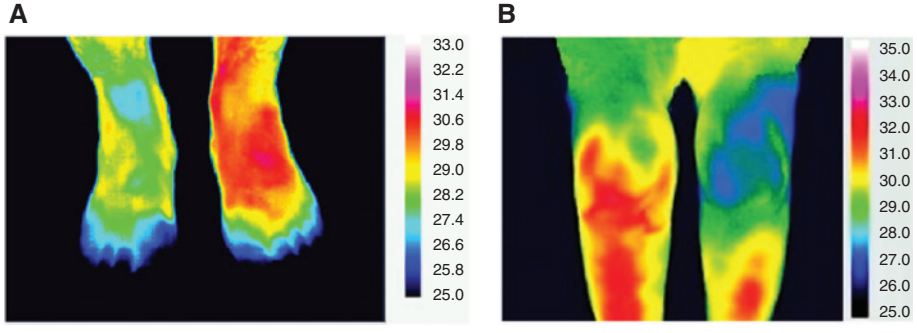

Figure 1: In both cases, IRT identified changes in skin temperature and localized the inflammatory area which appears more red/yellow than green.
(A) Chronic inflammation of the forefoot following a sports injury. (B) Rheumatoid arthritis of one knee (left of the image) [10].

Table 1: IRT and arthritic inflammation in humans.

Authors	IRT device	Findings
Bhowmik et al. [15]	FLIR T650sc thermal camera	IRT could detect the presence of knee arthritis (OA and RA) in the human body
Lerkvaleekul et al. [19]	FLIR E60 camera	IRT was a reliable technique for the diagnosis of wrist arthritis in humans
Denoble et al. [18]	Meditherm Med2000™ Pr camera	There was correlation between knee temperature assessed by IRT and severity of OA knee
Ilowite et al. [20]	Liquid cholesterol crystals embedded in elastic sheets (Flexi-Therm, Westbury, NY, USA)	There was significant correlation between the visual analog pain score determined by parents and physicians and the temperature of the diseased joint measured by the IRT There was significant correlation between the pain intensity and joint temperature only in the youngest children

OA, osteoarthritis; RA, rheumatoid arthritis; IRT, infrared thermography.

relationship between the severity of arthritis and absolute temperature changes.

Denoble et al. conducted a study in patients with knee OA using IR [18]. The participants were selected according to Kellgren–Lawrence (KL) radiographic criteria: knee OA cases had a KL grade of 2 and 3. The knee temperature measured at the patella (region of interest) was higher for KL3 cases (30.5 °C) than for KL2 cases (30.1 °C). Even though the results were not statistically significant, an association between knee temperature and the severity of the pathology was found as in the previous study.

Ilowite et al. [20] studied the relationship between pain and the degree of joint inflammation measured by IRT in children from 4 to 16 years with juvenile RA (pauciarticular arthritis, polyarticular arthritis, and systemic onset disease). Pain was assessed using a visual analog scale by the children themselves, then by their parents, and finally by a pediatric rheumatologist immediately after a physical examination. There was a significant correlation between the pain score determined by the parents and physicians and the temperature of the diseased joint measured by IRT. The only significant correlation between the pain intensity assessed by children themselves and the joint temperature was in children under the age of seven.

All these studies confirm the feasibility of IRT as a reliable technique to detect inflammation related to arthritis (Table 1). However, except in one study, classical pain scores were neither included nor correlated.

Inflammatory pain and infrared thermography

Only a few studies used IRT as therapeutic monitoring tool for pain assessment. Hegedűs et al. evaluated the efficacy of low-level laser treatment for knee OA and employed IRT to verify the therapeutic effects [21]. OA patients receiving low-level laser treatment were compared with untreated control patients. The efficacy of treatment to reduce pain in patients was evaluated by a subjective scale of pain from 0 to 10, sensitivity of the knee to pressure, and measurement of the skin temperature of the joint by IRT before, during, and after treatment. This study found a significant change of skin temperature of the knee measured by IRT in patients who had experienced pain relief.

Kwon et al. compared the analgesic effect of bee venom administered with traditional acupuncture in patients with OA of the knee [22]. The comparison was based on heat (IRT) and pain relief (patients were asked to choose a category from 1 to 4 that best described the reduction of their pain: excellent “4”, good “3”, fair “2”, and poor “1”). After 4 weeks of treatment, patients receiving bee venom had a better reduction in knee pain and skin temperature than those given traditional acupuncture.

The ability of Hyalgan (1% hyaluronic acid solution) to improve pain reduction after knee surgery in patients with OA was observed in the study by Zazirnyĭ et al. [23]. The intensity of pain (visual analog scale) and the temperature of the skin over the sick joint (measured by IRT) revealed that 5 weeks of treatment with Hyalgan improved the effectiveness of OA surgery. Overall, these studies suggest that IRT can be an interesting method to assess inflammatory pain (Table 2).

Limitations of infrared thermography

Some factors may impact the IRT signal, such as equipment specifics, room temperature, changes in the distance between the joint and the camera, angle of measurement, and internal factors such as variability of the blood flow

Table 2: IRT and inflammatory pain in humans.

Authors	IRT device	Findings
Hegedűs et al. [21]	AGA Thermovision	Elevation of skin temperature of the knee measured by the IRT in patients who had experienced pain relief
Kwon et al. [22]	IRT system (Dorex Inc., Orange, CA, USA) using computer-assisted thermographic software and an IBM PXT for digitization of signals, storage	Better reduction of pain and knee skin temperature assessed by IRT in patients treated with bee venom acupuncture than those treated with traditional needle acupuncture
Zazirnyĭ et al. [23]	Not mentioned	Improved effectiveness of the OA surgery by treatment with Hyalgan

OA, osteoarthritis.

due to blood composition (rheology) and/or mechanical disturbances of the local blood flow (e.g. deep vein thrombosis [DVT]) [24]. These factors must be considered when using IRT. For better reproducibility of IRT, it is important to determine the region of interest on which the temperatures are to be measured. This region can be determined by the association of history of the disease and the apparent clinical signs of inflammation [11].

Another potential limitation for the use of IRT in clinical routine is the cost factor. The cost for IRT basically includes those of the IR camera and a laptop computer. Usually, no disposables or chemicals are needed. The cameras must be medically approved, and thermography costs are covered in many health care systems. In comparison to other noninvasive systems capable of recognizing changes of skin perfusion related to joint inflammation, such as laser Doppler flowmetry or laser speckle imaging, the IRT equipment is significantly less expensive.

Conclusions

IRT is a simple, accurate, inexpensive, noninvasive, and radiation-free technique to assess skin temperature. In the diagnosis and therapeutic follow-up of pathologies such as arthritis, numerous studies have demonstrated its effectiveness and its reproducibility to detect inflammation. Some authors have examined the relationship between pain and the degree of joint inflammation and have found a correlation between the temperature of the skin measured by IRT and the intensity of the pain. Despite some limitations such as the influence of the environment and blood flow variation in its measurements, IRT is a useful tool for assessing inflammatory pain.

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