Potential of Thermography in Pain Diagnosing and Treatment Monitoring

Mahnaz Etehadtavakol and Eddie Y.K. Ng

Abstract Pain has been a problem to be differentially diagnosed for years since it has been diagnosed subjectively. Thermography can provide data of pain quantitatively as it reports detail and deep thermal variations. Hence, this method can be useful to diagnose pain objectively. It is a noninvasive complementary diagnostic approach that allows the practitioners to see and quantify alterations on skin temperature. Since in a healthy human individual, there is a high degree thermal symmetry in terms of both magnitude and pattern in the same regions in contralateral parts of the body, subtle skin temperature changes can be easily detected. According to thermography pain is classified based on which part of the body is involved. It is mostly classified in diseases as neural, inflammatory, musculoskeletal, and vascular. Nowadays with the new generation of infrared cameras and very advanced sensitive sensors, thermography has been applied in many medical applications. Pain diagnosis is one of the many uses of thermography in medicine. This chapter introduces pain and application of thermography for diagnosis of different pain categories as well as monitoring the treatments.

Keywords Thermography · Pain diagnosing · Treatment monitoring

1 Introduction

In very old practice of medicine, practitioners measure temperature by hands. Hippocrates, approximately four decades B.C., applied wet sludge to patient's body to identify superficial body temperature. The areas that had disease dried more quickly. It is obvious that a number of pathological factors are involved in

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thermoregulation of human body. Hence, extracting thermal patterns of human body can help to access valuable information regarding the underlying physiological process causing diseases. Dissipation of heat through the skin generates infrared radiation that can be captured by sensitive infrared detectors. Pain is a complicated experience and the most familiar explanation for patient–clinician discussion in most developed countries. It is a major symptom in many medical conditions. We briefly introduce different pain categories in Sect. 2. Physiology of human skin is discussed in Sect. 3. Section 4 is about interpretation guidelines. Application of thermal imaging to diagnose different pain categories and treatment monitoring are presented in Sect. 5. Conclusion is provided in Sect. 6.

2 Classifications of Pain

There are many ways to classify pain and classifications may overlap. The International Association for the Study of Pain (IASP), in 1994, categorized pain in accordance with particular aspects: (1) area of the body complication such as lower limbs and abdomen, (2) system whose abnormalities may produce the pain such as gastrointestinal and nervous system, (3) continuation and form of happening, (4) strength and duration, and (5) etiology [1]. Although this introduced system was disapproved by Woolf et al. [2] as insufficient for leading study and therapy, three categories of pain were proposed by them as nociceptive pain, inflammatory pain that is related to tissue undesirable event as well as the immune cells incursion, and pathological pain which is a disease condition caused by nervous system corruption or by its irregular behavior such as irritable bowel syndrome, fibromyalgia, tension type headache, etc. [3]. However, classification of pain is a complicated issue and still many physicians are uncertain about it. Consequently, many clinicians often practice several different classification systems and clear separation of them is not always achievable.

a. **Nociceptive pain**:

Nociceptive pain is a chronic pain generated by injury to body tissue and often characterized as a sharpened, aching, or pulsating pain. This type of pain can be a result of benign pathology or by tumors or cancerous cells that are expanding and spreading to the tumor region neighborhood. Nociceptive pain may also be due to cancer growing to the muscles, joints, or bones or that brings about the closure of an organ or blood vessels [4, 5].

b. **Neuropathic pain**:

Neuropathic pain happens when there is a real nerve injury. Nerves accompany the spinal cord to the remnant of the body and permit the brain to interact with the skin, within organs and muscles. Nutritional disparity, alcohol addiction, toxicant substances, infections, or auto-immunity can all harm this network and generate pain. In addition neuropathic pain can be generated by a cancer tumor pressuring on a nerve or

a group of nerves. Patients usually characterize this pain as a flashing or severe sensation, or numbness toward the damaged nerve direction [6–8]. Thermal (vasomotor) variations which are reactions to the afferent noxious impulses of the unmyelinated sensory (thermoreceptors) nerves in the wall of microvasculature produce the neuropathic pain, while the ordinary somatic (somesthetic) pain is not often associated with circulatory dysfunction. The somesthetic pain involves afferent somatic (spinothalamic) nerves normally with no circulatory disturbance. Hooshmand et al. [9] found a case in which dermatomal pattern is developed in the extending of nerve roots and nerve trunks with somatic pain. However, the thermatomal distribution of neuropathic pain 'matches' to an arterial distribution including femoral, carotid, or brachial arteries. Hypothermic and hyperthermic variations in pathologic stages reflected in thermal imaging can be very valuable to choose a suitable treatment protocol. Magnetic resonance imaging, computed tomography, and physiological tests including electromyography and nerve conduction velocity tests are anatomical tests that are used as major identification techniques in the somesthetic (somatic) pain management, while they are not generally descriptive techniques in neuropathic pain recognition. However infrared imaging has potential to record neurovascular connection in neuropathic pain. Hooshmand et al. [9] found that thermogram produces information regarding diagnosis and treatment information restricted to complications connecting to neurovascular, autonomic, and neuro-inflammatory changes. Contrarily, it cannot assist diagnosing nerve damages with no microvascular connection including somesthetic nerve damages.

c. **Inflammatory pain**:

Inflammation is a reaction caused by injury of living tissues. The inflammatory reaction is a defense process that expanded into higher organisms to take care of them from infection and harm. The reaction incorporates changes in blood flow, a rise in blood vessels permeability, and transferring of fluid, proteins, and white blood cells (leukocytes) from the spread to the tissue corruption spot. If an inflammatory reaction ends only in a few days, it is named acute inflammation; however, a reaction of greater lasting is termed to as chronic inflammation. Despite the fact that acute inflammation is normally advantageous, it usually motivates displeasing sensations. Unpleasantness is generally lasting only a short while and ends when the inflammatory reaction has finished its task. However, in some occasions inflammation can cause harm. Tissue damage can happen when the managing processes of the inflammatory reaction are abnormal or the capability to improve harmed tissue and irrelevant individuals is damaged. The four important signs of inflammation, introduced by Aulus Cornelius Celsus in the first century, are as follows: redness (Latin rubor), heat (calor), swelling (tumor), and pain (dolor). Redness is generated by the expansion of small blood vessels in the region of damage. By increasing blood flow direct to the region, heat is generated and is accomplished solely in peripheral parts of the body such as skin. Fever boosts the temperature at the destroyed region by chemical attributors of inflammation. Basically fluid outside the blood vessels is built up and develops swelling or edema

[10]. When tissue is first damaged, the small blood vessels in the injured region are prohibited temporarily through a mechanism called vasoconstriction. Subsequent to this transient phenomenon, the process of vasodilation occurs or the blood vessels enlarge, rising blood flow into the region. Vasodilation period varies from 15 min to a few hours. Subsequently, the walls of the blood vessels, which typically admit simply only water and salts to pass through, eventually be more penetrable. Exudate or protein-rich fluid is instantly capable to leave and arrive at the tissues. Materials in the exudate involve clotting factors, which aid the expansion of infectious agents all over the body to be limited. Other proteins involve antibodies that enhance to demolish the attack of microorganisms. If a generated inflammation cannot be removed, or if the healing mechanism occurs, then an acute inflammatory reaction may develop to the chronic phase. If acute inflammation events happen again, a chronic inflammation is generated. The physical extent, duration, and impacts of chronic inflammation change with the originator of the injury and the body's strength to becoming better. However in some situations, chronic inflammation is not ended to acute inflammation. Some of the most typical and impairing human diseases, including tuberculosis, rheumatoid arthritis, and chronic lung diseases, are described by this kind of inflammation. Chronic inflammation can be achieved by infectious organisms that are capable of opposing host defenses and remain in tissues for a lengthened time.

d. **Musculoskeletal Pain**:

Impairment of muscles, joints, ligaments, bones, tendons, or a combination can cause musculoskeletal pain. The most typical cause of pain is injuries. Fibromyalgia may produce pain in the muscles, ligaments or tendons. The pain is normally involved with tenderness in multiple sites and sometimes is hard to express it accurately. However it is commonly not originating from the joints. Patients often complain other symptoms, such as poor sleep and fatigue. Compressing nerves may generate pain in some musculoskeletal impairment. These situations are introduced in the tunnel syndromes (for instance cubital tunnel, carpal tunnel, and tarsal tunnel syndromes). The pain spread diffusely along the path provided by the nerve and may be burning [11]. It is often associated with numbness, tingling, or both. When muscle strain occurs, heat elevation is observed due to the discharged chemicals. Consequently a strong hyperthermia pattern can be observed in the affected area or provoked site as an example of fibromyalgia.

3 Physiology of Human Skin

The skin is the largest organ of the body. Body temperature regulation is obtained by skin assistance that the human body has allowances to maintain its core internal temperature. Homeostasis is a condition that the internal temperature distributed evenly and all thermoregulation processes attempt the body back to the homeostasis

condition. Healthy body has a very limited temperature range of 37 °C (98 °F)–37.8 °C (100 °F). Body temperature can be affected by various factors. Diseases are the most familiar factors. Thermoregulation may lead to either cooling down or warming up. Thermoregulation for cooling down occurs in two major steps. In the first step, signals are sent to the hypothalamus by the sensors in central nervous system (CNS) to indicate the rise of internal temperature and in the second step, the hypothalamus in controlling thermoregulation mechanism stimulates one of several processes for temperature reduction. The mechanism can be considered as a negative feedback as shown in Fig. 1.

Conversely, the thermoregulation mechanism of body warming can be summarized as shown in Fig. 2.

Thermoregulation is a very complex and striking mechanism that we are not able to consider the details in this chapter. Spectrum of human skin blood circulation is very wide. It can be extended from almost zero when the whole body or a part of it is in cooling situation to up to 8 l/min (or equal to $\sim$60% of cardiac output) in extreme heat situations [12, 13]. Hence, the skin blood perfusion is a complicated process that the blood is capable to flow from very high to very low levels and able to control all within levels in order to satisfy the combined conditions of human physiology. There are two systems for reflex sympathetic innervation of the cutaneous circulation in human bodies. These two systems are non-noradrenergic active vasodilator system and sympathetic noradrenergic vasoconstrictor system. In normothermic environments, noradrenergic vasoconstrictor nerves are typically active and their activities are improved with cold stimulation, then norepinephrine as well

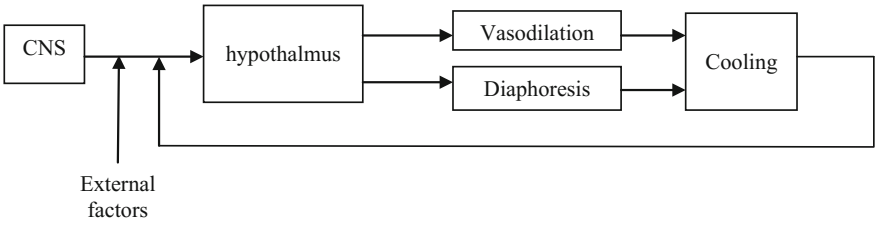

Fig. 1 Thermoregulation for cooling down

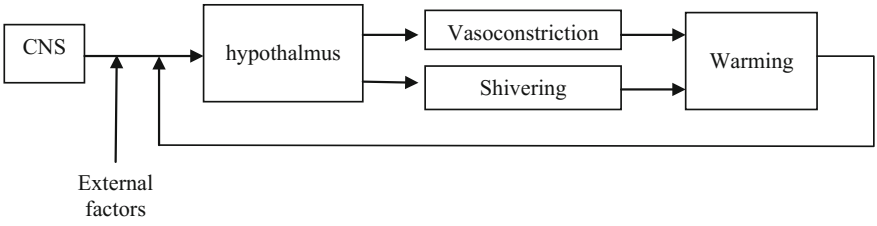

Fig. 2 Thermoregulation for warming up

as cotransmitters are released and consequently skin blood flow is decreased. However, the active vasodilator system is activated only when the body temperature is increased by heat stimulation. By cholinergic nerve cotransmission, active cutaneous vasodilation is developed. Long-term factors, such as illness, aging, and reproductive hormones as well as short-term factors such as hydration and exercise affect the processes of reflex cutaneous vasoconstriction and vasodilation [14, 15].

Skin temperatures in healthy individuals are symmetric since skin temperatures are controlled by one central controller which produces a uniform and simultaneous control system [16, 17]. Consequently, asymmetric thermal patterns of contralateral sides of the body (more than a certain level) can be a remarkable indicator of abnormality. Infrared radiation is one of different ways of human body heat loss. Planck's law considers the dry human skin nearly an ideal black body with an emissivity factor of 0.98. Hence it can be studied as a long wave infrared with a wavelength emissivity of 9.3 μm at most. The highest temperatures of human body are in the head and neck area, next trunk, and then declines over the limbs approaching the acral regions. One of the most crucial aspects of skin temperature pattern of the human body is bilateral symmetry [18–20].

4 Interpretation Guidelines

The following guidelines can be helpful to diagnose pain in using thermography method:

(1) Providing contralateral skin temperature differences in normal individuals: mean temperature difference for each part of the body. Different parts have different difference values
(2) Providing normal thermal pattern of the skin. For examples, hyperthermia is observed on the muscles (brachioradialis, trapezius, anterior tibia) [21], overlapped skin areas (under the breast, ham, axilla, groin (inguen)). While hypothermia is observed on the joint area (knee, elbow), distal area (finger tips (palm side), toe tips, cheek, heel, nose), fat area (breast, buttock, brachial region)
(3) Engaging patient's complain
(4) Identifying region of interest
(5) Testing the contralateral heat pattern to check the symmetries
(6) Testing the mean temperature difference for each part of patient's body
(7) Exploring different colors in patients' thermogram. In thermography certain colors have different interpretations. For example inflammatory disease, muscle activity related disorders and acute stage are indicated by bright red color, while neural disease and chronic stage by dark blue
(8) Discovering shape of heat from patient's thermal pattern. Shape of heat also has different implication in thermography. For instance, local muscle activity is mostly indicated by localized form (spot type), somatic or visceral induced

disorders by regional form (referred type) and thermatome, neuropathic pain by patterned form.

Many studies have been done to establish some of the guidelines. In a study, Niu et al. [22] provided normative data of the skin temperature in different areas to investigate contralateral thermal symmetry in young and old as well as male and female normal individuals in Taiwan. They tested 57 healthy subjects. They found that the neck had the highest skin temperature average of 31.9 °C with standard deviation of 0.6, while the toes had the lowest ones with average of 27.5 °C and standard deviation of 0.2. They also found slight contralateral thermal differences no more than 0.5 °C. In addition, they understood that old people had lower skin temperature particularly in the distal parts of extremities. Lower temperatures are found in different truncal regions in elderly females [22]. Gatt et al. investigated thermal patterns of the upper and lower limbs of 67 subjects. They discovered thermal symmetry in terms of both magnitude and pattern in the same regions in contralateral limbs. The warmest finger was thumb and the temperature declined gently for the second and the fifth digits. The big toe and the fifth toe were the warmest digits while the second to the fourth toes the coolest ones [23].

5 Application of Thermal Imaging

(a) **Diagnosing Different Pain Categories**

According to thermography pain is classified based on which part of the body is involved. It is mostly classified in neural disease, musculoskeletal disease, inflammatory disease and vascular disease. Pain has been a problem to be differentially diagnosed for years since it has been diagnosed subjectively. On the other hand, thermography can provide data of pain quantitatively. Hence, it can diagnose pain objectively. Thermography presents crucial data concerning neuropathic pain as a result of perivascular microcirculatory sympathetic dysfunction. It can help the physician to select a suitable and safe treatment protocol, particularly preventing needless surgery. Brusselmans et al. [24] did a test in healthy and fibromyalgia groups. They measured the autonomic response of individuals during a cold-water test. They concluded that the central body temperature, forearm temperature and peripheral (forearm)-central (ear) temperature ratio are significantly different in the two groups. In addition, fibromyalgia subjects had less tolerance to cold water than healthy subjects. They also studied the cool down rate, thermal recovery, and total temperature reduction in the two groups. In a project, Goto et al. [25] aimed to detect differentiating aspects in thermal images of venous leg ulcer (VLU), to evaluate VLU-related nociceptive pain. They concluded thermal patterns may catch nociceptive pain of VLU received by inflammation and has potential to evaluate pain as a simple and fast method. Hooshmand et al. [26] in a study investigated the role of thermal imaging for identification and management of pain. Herry et al. [27] introduced an algorithm that thermographic image of pain was computerized

automatically for pain evaluation in order to assist specialists to diagnose the diseases. A considerable betterment in circulation and indicative response to decreased pain with Electron Transfer Technology sleep system after applying it for only 4 nights was obtained by the thermal images in a case with chronic neck and upper back pain, reported by Dr. William Amalu [28]. A common cause of pain in situations of varicose veins is thrombophlebitis which results painful legs. Inflammation is generated by increasing the venous diameter that results in increase in volume, and consequently by a decrease in serous velocity [29]. Thermography helps us to visualize superficial vascular patterns of legs. Thermogram of a patient experiencing phlebitis, the inflammation of a vein, is shown in Fig. 3.

Figure 4 shows a patient with a Complex Regional Pain Syndrome in right foot with an asymmetry of 3.7 °C of contralateral feet. The patient went through the cold stress test indicating no sympathetic change. The disease spread in the right foot following the fracturing of the calcaneum 18 months earlier. At first, the disease was not recognized by nuclear imaging and failed. However, thermography could show the alterations.

Very few methods are available to indicate pain located in the metal implants sites. Glehr et al. [30] concluded that thermography had potential to identify and assess pain more accurately. They showed that the skin temperature on the painful regions of individuals complaining of anterior knee pain after implantation of

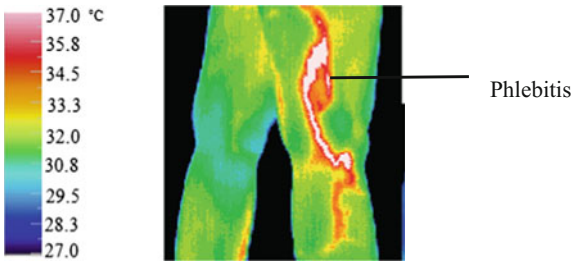

Fig. 3 Thermogram of a patient experiencing phlebitis [29]

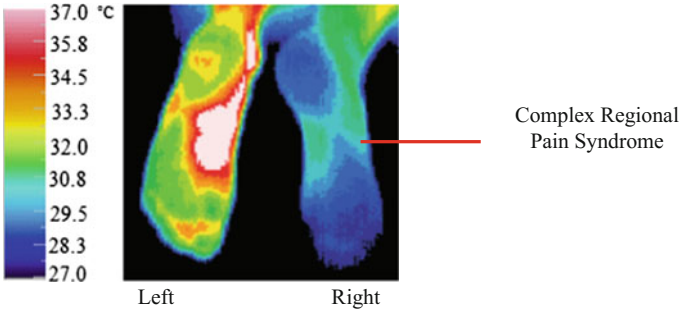

Fig. 4 Thermogram of a patient with a complex regional pain syndrome in right foot [29]

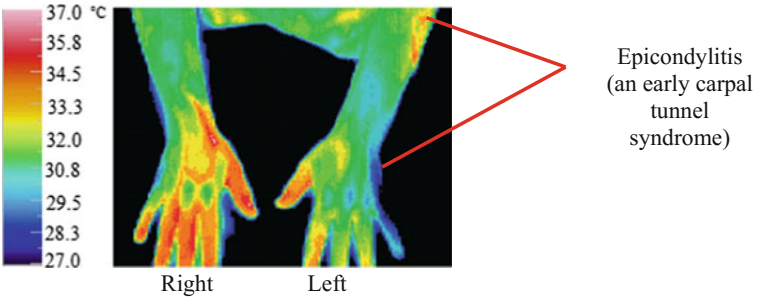

Fig. 5 Thermogram of a patient with golfer left elbow [31]

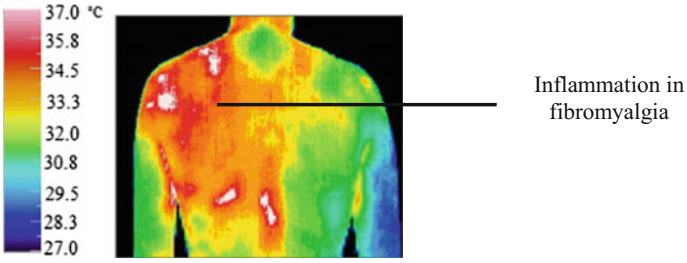

Fig. 6 Thermogram of a fibromyalgia patient [32]

artificial knee joints was significantly higher. Thermography can be helpful for patients that suffering pain that other tests cannot diagnose. Patients with golfer elbow are complaining of pain due to the condition that causes pain where the tendons of the forearm muscles attach to the bony bump on the inside of the elbow. Golfer elbow and, in some cases carpal tunnel syndrome, are all problems associated with the inflammation of the soft tissues in the wrist and elbow. Repetitive physical motion in sports or work, producing repeated impacts to the arm that finally pain can be induced from the wrist to the elbow. Thermogram of a 28-year-old male carpet layer with golfer left elbow who has pain that radiates distally through the ulna into the smallest finger is shown in Fig. 5. By doing thermography cold stress test, an early carpal tunnel syndrome was indicated [31].

A multiple symptoms such as ache, muscle tenderness, headaches, anxiety, depression, sleep pattern disruptions, fatigue as well as pain and ache throughout the body can be observed with fibromyalgia patients. Thermography is very useful to identify the muscular and myofascial inflammation accurately and objectively thus allowing the physician to monitor a comprehensive action plan of treatment. Thermogram of a fibromyalgia patient is presented in Fig. 6. Areas of pain and inflammation associated with fibromyalgia are demonstrated with different colors [32].

(b) **Treatment monitoring**

Blood circulation improvement is a powerful sign of physiological recovery. By comparing thermal images of pre- and post-therapy, treatment progress can be assessed. Consequently, if the image of post-therapy is not indicating major thermal recovery, then additional therapies could be considered. As shown in Fig. 7a, around the lower patella there is an extensive hyperthermia that indicates the inflammation development associated with swelling and pain. However, as shown in Fig. 7b, the same knee after 6 months of treatment by a comprehensive rehabilitation program [33].

Another example is a case with severe alpine skiing accident with a serious injury as a fracture. The thermogram shown in Fig. 8a was provided 3 months after a combined fracture of the tibia and fibula with intramedullary nailing [33]. However, no clear differences of the thermal pattern of two sides were observed and complete recovery was approved and confirmed with physical examination as it is evident in Fig. 8b.

In an encyclopedic study, Hooshmand et al. [34] indicated that the most sensitive tool to detect Reflex Sympathetic Dystrophy is thermography method and no other

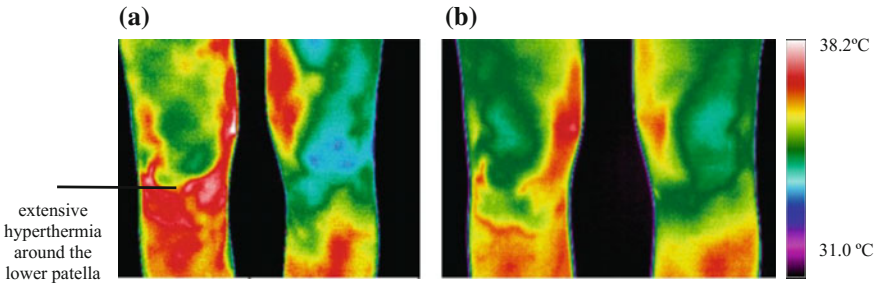

Fig. 7 Inflammation monitoring [33]. **a** Pre-therapy **b** post-therapy

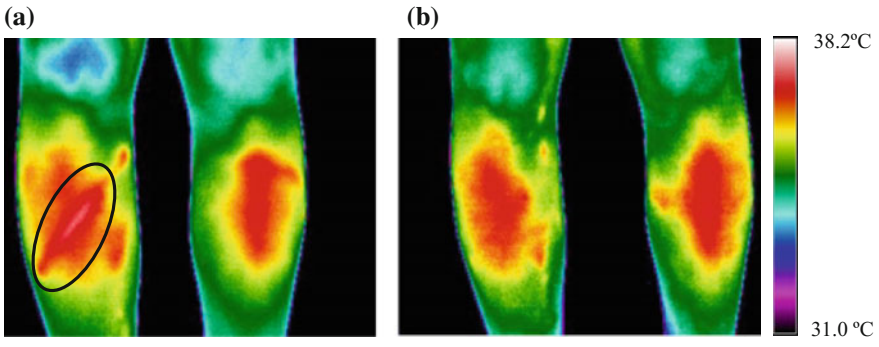

Fig. 8 Treatment monitoring of a case with severe alpine skiing accident [33]. **a** Pre-therapy **b** post-therapy

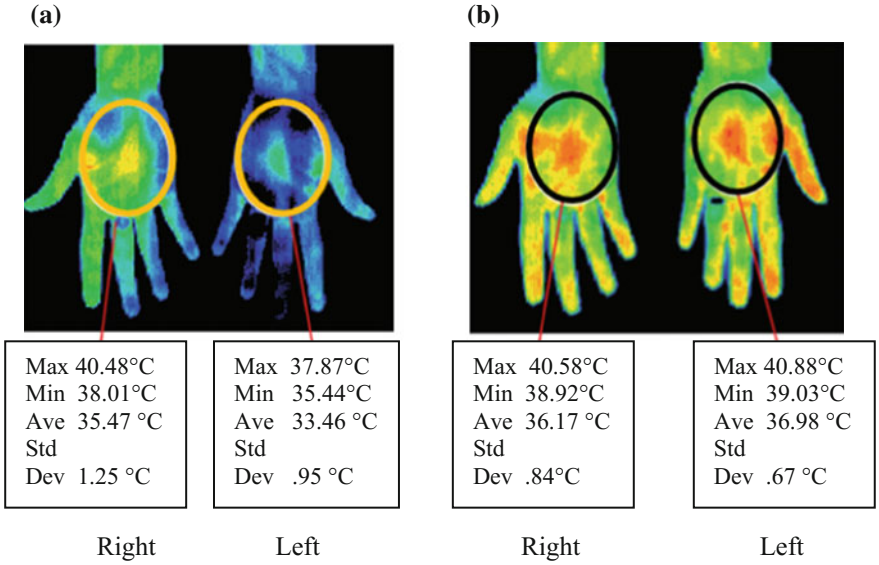

Fig. 9 A patient with reflex sympathetic dystrophy (complex regional pain) [29]. **a** Pre-therapy **b** post-therapy

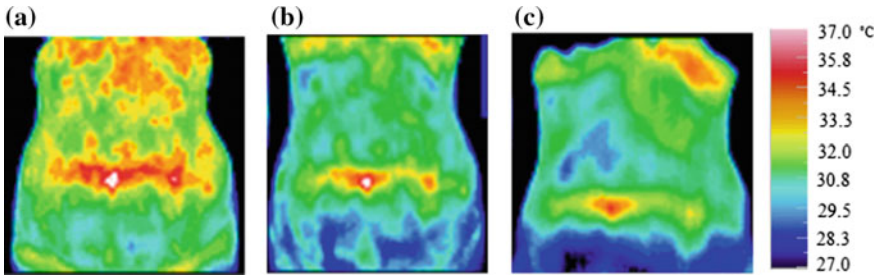

Fig. 10 Treatment monitoring of one irritable bowel syndrome (IBS) patient by taking aloe vera juice [35]. **a** Pre-treatment **b** after 5 days **c** after 13 days

test can compete with it [34]. There was a patient with Reflex Sympathetic Dystrophy (Complex Regional Pain) that had a "glove-like" hypothermia zone in the left hand as shown in Fig. 9a. The temperature differential was 1.5 °C and asymmetry was 5 °C. These numbers were notable. The patient went through the cold stress test showed the right hand had sympathetic function while the left had nothing. Provided thermal patterns of post-therapy indicated thermal symmetry as shown in Fig. 9b. In addition, cold stress test also indicated sympathetic function in both hands [29].

Figure 10a–c, are thermal images of one irritable bowel syndrome (IBS) patient who is treated with aloe vera juice. Figure 10b, c show the treatment by taking aloe vera juice 5 days and 13 days, respectively [35].

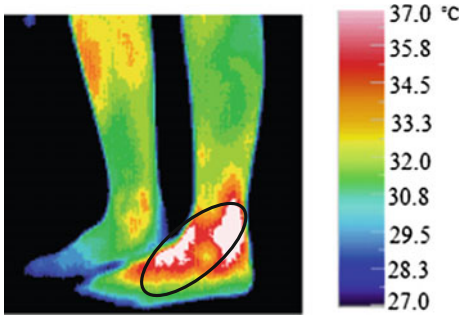

Fig. 11 A thermogram after removing the cast of a patient who had a fracture and still needs further treatment [36]

Figure 11 shows an individual who had a fracture in the left ankle. The cast was removed and unfortunately healing response was poor. Left ankle was monitoring for further treatment [36].

6 Conclusion

Pain diagnosis has been a problem for many years since the diagnosis is a very subjective and an individual experience. There is no test can provide data indicating the accurate information regarding the location and amount of the pain. Hence, clinicians count on the patient's own explanation of the location, form and timing the pain. However, thermography can provide data of pain quantitatively and be useful to diagnose pain objectively. It is a noninvasive complementary diagnostic method that can help the clinicians to discover any alterations on the skin temperature. With the new generation of infrared cameras, many specialists have considered thermography as a method to diagnose the type and location of pain precisely. It has been recognized that thermography is the most sensitive test to detect pain in some diseases for example Reflex Sympathetic Dystrophy and no other is able to compete with it. Hopefully, specialists are getting familiar with this powerful technique to use it for accurate detection of different pain categories and monitoring of different pain treatments in the near future.

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