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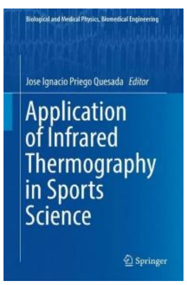

Application of Infrared Thermography in Sports Science
by Jose Ignacio Priego Quesada (Editor)
ISBN-13: 9783319474090
Springer International Publishing

This book addresses the application of infrared thermography in sports, examining the main benefits of this non-invasive, non-radiating and low-cost technique. Aspects covered include the detection of injuries in sports medicine, the assessment of sports performance due to the existing link between physical fitness and thermoregulation and the analysis of heat transfer for sports garments and sports equipment. Although infrared thermography is broadly considered to be a fast and easy-to-use tool, the ability to deliver accurate and repeatable measurements is an important consideration. Furthermore, it is important to be familiar with the latest sports studies published on this technique to understand its potential and limitations. Accordingly, this book establishes a vital link between laboratory tests and the sports field.

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1. Sports Medicine

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A. The Application of Medical Infrared Thermography in Sports Medicine

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Introduction

Medical Infrared Thermography (MIT) is a non-radiating and contact-free technology to monitor physiological functions related to skin temperature control. The efficiency, safety and low cost of MIT make it a useful auxiliary tool for detecting and locating thermal abnormalities characterized by increases or decreases in skin surface temperature. It has been successfully utilized in the field of veterinary medicine to detect locomotion injuries in racehorses and to monitor their health status. However, research on human athletes with modern infrared sensor technology is more rare. Athletes are exposed to physical stress in training and during competition season. Overuse reactions and so-called "minor traumas" are very frequent; therefore, early detection is critical to avoid injuries. Research suggests that the most beneficial application of MIT is the screening of individuals for overuse injuries. In the following chapters, the use of MIT in clinical practice is presented with special focus on sports injuries and exercise-induced physiological functions. Case studies illustrate the clinical applicability.

MIT – Quo Vadis?

2.1 History and development The association between changes in temperature and disease is almost as old as medicine itself. Hippocrates stated, "should one part of the body be hotter or colder than the rest, then disease is present in that part". The first application of thermal imaging was in the early 19th century and did not have any commercial purpose. Following the 2nd World War, infrared imaging systems were used to monitor changes in skin temperature in relation to certain diseases (Ring, 2007). Poor quality imaging systems and a lack of methodological standards in the past has limited quality, resulting in non-acceptance of the technique (Elliot & Head, 1999). Technological advances in infrared cameras within the last few years have promoted MIT as a powerful measurement tool. A new generation of high-resolution cameras, appropriate software and standardized protocols have been developed for medical imaging, resulting in improved diagnostic capability and reliability (Plassmann et al., 2006; Diakides & Bronzino, 2008). In 1987, the American Medical Association recognized MIT as a feasibleThe following worldwide Thermographic organizations promote the proper application of medical thermal imaging.

- International Academy of Clinical Thermology
- International Thermographic Society
- American Academy of Medical Infrared Imaging
- European Association of Thermology
- Northern Norwegian Centre for Medical Thermography
- German Society of Thermography and Regulation Medicine

2.2 Technical principles Most of the diagnostic imaging modalities in medicine utilize portions of the electromagnetic spectrum (Hildebrandt et al., 2010). However, in contrast to other medical devices, MIT uses non-ionising radiation, thus allowing an unconstrained and harmless application in patients. Using infrared radiation, infrared cameras generate thermal images based on the amount of heat dissipated at the surface. Roughly 80% of the emitted infrared radiation of human skin is in the wavelength range of 8-15μm (Steketee, 1973). The technology operates in the long-wave infrared region and is a sophisticated way of receiving electromagnetic radiation and converting it into electrical signals. These signals are finally displayed and matched to colors on the screen for calculations. Modern focal plane array detectors ensure a stable image with high thermal resolution. Sensitivity and resolution are important parameters for medical devices (Plassmann et al., 2006). High-resolution cameras with focal plane arrays of 320×240 pixels, a thermal sensitivity less than 50mK and a spatial resolution of 25-50μm ensure useful thermal and spatial details (Ring & Ammer, 2000). The resulting information can be used to provide instant feedback on the patient or athlete. Unlike other medical imaging modalities, MIT is not related to morphology. However, to study cutaneous circulation, the non-contact method of MIT was compared with other medical imaging modalities. Merla et al. (2007) calculated blood flow by using MIT and laser Doppler imaging (LDI) and showed that cutaneous blood perfusion values obtained from MIT correlate with those obtained by means of LDI and have the advantage of a better time resolution.   2.3 Biological principles Human skin, with an emissivity (an object's ability to emit radiation) of 0.98, is almost equal to a black body radiator (Steketee, 1973). The physics of heat radiation and the physiology of thermoregulation in the human body make the reliable and valid interpretation of thermal images difficult. Skin temperature regulation is a complex system that depends on blood-flow rate, local structures of subcutaneous tissues and the activity of the sympathetic nervous system (Kellog & Pergola, 2000). However, there is evidence that the sympathetic nervous system is the primary regulator of blood circulation in the skin and is, therefore, the primary regulator of thermal emission (Charkoudian, 2003). Vasoconstriction and vasodilation of the blood vessels function to regulate blood flow in the skin. Thermoreceptors in the skin, also known as Ruffini corpuscles, recognize the ambient temperature. An increased temperature results in vasodilation, leading to increased blood flow to the skin, whereas vasoconstriction occurs by adecrease in temperature and results in reduced blood flow to the skin (Wallin, 1990). These physiological processes combine with heat transfer and thermoregulation in convection, conduction, radiation and sweat evaporation. Heat transfer by radiation is of great value in medicine (Blatteis, 1998). To date, the mechanism of thermoregulatory adaption to exercise is complex and not entirely understood.

MIT – What is its place in medicine?

3.1 Human medicine MIT is used in a variety of medical applications in the fields of neurology, oncology, orthopedics, and dermatology (Diakides & Bronzino, 2007). The technique has gained widespread use in breast cancer research (Arora et al., 2008; Ng, 2009; Kontos et al., 2011). Tumors are characterized by increased angiogenesis and, therefore, increased metabolic activity, leading to higher temperature gradients compared to surrounding tissue. In addition, MIT is well accepted in surgery. In aortic-coronary bypass surgery, it is possible to monitor the restart of blood flow through the coronary blood vessels (Wild et al., 2003). In plastic surgery, an infrared camera can evaluate the reperfusion of perforator flaps (de Weerd, 2006). For all medical areas, it should be noted that MIT, as an outcome measure, provides a visual map of the skin temperature distribution but cannot quantify absolute temperature values. In addition, MIT alone should not be used as a diagnostic tool; clinical examinations must be included for interpreting thermograms. Several global medical institutions are concerned about scientific work, and the practical application of MIT in medicine has lead to an increased number of publications in peer-reviewed journals.   3.2 Sports medicine MIT has been successfully utilized in the field of veterinary medicine to detect locomotion injuries in racehorses and to monitor their health status (Turner, 2000; Eddy et al., 2001). By using an infrared camera, Turner et al. (2000) examined tendonitis in race horses and detected hot spots before clinical evidence of swelling and lameness. However, research on human athletes is more rare. Sports medicine must provide high-quality care for athletes, and a modern approach for identifying risk factors and injury prevention should be of primary importance (Bruckner & Khan, 2006). Athletes are exposed to great physical stress in training and during competition. Overuse reactions are frequent; therefore, their early detection is important. Furthermore, early detection and localization of inflammation is a critical step in determining the appropriate treatment. Inflammation will usually cause a localized increase in skin temperature, thereby disturbing the "normal" symmetry. Nerve damage or disturbances to the autonomic nervous system may also cause a change and may lead to a localized cooling of the affected area. Because this is a remote sensing technique, it is possible to monitor body surface temperature during and after movement and thereby detect changes in skin temperature caused by the exercise or therapy (Ring & Ammer, 1998, Hardaker et al., 2007). Within the field of sports medicine, long-time sport specific changes in physiology and therefore thermoregulatory processes, as well as changes in anatomy such as muscle structures, needs to be considered.   3.3 Standardization methods Modern state-of-the-art technology has made MIT a reliable measurement tool (Jiang et al., 2005). When used as an outcome measure it must satisfy the basic criteria of measurement. The quality of thermal imaging depends on the technical equipment and the experience of the examiner (Plassmann etal., 2006, Ring & Ammer, 2000). Proper care must be taken with standardization of the imaging procedure to avoid misinterpretation of the thermograms. Thermography societies provide protocols including examination recommendations and technical guidelines. The following aspects are considered:

- Control of Examination Room Conditions
- Patient Preparation
- Number of Studies and Views
- Equipment
- Patient Identification
- Thermogram Analysis

A thermogram represents the human skin temperature profile illustrated by a color spectrum. However, false colors do not necessarily represent a particular temperature. To standardize the analyses of medical thermograms used for fever detection, the International Standards Organization (ISO) recommended the use of the “rainbow” temperature scale that represents high temperatures with red colors and low temperature with blue colors. To visualize differences within similar tissues or structures, the “rainbow strong-contrast” scale can also be used. When focusing on the vascular system, a gray color scale is preferred. Image fusion, merging the infrared image and a digital image, is another important step for reliable analyses. This technique allows better mapping of anatomical landmarks and therefore provides a precise definition of the region of interest (ROI). Additional labeling of anatomical landmarks within the ROI provides consistency for repeated measurements. To provide a standard for size, shape and placement of the ROI, a research group from the University of Glamorgan has proposed a protocol based on anatomical landmarks (Plassmann & Murawski, 2003; Ammer, 2008).

Applicability of MIT in clinical and athletic use

Peripheral circulation plays an important role in tissue healing and thermoregulation. To interpret skin temperature changes following injuries (non-thermal stimuli) and exercise (internal stress stimuli), we need to understand the different physiological responses in the structures involved.   4.1 Non-thermal stimuli / sport-specific case studies of injuries The following chapter focuses on case reports of specific sport injuries. Thermal images were taken with a modern infrared camera. Further technical details can be found in the article from Hildebrandt et al. (2010). Normal findings in human body skin temperature are a symmetrical distribution (Vardasca 2008; Selfe et al., 2008), and injury can affect this thermal symmetry. Figure 5 represents an example of a symmetrical temperature distribution of the knees from a healthy subject. On the anterior view the patella appears as a cold shield due to bony structure. The muscles of the upper and lower leg represent hot areas due to high metabolic activity in the muscles. The posterior aspect of the knee shows high temperature in the popliteal fossa because of the popliteal arteries and veins. From a qualitative point of view, side-to-side comparison shows a very symmetrical pattern. To define whether a thermogram is normal, a current project at the University of Glamorgan aimed to create a database of thermal images from different parts of the body from healthy subjects. Previous literature has shown that a difference of more than one degree centigrade between sides of the body may indicate a pathophysiological process (Selfe et al., 2008). However, long-time, observational data from injured and non-injured athletes needs to be investigated to define sports specific thermograms. An injury causes blood flow variations that then affect skin temperature. Many medical conditions are associated with regional vasodilation and constriction, hyperperfusion, hypervascularization and hypermetabolism that cause higher temperature profiles of the skin surface. Physicians need a deeper understanding of the biological nature of thermal signals and consistent thermal alterations of sport specific injuries for early intervention and correct treatment. In addition, the natural healing process of traumatic and overuse injuries can be easily monitored by using thermal imaging. However, this requires the comparison of baseline images prior to and following an injury. 4.1.1 Overuse injuries FOOTBALL High-intensity training combined with frequent competition pushes the locomotor system to its anatomical and physiological limits. Woods et al. (2002) stated that young football players are at a greater risk of minor injuries, overuse injuries, lower leg injuries and muscle strains during the preseason period. We conducted preseason measurements of 25 football players (mean age 17.6± 3.9 years, height 176.1± 8.1 cm, mass 67.8±9.1 kg) from a Football Academy. Fifty two percent of the athletes reported no injuries, 28% had an overuse injury and 20% sustained a traumatic injury within the previous 6 months. The following example shows a non-acute overuse injury of a 17-year old football player. He was diagnosed with recurrent medial shin splint on his left leg and was asymptomatic when the baseline images were taken. However, the area of referred pain on the left leg matches the area of cooler skin along the tibiae. This problem became even more visible following a sport-specific warm up program, indicating a low metabolic activity around the affected structures (Figure 6b). In addition, the athlete had a history of osteochondrosis at the tibial tuberosity of both knees. Especially following exercise, the tibial tuberosity on both knees appeared as a cold area. The following example of a 25-year old professional football player represents an incidental finding. Images were taken within the scope of a team screening. On the injury questionnaire, no acute problems were reported. Upon inquiry no signs of venous disease were reported. However, the subject´s right greater saphenous vein appeared very clearly as an area of increased warmth on the thermogram that may indicate a vascular dilatation with beginning venous insufficiency (Figure 7). Further observational research will determine if this abnormality predict future problems prior to the onset of symptoms.   RUNNING Epidemiological studies have shown an alarmingly high incidence of knee, foot, ankle and lower leg injuries in recreational and competitive runners. Most of these injuries were overuse injuries including stress fractures, shin splints, patellar tendinitis and, most prevalent, Achilles tendinitis (Hreljac, 2005). The following thermograms were taken of a 22-year old competitive middle distance runner who runs 40-100km a week. He reported pain in his right Achilles tendon that occurs gradually, especially during exercise. The athlete was diagnosed with mid-portion Achilles tendinopathy with mild morphological abnormalities. At the time the images were taken, there was a small but noticeable pain at rest and no swelling. The average temperature of the ROI on the right side was 1.6° C lower compared to the non-affected side. The lower temperature may indicate lower metabolic activity due to affected tissue with a loss of normal fiber structure. Following a treatment period of 8.5 weeks, including electro-physical and physio-therapeutic treatment, thermograms were taken again under resting conditions and following a 45-minute run of low intensity.The side-to-side temperature difference dropped to 0.6°C before exercise, indicating better metabolic activity of the affected side. Following exercise, the right Achilles tendon junction was colder compared to the left one, with a temperature difference of 1.0°C. The athlete reported no pain at rest or following exercise. The regular treatment seemed to improve the Achilles tendon metabolism. However, the impaired metabolic activity following the sport-specific exercise needs to be further addressed with continuing therapy to prevent recurrent problems.   SWIMMING A study, by Sein and co-workers in 2008, investigated shoulder pain in elite swimmers and found that 91% of the swimmers reported shoulder pain; moreover, 84% of the athletes demonstrated a positive impingement sign. The following thermal image was taken of a 27-year-old elite female swimmer under resting conditions (Figure 11). Following a high-volume swimming program, she reported pain and stiffness in both shoulders. With her right arm, she had difficulty reaching behind her back. The clinical examination confirmed overloading of the supraspinatus tendon and general stiffness of the shoulder muscles on both sides. The thermal image shows a hot area above the right deltoid muscle and a hot spot on both shoulders in the region of the humeral head, near the insertion of the supraspinatus muscle. Based on healthy baseline thermal images, MIT should be used to further monitor pathophysiological thermal changes during high-volume swim training prior to the onset of symptoms.   YOUTH SPORTS A common problem, predominantly in young, male athletes is the occurrence of enthesopathy of the ligamentum patellae (Gholve et al., 2007). This insertion tendinitis, caused by repetitive mechanical strain of the patella tendon, is characterized by pain, swelling and tenderness above the tibial tuberosity (Brukner & Khan, 2006). Thermal images clearly show a hyperthermic area above the tibial tuberosity (Figure 12). Long term evaluation of affected athletes from alpine skiing (n= 7), football (n=3), running (n=2) and tennis (n=1), who showed acute symptoms in one leg, revealed a side-to-side temperature difference of 1.1°C (± 0.71 °C). The technique provides a quick screening tool and should be used as a first-line detection tool prior to ultrasound or conventional X-rays.   4.1.2 Traumatic injuries Traumatic injuries usually involve a long, costly rehabilitation period, and they are challenging for the athlete. An injured athlete is under pressure to return to competition as soon as possible. High-quality treatment can reduce the duration and negative impact of the rehabilitation period. It is well known that richly vascularized areas heal faster compared to poorly vascularized areas (Singer et al., 1999). MIT may give information about the state of vascularization and the on-going healing process to ensure the most effective treatment and provide recovery information to decrease the likelihood of re-injury by returning to the sport too quickly.   ALPINE SKIING Knee injuries, especially ruptures of the anterior cruciate ligament (ACL), represent a significant problem in professional alpine skiing (Flørenes et al., 2009) as illustrated by the case of a 21-year-old skier. At

16 years the skier ruptured his left anterior cruciate ligament, medial collateral ligament and the medial meniscus. Since that time, he has suffered from periodic pain, predominantly around the patellae. At age 20 years he was diagnosed with articular cartilage, damage grade three. According to the International Cartilage Repair Society, grade three indicates that the lesion affects more than 50% of the cartilage layer. The average temperature difference of the left patellae was found to be 1.6°C lower compared to the right side. The temperature difference from the area above the upper kneecap showed a side difference of 1.2°C, indicating poor metabolic activity of the lower quadriceps muscle under resting conditions. TRIATHLON The incidence of tendon ruptures has increased in recreational sport activities, with the highest incidence in older age groups (Clayton et al., 2008). However, Rettig et al. (2005) stated that the potential risk of re-rupture is highest in athletes younger than 30 years of age. The infrared images below were taken of a 26-year old triathlete, 6 months following a complete rupture and direct operation of his right Achilles tendon (Figure 14). When the images were taken, he was referred with mild pain that was exercise dependent and a feeling of numbness in the outer toes. The ongoing healing process did not seem to be sufficiently complete. The temperature difference of an area from the upper Achilles tendon to the muscle belly of the musculus triceps surae was found to be 1.6°C, suggesting delayed healing with impaired circulation. In particular the cooler area of the musculotendinous junction should be considered further within physio-therapeutic treatment. The area of numbness becomes visible through a clear hypothermia on the affected toes and must be a target of further rehabilitation (Figure 15a,b). Future research will determine if tissue remodeling is still on-going after symptoms disappear. 4.1.3 Static versus dynamic measurements Baseline recordings, following a sport-specific strain, should be conducted to visualize thermal regulatory processes. Regarding infrared images of overuse injuries, repeated measurements following sport-specific exercise will clarify if symptom-free asymmetrical temperature distributions are predictive for presymptomatic identification of initiating overuse reactions. The following example of an 18-year old football player indicates a presymptomatic thermal abnormality during pre-season measurement. The thermogram at rest demonstrated symmetrical patterns. Following sport-specific exercise, local side differences on the knee were visible. The athlete reported no pain at that time.However, during the season, he reported a feeling of load-dependent, diffuse knee pain in his left leg. The medical examination confirmed a low threshold for pressure on the medial aspect of the knee. No clear diagnosis could be confirmed, indicating a local overuse reaction. Excessive stress should be administered with caution. 4.2 Thermal stimuli- time sequential images following different exercise Physical exercise and repetitive strain is a challenge to thermal homeostasis. During exercise, the thermoregulatory control of blood flow in the skin is important to maintain normal body temperature and leads to changes in hemodynamics, and, therefore, thermal signals (Kenney & Johnson, 1991). Using state-of-the art infrared sensor technology, cutaneous temperature changes during exercise can be evaluated. Skin blood flow is predominantly regulated by neural regulation (Thomas & Segal, 2004). By taking time-sequential images of exercise, the immediate response of the sympathetic nervous system via the somatocutaneous reflex can be visualized. The investigation of infrared images taken before and after sport-specific exercise may further determine the applicability of MIT to investigate the physiology of biological tissue. Furthermore systemic cutaneous blood flow regulation can be monitored as a function of exercise type, duration and intensity. AEROBIC VERSUS ANAEROBIC EXERCISE The mechanism of homeostasis during exercise is guaranteed through multiple functions, such as cardiac processes, peripheral circulatory control, blood pressure regulation and temperature control (Berne & Levy, 2000). A better understanding of the cutaneous circulation, and, therefore, the control of blood flow during exercise is a challenge in integrative physiology (Kellog & Pérgola, 2000). We investigated thermal characteristics of aerobic and anaerobic bicycle exercise to predict evidence of altered perfusion. Twelve athletic males (mean age 26.0 ± 2.7 years, height 177.2cm ± 4.3 cm, mass 71.1 ± 8.4 kg) performed both, anaerobic exercise (5 minutes, 80rpm, 90%HRmax) and aerobic exercise (45 minutes, 80rpm, 60%HRmax) under thermo-neutral conditions. Images were taken prior to (Figure 17a) and immediately following aerobic (Figure 17b) and anaerobic exercise (Figure 17c). The ROI was defined above the middle portion of the M. quadriceps. The temperature above the exercising muscle increased following aerobic exercise (0.7°C, $p=0.215$) and decreased following anaerobic exercise (- 5°C, $p=0.094$). In addition hot colored dots over the thigh occurred after aerobic exercise. To meet the increased metabolic demand of active muscles, short- term, intense exercise leads to a redistribution of blood flow away from inactive tissues such as the skin, to exercising muscles through the vasoconstrictor system (Kenney & Johnson, 1991). This process explained the marginal skin temperature decrease following anaerobic exercise. From a clinical point of view, this observation becomes interesting for patients with compromised cardiac function. As previously reported, these patients showed a higher magnitude of vasoconstriction compared to a healthy group, suggesting that the initial reflex vasoconstriction may be linked to cardiovascular functional capacity (Zelis et al., 1969). With continuing exercise, the body core temperature begins to rise. When internal

temperature increases toward a threshold, a regulating system starts to stimulate thermo-sensitive neurons in the central nervous system. This triggering of cutaneous vasodilation ensures the transfer of metabolic heat from the core to the skin (Charkoudian, 2003). The present study showed that the competing system of thermoregulatory drive for cutaneous vasodilation and the non-thermoregulatory drive for cutaneous vasoconstriction could be visualized by using MIT. As previously reported, the interactive control system, as a normal function of dynamic muscular exercise, seems to dependent upon the intensity and duration. The multiple hot spots seen on the thigh (Figure 17b) illustrate the so-called perforating blood vessels that originate in deeper lying tissue. The vasoconstrictor mechanism at the beginning of the exercise is mainly in the skin blood vessels, whereas the perforator vessels are less affected. As exercise duration increases, they contribute to the rewarming of the skin (Merla et al., 2010). The identification of a skin thermographic map of perforator vessels that includes their perfusion area can be important to define individual anatomy of certain tissues (Salmon et al., 1988). Further research should examine the time-course of thermal changes by taking multiple images during and following an exercise. In addition, the relationship between thermal changes, aerobic capacity and performance may further determine different functional states of the body dependent on intensity and duration.

Conclusion

High-quality scientific work with modern 21st-century technology coupled with a better understanding of the regulation of skin blood flow has improved the capability of MIT in medical use. Our research findings suggest that the most beneficial output of MIT seems to be in the screening of athletes for overuse injuries. We suggest combining baseline images with images taken following sport-specific exercise to provoke sufficient thermal alterations in the tissues. A main challenge is to combine the anatomical and physiological information demonstrated by the thermal pattern of the skin. The biological nature of thermal signals and consistent thermal alterations of different sport-specific injuries should be further addressed. Thermal screening of injured and non-injured athletes is the first step to create a sport-specific database with individual thermograms. Repeated follow-up measurements during the sport season will further clarify the link between asymmetrical temperature distributions, pathophysiological changes on the skin surface and the extent of injury. The long-term aim is to create a knowledge-based database of thermograms of overuse and traumatic injuries. However, it should be considered that within a certain time span, different pathologies could alter their patterns of temperature. A deeper understanding of the different time courses of injuries is important to clarify the benefit of MIT in injury management and to define whether a thermogram is “normal” or not. In terms of quantification of side-to side differences within a defined ROI, it is important to use the medical analysis function of image fusion. The main advantage of MIT is its safety, however, the disadvantage of MIT results from its physical limitations. The non-radiating, two-dimensional technique provides information about surface structures. A conclusion of processes in deeper tissues needs to be further investigated by combining different medical imaging modalities. In addition, it must be clearly stated that the aim of MIT use in sports medicine is not to be a substitute for clinical examination, but to enhance and support it. It can be concluded that MIT is a reliable, low-cost detection tool that should be applied for pre-scanning athletes.

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B. *An Overview of Recent Application of Medical Infrared Thermography in Sports Medicine in Austria*

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ABSTRACT

Medical infrared thermography (MIT) is used for analyzing physiological functions related to skin temperature. Technological advances have made MIT a reliable medical measurement tool. This paper provides an overview of MIT's technical requirements and usefulness in sports medicine, with a special focus on overuse and traumatic knee injuries. Case studies are used to illustrate the clinical applicability and limitations of MIT. It is concluded that MIT is a non-invasive, non-radiating, low cost detection tool which should be applied for pre-scanning athletes in sports medicine.

INTRODUCTION

Medical infrared thermography (MIT) provides a non-invasive and non-radiating analysis tool for analyzing physiological functions related to the control of skin-temperature. This rapidly developing technology is used to detect and locate thermal abnormalities characterized by an increase or decrease found at the skin surface. The technique involves the detection of infrared radiation that can be directly correlated with the temperature distribution of a defined body region [1]. An injury is often related with variations in blood flow and these in turn can affect the skin temperature. Inflammation leads to hyperthermia, whereas degeneration, reduced muscular activity and poor perfusion may cause a hypothermic pattern [2]. There are several applications of MIT in the field of human medicine, such as neurological disorders [3], open- heart surgery [4], vascular diseases [5], reflex sympathetic dystrophy syndrome [6], urology problems [7] and mass fever screening [8]. Much research has been focused on the successful evaluation of breast cancer [9]. According to Ng [10] breast thermography has achieved an average sensitivity and specificity of 90%. He reported that an abnormal breast thermogram is a significant biological marker for breast cancer. One possible explanation is that increased blood flow due to the vascular proliferation that results from angiogenesis is associated with tumors [11]. Reduced skin temperature has also been implicated in musculoskeletal disorder (MSD). In fact, a cold skin pattern around ankle sprains indicates a poor prognosis and a long recovery time [12]. Infrared sensor technology also contributes to the field of injury management in athletic animals [13–16]. Anatomical and physiological similarities between animals and humans may imply that modern infrared sensor technology can provide significant information for the functional management of injuries in human athletes. However, there is scant scientific evidence of its successful application in the field of human sports medicine. High performance training pushes the locomotor system to the edge of its anatomical and physiological limits. The knee is a weak link and is the most frequently affected joint in sports. Knee injuries are common in skiing and sports that involve jumping and abrupt direction changes [17]. Current trends indicate that in Austria, one of the top ski countries, the number of participants in competitive alpine skiing is greatly increasing, triggering a proliferation of knee injuries [18]. The incidence of long-term effects, such as osteoarthritis, are alarming. These injuries usually involve a long, costly rehabilitation period and are often career-ending for athletes. The need for further research in the field of injury prevention and management is crucial to counteract severe skiing injuries.

INTERNATIONAL STATUS OF MEDICAL INFRARED IMAGING

MIT has been recognized by the American Medical Association council as a feasible diagnostic tool since 1987 and was recently acknowledged by the American Academy of Medical Infrared Imaging. Various groups and associations promote the proper application of thermal imaging in the practice of sports medicine. These groups include the European Association of Thermology, the United Kingdom Thermography Association, and the Northern Norwegian Centre for Medical Thermography, the American Academy of Thermology and the German Society of Thermography and Regulation Medicine (DGTR) as one of the oldest medical thermography society. The overall aim of these groups is to further improve reliable standardized methods and to develop appropriate protocols for clinical application. The usefulness of MIT in sports medicine has been noted often [19]. However, some doubts about the technology highlight the necessity of doing further research. The major argument is whether MIT can accurately determine thermal variations to enable sufficient quantitative analyses [20]. Proponents of MIT state that "state-of-the-art" computerized systems using complex statistical data analysis ensure high quality results [21] and that thermal sensitivity has increased, creating a new dimension that should be exploited and applied [22]. The absence of a standardized reference images is also a problem [23]. A research group from the University of Glamorgan is currently conducting research to determine "normal" thermograms by creating an "*Infrared Atlas of Normal Human Skin Temperature Distribution".* Well-designed research studies can address these issues and help to resolve them.

PRINCIPLES AND TECHNIQUE OF INFRARED THERMOGRAPHY

3.1. Electromagnetic Spectrum There are several medical imaging modalities within the electromagnetic spectrum, which is defined as the range of electromagnetic radiation frequencies. Depending on their physical principles, these various techniques mainly provide anatomical information. MIT is essentially a digital two-dimensional imaging technique that provides data about the physiology of tissues [24]. Unlike most diagnostic modalities, MIT is non-invasive. The question is whether physiological images can change prior to anatomic disruption. Specific software makes it possible to incorporate anatomical and physiological information by image fusion, which helps to localize the affected area and extent of the injury. All images are obtained through the energy from the human tissue, leading to a classification based on the energy applied to the body. The energy content of the emission is related to the wavelength of the radiation. Regarding the spectral region, human skin is a black body radiator with an emissivity factor of 0.98 [25] and is therefore a perfect emitter of infrared radiation at room temperature. Planck's law describes the characteristics of infrared radiation emitted by an object in terms of spectral radiant emittance [26]. $W(\lambda,T)=\frac{2\pi hc^2}{\lambda^4}\left[\exp\left(\frac{hc}{\lambda kT}\right)-1\right]^{-1} W cm^{-2} \mu m^{-1}$ **Formula 1.** Planck's radiation law.

- H (Planck's constant) = 6.6256×10^{-34} Js
- K (Boltzmann's constant) = 1.38054×10^{-23} WsK^{-1}
- C (velocity of light in vacuum) = 2.9979×10^{8} ms^{-1}
- μ = wavelength in μm
- T = temperature in K

Human skin emits infrared radiation mainly in the wavelength range of 2–20 μm with an average peak of 9–10 μm [25]. Based on Plank's Law roughly 90% of the emitted infrared radiation in humans is of longer wavelength (8–15 μm).

INFRARED RADIATION

Emissivity refers to an object's ability to emit radiation [27]. Infrared cameras generate images based on the amount of heat dissipated at the surface by infrared radiation. The technology is a sophisticated way of receiving electromagnetic radiation and converting it into electrical signals. These signals are finally displayed in gray shades or colors which represents temperature values. Human heat energy is transferred to the environment via four mechanisms [28]:

1. Conduction: the transfer of heat energy via tissue layer by contact between two bodies of different temperatures;
2. Convection: the heat change between the skin and the surroundings; and
3. Radiation: a transfer of heat that does not require a medium. The energy is transferred between two separate objects at different temperatures via electromagnetic waves (photons)

4. Sweat Evaporation: which is the main mechanism for heat dissipation during exercise? The conversion of liquid into vapor allows the body to regulate its temperature. Evaporation results in a decrease of surface temperature.

The constructed thermogram yields a quantitative and qualitative temperature map of the surface temperature, which can be related to distinct pathological condition and blood flow. Different to a single detector thermal camera, focal plane array detectors generate thermal images of high resolution without a mechanical scan mechanism. These cameras operate in the long wave infrared region (8–15 μm) with the advantage that they are less affected by sunlight compared to the shorter waves. 4.1. The 21st Century Technique The medical usefulness of infrared thermography has been proven over the last several years but has largely been done without the advantage of 21st century techniques [29]. A new generation of high-resolution cameras has been developed, leading to improved diagnostic capability. Changes in the thermal pattern that may be very small but still meaningful can be properly assessed. These technical enhancements have made infrared thermography into a reliable and powerful measurement tool [30]. It has opened opportunities for very precise measurements by imaging very subtle changes in skin surface temperature. 4.2. Recommended Requirements for Human Medicine The thermal imaging group from the University of Glamorgan has recently published a battery of tests for checking the reliability of an infrared camera [23,31]. An infrared camera suitable for evaluating human skin profiles should have the following [31–33]:

1. High Spatial resolution which reflects the separation between two nearby spots. A resolution of 320 (horizontal) × 240 (vertical) pixel is the minimum requirement. The spatial resolution is very dependent on image focusing.
2. High Thermal resolution as an expression of sensitivity, defined as the minimum temperature difference that can be measured at two distinct spots.
3. Medical CE certification is recommended: As soon as a temperature value in degree celcius is stated, the device is classified as a medical modality with a measuring function and should be signed by a specific CE approval.
4. Narrow Calibration range accustomed to the human temperature range (*i.e.*, 20–40 °C) assures more detailed temperature readings.
5. Medical examination software including an export function, for medical analysis report and well-designed software tools for data analysis and image fusion

RELIABILITY STUDY

Reliable measurements have a substantial impact on the diagnosis and interpretation of pathophysiological abnormalities. Many investigations about reliability have focused on equipment and errors related to the physical principles of the technique [31,37]. In addition to technical variations, biological changes such as the circadian rhythm may also contribute noise to the measurements [38]. The reproducibility of the thermal pattern is important if MIT is to be used as a screening tool for injuries. Selfe *et al*. [36] conducted a study of inter-rater reliability and determined that MIT generated adequately reliable thermal patterns from the anterior knee. The amount of heat emitted from the knee is a complex phenomenon that is influenced by many factors and comparing images over time requires good standardization methods and quality assurance [39]. We conducted a preliminary study to evaluate the day-to-day repeatability [40]. 5.1. Methods of Reliability Study Mean temperature readings of the anterior aspect of the knee of 15 subjects were analyzed. To eliminate inter-rater error, the same person carried out the measurements each time. The examination was conducted according to the “Glamorgan Protocol” which was established to ensure quality control when using MIT for medical applications [23]. To provide consistency for repeated measurements, anatomical landmarks were marked on the subject to delineate the region of interest for data capture. 5.2. Results While high individual variations in knee temperature between subjects were noted, low variations between day-to-day measurements indicated the overall stable temperature of the knee. The one-way random intra-class correlation coefficient (ICC) indicated good intra-examiner reliability for absolute values of mean temperature for the right leg and moderately good reproducibility for the left leg In agreement with other studies, we concluded that MIT is a promising evaluation tool when administered under standardized conditions [1,39–41]. The results of these studies were recently published in the journal *Thermology International* and provide a more detailed description of methods [40].

CLINICAL APPLICATION IN ALPINE SKIING

Previous research has demonstrated that thermal images from the two sides of the body are usually symmetrical [42,43]. Any significant asymmetry of more than 0.7 °C can be defined as abnormal and may indicate a physiologic or anatomical variant in the loco-motor system. By comparing one side with the other, it may be possible to detect sub clinical problems before they are clinically relevant. One of the most beneficial contributions of MIT to sports medicine may be in the field of preventive medicine. Turner *et al*. [14] examined tendonitis in racehorses and thermographically detected hot spots two weeks before clinical evidence of swelling, pain and lameness. Early detection of abnormal changes in the tissues is important to counteract overuse injuries. The knee is exposed to a lot of physical stress during the alpine skiing competition season. The so-called “little traumatologies” are very frequent; therefore, their early detection is important [44]. However, it must be emphasized that the primary goal is to detect irregularities in the symmetry of temperature distribution rather than the measurement and comparison of absolute temperatures. There are currently no quick screening tools that are sufficiently predictive of impending symptoms. To verify the thesis that MIT could predict symptoms, we conducted a pre-season measurement of 35 female and 52 male junior alpine ski racers. This study included likewise athletes who were in rehabilitation after traumatic and acute injuries. 6.1. Methods Following an acclimatization period of 20 minutes, we recorded an image of the anterior/posterior and medial/lateral aspect of both knees with an infrared camera (TVS500EX). A fixed distance of 95 cm from the camera to the subject was used. Data were stored and analyzed with the iREPORT 2007 software, provided by the GORATEC GmbH. All images were corrected using an emissivity factor of 0.98. Image fusion was used to identify the area of interest. The room temperature remained constant ranging from 21.5–22.3 °C. Equally the relative humidity showed stable values over time (35–38%). Infrared images were taken twice to get pre- and postseason measurements. Thermographic evaluation was done according to the guidelines prepared by the medical members of the American Academy of Thermology (AAT) and the Glamorgan protocol [23], which incorporates the following seven aspects:

- Patient communication
- Patient preparation
- Patient assessment
- Examination guidelines
- Review of the imaging examination
- Presentation of the findings
- Exam time recommendation continuing professional education

An experienced team of sports physiotherapists conducted the musculoskeletal examination to obtain data about the functional aspects of the knees. Each subject had to fill in a questionnaire to get additional information about:

- Name, age, sex
- Sport history including information about training performed in the previous 7 days
- Health status

- Nutritional status
- Menstrual cycle

6.2. Case Studies 6.2.1. Overuse Injuries A common problem in alpine skiing is the occurrence of overuse injuries such as patellae tendinopathy, which is characterized by swelling, pain and tenderness above the tibial tuberosity [45]. This regional problem becomes apparent in the form of a hyperthermic pattern, in which the right knee is affected. The preseason training program includes excessive jumps, leading to mechanical strain and overuse of the patella tendon. In this study, a total of seven athletes showed symptoms of regional overuse reactions. The symptomatic athletes had a mean side temperature differences of 1.4 °C (±0.58 °C). The normal temperature range of the eight non-injured athletes showed a side-to-side variation of 0.3 °C (±0.61 °C). Four of the injured athletes reported pain, while the others were asymptomatic at that time. However, physical examination of the knee revealed that this hyperthermia was associated with a low threshold for pressure pain, as previously described in the literature [46]. Early detection and subsequent early therapy intervention program can reduce the severity of symptoms. Furthermore, the detection of at-risk athletes makes it possible to adjust their training program. 6.2.2. Traumatic Injuries Epidemiological studies have shown a high incidence of serious knee injuries among alpine skiers, with the most common injury being the rupture of the anterior cruciate ligament (ACL) [47,48]. A clear decline in swelling and inflammation can be seen. However, pain sensation is still present on the medial aspect of the right knee, as indicated by the hyperthermic area. Severe alpine skiing accidents may result in serious injuries such as fractures. In Figure 6, the infrared image on the right side was taken 3 months after a combined fracture of the tibia and fibula with intramedulary nailing. This injury resulted in a clear demarcation and localization making it possible to define the extent of the high metabolic activity in structures involved. Following treatment, no clear differences of the temperature distribution between the two sides could be noted. In conjunction with the clinical examination, the complete recovery was confirmed. However, a high temperature on the shank can be noted on both legs, possibility due to increased muscular activity. Follow up imaging is required for long-term evaluation.The incidence of soft tissue injuries such as muscle strains is relatively small in alpine skiing [44]. However, these injuries are a strong risk factor for future strain injury to the same muscle. Full recovery needs to be assured and may be visualized threw thermal imaging. It is very important to understand the pathophysiology, phases and time frame of normal tissue healing of traumatic injuries. Regular MIT measurements within the rehabilitation process provide information about the ongoing healing process and improve the therapist's ability to create an adapted rehabilitation and treatment program. Infrared images may give full recovery information by indicating by low side-to-side differences and decreasing the likelihood of re-injury by returning to the sport too quickly. These results are based on primary investigations and can be regarded as a first step to provide a scientific database for validating overuse and acute knee injuries when examined with MIT. Further research is intended to distinguish between normal and abnormal temperature patterns [49].

LIMITATIONS AND ADVANTAGES OF MEDICAL INFRARED IMAGING

The efficiency, safety and low cost of MIT make it an auxiliary tool in medical imaging and diagnostics [19,50]. It can be applied without any objections because this non-invasive technique works without damaging radiation. It has the potential for performing *in vivo* diagnosis on tissues without the need of sample excision; hence, it can be regarded as a passive measurement [30]. Furthermore, the resulting real time information can be used as instant feedback for the patient or athlete. Innovative concepts such as dynamic thermal imaging will be applied to further explore skin thermal properties in response to stresses such as excessive jumping performance and training, as one important part of specific training in alpine skiing [51]. Cutaneous temperature changes during exercise can now be detected by functional thermal imaging using state-of -the art infrared sensor arrays and may provide additional useful data [52–55]. However, infrared thermography becomes even more useful when its limitations are known. For future consideration, it is important to know that this can provide physiological information but cannot define aetiologies and local anatomy. The Individual variability combined with the complex character of thermoregulation limits the interpretation. The lack of specificity makes it necessary to combine these measurements with other, more structural modalities (X-ray, computed tomography), rather than using it as a replacement. The biggest challenge is to combine the anatomical and physiological information given by the thermal pattern of the skin surface. The use of instrumented techniques to measure circulatory conditions must be considered. Automated overlay of infrared and visual medical images as well as automated target recognition are also being actively studied [56,57]. By applying these new techniques we may reduce operator dependence and enhance accuracy and objectivity.

CONCLUSIONS

Thermal imaging in medicine is not new, but early investigation with old and insufficient techniques has led to work with dubious results. Recent work with modern 21st century technology has demonstrated the value of MIT in medical application when used as an auxiliary tool. Knowledge about thermoregulation, anatomy, physiology, morphology and pathophysiological processes is important to counteract inaccurate diagnoses. The aim of this technique is not to be a substitute for clinical examination but to enhance it. Further research and follow-up studies are warranted to create databases for clinical measurements and further determine its viability in real-world medical settings. Empirical evidence of correlation between pathology and infrared imaging is essential to further predict the value of MIR. It should be used as a multidisciplinary assessment tool by experts from different fields. Based on the advantages of MIT as a non-invasive, non-radiating, low cost first-line detection modality, it should be applied in the field of sports medicine as a pre-scan team assessment tool. The extension of sport specific databases may further contribute to the detection of high risk athletes and help them to start early intervention.

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C. *Assessment of hand osteoarthritis: correlation between thermographic and radiographic methods.*

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OBJECTIVE

Anatomical stages of digital osteoarthritis (OA) have been characterized radiographically as progressing through sequential phases from normal to osteophyte formation, progressive loss of joint space, joint erosion and joint remodelling. Our study was designed to evaluate a physiological parameter, joint surface temperature, measured with computerized digital infrared thermal imaging, and its association with sequential stages of radiographic OA (rOA).

METHODS

Thermograms, radiographs and digital photographs were taken of both hands of 91 subjects with nodal hand OA. Temperature measurements were made on digits 2-5 at distal interphalangeal (DIP) joints, proximal interphalangeal (PIP) joints and metacarpophalangeal (MCP) joints (2184 joints in total). We fitted a repeated measures ANCOVA model to analyse the effects of rOA on temperature, with handedness, joint group, digit and NSAID use as covariates.

RESULTS

The reliability of the thermoscanning procedure was high (generalizability coefficient 0.899 for two scans performed 3 h apart). The mean joint temperature decreased with increasing rOA severity, defined by the Kellgren-Lawrence (KL) scale. The mean temperature of KL0 joints was significantly different from that of each of the other KL grades ($P \le 0.002$). After adjustment for the other covariates, there was a strong association of rOA with joint surface temperature ($P<0.001$). The earliest discernible radiographic disease (KL1) was associated with a higher surface temperature than KL0 joints ($P = 0.01$) and a higher surface temperature than any other KL grade. Joint erosions were not associated with a change in joint temperature. CONCLUSION: Joint surface temperature varied with the severity of rOA. Joints were warmer than normal at the onset of OA. As the severity of rOA worsened, joint surface temperature declined. These data support the supposition that digital OA progresses in phases initiated by an inflammatory process. The cooler

surface temperatures in later stages of the disease may in part explain the paucity of symptoms reported by patients with hand OA. https://www.ncbi.nlm.nih.gov/pubmed/15126670

D. Thermal imaging – a hotspot for the future?: A case report

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CASE REPORT

A 6-year-old boy presented to accident and emergency with his mother complaining of a painful right elbow following a fall that day. He fell whilst walking up steps and gave a history of directly striking the elbow on the step. He had not been using the arm since. There was a recent history of a comminuted intra-articular fracture of the proximal ulna of the same elbow, and a cast had been removed just 5 weeks previously. The patient was seen and examined by an experienced A&E senior house officer. He was difficult to assess and was complaining of pain in the entire arm. There was no swelling or deformity and no apparent bony tenderness to the limb. He was unwilling to actively move the elbow joint, however there was a good range of passive movement throughout the arm and good grip strength was noted. An X-ray of the elbow was performed and no bony injury or effusion of the elbow joint was apparent. The child was treated for a soft tissue injury of the elbow, advised regular analgesia and discharged. The patient represented two days later complaining of persistent pain to the arm. He was now localising pain to the wrist and there was a corresponding area of tenderness over the distal radius. A thermal image was taken of the limb using a hand held FTI Mv thermal imager interfacing with LIPS Mini PC software. The image identified an obvious "hotspot" corresponding to the area of tenderness over the distal radius, which clearly differed from a thermal image of the normal wrist. Subsequent X-ray of the wrist revealed an undisplaced greenstick fracture of the distal radius. The child was treated with a plaster cast, referred to the orthopaedic fracture clinic and made an uneventful recovery.

DISCUSSION

Thermal Imaging has been considered for use in a wide range of medical circumstances. It has been shown to be useful in aiding diagnosis and guiding management of foot injuries in military recruits when combined with clinical examination, radiographs and bone scanning.4 Telethermography has been demonstrated as a useful tool in aiding diagnosis and management of sports injuries.5 Cole et al. demonstrated a significant relationship between early thermographic assessment of the depth of skin burns and clinical outcome.3 Various types of thermal imaging have also been used in studies of diabetic neuropathic feet,1 the detection of carpal tunnel syndrome,7 the investigation of tendon injuries in horses6 and in the monitoring of undesirable thermal proximity damage during surgical energized dissection and coagulation.2 During the international severe acute respiratory syndrome (SARS) crisis of 2003, thermal imaging was employed as a screening tool at border points. At Singapore's Changi International airport alone 442,973 passengers were screened and of those 136 identified for further investigation and observation.8 The modality's sensitivity for identifying passengers with even low grade pyrexia (>37.5 °C) highlights recent technological advances and brings to attention future possible uses. The main problems previously identified with the use of thermal imaging in the evaluation of a possibly injured limb include a lack of specificity in identifying the site and nature of pathology and difficulty in establishing normal references. While thermography could never replace radiography as a diagnostic tool, it may be useful as an adjunct to clinical examination and X-ray. As this case demonstrates, children can prove difficult to assess in the accident and emergency department environment. Injury localisation in this patient group can prove difficult and the "survey" of a limb with X-ray may result. The use of thermal imaging could improve the sensitivity of clinical examination and therefore assist in injury localisation, preventing unnecessary X-ray exposure. In this case it may be postulated that thermal imaging has detected a localised increase in temperature associated with the normal inflammatory response to a fracture. This is an early response and if it was shown to be reliable then the modality may be useful in a wider area of emergency medicine. Early radiological findings can be unreliable in conditions such as scaphoid fracture and the "toddler's" type fracture of the tibial shaft. Thermal imaging could potentially be used in early follow-up to exclude fracture in these situations and prevent prolonged immobilisation and possibly more invasive and expensive bone scanning. It is likely that thermal imaging would be of use when examining bones that are relatively superficial where temperature changes are going to be more apparent. Thermal imaging has been shown to be effective in assessing the depth of skin burns3 by measuring different skin temperatures created by varying states of perfusion. It may therefore be useful as a real time assessment tool examining changes in peripheral perfusion during the resuscitation of a shocked patient, giving a continuous recording of response to treatment. Modern thermal imaging is rapid, non-invasive, non-emitting and with improving technology becoming more user-friendly and more cost effective. Given these attributes and the potential applications to emergency medicine outlined above, there is a need for our speciality to study the technique further.

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E. Thermal signature analysis as a novel method for evaluating inflammatory arthritis activity.

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OBJECTIVES

To determine the potential usefulness of a novel thermal imaging technology to evaluate and monitor inflammatory arthritis activity in small joints using rat models, and to determine whether thermal changes can be used to detect pre-clinical stages of synovitis.

METHODS

Three different rat strains were studied in a monoarticular model of inflammatory arthritis of the ankle induced with an intraarticular (IA) injection of complete Freund's adjuvant (CFA), and compared with the contra-lateral ankle injected with normal saline. Arthritis activity and severity scores, ankle diameters, pain related posture scores, and thermal images were obtained at ten different time-points between 0h (before induction) and day 7. The pristane-induced arthritis (PIA) model was used to study pre-clinical synovitis. Thermal images were obtained at each time-point using the TSA ImagIR System and digitally analyzed.

RESULTS

Rats developed similar ankle arthritis detected 6h after the IA injection of CFA, which persisted for seven days. All ankle clinical parameters, including arthritis activity and severity scores, significantly correlated with ankle thermal imaging changes in the monoarthritis model (P<0.003). No thermal imaging changes were detected in pre-clinical stages of PIA. However, PIA onset coincided with increased ankle thermal signature.

CONCLUSION

Thermal measurements significantly correlated with arthritis activity and severity parameters. This technology was highly sensitive and could directly measure two cardinal signs of inflammation (warmth and edema – based on ankle diameter) in an area (ankle) that is less than half the size of a human interphalangeal joint, suggesting a potential use to monitor drug responses of rheumatoid arthritis in drug trials or clinical practice. http://www.ncbi.nlm.nih.gov/pmc/articles/PMC1798043/

F. Thermatomal changes in cervical disc herniations.

Yonsei Med J 1999 Oct;40(5):401-12 *Zhang HY, Kim YS, Cho YE; Department of Neurosurgery, Yongdong Severance Hospital, Yonsei College of Medicine, Seoul, Korea.* Subjective symptoms of a cool or warm sensation in the arm could be shown objectively by using thermography with the detection of thermal change in the case of radiculopathy, including cervical disc herniation (CDH). However, the precise location of each thermal change at CDH has not been established in humans. This study used digital infrared thermal imaging

(DITI) for 50 controls and 115 CDH patients, analyzed the data statistically with t-test, and defined the areas of thermatomal change in CDH C3/4, C4/5, C5/6, C6/7 and C7/T1. The temperature of the upper trunk and upper extremities of the control group ranged from 29.8 degrees C to 32.8 degrees C. The minimal abnormal thermal difference in the right and left upper extremities ranged from 0.1 degree C to 0.3 degree C in 99% confidence interval. If delta T was more than 0.1 degree C, the anterior middle shoulder sector was considered abnormal ($p < 0.01$). If delta T was more than 0.3 degree C, the medial upper aspect of the forearm and dorsal aspect of the arm, some areas of the palm and anterior part of the fourth finger, and their opposite side sectors and all dorsal aspects of fingers were considered abnormal ($p < 0.01$). Other areas except those mentioned above were considered abnormal if delta T was more than 0.2 degree C ($p < 0.01$). In $p < 0.05$, thermal change in CDH C3/4 included the posterior upper back and shoulder and the anterior shoulder. Thermal change in CDH C4/5 included the middle and lateral aspect of the triceps muscle, proximal radial region, the posterior medial aspect of the forearm and distal lateral forearm. Thermal change in CDH C5/6 included the anterior aspects of the thenar, thumb and second finger and the anterior aspects of the radial region and posterior aspects of the pararadial region. Thermal change in CDH C6/7 included the posterior aspect of the ulnar and palmar region and the anterior aspects of the ulnar region and some fingers. Thermal change in CDH C7/T1 included the scapula and posterior medial aspect of the arm and the anterior medial aspect of the arm. The areas of thermal change in each CDH included wider sensory dermatome and sympathetic dermatome. There was a statistically significant change of temperature in the areas of thermal change in all CDH patients. In conclusion, the areas of thermal change in CDH can be helpful in diagnosing the level of disc protrusion and in detecting the symptomatic level in multiple CDH patients. https://www.ncbi.nlm.nih.gov/pubmed/10565248

G. Foot evaluation by infrared imaging

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ABSTRACT

For better assessment of foot injury severity during basic military training, we evaluated a simple noninvasive technique: thermography. With this infrared imaging method, we determined normal foot parameters (from 30 soldiers before training), thermographic findings in different foot stress fractures (from 30 soldiers so diagnosed), and normal responses to abnormal stresses in 30 trainees who underwent the same training as the previous group but did not have musculoskeletal complaints. We found that normal foot thermograms show onion peel-like progressive cooling on the plantar surface, with a medially located warm center at the instep. Thermograms of injured feet show areas of increased heat, but excessive weight-bearing pressures on feet, new shoes, or boots also cause increased infrared emission even without discomfort. Differentiation remains difficult; however, thermography can detect injury early. It does not reveal exact diagnoses, but its greatest benefit is easy follow-up to monitor severity and healing. https://www.ncbi.nlm.nih.gov/pubmed/12053846

H. The use of thermal infrared imaging to assess the efficacy of a therapeutic exercise program in individuals with diabetes.

Al-Nakhli HH, Petrofsky JS, Laymon MS, Arai D, Holland K, Berk LS.1 Loma Linda University, Loma Linda, California. Exercise is of great value for individuals with diabetes in helping to control their hemoglobin A1c levels and in increasing their insulin sensitivity. Delayed-onset muscle soreness (DOMS) is a common problem in healthy individuals and in people who have diabetes. …
Conclusion: Infrared thermal imaging may be a valuable technique of seeing which muscles are sore hours or even days after the exercise is over. Thus, thermal imaging would be an efficient and painless way of looking at DOMS in both healthy individuals and individuals who have diabetes, even if they are facing neurological problems. http://www.ncbi.nlm.nih.gov/pubmed/22011006

An overview of temperature monitoring devices for early detection of diabetic foot disorders.

Roback K. Center for Medical Technology Assessment (CMT), Department of Medical and Health Sciences, Linköping University, Linkoping, Sweden. Diabetic foot complications are associated with substantial costs and loss of quality of life. This article gives an overview of available and emerging devices for the monitoring of foot temperature as a means of early detection of foot disorders in diabetes. The aim is to describe the technologies and to summarize experiences from experimental use. Studies show that regular monitoring of foot temperature may limit the incidence of disabling conditions such as foot ulcers and lower-limb amputations. Infrared thermometry and liquid crystal thermography were identified as the leading technologies in use today. Both technologies are feasible for temperature monitoring of the feet and could be used as a complement to current practices for foot examinations in diabetes. http://www.ncbi.nlm.nih.gov/pubmed/20822392

I. The application of infrared thermography in the assessment of patients with coccygodynia before and after manual therapy combined with diathermy.

Wu CL, Yu KL, Chuang HY, Huang MH, Chen TW, Chen CH. Source Graduate Institute of Medicine, College of Medicine, Kaohsiung Medical University, Kaohsiung, Taiwan.
ABSTRACT

OBJECTIVE

This study examines the potential usefulness of a novel thermal imaging technique in the assessment of local physiologic responses before and after conservative therapies for coccygodynia.

METHODS

Patients with coccygodynia were selected on the basis of detailed history taking, clinical examination, and dynamic series radiography. They underwent therapeutic modalities consisting of 6 to 8 sessions of manual medicine treatments (massage of the levators followed by Maigne's manipulative technique) and external physiotherapy (short-wave diathermy) 3 times a week for 8 weeks. We performed the assessments with numeric pain rating scale (NPRS) and infrared thermography (IRT) before treatment and at 12 weeks.

RESULTS

A total of 53 patients (6 males and 47 females) ranging from 18 to 71 years of age and clinically diagnosed with coccygodynia received the full course of therapy and assessments. There were significant differences in both NPRS and surface temperature obtained by IRT in the 12-week follow-up ($P < .05$). The correlation between NPRS improvement and temperature decrement was significantly high ($r = 0.67$, $P < .01$).

CONCLUSIONS

The study shows that IRT can objectively show the decrement of surface temperatures correlating with changes in subjective pain intensity after treatment of coccygodynia. With the advantages of being painless, noninvasive, and easy to repeat, IRT appears to be useful as a quantifiable tool for monitoring the dynamics of the disease activity in coccygodynia. http://www.ncbi.nlm.nih.gov/pubmed/19447265

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2. Vascular Health

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a. Thermographic Assessment of a **Vascular** Malformation of the Hand: A New Imaging Modality.

b. Infrared thermal imaging as a novel evaluation method for deep vein thrombosis in lower limbs.
c. Digital thermography of the fingers and toes in Raynaud's phenomenon.
d. Vascular surgical society of great Britain and Ireland: analysis of cold provocation thermography in the objective diagnosis of the hand-arm vibration syndrome.
e. Detection of dialysis access induced limb ischemia by infrared thermography in children.
f. Infrared thermal imaging for detection of peripheral vascular disorders.
g. Peripheral vascular reactions to smoking–profound vasoconstriction by atherosclerosis.
h. Intraoperative thermographic monitoring during neurogenic thoracic outlet decompressive surgery.

a. Thermographic Assessment of a Vascular Malformation of the Hand: A New Imaging Modality.

Hardwicke JT, Titley OG ABSTRACT

Vascular malformations of the hand are rare. Angiography is the current Gold Standard imaging modality. Thermal imaging is an emerging noninvasive, non-contact technology that does not require intravenous contrast agents. We present the case of a patient with an arteriovenous malformation affecting the hand in which thermal imaging has been used as an adjunct to capture baseline images to allow monitoring of progression. We suggest that thermal imaging provides an adjunct that can be used in addition to clinical examination and/or angiography for the diagnosis and routine follow-up of conservatively managed arteriovenous malformations, to monitor progression or vascular steal, and also for recording recurrence after surgical excision for which there is known to be a significant incidence. With the benefit of being a noninvasive imaging modality that does not require intravenous contrast, or ionizing radiation exposure, office-based thermal imaging may become commonplace.

www.ncbi.nlm.nih.gov/pubmed/27195175

b. Infrared thermal imaging as a novel evaluation method for deep vein thrombosis in lower limbs.

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Purpose

Early detection of deep vein thrombosis (DVT) is critical to prevent clinical pulmonary thromboembolism. However, most conventional methods for diagnosing DVT are functionally limited and complicated. The aim of this study was to evaluate the value of infrared-thermal-imaging (IRTI), a novel imaging detection or screening technique, in diagnosis of DVT in animal models.

Methods

DVT model of femoral veins was established in nine New Zealand rabbits. The right hind femoral vein was embolized and the contralateral one served as a nonembolized control. Measurements of IRTI, compression ultrasonography (CPUS), and angiography under ultrasonic observation (AGUO) were performed at three time points: T1 (baseline, 10 min prior to surgery), T2 (2 h after thrombin injection), and T3 (48 h postoperatively). Qualitative pseudo color analysis and quantitative temperature analysis were performed based on mean area temperature (Tav) and mean curvilinear temperature (Tca) of the region of interest as shown in IRTI. Temperature differences (TD) in Tav (TD(Tav)) and Tca (TD(Tca)) between the DVT and control sides were computed. Comparative statistical analysis was carried out by paired t-test and repeated measure, while multiple comparisons were performed by using Greenhouse-Geisser and Bonferroni approach. Values of $P < 0.05$ and $P < 0.01$ were considered statistically significant and highly significant.

Results

Modeling of DVT was successful in all rabbits, as confirmed by CPUS and AGUO and immediately detected by IRTI. IRTI qualitative analysis of pseudo color revealed that the bilateral temperatures were apparently asymmetrical and that there were abnormally high temperature zones on the DVT side where thrombosis formed. The results of paired t-test of Tav and Tca between DVT side and control sides did not reveal statistical difference at T1 (Tav: $P = 0.817$; Tca: $P = 0.983$) yet showed statistical differences at both T2 (Tav: $P = 0.023$; Tca: $P = 0.021$) and T3 (Tav: $P = 0.016$; Tca: $P = 0.028$). Results of repeated measure and multiple comparisons of TD(Tav) and TD(Tca) were highly different and significant differences across the T2 (TD(Tav): $P = 0.009$; TD(Tav): $P = 0.03$) and T3 (TD(Tav): $P = 0.015$; TD(Tav): $P = 0.021$).

Conclusions

IRTI temperature quantitative analysis may help further detection of DVT. Additionally, IRTI could serve as a novel detection and screening tool for DVT due to its convenience, rapid response, and high sensitivity.

www.ncbi.nlm.nih.gov/pubmed/23231273

c. *Digital thermography of the fingers and toes in Raynaud's phenomenon.*

Lim MJ, Kwon SR, Jung KH, Joo K, Park SG, Park W. ABSTRACT

The aim of this study was to determine whether skin temperature measurement by digital thermography on hands and feet is useful for diagnosis of Raynaud's phenomenon (RP). Fifty-seven patients with RP (primary RP, n = 33; secondary RP, n = 24) and 146 healthy volunteers were recruited. After acclimation to room temperature for 30 min, thermal imaging of palmar aspect of hands and dorsal aspect of feet were taken. Temperature differences between palm (center) and the coolest finger and temperature differences between foot dorsum (center) and first toe significantly differed between patients and controls. The area under curve analysis showed that temperature difference of the coolest finger (cutoff value: 2.2℃) differentiated RP patients from controls (sensitivity/specificity: 67/60%, respectively).

Temperature differences of first toe (cutoff value: 3.11℃) also discriminated RP patients (sensitivity/specificity: about 73/66%, respectively). A combination of thermographic assessment of the coolest finger and first toe was highly effective in men (sensitivity/specificity : about 88/60%, respectively) while thermographic assessment of first toe was solely sufficient for women (sensitivity/specificity: about 74/68%, respectively). Thermographic assessment of the coolest finger and first toe is useful for diagnosing RP. In women, thermography of first toe is highly recommended.

http://www.ncbi.nlm.nih.gov/pmc/articles/PMC3991792/

d. *Vascular surgical society of great Britain and Ireland: analysis of cold provocation thermography in the objective diagnosis of the hand-arm vibration syndrome.*

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BACKGROUND

The hand-arm vibration syndrome (HAVS) is the commonest prescribed disease in the UK. Presently the diagnosis is subjective and the need for an objective investigation to support the diagnosis has been highlighted. This study analyses the potential of cold provocation thermography (CPT) to fulfill this role.

METHODS

CPT was performed in ten controls (five men, five women; median age 35 (range 24-78) years) and 21 patients with HAVS (20 men, one woman; median age 45 (range 29-81) years). With an infrared camera, a pre-cooling (PC) image was taken and then, following hand cooling in water at a temperature of 5 degrees C for 1 min, further rewarming images were taken every minute for 10 min.

RESULTS

Patient finger tip temperatures were significantly cooler than control temperatures at all time points ($P < 0.01$, Student's t test). The following Table shows the sensitivity, specificity and PPV of CPT.

CONCLUSION CPT provides strong objective evidence to support the clinical diagnosis of HAVS.

http://www.ncbi.nlm.nih.gov/pubmed/10361321

e. Detection of dialysis access induced limb ischemia by infrared thermography in children.

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Abstract

High arteriovenous fistula (AV fistula) blood flow may impair distal limb perfusion and cause irreversible ischemic damage. Since tissue temperature reflects blood perfusion, we tried to assess distal blood flow using an infrared camera. We examined all 12 patients with an AV fistula in our dialysis unit. Seven were pediatric patients aged 11.0-18.9 years (mean 14.9 years) and five were adults aged 26.9-62.1 years (mean 38.6 years). Infrared thermal imaging (thermography) of their hands was performed after the completion of their regular dialysis sessions. In each patient, the spot temperature of each fingertip on both hands was assessed separately, with three measurements being performed for each measuring point. The mean spot temperature of all fingertips was calculated for each hand and the results compared. A statistically significant difference ($P < 0.05$) indicated distal perfusion insufficiency. Perfusion of the hands was also assessed by inspecting the visualized temperature distribution on the thermal image. Finally, we compared the results to the clinical findings in relevant patients. In 8/12 patients (66.7%), the mean spot temperature of the fingertips was statistically significantly lower on the fistula side ($P < 0.05$). Only 4/12 patients (33.3%) had clinical symptoms, and all were detected by thermography. Abnormal findings were more frequent in elderly patients. Although we realize that the diagnosis of steal syndrome is primarily clinical, thermography might be a safe, noninvasive, cheap tool for the timely detection of children at risk of developing symptoms of hand ischemia.

http://www.ncbi.nlm.nih.gov/pubmed/21624080

f. Infrared thermal imaging for detection of peripheral vascular disorders

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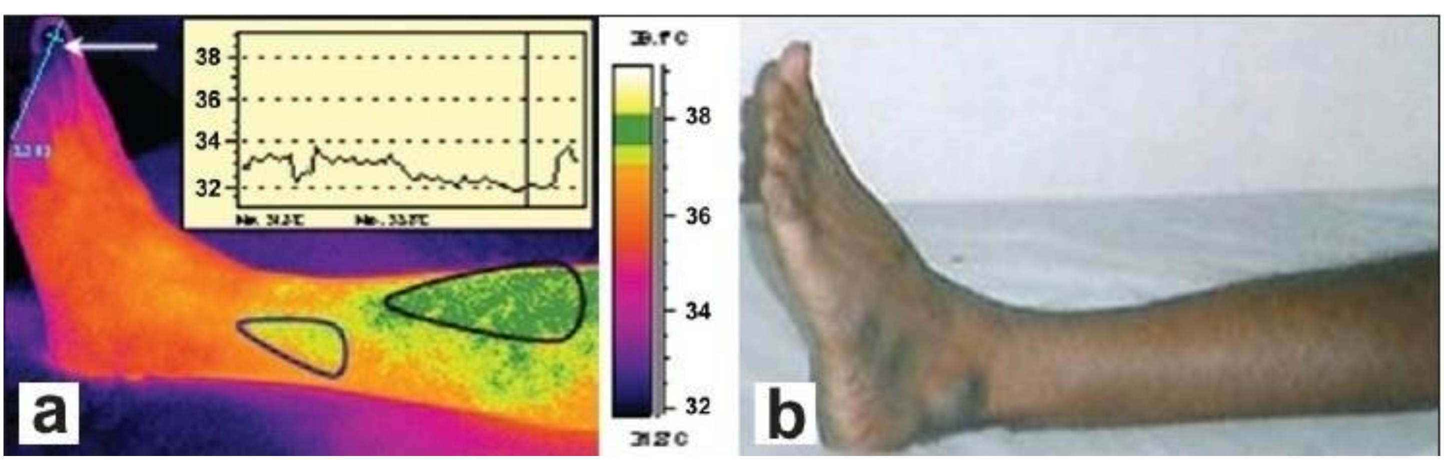
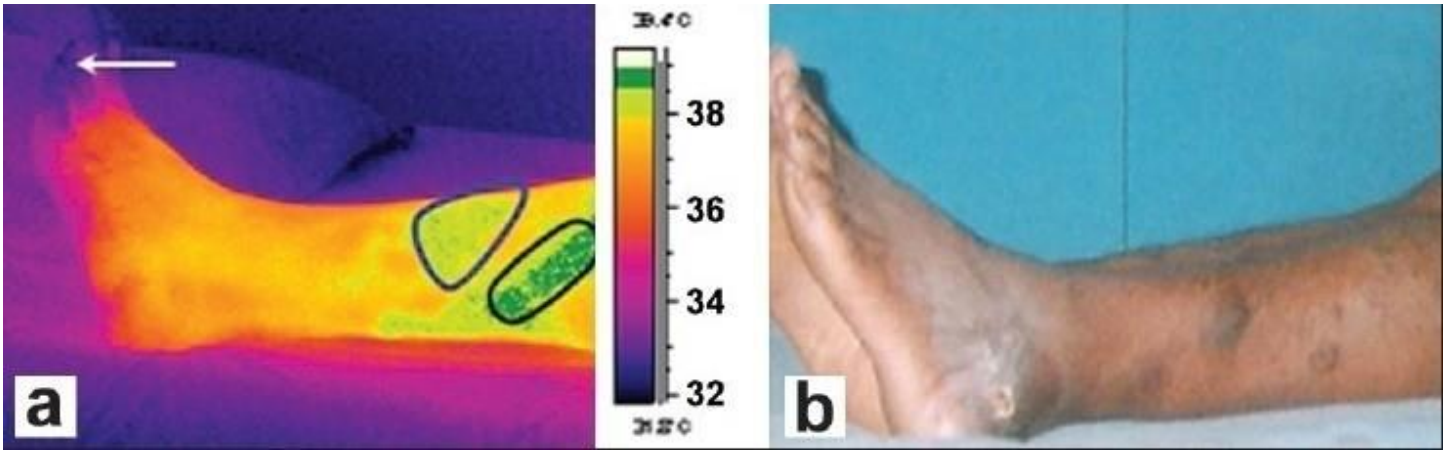
Abstract Body temperature is a very useful parameter for diagnosing diseases. There is a definite correlation between body temperature and diseases. We have used Infrared Thermography to study noninvasive diagnosis of peripheral vascular diseases. Temperature gradients are observed in the affected regions of patients with vascular disorders, which indicate abnormal blood flow in the affected region. Thermal imaging results are well correlated with the clinical findings. Certain areas on the affected limbs show increased temperature profiles, probably due to inflammation and underlying venous flow changes. In general, the temperature contrast in the affected regions is about 0.7 to 1° C above the normal regions, due to sluggish blood circulation. The results suggest that the thermal imaging technique is an effective technique for detecting small temperature changes in the human body due to vascular disorders. Introduction The correlation of body temperature and diseases has been known for centuries, but in recent years, due to advent of new technologies, skin temperature has been used as a convenient and effective diagnostic tool to detect diseases.[1–2] Human body temperature has been recorded with thermocouples, thermistors, and thermopiles, for almost 60 years, and these sensors are very large in size, slow in response, and difficult to attach to the skin.[3] The first documented application of thermography was a method of research for early preclinical diagnosis of breast cancer in the year 1956.[4] Infrared thermography or infrared imaging or thermal imaging is a non-contact tool, which maps the surface temperature of a body or an object and it has a wide range of applications starting from condition monitoring in industries to medical imaging.[5–9] Medical infrared thermal imaging has been used to study the flow of blood, the detection of breast cancer, and muscular performance of the human body.[10,11] Thermal images have been used to quantify sensitive changes in skin temperature in relation to certain diseases.[12] Blood flow can be assessed by many methods including the washout technique, laser Doppler flowmetry,[13] and medical infrared thermal imaging.[14] Of these, infrared thermography has the advantages of being noninvasive,[15] fast, reliable, with non-contact, capable of producing multiple recordings at short time intervals, and absolutely safe for patients and doctors. In all these studies, only the relative and not absolute temperatures are significant and the relative temperatures have to be measured at many points on the skin, and in this sense, the Infrared (IR) sensing device has many advantages over conventional devices.[16,17] IR radiation covers a wavelength that ranges from 0.75μm to 1000μm, among which the human body emissions that are traditionally measured for diagnostic purposes occupy a narrow band of wavelengths ranging from 8μm to 12μm. This region is also referred as the long wave IR (LWIR) or body infrared rays. Another terminology that is widely used in medical IR imaging is thermal infrared (TIR), where the wavelength is beyond 1.4μm. Within this region, the infrared emission is primarily heat or thermal radiation. The image generated by TIR imaging is referred to as thermogram. The near infrared (NIR) region occupies wavelengths between 0.75μm and 1.4μm. Although the NIR and mid-wave IR (MWIR) regions are not traditionally used in human body screening, the new generation detectors enable the use of multispectral imaging in medicine, in which these regions are observed in different diagnostic cases.[18,19] The fundamental equations that link the absolute temperature of the object with the intensity and wavelength of the emitted radiation are given by the Planck's, Stefan Boltzmann, and Wein's Displacement law.[20] The energy radiation after Stefan Boltzman law is $W = \varepsilon \sigma T^4$, where ε is the emissivity and T the absolute temperature. The emissivity (ε) of a material is the ratio of energy radiated by a particular material to the energy radiated by a black body at the same temperature. It is a measure of a material's ability to radiate absorbed energy. A true black body would have an emissivity value of unity (ε = 1), while any real object would have ε < 1. Emissivity depends on factors such as, temperature, emission angle, and wavelength. For a black body the total heat energy radiation is proportional to T^4. A perfect black body is a perfect emitter and a perfect absorber for all wave length energies radiated, depending on the temperature of the material. Human skin keeps the body temperatures normally at 37°C. When the skin is in cooler surroundings, it cools down, emitting heat. Similarly when skin is in warmer surroundings, it absorbs heat making the body adjust itself by sweating, to keep the temperature at 37°C. In both situations, therefore, the skin acts like a black body with emissivity of 0.98, as observed. It has been shown that the emissivity of skin (black, white, burnt, male, and female) independent of the wavelength and its value is close to 0.98.[21–23] Therefore, human beings can be treated as true black bodies. The infrared radiations from the object are converted using a suitable IR detector and displayed as color or black and white image. The colors are simply a visual aid to show the temperature differences at different regions in each image.[24] Medical infrared diagnostics uses the fact that many pathological processes in the human organs manifest themselves as local changes in heat production and also as changes in the blood flow pattern of the affected organs or tissues. Infrared thermography involves recording a sequence of thermograms at several stationary positions of the human being, inspected in his natural condition. Focal plane array (FPA) based systems are more efficient for medical applications than systems previously using single element detectors.[25–27] In clinical diagnostics infrared imaging is used as a physiological test that measures the subtle physiological changes that might be caused by many conditions, e.g., contusions, fractures, burns, carcinomas, lymphomas, melanomas, prostate cancer, dermatological diseases, rheumatoid arthritis, diabetes mellitus and associated pathology, deep venous thrombosis (DVT), liver disease, bacterial infections, etc. These conditions are commonly associated with regional vasodilation, hyperthermia, hyperperfusion, hypermetabolism, and hypervascularization [18] which generate a higher-temperature heat source. The heat emanating onto the surface from the heat source and the surrounding blood flow can be quantified by using the Pennes' bio-heat equation, as follows, $k\Delta 2 - c_b w_b (T - T_a) + q_m = 0$ (1) Where k is the conductivity, q_m is volumetric metabolic rate of tissue, is the product of the specific heat capacity and the mass flow rate of blood units per volume of tissue, T is the unknown tissue temperature, and T_a is the arterial temperature.[21] Materials and Methods The patients were allowed to rest in a room where relative humidity and room temperature were controlled (to achieve equilibration body temperature with the ambient temperature). No parts of the patient were in contact with any hot or cold sources. Only a minimum number of persons were allowed inside the room. The patients were kept away from air convection sources. These precautions had been taken to minimize the variables that might influence temperature measurement. The main objective in the preparation of the above protocol was to ensure all the variables that might have influence during thermal image were fixed. The patient was thoroughly examined by a team of doctors and a clinical report was recorded. Patients undergoing examination by thermal imaging were disrobed in the affected region for 15 minutes, in the room. A wall–mounted, air-conditioning unit provided the required temperature inside the room. The infrared thermal camera was positioned 1 m away from the affected portion of the patients and healthy volunteers. Standard views were taken with the camera mounted on a tripod stand. The regions of interest were the anterior, posterior, and lateral views. The same views of the corresponding contra-lateral region of the patient and of normal controls were also taken. The same region was continuously monitored on a color display unit with pseudo color, making temperature changes easily discernible. Thermal imaging of the patients was carried out using the Thermovision-550 system. This is a compact lightweight focal plane array based system with a temperature resolution of 0.1K. A high-resolution color image is provided in real time, which can be viewed on a miniature screen provided with the system or by using an external monitor. The image is captured and stored in the removable PC-card. The surface temperature profiles of the patients are recorded and later analyzed using the IRWIN software. The thermal profile of the area of examination is compared with the counterpart region of the same subject and the same region of a healthy volunteer. Using the spot meter, area, and profiling tools, the change in temperature in the region of interest is determined. Results and Discussions Case 1 A 28-year-old male, with a history of pain in the left lower limb, which was getting aggravated on prolonged standing, was examined using thermal imaging. He had varicosity of the long saphenous system of the left lower limb. The patient was suffering from complications of varicosity for the past one year. He was using crepe bandages. The patient was febrile and comfortable at rest and was not a smoker or user of alcohol. The respiratory system (RS), cardiovascular system (CVS), central nervous system (CNS), and per abdominal examinations were normal. Local examination of the lower limbs showed dilated veins present in the dorsal aspect of the foot, extending up to the lower one-third of the leg on the right lower limb. There were dilated tortuous veins in the dorsum of the foot in the left lower limb. The radial pulse, carotid pulse, dorsalis pedis, and posterior tibial pulse were normal. Figure 1a and 1b show the thermal image and photograph of the affected patient's left leg. The line profile inset in Figure 1a shows the temperature profile along the toe tips. From the thermal image shown in Figure 1a, it can be clearly seen that a lower temperature is noted at the distal portion (indicated by white arrow in Figure 1a). This is probably due to sluggish blood circulation in the toes and venous drainage being inadequate due to the varicosity. In the patient, the area outlined by a black line, i.e., the demarcated dark-green patches, and a blue line, i.e., the demarcated pale-green color patch [Figure 1a] show abnormal temperatures compared to the temperature of the surrounding area of the same patient's leg and to that of a normal person's leg. The temperature in these marked regions is, on an average, 0.7 to 1°C above the normal regions. The abnormal temperature is due to varicose veins, with probable mild inflammation, which was not evident on clinical examination. The human body creates heat through the metabolic activity, which is the basic reaction of life. The blood in the near-surface veins, heats the surface more than the normal veins and arteries. Localized elevated temperatures are easier to discern when the person is in a cool room for at least 20 minutes. A uniform temperature can be seen in the leg of a normal person.



(a) Isothermal image and (b) Photograph of the affected patient's leg Case 2 A 31-year-old male, who has a history of swelling in both the lower limbs on prolonged standing, for five years, had recurrent ulceration over the left lateral malleolus, associated with pain and discharge of pus. The patient underwent treatment and surgery four years back, for the same complaint. The RS, CVS, CNS, and per abdominal examinations were normal. Local examination of the left lower limb showed tortuous dilated veins, recurrent healing ulcers on the left lateral malleolus, ulcers covered with slough and pus discharge. Old healed scars were about 8 × 1 cm in length, present in the medial aspect of the lower limb. In the right lower limb, dilated tortuous veins, mild edema over the right ankle joint, and also old healed scars were noticed. The palpable arterial pulse was normal. The patient had systemic hypertension noted six months ago and he was under medication for the same. Figure 2a and 2b show the dorsal thermal images and photograph of the affected patient's left leg. Clinically detected areas with varicosity show up as areas of increased warmth in the thermal images. From the thermal images, the warm areas are noted on the lateral side of the left leg as well, an unusual finding, because most patients have varicosity located only on the medial side of the leg. The distal region near the toes seems to be dark or with lower temperature due to the poor perfusion of blood (indicated by a white arrow in Figure 2a, and is attributed to stasis of circulation due to varicosity.



(a) Isothermal image and (b) Photograph of the affected patient's leg (Dorsal view) Areas outlined by black lines, i.e., the demarcated dark-green patch and blue line, i.e., the demarcated pale-green color patch in Figure 2a show abnormal temperature compared to the temperature of the normal person's leg, for the same region. The demarcated area in the thermal image shows a higher temperature due to the tortuous venous carrying warm blood at a sluggish speed when compared to normal venous drainage and probable mild inflammation in those areas. The temperature changes as noted on the patient are not seen in the leg of the normal person. Case 3 A 48-year-old male has had pain in the left leg (calf muscle) for the past two years. The pain has been severe for the past six months. He has had a history of pain aggravation on walking and pain being relieved by rest. On prolonged standing the pain increased. The RS, CVS, CNS, and per abdominal examinations were normal. The upper limb pulses were felt normally in the right and left lower limbs, the dorsalis pedis was normal in the right, with feeble low volume in the left lower limb, and the posterior tibial pulse was normal on the right, with low volume on the left. The patient is an occasional smoker and user of alcohol. There was an injury in the left big toe eight months ago. He had a nonhealing ulcer on the left great toe and gangrenous tissue was found on the great toe. From the thermal images, the left leg medial view of the patient shows elevated temperatures because of thrombosis, a condition marked by blood clotting within the blood vessels. This disease may be potentially life threatening if dislodgment of the thrombus results in pulmonary embolism. It may be burger disease because of arterial insufficiency. It is an arterial obstruction. The clinically recorded information shows severe pain in the calf muscle, the area represented in the thermal image as a warm area shows abnormal temperature compared to the temperature of the normal person's leg, for the same region. These temperature changes are not seen in the thermal image of the normal person's left leg. Case 4 A 40 year-old-male had a swelling in the little finger of the left hand that was two months old. The swelling was present with a pricking type of pain and pus discharge from the left ring, middle, and index fingers. Pain was radiating from the left hand and forearm to the left chest and distal phalanges. The RS, CVS, CNS, and per abdominal examinations were normal. Local examination of the patient's right upper limb was normal. The left upper limb on inspection showed gangrenous swelling with inflammation in the left little, ring, middle, and index fingers. There was purulent discharge from the nail beds that had a foul smell. There was hyperpigmentation present in the left palm. The patient was a smoker for the past 10 years (10 – 15 beedis per day), and an occasional user of alcohol. He has no history of any surgery in the past. Due to pain he was unable to sleep and has had a reduced appetite. From the thermal images it is clearly seen that the temperature of the fingertips of the left hand is cooler than the normal body temperature, which may be attributed to vascular insufficiency. These abnormalities are due to ischemic necrosis (death of tissue affected by local injury due to loss of blood supply) of the distal phalanges. It can be seen that the temperature increase in the affected person's hand was almost 1.5°C compared to the normal hand. Conclusions Thermal imaging has been successfully used for medical diagnosis of vascular disorders. The temperature in the affected regions of patients with vascular disorders was low in the extremities due to obstructed arteries. However, in some areas it showed 0.7 to 1°C higher temperature than the normal areas due to inflammation and venous flow alteration. In general, the thermal image findings were in good agreement with the clinical findings. However, the areas showing higher temperature contrast were noted not to be obvious in the clinical examination. This study demonstrates the usefulness of thermal imaging for medical diagnostics, with high reliability. Acknowledgments We thank Dr. P. R. Vasudeva Rao, Director, Metallurgy and Materials group, IGCAR, for his support and encouragement. The authors also thank Dr. Hussain, Head of the Department and Dr. Rajkumar, Surgeon, Department of Vascular Surgery, Government General Hospital, Chennai, for referring the problem. Footnotes Source of Support: Nil Conflict of Interest: None declared.

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g. *Peripheral vascular reactions to smoking–profound vasoconstriction by atherosclerosis.*

Fushimi H, Kubo M, Inoue T, Yamada Y, Matsuyama Y, Kameyama M; Department of Medicine, Sumitomo Hospital, Osaka, Japan. Diabetes Res Clin Pract 1998 Oct;42(1):29-34 Analyses of direct effects of smoking on peripheral arteries were done using thermography, blood fluorometry and echography on 97 habitual smoker diabetics without triopathy. There were found to be four types of thermographic changes following smoking, which varied according to the degree of atherosclerosis of the artery. The smoking-stimulated thermographic pattern in the control group of healthy volunteers was a small wavy pattern, fluctuating along the base line every few minutes within a temperature range of 1.0-1.5 degrees C (N type). In diabetics, four types of thermographic patterns were produced: normal (N) type as control, increasing (I) type (increasing in skin temperature), decreasing (D) type (decreasing in temperature), and F type (no changes in temperature). The most significant finding was the decreasing pattern which closely connected to clinical and echographic aspects of macroangiopathic changes. The increasing type was characterized by a paradoxical increase in temperature after smoking in order diabetics with good blood glucose control and who were less atherosclerotic. Blood flow was correlated to the skin temperature at the base state and changes after smoking. Moreover, blood flow changes measured by fluorometry suggest that vasoconstriction or vasodilatation following smoking took place. These results suggest that this smoking test might be a good tool for diagnosing for the degree of atherosclerosis and for its following up. https://www.ncbi.nlm.nih.gov/pubmed/9884030

h. *Intraoperative thermographic monitoring during neurogenic thoracic outlet decompressive surgery.*

Ellis W, Cheng S. Source Division of Vascular Surgery, University of Hong Kong Medical Center, Queen Mary Hospital, Hong Kong, China. Abstract This article reports the use of thermography to monitor 123 plexus decompressions for neurogenic thoracic outlet syndrome. The diagnosis and management of this disease continues to be controversial. Questions about pathologic mechanisms, the extent and frequency of muscular entrapment, scar, and interdigitations, as well as their relative contributions, remain. Thermographic visualization of the operated extremity allowed us to map and correlate thermal changes with specific surgical manipulations, as well as to analyze the tissues resected to better answer these questions. Initial thermal abnormalities indicating, usually, ulnar entrapments or irritation, normalized sequentially as discrete entrapments were resected. Thermographic monitoring continues to provide surgically useful information in one third of operations. https://www.ncbi.nlm.nih.gov/pubmed/12894367

3. Inflammation & pain

i. USEFULNESS OF THERMOGRAPHY IN DIAGNOSIS OF COMPLEX REGIONAL PAIN SYNDROME TYPE I AFTER TRANSRADIAL CORONARY INTERVENTION

Min-Young Jeong, MD, Jin-Sok Yu, MD, Woo-Baek Chung, MD Volume 25 – Issue 9 – September, 2013

ABSTRACT

Complex regional pain syndrome (CRPS) is a very rare complication of transradial coronary intervention (TRI). We present the case of a 51-year-old man who suffered severe pain of the right forearm after TRI and progressed to type I CRPS. The patient had effort angina and underwent successful coronary artery stent deployment on the right coronary artery. After removing the hemostatic device, the patient had swelling and severe pain that was not relieved by analgesics. Continued pain progressed to allodynia, hyperalgesia, and hyperesthesia, which met the diagnostic criteria for CRPS. Electromyography showed no abnormalities in nerve conduction and thermography of the forearm showed temperature discrepancy between both forearms, which confirmed the diagnosis of CRPS. We treated the patient with sympathetic nerve block, but he still suffers from minor pain in the right forearm. This case demonstrates that unalleviated pain after TRI can progress to CRPS, and that thermography is a useful method to diagnose CRPS.

J INVASIVE CARDIOL 2013;25(9):E183-E185

Transradial coronary intervention (TRI) is now a widely utilized technique and is considered a relatively safe procedure compared to the transfemoral approach. Distinguishing anatomical features of the radial artery puncture site, namely, its placement over the radius bone and the absence of any major veins or nerves located near the artery, provide advantages to hemostasis after the procedure. Nonetheless, radial artery occlusion does occur, with a reported incidence of 4.4% at an early stage and 3.2% after 1 month. The incidence of radial artery hematoma has also been reported, with an incidence of approximately 5%.3 The dual vascular supply of the palmar region prevents vascular complications from resulting in pain or ischemic changes. The incidence of complex regional pain syndrome (CRPS) from vascular interventions is extremely rare; only 3 cases of CRPS after TRI have been reported in the literature. The case presented here, which demonstrated the typical thermographic findings of CRPS, is the first report of CRPS after TRI diagnosed by thermography.

CASE REPORT

A 51-year-old man with chronic stable angina was referred to our hospital for management of 70% tubular stenosis at the mid-portion of the right coronary artery (RCA) revealed by computerized tomographic coronary angiography at another hospital. He had a smoking history of 35 pack years and was diagnosed with diabetes and hypertension 10 years ago, which had been treated with antiglycemic (metformin 1000 mg) and anti-hypertensive (amlodipine 5 mg) agents. The patient's initial electrocardiography, chest x-ray, and routine laboratory studies were all within normal limits. A TRI was scheduled for confirmative diagnosis and treatment. Allen's test of the right hand, performed before the procedure, was normal. The right radial artery was punctured and a 6 Fr radial sheath was accessed. An everolimus-eluting stent was successfully deployed at the RCA lesion without event (Figure 1). A hemostatic device (TR band; Terumo Corporation) was applied. Fifteen mL of air were inflated after removing the radial sheath and 3 mL of air were deflated every 2 hours thereafter. The TR band was removed 6 hours later without any complications. However, 4 hours after TR band removal, the patient complained of mild, dull pain and swelling at the puncture site; tramadol (150 mg) was prescribed. Three days after TRI, the patient was discharged from the hospital. One week after discharge, the patient visited an outpatient clinic with complaint of severe continuous stabbing pain at the puncture site that radiated to the right upper arm and shoulder. Swelling of the puncture site extended to the upper arm, though the right radial pulse was intact. We treated the pain with acetaminophen (975 mg) and gabapentin (1500 mg). Swelling of the arm spontaneously resolved after 1 week, but medication did not alleviate the pain. One month later, the patient complained of continuous pain in the right hand, arm, and shoulder, hyperesthesia in the right fingers, and difficulties in performing normal daily activities, such as driving and using chopsticks. An electromyography was performed to determine nerve damage, and showed no abnormalities on either motor or sensory nerve conduction studies. An F-response was performed and showed normal latency range in all tested nerves, while a needle electromyography did not reveal evidence of abnormal resting denervation potentials for any of the tested muscles. Right brachial arteriography was performed to evaluate vascular complications and radial arterial occlusion was noted. Thermography was then performed to evaluate the chronic pain, which demonstrated that the temperature at the pain site was 2 °C higher than the unaffected left arm. Findings from thermography suggested that the chronic pain was due to reflex sympathetic tone abnormality because ischemia may lower the temperature at the pain site. Based on the diagnostic criteria established by the International Association of the Study of Pain, type I CRPS was a possible diagnosis, and thermographic findings were confirmative. The patient was treated with cervical epidural block and repeated right stellate ganglion blocks, and prescribed 1800 mg of gabapentin, 10 mg of nortriptyline, 200 mg of revaprazan, and 10 mg of hydromorphone. Twelve months after treatment, the patient was still suffering from mild pain, but improvement was noted in the patient's ability to perform daily activities.

DISCUSSION

By definition, CRPS results from neuropathic pain derived from abnormalities of the sympathetic nervous system. CRPS is diagnosed by a constellation of subjective symptoms, including immobilization, continuous pain, allodynia, hyperalgesia, hyperesthesia, and vasomotor symptoms. All other conditions that would otherwise explain the degree of pain and/or dysfunction must be excluded. There are two sub-types of CRPS: type I is with no identifiable nerve injury and type II is with a history of an identifiable nerve injury. A diagnosis of CRPS is further supported by the relatively higher temperature of the pain-affected area; increased sympathetic activity is the reason for the higher temperature. If the forearm pain was the result of limb ischemia, thermography of the forearm should demonstrate a lower temperature. The thermographic findings of this case suggested that right radial artery occlusion did not affect the development of the intractable pain. Thermography is an effective modality for assessing increases in reflex sympathetic tone and was recently proven to have a high sensitivity and specificity in diagnosing CRPS. Two degrees Celsius higher temperature in the pain-affected area demonstrated a diagnostic sensitivity of 73% and specificity of 94%.

Papadimos et al reported a case of type I CRPS secondary to radial artery occlusion, after 20 hours of compression by hemostatic device (Hemaband; TZ Medical). Sasano et al also reported a case of type II CRPS that was associated with a post-TRI median nerve injury resulting from excessive compression. Lai et al reported a case of type II CRPS due to a median nerve injury after TRI, diagnosed by plethysmography, electromyography, and nerve conduction studies. There was only 1 previously reported case of type I CRPS; in that case, pain developed from prolonged and excessive compression of the puncture site and was diagnosed by the pain criteria of the International Association for the Study of Pain. None of the previous cases described remarkable arm swelling, which was a suggestive finding of hematoma. However, in this case, radial artery hematoma was the main cause of pain. Puncture site swelling after removal of the hemostatic device and extension to the upper arm suggests there was hematoma. This may result in prolonged compression of the radial artery and increased pressure in the carpal tunnel. Acute pain developed from ischemia secondary to radial artery occlusion and compression of nerves, lasted more than a week and progressed to chronic pain, which eventually aggravated to CRPS. Acute severe pain and arm swelling after TRI should be considered for compartment syndrome, but in this case, arm swelling was not so severe and resolved spontaneously. Thermography demonstrated meaningful information for confirmative diagnosis of type I CRPS in this case.

CONCLUSION

We presented the first thermographically diagnosed case of post-TRI type I CRPS. The patient suffered intractable pain and arm swelling immediately after TRI, and was treated with analgesics. Arm swelling resolved spontaneously, but unalleviated pain lasted for a considerable time period. Allodynia, immobilization, and hyperesthesia developed in the right arm, and type I CRPS was confirmed by normal electromyography findings and abnormal thermography findings. The clinical course of the patient suggests that pain after TRI should be treated thoroughly and swelling of the puncture site should not be neglected, because it can progress to serious complications such as CRPS. Moreover, this case demonstrates that reflex sympathetic tone dysfunction can be effectively examined by thermography, a modality also helpful in diagnosing CRPS.

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ii. THE ROLE OF INFRARED THERMAL IMAGING (ITI) IN MANAGEMENT OF NEUROPATHIC PAIN

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ABSTRACT

The value of Infrared thermal imaging (ITI) is limited to evaluation of neurovascular dysfunction. It provides useful diagnostic and therapeutic information in the management of neuropathic pain. Key Words: Infrared thermal imaging, neuropathic pain, ITI in pain management.

INTRODUCTION

The nociceptive chronic pain is usually due to involvement of large somesthetic (somatic) nerve fibres. Electromyography (EMG) and nerve conduction velocity (NCV) tests are usually the diagnostic tools for the study of somesthetic pain. In contrast, these tests are normal in neuropathic pain because they can not detect changes in the microscopic thermosensory neurovasculature. The diagnosis and management of neuropathic pain requires neurovascular autonomic tests such as infrared thermal imaging.

METHODS

The role of ITI in pain management was studied in 762 successive complex pain patients evaluated with ITI. The results were compared with a meta analysis of medical literature. A Bales Scientific Infrared Thermal Processor and an Agema (Flir) Infrared Thermal Processor were utilized in this study. The patients were cooled down in a 20-21ºC steady state room for 30 minutes of equilibration without clothing. No prior smoking for 90 minutes. A standard sensitivity of 24-34ºC was done. If the areas were not properly visualized the physician would adjust the sensitivity accordingly. Two identically reproducible images recorded on laser disc were required.

RESULTS

The study revealed the importance of proper technique and proper clinical correlation. ITI is useful in the study of complex neuropathic pain. It provides indispensable diagnostic and therapeutic information. Both superficial and deep temperature changes influence the ITI test. The skin is an almost perfect radiator of both deep and surface heat. This radiator, has 98% emissive efficiency. The ITI records pathological temperatures at least as deep as 27 mm in the extremities, and even deeper in the breast.

CONCLUSION

ITI exclusively provides diagnostic information in neuropathic pain. Such information cannot be achieved by EMG or NCV. ITI is useless in diagnosis and management of cervical and lumbar sprain. It can spare patients from unnecessary amputation, carpal tunnel, temporomandibular joint, spinal disc surgeries and migraine. It is helpful in differentiating cervicogenic headache from migraine-each requiring opposite forms of treatment. In electrical injury ITI identifies points of entrance and exit of electricity. This picture is pathognomonic and is exclusively seen in electrical injury. ITI identifies hyperthermic foci of permanent sympathetic system damage sparing the patient from further damage by trauma of sympathetic nerve blocks.

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iii. Infrared Thermographic Vasomotor Mapping and Differential Diagnosis

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When performed with proper technique and under controlled conditions, thermography (Computerized Infrared Imaging or CII) is the test of choice for mapping of vasomotor instability and asymmetry. The findings provide important clinical insights into those structures that generate aberrant sympathetic responses for pain syndromes such as Reflex Sympathetic Dystrophy (RSD), Complex Regional Pain Syndrome types I and II (CRPS), Thoracic Outlet Syndrome (TOS), Cervical Brachial Syndrome, Fibromyalgia, and Barre-Lieou. In addition, the presence of abnormalities and the distribution of findings can be invaluable in differential diagnosis of these conditions.

The medical community has demonstrated increased awareness of sympathetic pain syndromes over the last decade. New interventions and approaches toward alleviating symptoms in those afflicted have been tried, some with success. Even better results can be achieved through a greater understanding of which structure is initially responsible for generating the condition.

The sympathetic system, which is largely responsible for the control of surface skin temperature, innervates all tissue of mesodermal and ectodermal origin. For non-visceral soft tissues, this includes muscle, ligament, synovium, tendon, fascia, dura, disc, and peripheral nerve fibers. Other less obvious but equally important structures, such as interosseous membrane and neuro-lymphatic sphincters, can be richly innervated by the sympathetic system as well. Essentially, the innervation of the sympathetic system is ubiquitous.

Since one of the primary functions of the sympathetic system is to monitor those tissues that it innervates, it is not surprising that when an injury occurs to one of those structures, the system may occasionally function improperly. Why this occurs remains speculative, but the net result is an alteration in trans-membrane electric potential of the affected sympathetic nerve fibers. Direct structural injury, vascular ischemia, infection, and coagulopathy are just a few of the mechanisms that might lead to such an alteration.

From a thermographic perspective, what is important is whether the resultant vasomotor response is great enough to create a change in skin temperature of greater then 1º C compared to the contralateral side or with respect to the surrounding dermatome, sclerotome, or vasotome. While dermatomes represent the distribution of sensory nerve fibers upon skin, a sclerotome reflects the distribution of skin galvanic impedance influenced by a visceral or non-visceral soft tissue structure. Numerous sclerotomal patterns exist. Examples of clinical conditions with identified sclerotomal patterns (often described as referred pain) include facet syndromes, myofascial, ligament, and dural pain syndromes.

It is important to recognize that while sclerotomal patterns frequently mimic pain patterns such as herniated disc, they are not at all pathognomonic for the same. For example, a fibulocalcaneal ligament strain may very well have thermographic change that tracks in an L5 distribution, but that does not mean that the L5 nerve root or disc is the source of those findings. While the nerve root or disc may be the source, all structures that refer within that sclerotome must be considered when deciding which structure is responsible for the abnormality.

Likewise, it is important to understand that treating any structure within the sclerotome may actually correct the abnormality. Sometimes all that is required to restore skin galvanic impedance to normal, and its associated vasomotor instability or asymmetry, is to remove the stimulus that initially generated the sympathetic response. This may mean an injection of a medicine into a torn ligament that stops inflammation or repairs the tear, or of a neurolytic agent that alleviates a persistent non-physiologic contraction of muscle. Naturally, other examples exist, such as hyaluronidase injection into a knee, and oral or topical medications that restore blood flow and modulate sympathetic tone.

Not withstanding the above, there is also every reason to believe that treating cephalad to the most proximal portion involved will be more effective then treating caudal to it. The medical literature is replete with references demonstrating the benefit of spinal blocks for sympathetic pain syndromes. It is not, however, as clear why some blocks are more successful then others.

If a lumbar thermographic study demonstrates vasomotor asymmetry that tracks in an L34 dermatome or sclerotome, it would be reasonable to speculate that a sympathetic block at L3 would be more effective then an epidural block at L5. In addition, if the original injury was in the ankle at the medial collateral ligament of the knee, then a concurrent injection with intensive physical therapy at that locale may prove to be even more rewarding than either intervention alone. By obtaining thermographic imaging, powerful answers as to the extent and distribution of involvement can be obtained.

The thermographically generated vasomotor map also provides invaluable information for therapeutic decision-making when treatment previously based upon it fails. For example, if a lumbar block does not produce pain relief in an L5 vasomotor-mapped patient, the patient may still show dramatic response to a peroneal nerve block (another L5 innervated structure). A combination of expertise in the basic anatomy of those structures that can exert influence in the distribution of the vasomotor abnormality found, and the ability to objectify where the vasomotor asymmetry actually occurs, allows for a more rational approach to intervention that is otherwise not available.

Vasotomes represent another pattern of abnormality that the examiner must understand. They should not be confused with vasomotor instability of sympathetic origin. Vasotomes are not dependent upon sympathetic control of skin galvanic impedance, cutaneous vasculature or sweat glands, but rather represent peripheral vascular supply zones.

Likewise, local inflammatory conditions, such as a hot joint in rheumatoid arthritis or erythema associated with a rash should not be confused with local vasomotor dysfunction under sympathetic influence. By completing a full thermographic study (bilateral extremities from multiple views and corresponding spinal segments), it is not at all difficult to differentiate local inflammatory, venous, or peripheral artery abnormalities from sclerotomal or dermatomal patterns.

A normal study is also clinically helpful. It is not uncommon for a patient to be given a diagnosis of CRPS/RSD and yet be non-responsive to sympathetic block. Prolonged, hopeless medical management or invasive procedures such as spinal cord stimulators can result. A normal study helps rule out the original diagnosis, or at least suggests that a sympathetically independent pain syndrome may exist.

A localized thermographic pattern inconsistent with other recognized patterns can provide useful information as well. For example, when warming is present in the dorsolateral aspect of the foot alone, the examiner should look for a missed fibulotalo ligament strain that, when treated, may be miraculously responsive. Since sympathetic variants such as the Angry Backfiring C syndrome (where a backfiring of the C fiber results in excess Substance P accumulation) may also create a similar picture, differential diagnostic skills must still be employed.

"While dermatomes represent the distribution of sensory nerve fibers upon skin, a sclerotome reflects the distribution of skin galvanic impedance influenced by a visceral or non-visceral soft tissue structure."

In the case of ABC syndrome, sympathetic block may not only fail, but can create a paradoxical worsening of symptoms, as the painful part is already vasodilated. In this instance a pharmacologic approach that is intended to deplete Substance P or target receptors responsible for vasoconstriction, or employment of electric sympathetic block (where different aspects of the voltage gate can be targeted) may prove more effective then a chemical sympathetic block. Whenever a paradoxical response to sympathetic block occurs, this should be kept in mind.

In addition to objectifying the presence of a paradoxical effect, Infrared Thermographic monitoring during blockade can be quite helpful in assessing if intended ipsilateral vasodilatation was accomplished. Even when a Horner's is observed with a stellate block, as many as 40% of patients do not get limb vasodilatation. Their lack of clinical responsiveness to the block may lead to a false impression that CRPS/RSD does not exist.

The Triple C syndrome, consisting of cold hypesthesia, cold allodynia and cold skin, is another localized sympathetic variant. As expected, with this syndrome Infrared Thermographic imaging reveals a localized cold asymmetry pattern. The more distal the occurrence of this syndrome, the less responsive the patient is to a spinal block. With Triple C syndrome, combination interventions, including localized therapy and pharmacologic agents, should be more aggressively used.

Diffuse vasomotor instability involving an entire limb or limb segment, and not confined to a particular dermatome or sclerotome, is a hallmark finding of a true RSD syndrome. Dural, neuro-immuno-infectious interactions and multiple generators should be aggressively investigated. While any case of sympathetic pain with vasomotor instability can spread, when diffuse vasomotor asymmetry exists, symptomatic intervention with an eye towards prevention of spread, limb trophic changes, edema, contracture or Sudeks atrophy should be emphatically employed.

Stopping progression is one of the most effective treatments a physician has to offer in the treatment of CRPS/RSD. Early diagnosis, due to high sensitivity, is one of the great advantages that thermography offers over triple phase bone scan or diagnostic block in the management of sympathetic pain syndromes. Findings of diffuse vasomotor asymmetry should alert the physician to intercede promptly to interrupt the progression of CRPS/RSD toward stages two and three.

The physician must keep in mind that thermography is no different than any other objective study. Ultimately, it is always best to treat patients based upon both clinical and diagnostic impressions, not test results alone. This approach will help avoid the potential pitfall case wherein a localized, or clearly defined, asymmetry pattern unexpectedly shows rapid progression to escalating stages.

The International Association for the Study of Pain (IASP) has published diagnostic criteria for the diagnosis of CRPS types one and two and revisions have already been suggested. Whether the revised clinical and research criteria, or the original criteria are used, objective signs of vasomotor instability (changes in skin blood flow or evidence of temperature asymmetry) remain a diagnostic criterion. This is important as it is well established that palpation alone is a poor way to assess for skin temperature change.

In addition to being insensitive, palpation provides no ability to map the distribution of those changes. In cases where allodynia, hyperalgesia or barometric weather sensitivity exist, only thermography offers the ability to objectify if the vasomotor instability criterion is satisfied. In addition, the American Medical Association's "Guides to the Evaluation of Permanent Impairment" recognizes that "…regional sympathetic blockade has no role in the diagnosis of CRPS." Instead, it cites objective criteria inclusive of vasomotor change.

Perplexed by the CRPS/RSD patient, “The Guides” suggest rating impairment based on alteration in activities of daily living, loss in motion of each joint involved, sensory and motor deficits for the nerve involved or sensory deficits, loss of power, and pain for the body part involved. While this approach attempts to sidestep the problem of objectifying which body part is involved, it is still left to the physician to address the issue.

In this light, the body part involved becomes not only a clinical issue, but also a medical-legal one. Just as a post-stroke, shoulder-hand syndrome patient may present with a swollen hand and be unable to communicate that there is proximal pain, a patient with a crush injury to the hand cannot be expected to articulate that he has vasomotor instability as far proximal as the shoulder or that the perception of compensatory proximal pain is actually sympathetic involvement of the entire limb.

Only after vasomotor mapping has been completed can the distribution of asymmetry be fully determined and the question of which body part is involved be properly addressed. There are many other difficult situations in which thermography is extremely useful in objectifying the extent or presence of involvement. These include thoracic outlet syndrome, cervical-brachial syndrome, vasomotor headache, atypical facial pain, the posterior cervical sympathetic syndrome of Barre-Leiou, and failed back syndrome.

While a sympathetic component should be considered in each of the aforementioned conditions, TOS deserves special attention. Patients who suffer from this malady often undergo extensive workups only to find the results to be negative. X-ray examination for a cervical rib is only found in a minority of cases and, when present, an even smaller number of cases show positive arteriograms.

Although other conditions that may be confused with TOS, such as radiculopathy or ulnar neuropathy, may be exposed, electrodiagnostic studies are usually not diagnostic for TOS. The vast majority of TOS cases are not due to overt vascular or lower trunk neurologic pathology, but rather secondary to numerous musculoskeletal conditions such as scalene anticus spasm, scapulothoracic dysfunction with resultant tension or mechanical torque across the thoracic outlet, and cervical-thoracic interspinous ligament strain with reflex myotomal spasms or myosfasical pain.

“Thermography is no different than any other objective study. Ultimately, it is always best to treat patients based upon both clinical and diagnostic impressions, not test results alone.”

Irrespective of which of these somatic issues is the source, patients complain of cold, burning, numb sensations, typically radiating from the neck or shoulder down the medial aspect of the arm and into the fourth and fifth fingers. In some cases, vasomotor instability is visible to the naked eye with obvious skin color changes. These patients frequently respond to a stellate or cervical plexus block.

Thermography is the obvious test of choice to objectify the presence or absence of a vasomotor instability consistent with TOS. Many surgeons have an aversion toward operating upon the TOS patient. In the absence of an absolute surgical indication for TOS, such as an obvious cervical rib that creates clear-cut stenosis on arteriography, thermography is the most cost-effective and diagnostic approach.

A positive study clearly demonstrates a heat emission asymmetry pattern across the medial aspect of the arm and forearm. Radiation to the medial aspect of the fourth and fifth fingers may be present as well. If a study is positive, and the clinician feels the need, then an apical chest X-ray to assess for cervical rib or arteriography can always be obtained later on.

Thermography is ideally suited for diagnosing Barre-Lieou, another common condition. There is no other diagnostic study that can objectify the presence of associated vasomotor instability. In Barre-Lieou, the posterior cervical sympathetic chain generates aberrant impulses that can result in facial heat emission asymmetry patterns.

There are several possibilities as to why the syndrome occurs, including a direct traction injury on the chain as in a whiplash-type injury, ischemia, or hidden infection. In any event, the result is recalcitrant head and neck pain — with or without scapulo-thoracic pain — associated with blurred vision, tinnitus, vertigo, or nausea.

Barre-Lieou is frequently responsive to sympathetic block. Infrared thermographic imaging of the face, cervical spine, and extremities effectively demonstrates vasomotor asymmetry in these cases. Through its unique mapping ability, thermography can also provide the physician with insight into which somatic level is responsible for the abnormality.

While proving the presence of heat emission asymmetry has great clinical significance, the benefit of objectifying its absence should not be overlooked. When criteria for CRPS are satisfied, but there is no vasomotor abnormality as with RSD, sympathetic independent pain should be more seriously considered. In this instance, relief from sympathetic block is far less likely and alternate conditions or interventions should be considered.

Secretan's Syndrome, which consists of post-traumatic peritendonous fibrosis, brawny edema, loss of finger extensor function, and trophic skin changes, is a relatively uncommon disorder that can mimic CRPS/RSD. This condition has no vasomotor or sudomotor component, so Infrared Thermographic imaging will be negative.

Glomus tumor of the hand, due to neuro-myoarterial tumor formation, is associated with excruciating distal finger pain, cold intolerance, and pain triggered by palpation. Abnormal blood flow in the distal phalanx does occur, but typical vasomotor asymmetry patterns do not.

If it were not for the unique qualities of medical thermography, the information obtained by it would not be otherwise available. Failure to consider the objective information made available by thermography limits clinical assessment and rational decision-making when developing a treatment approach for relevant conditions. Thermography is a unique imaging study that provides the physician with invaluable information in the diagnosis, treatment, and management of patients with suspected or bonafide sympathetic pain syndromes.

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iv. Infrared Thermography in Pain Medicine

Francis Sahngun Nahm, MD

INTRODUCTION

Since BC 400 when Hippocrates used temperature in a diagnosis by applying mud to a patient's body and speculating that dry areas had disease, temperature has been an important area of interest in medicine. The skin is a very important organ in temperature regulation, and body temperature is controlled by the combined control of the central and autonomic nerve system. Infrared thermography (IRT) detects infrared light emitted by the body to visualize changes in body heat due to abnormalities in the surface blood flow of diseased areas. IRT is not a tool that shows anatomical abnormalities, but is a method that shows physiological changes. It objectively visualizes subjective symptoms, therefore, it is useful in making diagnoses and doing evaluations in the field of pain medicine where a diagnosis is based on subjective complaints of symptoms. The advantages of IRT is that it is non-invasive and painless, it is not harmful to the patient, it is possible to conduct tests in a physiologically natural state, and its testing time is short. The aim of this paper is to introduce the basic mechanism of IRT, significance in interpretation, and clinical utilization.

BASIC MECHANISM

The most important theoretical background of IRT is that the distribution of body heat in a normal body is symmetrical. Therefore, the symmetry of body heat is considered to be the most important element when interpreting IRT images. An infrared camera is used to measure infrared light emitted from the body and displays this on the screen, and pseudocolor mapping is done on the obtained infrared image to facilitate visual interpretation. Therefore, when comparing the distribution of body heat on both sides of the body, the region of interest (ROI) is set to an equal size on each side of the obtained pseudocolor image, and the mean temperature within each ROI is calculated to compare the difference. There are two methods to compare the temperature difference within an ROI of the affected and unaffected sides. The first method is to define a significant difference such as when the asymmetry of temperature deviates from 1-standard deviation of the unaffected side ROI, and second is to define the significance such as when the difference in mean temperature of both ROIs is more than the ‘reference temperature difference’. The latter method is mainly used in the clinical field.

UTILIZATION OF IRT IN PAIN MEDICINE

After Galileo designed the first thermometer in 1592, infrared light was discovered by William Herschel in 1800, and the first diagnostic IRT was used in diagnosis of breast cancer by Lawson in 1956. Then, in 1982, the US Food and Drug Administration approved IRT as an adjunctive screening tool of breast cancer, and up to now, there have been many studies regarding the usefulness of IRT in various areas such as complex regional pain syndrome (CRPS), postherpetic neuralgia, whiplash injury, inflammatory arthritis, temporo-mandibular joint disorder, headache, and myofascial pain syndrome. The diseases where IRT can be used are presented in. Considering that IRT visualizes physiological and functional abnormalities rather than anatomical abnormalities, there is no doubt that compared to other imaging diagnostic methods, IRT is an effective diagnostic method for diseases difficult to diagnose with CT or MRI, such as CRPS, neuropathic pain, headache, and myofascial pain. In fact, for CRPS, it is known to have higher sensitivity compared to MRI or three phase bone scan, and it is reported that thermography has higher sensitivity in diagnosis of neuropathic pain compared to the sympathetic skin response test. When deciding an abnormality in specific diseases, there are different views on what the ‘reference temperature difference’ should be according to researcher, and for CRPS, standards such as 0.6℃ and 1.0℃ are used. Meanwhile, regarding the reliability of IRT, research has been conducted for CRPS and myofascial pain syndrome, and it was reported that there is high reliability for these diseases. In terms of correlation between pain and temperature difference measured with IRT, it was reported that there was a significant correlation between the severity of pain caused by lumbar disc herniation with the difference in skin temperature. It was also reported that there was a significant correlation between the pressure pain threshold and the temperature difference in myofascial pain syndrome. Recently, the technique, which obtains a dynamic image using a stress loading test as well as static IRT, is widely used. The theoretical basis for this is that normally the temperature change on both sides of the body after stress loading is symmetrical, and the degree of temperature restoration after removing the stress is symmetrical on both sides. Therefore, when restoration of temperature is asymmetrical after removal of stress, it is considered that physiological abnormalities exist. For the stress loading test, cold/warm stress, exercise, pharmacological stress, vibration, and visual stimulation are used as stress, and from these, the cold stress test is used the most. When using cold stress thermography, it is known that sensitivity and specificity is enhanced for diagnosis of CRPS, but it causes pain for the patient during the cold stress thermography, and a standardized guideline for the stress loading test has not been established.

POSSIBILITY OF ERROR IN COMPARING THE TEMPERATURE DIFFERENCE OF BOTH SIDES ACCORDING TO THE ROI SETTING

Currently there are no established standards for setting an appropriate ROI. The ROI is set as symmetrical on the pseudocolor image based on the discretion of the examiner taking into consideration the medical history and symptom area of the patient. Therefore, according to the size and shape of the ROI, the temperature difference on both sides can be calculated differently. In addition, the IRT equipment currently used only shows the mean temperature and standard deviation within the fixed ROI, and the actual interpretation of the IRT image only compares the mean temperature of the ROI without considering the size of the ROI. In principle, when comparing two means, statistical difference is determined by considering the mean, standard deviation, and sample size. Thus, when only the mean values are simply compared without considering all these items, there is the possibility of error based on statistical interpretation. Therefore, considering the number of pixels in the fixed ROI (reflecting sample size), and the mean and standard deviation of the temperature in interpreting results can reduce false positives and false negatives, and enable objective interpretation of the results. For this, an ROI of equal size symmetrical for both sides of the body is set, and the t-test can be used taking into consideration the mean temperature, standard deviation, and number of pixels in the ROI, or the pixels on each side can be matched 1:1 to conduct a paired t-test for the temperature difference in each matched pixel. Based on personal opinion, it is difficult to satisfy the assumption that the left and right side of the body are independent; thus, using the paired t-test with matched pixels is thought to be a more valid method statistically. However, there is no testing equipment which provides this kind of function presently. Hence, it is anticipated that an IRT system will be developed to enable such statistical analysis in the future.

DEVELOPMENT OF IRT TECHNOLOGY

Recently, there has been much effort to improve the hardware and software of medical IRT. Developments have been achieved such as enhanced performance of the infrared sensor, improved image quality, real-time image processing, and a multi-channel system. As a result, it is possible to obtain precise images with a thermal resolution of 0.08℃ or lower and a special resolution of 1×1 mm or lower. A 3-dimensional image technique was also developed to show the body heat in a more detailed image compared to the existing 2-dimensional image. In addition, recently a remote diagnosis system was established to decipher images from a long distance away.

CONCLUSION

IRT is a non-invasive and safe diagnostic method which visualizes functional abnormalities and is used effectively in the diagnosis of numerous diseases and in the evaluation of treatment effect. Compared to other imaging diagnostic methods, it shows high diagnostic performance in pain diseases, and even higher sensitivity and specificity is obtained when using the stress loading test. Together with the development in medical technology, it is anticipated that the use of IRT will gradually increase in the field of pain medicine.

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v. Parameters of thick and thin nerve-fiber functions as predictors of pain in carpal tunnel syndrome.

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Pain intensity in carpal tunnel syndrome (CTS) was correlated with neuro and psychophysiological parameters related to the function of different nerve fiber classes within the median nerve in 23 patients. Control data were obtained from 16 normal subjects. Mean intensity of all pain attacks which occurred 14 days before surgical treatment was assessed on visual analogue scales (average CTS pain). Functions of thick myelinated nerve fibers were determined by motor and sensory nerve conduction studies. Functions of thin myelinated and unmyelinated nerve fibers were evaluated by measuring thresholds of warmth, cold and heat pain on the index and little finger. Pain intensity and neurogenic vasodilatation following noxious mechano-stimulation on the interdigital web between index and middle finger provided additional information on the functioning of nociceptive nerve fibers. Sympathetic reflexes induced by these painful stimuli were assessed by means of infrared thermography and photoplethysmography. Mean intensity of pain attacks (40 +/- 19% VAS) correlated significantly with latency ($r = 0.58$, $P < 0.01$) and amplitude ($r = -0.50$, $P < 0.01$) of the compound action potential from abductor pollicis brevis muscle following distal median nerve stimulation. Thresholds of warmth, cold and heat pain on index finger were significantly increased during CTS when compared to the control subjects. The magnitude of neurogenic vasodilatation and sympathetic vasoconstrictor reflexes were not significantly different. Average CTS pain correlated inversely to the threshold of heat pain on index ($r = -0.46$, $P < 0.05$), but also on the little finger ($r = -0.41$, $P < 0.05$), which is not innervated by the median nerve.

vi A Review on Inflammatory Pain Detection in Human Body through Infrared Image Analysis

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ABSTRACT

Temperature difference in the skin surface reflects the abnormality present in the human body. Considering the phenomenon, detection and forecasting the change of temperature is the principal objective of using Medical Infrared Thermography (MIT) as a diagnostic tool for inflammatory pain diseases. Medical Infrared Thermography (MIT) is a noninvasive, non-contact and fast imaging technique that record and monitor the flow of body temperature by receiving the infrared emitted from the skin surface. Based on the standardization of thermogram acquisition and processing techniques and by the adoption of advanced infrared cameras, presently it is feasible to detect the minor temperature difference of the skin surface in the high-resolution infrared images. Recently, the research on inflammatory pain detection using medical infrared thermography concentrated on the area of temperature and statistical analysis based automated detection of abnormality from the thermograms. The paper introduces a significant review focusing on the area of different inflammatory pain detection using infrared thermography along with the environmental condition, protocol selection, and acquisition system specification in summarized tabular format. Based on the rigorous study of the publications in the area of inflammatory pain thermography, the paper also explores the area of thermogram processing and analysis of pain in a review work format.

I. INTRODUCTION

Human body distribution of temperature is widely affected by pathological abnormalities. Hence the recording of inflammation of the skin surface related with the core temperature distribution can provide essential information regarding the underlying physiological activities. The dissipation of inflammation from the skin surface is radiating in nature and lies in the infrared spectrum of light [1]. The spectrum range of inflammation makes the infrared detector suitable for recording and analysis of the thermoregulatory distribution of the skin. Medical Infrared Thermography is a non-invasive imaging technique that can detect abnormality by allocating and quantifying the inflammatory changes in the skin surface related to the temperature distribution. Since 1987, it has been accepted as a diagnostic imaging technique by the American Medical Association Council and also recently approved by American Academy of Medical Infrared Imaging for medical imaging [2]. The detection method of the Medical Infrared Thermography is primarily based on the evaluation of temperature distribution among contralateral parts of the body. In case of healthy subjects the difference in temperature distribution is not higher than 0.5-degree Celsius [3]. Starting from the last eighties, detection of pain using thermal imaging was examined in many past investigations. Most of the investigations provide statistical quantification techniques for the abnormality analysis. Based on the study of the most relevant works published in the past, the paper represents a review work on pain detection using Medical Infrared Thermography along with the survey of acquisition conditions.

In the rest of the paper, the section II describes some inflammatory pains that can be detected using Medical Infrared thermography. Section III contains the methodological review work related to the pain thermography. The section IV and V represent the review work related to protocol selection for thermogram acquisition, thermal camera specification and disease related thermogram description in descriptive and tabular format. Finally the conclusion along with future work is made in section VI followed by the acknowledgement and the reference part.

II. MEDICAL INFRARED THERMOGRAPHY IN INFLAMMATORY PAIN DETECTION

Temperature distribution analysis and early detection of abnormality due to inflammatory pain are recognizable by Medical Infrared Thermography. Thermographic detections are compared with the clinical observations and tests for possible confirmations. Although the technique heavily depends on the surrounding and background environment, there are a number of reasons for accepting the technique for diagnosis of inflammatory pain. In general, inflammation is related to pain diseases like arthritis, frozen shoulder, Prolapse Intervertebral Disc (PIVD), spondylosis, etc. which are not defense system begins attacking the healthy tissues instead of detected by clinical observations. In case of arthritis, the immune system of the body become affected and the body foreign substances, and it causes inflammation, pain and joint damage. The presence of additional inflammation due to arthritis can be detected using medical infrared thermography.

In frozen shoulder also, pain and restriction of movement arises due to inflammation. The capsule in the shoulder area has ligament and holds the bones of the shoulder with each other. The inflammation in capsule area restricts the movement of joints and generates pain that can be early detected by the thermal imaging. The inflammation due to Prolapse Inter Vertebral Disc (PIVD) pain can generate neuronal activity along with swelling in compression of a nerve in the intervertebral region. Detection and treatment of inflammation using thermography in the initial stage can avoid the nerve compression stage in the human body.

III. METHODOLOGICAL REVIEW OF PAIN THERMOGRAM ANALYSIS

The skin of the human body contributes an important part in thermoregulation by preserving or dissipating heat. The infrared thermal imaging or the clinical thermography reports the distribution of temperature in human skin by receiving infrared radiation from the surface of the human body [4], [5]. In the past years, authors had detected the abnormality in a human body based on the analysis of temperature distribution and correlated intensity distribution of thermograms. In 1995, Kim et al. [6] analyzed the thermal difference to detect the lumbar disc herniation. For this purpose, the severity of pain was measured by Visual Analog Scale (VAS) and Graphic Rating Scale (GRS) and compared with the thermal difference to differentiate and detect acute and chronic disc herniation and its level. The thermal difference that they measured for acute and chronic disc herniation was based on the degree of pain, duration of clinical symptom, comparison with clinical signs, types of herniation according to radiological study and based on level of herniation like mild, moderate and severity of pain and compare with the radiological studies like CT Scan, MRI etc. In the year 1997, Hooshmand, H [7] also detected abnormality in the whole body related to pain using the temperature analysis method. The analysis had been performed on the control volunteers group and neuropathic pain patients. The method was based on the concept that unmyelinated perivascular sympathetic small c-fibers are the origin of neuropathic pain. As because the c-fibers are too small so that they are best evaluated with infrared thermal imaging compared with EMG/NCV or MRI or CT. After analysis, the rate of true positive was 78% and false positive detected 14%.

To analyze pain in the human body using thermal images, Herry et al. [4] suggested a computer aided decision support technique and summarized the result of the analysis in the year 2002. This technique was the combination of image processing and temperature analysis method. In this technique, in the first step, to remove noise from thermal images , they had followed Poisson distribution and removed noise using Wavelet-based removal technique proposed by Nowak and Baraniuk[8]. Then edge detection and morphological operations were adopted for classification of a body part from the image. In the next step, analysis of abnormal high or low temperature areas was performed by statistical analysis and comparison of intensity distributions of symmetrical or comparable regions of interest and the result is summarized in a computer aided decision support scheme.

Again in the year 2003, Frize et al. [9] reported a technique based on thermal pattern analysis to detect physiological disorder caused by pain in the human body. The technique was focused on the thermal pattern analysis of normal subjects and abnormal subjects related to pain. For denoising, the thermal images they again followed wavelet-based noise removal technique. To improve the efficiency of images,they removed the undesirable portion of the image. Then to detect the region of interest, classical grid of polygon and isothermal representation of images were used. In the output of image rocessing steps, the statistical analysis was performed to detect an abnormality.

Subsequently to detect Rheumatoid Arthritis (RA) Frize et al. [5] proposed a temperature measurement based statistical analysis method in the year 2011. This analysis was performed on a normal group of persons with no rheumatoid arthritis and a group of patients suffering from rheumatoid arthritis. In the first step of the analysis, the difference between the average temperature of joints in the control group and the patient group was determined. In the next step, the identification of joints was performed which gives the best confirmation of the presence of Rheumatoid Arthritis based on the temperature difference. In the last step, statistical analysis was performed to find out the significant statistical difference of temperature of joints in the control group and the patient group. The statistical features used for the analysis was skewness, kurtosis, variance, mode/max, median/max, min/max, maxmin, (mode-mean)2,mode/min, median/min and mean/min.

For shoulder impingement analysis, Park et al. [10] also used statistical analysis method to analyze the temperature distribution of related thermograms. The thermography screening was applied to the region of interest of both the control group and patient group. The statistical analysis of thermogram was performed by SPSS 13.0 using the independent t-test for comparison of each Region Of Interest of patient group and control group. The clinical symptoms, physical examination findings and the thermographic findings are compared by 1- way analysis of variance with a Bonferroni post hoc test on numeric data and Pearson x2 analysis for the binomial data. Pearson linear correlation was performed to find the correlation between the clinical and thermographic data. Clinical abnormality was determined based on the finding of asymmetrical distribution of temperature in between the contralateral body parts.

In 2008, Lee, Junghoon, et al. [11] proposed a technique for automatic detection of suspicious pain regions on digital infrared thermal images based on SOFES (Survival of the Fitness kind of the Evolution Strategy) algorithm. The suspicious pain region can be detected by using multimodal function optimization algorithm, such as SOFES algorithm [12] based on the concept that the painful region represents a low temperature or high temperature compared with its neighbor regions on one's skin in thermography. The preprocessing steps that were required before applying SOFES algorithm are Region of Interest (ROI) detection, FPA sensor's output signal extraction and applying Gaussian to blur the image.

In 2010,Tkacova, M., et al.[13] performed infrared thermography analysis in a group of patients suffering from carpal tunnel syndrome. The analysis was based on the asymmetry factor calculation using the histogram of the temperature distribution of contralateral hand parts. To determine the asymmetry factor, the authors used the method explained by Huygen et al.[14] in the year 1998. The authors Zivcak, J., et al [15.]extended their work in the year 2011 by applying statistical features in the large no. of thermogram to calculate the asymmetry of temperature distribution. The temperature analysis was performed in 5 points of the dorsal side of the hand. The analysis indicates that the temperature distribution of the median nerve in the dorsal hand side was significantly different between the control group and carpal tunnel syndrome group. The analysis shows 0,714 sensitivity with 0,714±0, 1207 confidence interval and 0,852 specificity with 0,852±0,095 of confidence interval.

In 2011, Borojevic, N., et al. [16.] also analyzed the thermogram of rheumatoid arthritis and osteoarthritis in human hand. The basic statistical analysis of temperature was performed. The asymmetry of temperature distribution was measured using 4 ways ANOVA test in between the ventral and dorsal side of hand of healthy and arthritis subjects. The mean value showed the best significant difference between the two subjects (healthy and arthritis subjects).

The heat distribution related to rheumatoid arthritis was again evaluated by Snekhalatha, U., et al.[17] in 2012 depending on the heat distribution index. The authors also segment the region of interest using fuzzy c means and Expectation Maximization algorithm. From the analysis, they predicted an abrupt temperature variation in the affected due to rheumatoid arthritis.

IV. SURVEY ON IMAGE ACQUISITION PROTOCOLS

For thermal imaging related to pain, there is no protocol that is universally accepted as acquisition standard at present. For this reason, each clinic or university or research group follows their own protocol as per their needs. But there is a similarity found in the acquisition condition of patients, room temperature, and other different factors. Frize et al. [5] recommended the thermography at 20°C room temperature. They instructed their patients, not to apply talcum powder, lotion or deodorant on skin on the day of examination. Some controllable factors such as hot drinks, alcohol, physical exercise, etc. could potentially produce effect on the skin. For this purpose, they recommended not to take hot drinks one hour prior to the imaging, not to smoke two hours prior to the examination and to avoid prolonged sun exposure for a week before imaging. Also they suggested avoidance of alcohol twelve hours prior to the imaging and also avoidance of acupuncture, hot or cold presses, physiotherapy, TENS (Transcutaneous Electrical Nerve Stimulation) and physical exercise twenty-four hours prior of the session. According to Park et al.[10] room temperature needs to be set on 19 to 20°C and patients need to be in upper body disrobed condition 15 minutes before the screening to get a stabilized condition. Lee, Junghoon, et al.[11] recommended their patients not to apply any lotion or ointments and also to put off rings, necklaces, and watches. They also recommended that patients should quit physical therapies. According to their preparation for thermography, in order to be stabilized, patients should keep themselves undressed for more than 20 minutes before imaging. Tkacova, M., et al[13] and Zivcak, J., et al [15] also suggested to keep the region of interest for thermography in undressed condition for 20 minutes before capturing of thermogram at 20°C . The room for thermography was retracted blind from solar radiation. Borojevic, N., et al.[16] performed their acquisition in a stable condition of temperature and humidity. Snekhalatha, U., et al[17] also recommended to perform the capturing in a stable temperature of 20°C with 20 minutes stabilization of patients in disrobed condition at the area of imaging.

V. SURVEY ON THERMAL CAMERA AND THERMOGRAMS

Kim et al. [6] analyzed thermography related to lumbar disc herniation of 147 patients and grouped them into acute and chronic based on severity of pain which was measured by Visual Analog Scale (VAS) and Graphic Rating Scale(GRS). The number of cases related to acute disc herniation was 78 and 69 were present in chronic disc herniation. The thermography camera used by the author was Digital Infrared Thermographic Imaging (D.I.T.I. DOREX Inc) for evaluation of pain based on thermograms. Hooshmand, H [7] studied the thermography related to neuropathic pain in the human body using Agema Cameras with Bales Scientific Thermal Processor. For this purpose, 682 thermograms of neuropathic pain patients and 100 thermograms of control volunteers had been taken for the study. Herry et al. [4] considers 100 patients from the Pain Clinic of the Moncton Hospital, New Brunswick, Canada in between the year 1981 and 1984 by using a thermal camera of 128×128 pixels with 256 gray intensities level named as AGA Thermovision 680 medical ans AGA OSCAR. Frize et al. [9] captured the first set of 100 thermograms related to pain in the human body from Pain Clinic of the Moncton Hospital, New Brunswick, Canada, between 1981 and 1984. The second set of 24 thermograms related to normal healthy volunteers had been taken in the year June 2002 for comparison and analysis with thermograms related to pain. All the thermograms were of the back and legs of the human body. Frize et al. [5] used a thermal camera of 320×240 pixels to analyze the thermograms of patients suffering from Rheumatoid Arthritis. They had taken thermograms of 13 patients and 18 normal subjects, and those images were collected from knees, wrists, palms and from joints of hand. Among those 13 patients, 9 were female, and 4 were male and out of 18 normal subjects 8 were female and 10 were male. The wavelength of the thermal camera was from 7.5 to 13 μm, and Field of View (FOV) was 24°x18° with 1.3 mrad spatial resolution and 0.05°C at 30°C thermal resolution. The minimum focus distance was 30 cm, and the imaging speed was 30 frame/sec. Park et al. [10] present a research related to the thermographic imaging in patients with shoulder impingement syndrome. This was performed by using the IRIS5000 (Medicore, Seoul, Korea) and consisted of a computer, an infrared camera and a liquid crystal display monitor. Thermograms of upper body of 100 selected patients in 4 views were taken from shoulder and elbow joints at the clinic in the Department of Orthopaedic Surgery. The four views were posterior, anterior, left and right lateral views and, among those 100 patients, 55 were men, and 45 were women. They had also taken 30 thermograms of the same four views from normal persons without any pain or problem to study the thermography related to shoulder impingement. Lee, Junghoon et al. [11] collected thermograms of patients suffering from glycosuria, degenerative arthritis and varicose vein using a Thermal Vision of MESH Co., Inc. in Republic of Korea. The images were of size 320×240 pixels, and the thermal sensitivity of the camera was less than 50 mk. For analysis, Tkacova, M., et al [13] collected 7 thermograms related with carpal tunnel syndrome patients and also collected 7 symmetrical thermograms of healthy persons using ThermaCam Fluke Ti55/20 acquisition system. with thermal sensitivity 0.05°C at 30°C and resolution 320×240 pixels. The spectral range of the camera was 8 to14 μm. The dorsal view of the hand was taken parallel at the distance of 0.55 meter and in extended analysis, Zivcak, J., et al [15] had taken total 268 thermograms of dorsal hand side of both the healthy patients and pathological hands containing Carpal Tunnel Syndrome with 0.98 thermal camera emissivity. Borojevic, N., et al [16] captured ventral and dorsal side of hand using Thermo Tracer TH7102WL system. Their analysis was performed on the thermograms of 6 healthy volunteers, 8 patients containing rheumatoid arthritis and 7 patients of osteoarthritis. Snekhalatha, U., et al. [17] also captured thermogram of anterior and posterior view of hand for rheumatoid arthritis using ThermaCAMT400 camera from 1-meter distance of the region of interest. The thermograms was taken from 10 patients with rheumatoid arthritis and for analysis thermogram of 10 normal persons are also taken and analyzed. The Table III represents summary of camera specification and details of thermogram and disease in tabular form.

VI. CONCLUSION AND FUTURE WORK

With the advent of high sensitivity infrared cameras, Medical Infrared Thermography is becoming an alternative diagnostic tool for inflammatory pain detection. In addition to high sensitivity, thermogram resolution and accuracy, infrared thermography is a non-invasive methodology with harmless imaging technology. The thermograms are stored digitally for further analysis using various software packages and image processing based analysis to obtain the pattern of temperature distribution. In this paper, the methodological review briefly describes the analytical methods of pain thermograms. Studies so far indicate that, the statistical analysis of temperature distribution of thermogram is common and widely accepted method for abnormality analysis related to inflammatory pain. The review based study also shows that, the control environmental condition and proper protocol selection for minimum interference are effective parts of the accurate thermogram acquisition. But there is no protocol that is universally accepted for inflammatory pain analysis a present. In the future phase, the work will be extended by creation and analysis of database related to inflammatory pain in the human body by following required standardized protocols of thermogram acquisition.

ACKNOWLEDGMENT

The work presented here is being conducted in the Bio-Medical Infrared Image Processing Laboratory (B-MIRD), Department of Computer Science and Engineering, Tripura University (A Central University), Suryamaninagar-799022, Tripura(W). The research work was supported by the Grant No.BT/533/NE/TBP/2013, Dated 03/03/2014 from the Department of Biotechnology(DBT), Government of India. The first and second author would like to thank hon'ble Vice Chancellor Professor Anjan Kumar Ghosh, Tripura University (A Central University) and Professor Barin Kumar De, Department of Physics, Tripura University (A Central University) for their kind support to carry out this work.

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