Faculdade de Engenharia da Universidade do Porto

The Use of Thermal Infra-red Imaging to Reveal Muscle Injuries Caused by Physically Demanding Jobs in Industrial Operations

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Dissertação realizada no âmbito do
Mestrado de Engenharia Biomédica

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Setembro de 2016

U.PORTO
FEUP FACULDADE DE ENGENHARIA
UNIVERSIDADE DO PORTO

MEB - MESTRADO EM ENGENHARIA BIOMÉDICA 2015/2016

A Dissertação intitulada

"The Use of Thermal Infra-red Imaging to Reveal Muscle Injuries Caused by Physically Demanding Jobs in Industrial Operations"

foi aprovada em provas realizadas em 18-10-2016

o júri

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Resumo

As Lesões Musculosqueléticas (LME) podem afetar diversas partes do corpo e quando surgem através da atividade profissional são designadas por Lesões musculosqueléticas relacionadas com o trabalho (LMERT). Pretende-se avaliar a possibilidade de usar a termografia como uma ferramenta de diagnóstico preliminar na deteção e monitorização de trauma e ocorrência de lesões.

O aparelho utilizado foi uma camara térmica, em que consegue detetar o calor produzido pelo corpo humano. A partir desta camara adquiriu-se várias imagens térmicas. As imagens foram processadas em software Matlab, com recurso a operações de binarização e de morfologia. Todas as implementações foram realizadas em MATLAB com 26 casos reais de imagens térmicas com lesões musculosqueléticas variáveis e 26 casos reais de imagens térmicas sem qualquer tipo de lesão.

Foi realizada uma análise entre os diagnósticos obtidos pelo enfermeiro, pelo programa desenvolvido em Matlab, e pelo enfermeiro observando as imagens térmicas não processadas. Verificou-se concordância dos diagnósticos entre o programa desenvolvido em Matlab e o diagnóstico do enfermeiro olhando para as imagens térmicas não processadas.

Os resultados obtidos são gratificantes e demonstram o potencial da termografia como ferramenta de apoio ao diagnóstico do enfermeiro.

Palavras-chave: Termografia infravermelha, lesões musculosqueléticas relacionadas com o trabalho, operações industriais, imagens térmicas, processamento de imagem.

Abstract

The musculoskeletal injuries (MSIs) can affect various parts of the body and when they arise through professional activity are called work-related musculoskeletal disorders (WMSDs). It is intended to assess the possibility of using thermography as a primary diagnostic tool in detecting and monitoring the occurrence of trauma and lesions.

The device used was a thermal camera, which can detect the heat produced by the human body. From this chamber was acquired several thermal images. The images were processed using Matlab software, using binarization and morphological operations. All implementations were done in MATLAB with 26 actual cases of thermal images with musculoskeletal injuries variables and 26 real cases of thermal images without any injury.

An analysis of the diagnoses obtained by the nurse was done, the program developed in Matlab, and the nurse watching the unprocessed thermal images. There was agreement between the diagnostic program developed in Matlab and the nurse's diagnosis looking for unprocessed thermal images.

The results are gratifying and demonstrate the potential of thermography as a support tool for the diagnosis of nurses.

Keywords: Infrared thermography, work-related musculoskeletal disorders, industrial operations, thermal imaging, image processing.

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Abbreviations, Acronyms and Symbols

List of abbreviations and acronyms

CTD	Cumulative Trauma Disorder
CTS	Carpal Tunnel Syndrome
DGS	Directorate General of Health
ESWC	European Survey on working Conditions
EU	European Union
EU-OSHA	European Agency for Safety and Health at work
EWA	Ergonomic Workplace Analysis
FDI	First Dorsal Interosseous
FPA	Focal Plane Arrays
HRM	Highly Repetitive Movements
IACT	International Academy of Clinical Thermology
IEA	International Ergonomics Association
IPT	Image Processing Toolbox
IR	Infrared
IRT	Infrared Thermography
LART	Lesion Atribuable aus Trauvaux Répétitifes
LCT	Liquid Crystal Thermography
LoG	Laplacian of a Gaussian
LW	Long-Wave
MDT	Mean Dorsal Skin Temperature
MSIs	Musculoskeletal Injuries
MW	Midwave
MWT	Microwave Thermography
OA	Osteoarthritis
OOS	Occupational Overuse Syndrome
QNM	Nordic Questionnaire Musculoskeletal
RBV	Relative Blood Volume
RSI	Repetitive Strain Injuries
SW	Shortwave
TMS	Troubles Musculosquelettiques
Tsk	Skin Temperature
UEMSD	Upper Extremity Musculoskeletal Disorder
UL	Upper Limbs
US	United States

USA	United States of America
VPT	Vibration Provocation Test
WMSDs	Work-Related Musculoskeletal Disorders

List of symbols

ε	Emissivity
σ	Stephan-Boltzmann constant
T	Cutaneous Absolute Temperature
K	Boltzmann Constant
h	Planck Constant
c	Speed of Light
B	Spectral Radiance
W	Radiant Energy Flux Emitted
f	Imput image
g	Image logic

Chapter 1

Introduction

1.1 - Problem Description

Currently, skeletal muscle injuries are a major public health problem that affect millions of workers all over the world. These lesions are of great concern because they affect workers health and increase business and social costs. In the present study we give attention to musculoskeletal injuries (MSIs), studding them in enterprise environment because theses is the ambience where workers are constantly subjected to very demanding efforts, hence, resulting, very often, in pathologies such as lumbago, shoulder pain, neck pain, knee pain and many others. Diagnosing these diseases is not always an easy task, and even harder is to identify the exact point of the lesion without the help of technological equipment. In order to help health professionals to overcome these difficulties is, many times, used Infrared thermography (IRT), a technology that helps minimize absenteeism and increase the success rates of lesion treatments.

1.2 - Framework

Muscle injuries are very common in athletes, labourers, individuals that perform repetitive movements or in physically active persons, and they are characterized as a type of MSIs. These lesions have to be treated, and the treatment depends on the diagnosis and monitoring the state of the lesion.

Muscle damage is now very common and usually happens because the muscle was stretched beyond its limits, or because he was forced to borrow heavily. These lesion arises due, for example, to muscle overload and occur at high speed and load muscles and tendons, leg (quadriceps), spine and biceps [1].

The WMSDs acquired a lot of notoriety all over the world because it affects millions of workers in different sectors of activity. In the United States (US) about 60 million operators have symptoms of this type of injury, and in Europe it is considered one of the 10 most prevalent diseases of occupational origin [2].

These lesions require great attention because, as already mentioned, in addition to affecting the worker health it also affect the company, reducing productivity and increasing absenteeism [3]. It is important to note that millions of European workers affected by MSIs, costs billions of euros in lost of productivity and social costs [4].

These workers are from various sectors, but one that has greater risk is the industry sector because it is a professional area that demands de moving of loads, such as vehicles, furniture and textiles [2].

Of all Member States of the European Union (EU), Greece is the only country that overcomes Portugal in regards to the eminence of workers with spine pain and UL. The MSIs of the spine and the UL, currently have a very significant importance [5]. In 1998, the most industrialized districts of Portugal were Lisbon, Porto and Setubal, and, in these regions, MSIs occupied the first place in the occupational diseases [6].

Thermography may have an important role and a great clinical application in the assessment of individual muscle injuries, which are difficult to diagnose. These technique can offer two types of important information when it comes to evaluate a muscle injury: it can locate an area of inflammation associated with a muscle or muscle group and it can illustrate atrophy well before it becomes apparent clinically [7].

IRT is a simple, non-invasive and inexpensive technique that provides valuable information to determine whether to continue with more specific studies [8,9]. This technique does not use radiation of any kind, so it can be used in children and pregnant women without any risk. In addition, it can be repeated as often as necessary, with assurances regarding the repeatability of results.

The IRT differs from usual radiographic studies of image that show structural abnormalities because it t allows the expression of physical and functional changes that justify the patient's symptoms. The type of thermal change depends on the intensity of the biological phenomenon that is occurring, and the size and depth of the tissue involved [8].

Originally, thermography was developed for military purposes but, currently, it is widely used for engineering applications and, in the last 50 years it's also used for medical imaging [10].

IRT has also been used as an adjunctive assessment method in several cases, such as WMSDs [11], muscle damage induced by exercise [12], ulcer prevention study by pressure, prevention, detection and tracking of injury gymnasts [13].

It is believed that in recent years the presence of injuries in the workers muscles has increased, due to limited information on the topic. Therefore, this study aims to contribute to the knowledge of the actual scale of the problem, and the data prevalence beyond muscle injuries in workers caused by physically demanding jobs in industrial operations.

The image of use in medicine is currently considered an important resource in the development of medical diagnostics. The processing and image analysis focuses on developing procedures for extracting information of an image appropriately for their computer processing [14].

According to health authorities representing that represent company's, there are several operators with symptoms of muscle injuries, mainly in the arms and spine, but it is unknown to what extent is the severity of an injury. These injuries occur because the workers are constantly subjected to repetitive movements, the movement of heavy loads and awkward postures while working. Thus, we intend to proceed with the use of thermography as a preliminary diagnostic tool in detecting and monitoring this type of lesions. For that it becomes necessary to initiate an improvement of the thermal images with MSIs in order to facilitate observation of medical and other technical detection.

1.3 - Goals

According to the topic of the present thesis "The use of thermal infra-red imaging to reveal muscle injuries caused by physically demanding jobs in industrial operations" the objective of the project is to evaluate the possibility of using thermography as a preliminary diagnostic tool in detecting and monitoring trauma and injury occurrences. It's also our aim to sustain that is a simple, compact and cost-effective technique, that is suitable for a clinical environment and many advantages such as being reliable and of straightforward interpretation, allowing real-time monitoring during the diagnosis.

It is expected that tasks such as hardware selection, setup, image processing, clinical trials are accomplished along this project.

1.4 - Work Organization

In the following chapter, State of the Art, the prominent issue is the MSIs. In this chapter we are going to make a theoretical review of the subject and also a general review to consider these injuries in a worldwide perspective. After this first approach it will be presented the thermography as the solution to the problem. Deepening the theme of thermography we also are going to present their types, giving more emphasis to IRT because it is used in this work. At the end of the chapter, is made the description the use of thermography in two different ways and presented some applications of IRT, as in WMSDs, muscle injuries and physical exercise.

The third chapter is fully devoted to image processing and analysis, covering the algorithms used in this project.

In the fourth chapter presents the methodological procedure, which is displayed throughout the procedure performed in this work.

The main results obtained and discussion in the practical component are presented in the fifth chapter.

Finally, on the sixth presents the conclusions and future work proposals.

Chapter 2

State of the Art

In the present chapter the prominent issue is the MSIs. In order to fully analyse it we present a theoretical review about the theme also considering an Ergonomics and Ergonomic Workplace Analysis, in the beginning of the chapter, as a way to fulfil the need of broad understanding of the main theme.

The MSIs and WMSDs is presented in section 2.2 and at 2.3 we are going to grapple Thermography presenting it as the solution to the problem. Still in this chapter we address to Thermography considering the concept of Liquid crystal thermography (LCT), Microwave thermography (MWT) and IRT. Section 2.5 is about Thermography and WMSDs and highlight the connection between the two main concepts. In the end of the chapter, section 2.6, conclusions are made.

2.1- Ergonomics

The word ergonomics comes from the Greek, *ergo*, meaning work, and *nomos*, as the Greek word for laws or rules. Considering its etiology we can synthesize ergonomics as the laws governing work [15]. Nowadays there are various definitions for ergonomics, but some of them can lead us to a wrong interpretation because, sometimes it also refers to the "human factors engineering" or simply "human factors" [16,17]. In August 2000, the International Ergonomics Association (IEA) presented the official definition of ergonomics, describing it as "scientific discipline related to the understanding of interactions among humans and other elements or systems, and the application of theories, principles, data and methods, projects to optimize human well-being and overall system performance" [16].

The Ergonomics is defined by many authors as a set of scientific knowledge relating to man and necessary for the design of tools, machines, device and environment that can be used with the maximum comfort, safety and efficiency in their jobs. As a science it involves the application of knowledge of anatomy, physiology, psychology, biomechanics and anthropometry and can be stated as the solutions arisen from this relationship, it is concerned primarily with the physiological aspects of project work and with the human body and how it should adjust to the environment [17, 18]. In this sense, ergonomics studies aspects such as posture and body movements (sitting, standing, pushing, pulling and lifting weights); environmental factors (noise, vibration, lighting, thermal environments, chemicals); information (captured by vision, hearing and other senses) and tasks. The correct combination of these factors represented in the figure 2.1, contributed to the success of any ergonomics program, as it enables , healthy, comfortable, efficient and safe working environments.

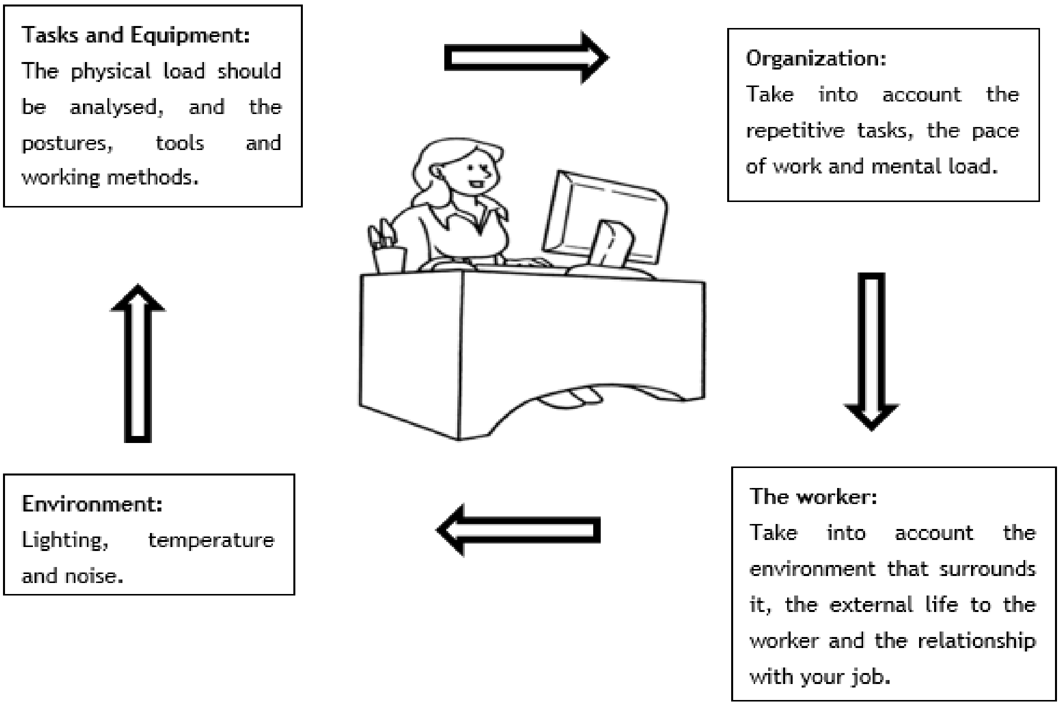


Figure 2.1 - Factors contributing to the success of an ergonomics program [19].

The IEA divides ergonomics in three areas of expertise. Therefore we have **Physical Ergonomics** consisting on characteristics of human anatomy, anthropometry, biomechanics and physiology of physical activity. It includes material handling, physical arrangement of workstations, work demands and factors such as repetition, vibration, strength and static posture related MSIs.

It also features **the Cognitive Ergonomics that** is related to the mental processes such as perception, memory, reasoning and motor response that affect the interactions of humans and other elements of a system that includes mental load, monitoring, decision making, performance skills, human error, human-computer interaction and training. And finally, it the area of **Organizational Ergonomics** with refers to the optimization of socio-technical systems including shift work, work schedule, job satisfaction, motivational theory, supervision, teamwork, teleworking and ethics [20].

Ergonomics can be applied in various sectors of activity. Everyday household is an example of that, such as industry, education, services and transportation. Currently, the word ergonomics is used to describe the science of designing a task that suits the worker, instead of forcing the worker to adapt to the task.

Ergonomic Workplace Analysis

One of the methods most used today is the EWA that consist in a realistic analysis of the work, in order to identify and evaluate the action of the main conditions that may affect the work, the worker and the organizational context.

The EWA unfolds in three stages: first, the analysis of demand, secondly the analysis of the task and, finally, the analysis of the activities. The analysis of demand is the first phase of the EWA process, and aims to define with perspicuity the problem to be analysed doing so starting from a negotiation with the various actors involved (managers, supervisors, workers, ergonomists) [21]. The conditions of the work environment, such as environmental temperature, postural conditions for workers and the noise level, can be checked from this analysis. On the other hand, we have the ergonomic analysis of the task consisting in the analysis of work, technical and organizational environment. Finally, the ergonomic analysis of activity that corresponds to the analysis of the behaviour of human beings at work (gestural, informational, regulatory and cognitive). No worker should be exposed for more than 50 minutes without break to recovery, after that period of time. And it's important that 10 minutes are devoted to recovery in order to avoid future health problems. WMSDs arise in individuals who are exposed to repetitive and continuous activities. These group of workers often presents complaints of pain, which mainly affect the UL. MSIs are already considered a major public health problem, and, in the workplace, is considered the most serious one, affecting workers all around the world. The change of function or worker's departure from his job can contribute to a healthy recovery when the worker accuses injuries of this type. The ergonomic intervention focused only on work organization is not the best option to solve the workers health problem [18].

A good job helps prevent fatigue and musculoskeletal disorders that may be followed by more generalized fatigue and postural distortions that results from bodily adjustments made to achieve better visualization of components placed inappropriately [17].

2.2- Musculoskeletal Injuries

The musculoskeletal system of the human body consists of several organs and tissues which function is to promote movement and locomotion. When there's a malfunction MSIs can occur. The MSIs lead to inflammatory and degenerative diseases, and can be conceptualized as a disorder of the musculoskeletal tissues, such as muscles, joints, tendons, ligaments, nerves and bones. It also relates to localized diseases of the circulatory system. These injuries are often associated with temperature changes on the skin surface (inflammation, pathological or vasoconstriction vasodilation, paresis or plagiarise, atrophy, etc.) [22, 23].

The presence of a pathology may affect the thermal balance in place, increasing (e.g. inflammation contraction or muscle) or decreasing (e.g. reduced blood flow or decrease in muscle activity) Tsk. It also exists a condition where there is asymmetry of more than 0.7ºC [24].

The MSIs are recognized by the EU as one of the main causes of poor living quality and absenteeism. Currently physical factors in the workplace have been linked to this type of injury as well as leading to several consequences on the enterprise level, such as an increase in costs, a loss of productivity in the labour field and competitiveness [25, 26].

2.2.1- Work-Related Musculoskeletal Disorders

WMSDs has not always been a subject of attention or importance by the occupational health community in fact until the first half of the twentieth century little or nothing was known about this type of injury [5]. However, nowadays, it is considered the main factor behind injuries that cause disabilities, work absences and extreme care needs. The increase of company's competitiveness, and the highlighting of productivity with lower costs, came to emphasize the problem and promote the development of studies in order to surpass it, so that the capitalized industries could obtain gains in the work pace and long shifts, bypassing ergonomically unsuitable environments [27, 28].

The WMSDs as mentioned above, affects the "work force" and represents one of the largest categories of occupational diseases. The relationship between MSIs and work is already formally recognized, and keeps as a mainstream subject to scientific community, because the relationship between the appearance of diseases and the ergonomic on the work place is not always very clear [23,26].

The lesions we have been taken in consideration are defined by the European Agency for Safety and Health at Work (EU-OSHA) as an organic structure of injuries such as muscles, joints, tendons, ligaments, nerves, bones and localized circulatory diseases caused or especially aggravated by occupation, and by the effects of the immediate environment where this activity takes place [3].

According to the General Health Department of Portugal, the WMSDs can be described as injuries that result from the action of professionals risk factors which occurs repeatability, and also results from a bad posture adopted during work, having also to be considered factors as duration, frequency and intensity (magnitude). Repeatability, as a matter of fact, is a major factor in de increasing of WMSDs rates. This factor relates to the fact of an individual being performing repeatability identical movements for over two to four times per minute, over 50% of the work cycle time for a total of 8h, which corresponds to one working day, in our country.

The symptoms of WMSDs may be pain, numbness, feeling of heaviness, fatigue and feeling of loss of strength. These symptoms are most evident on the worker at the end of a working day or even in production peaks.

The problem with this type of injury is that, at an early stage, symptoms are not perceivable. Instead, when the development is detected, because injuries are already installed, there are not much to do in order to avoid the problem. Injuries are there and, more often, affect the spinal column, also, the knee and the ankle [29]. After a literature review, it was concluded that there are several classifications to these lesions, depending on the country, as we can see in Table 2.1.

Table 2.1- Different classifications adopted in different countries [4].

Country	**Nomenclature**
United States of America (USA)	Comulative Trauma Disorders (CTD)
United Kingdom	Repetitive Strain Injury (RSI) or WMSD
Sweden	Occupational Cervicobrachial Disorder
Brazil	Lesões por Esforços Repetitivos (LER) Distúrbios Osteomusculares Relacionados com o Trabalho (DORT)

Australia	Occupational Overuse Syndrome (OOS)
France	Lésion Attribuable aus Trauvaux Répétitifes (LART)
Canada	Repetitive Strain Injuries Troubles Musculosquelettiques (TMS)
Portugal	Lesões Músculo-esqueléticas Relacionadas com o Trabalho (LMERT)

2.2.2- Incidence of work-related musculoskeletal disorders at a world level

The WMSDs acquired a very important patency in the world, affecting millions of workers from different sectors of activity. In the US, about 60 million operators feature symptoms of this type of injury, and in Europe these disease is considered one of the 10 most prevalent disorder with occupational origin [2]. Neurological diseases, lung diseases, diseases of the sensory organs, and skin diseases are some examples of other health disorders that have high prevalence rates in the EU (Figure 2.2).

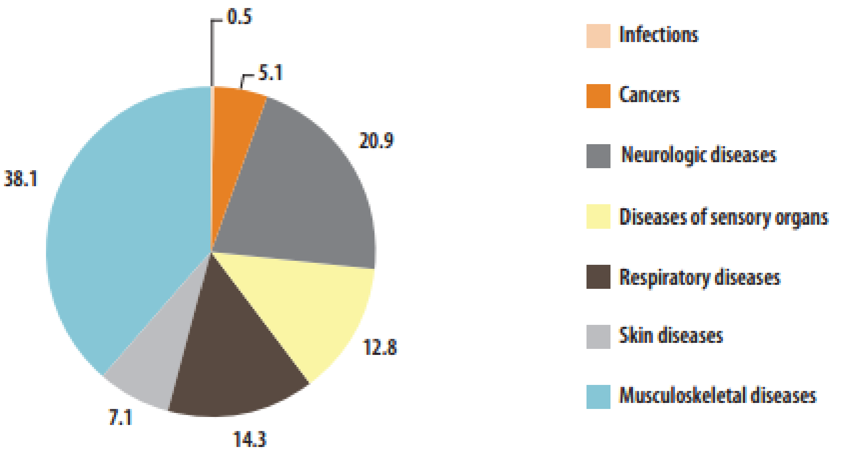


Figure 2.2 - Proportion of occupational diseases in Europe workers in 2005 [30].

These lesions require great attention, because as already mentioned, in addition to affecting the workers health they also affect the company, reducing productivity and increasing absenteeism [3]. Thus, it is important to note that millions of European workers affected by MSIs, costs Europe billions of euros in lost productivity and social costs [4], these workers are from various sectors, but the industry that represents the greater risk is the one that demands the move of loads, such as vehicles, furniture and textiles [2].

The US, Nordic countries and Japan are the countries that have a longer track record of occupational diseases worldwide, about one-third. Comparing the developed countries with the developing countries, it appears that WMSDs in developed countries account for about 3.4% of total global professional illnesses unlike developing countries that account for about 1.7%. It is assumed that one of the reasons for these figures is the fact that in developed countries there is a greater knowledge and greater awareness of workers and health professionals [6].Of all members of the EU States, Greece overcomes Portugal, regarding the eminence of workers with spine pain and UL. The MSIs of the spine and the UL, currently, have a very significant importance [5]. In Portugal, the low spine pain has a share of 2.85% and 3.66% in the construction industry and lesions in the UL (shoulder and wrist) contain a percentage of 1.5%, 16.2% and 2:43% in the electrical industry, electronics and automotive [31]. In 1998, the most industrialized districts of Portugal were Lisbon, Porto and Setubal, where MSIs occupied the first place in the occupational diseases [6]. In the figure 2.3, we can see that the workers consider that work affects health in a meaningful way, being the spine pain and muscle pain the most significant health problem among these population [30].

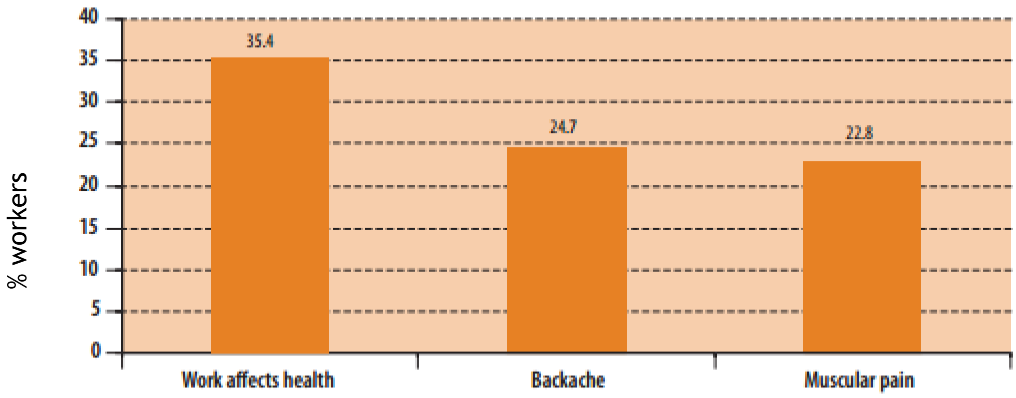


Figure 2.3 - Percentage share of workers reporting health problems [30].

As mentioned earlier, the industrial workers are those with an increased risk of developing WMSDs due to the heavy and repetitive work. A study has shown that 92% of these risk group is suffering from this type of injury in any region of the body, being the lumbar region the one that is most prevalent, presenting an affected rate of 54%, then the neck, 43%, and, finally, shoulders with 42% [32]. Currently, there is still much research in this area to be made, either at national and international level, in order to try to better statistics.

2.2.3- Main Types of Work-Related Musculoskeletal Disorders

The WMSDs are associated with a group of pathologies of lower evolution and manifest themselves in terms of tendons, muscles, nerves, joints, and vascular system [27]. These lesions, that are associated with occupational activities, may occur due to a repetitive work, postural maintenance and/or manual inappropriate loads over a prolonged period of time. The main lesions affecting workers exposed to repetitive work, postural maintenance and/or handling charges are the neck pain, spine pain and injuries in the UL and lower limbs [3].

The main WMSDs, shown in Tables 2.2 and 2.3, can be grouped by affected anatomical areas (such as shoulder / neck, spine, knee, elbow, hand and wrist) and type of pathology [29, 33].

Table 2.2 - WMSDs grouped by affected anatomical areas [2, 4].

Anatomical Area	Injuries
Shoulder and Neck	Syndrome conflict or thoracic outlet
	Trapezius myalgia, Cervical syndrome, biceps tendinitis
	Tendinitis of thorny above, Bursitis sub-acromion-deltoidea
	Tendonitis of the rotator cuff
Elbow	Radial tunnel syndrome, Cubital tunnel syndrome
	Elbow bursitis, epicondylitis and golfer's elbow
Hand and Wrist	Guyon's canal syndrome, Carpal tunnel syndrome (CTS)
	De Quervain's disease, Köhler disease
	Tendinitis of the flexor / extensor wrist
	Hand hygroma, Raynaud's syndrome, rhizarthrosis
	Digital stenosing tenosynovitis, Kienböck Disease
	Hand cramps, contracture of Dupuytren
Knee	Bursitis prepatellar, gonarthrosis
Spine	Neck pain, spine pain, slipped discs

Table 2.3 - WMSDs grouped by type of pathology [2, 4].

Typology	Injuries
Injuries at the level of the tendons	Tendinitis, tenosynovitis, Stenosing tenosynovitis, synovitis, Peritendinites, ganglion cysts, Epicondylitis lateral or median, De Quervain's Disease Dupuytren's contracture
Lesions on peripheral nerves	CTS, Guyon's canal syndrome, Syndrome of the radial channel, Cubital tunnel syndrome, Pronator teres syndrome, Thoracic outlet syndrome, digital neuritis
Muscle injury	Focal dystonia, fibromyositis, Myositis, myalgia, cervical muscle strain
Muscular and neuromuscular injuries	Thrombosis of the ulnar artery syndrome of hand arm vibration syndrome hypothenar
Injuries in terms of articulating or synovial bags	Injuries in terms of articulating or synovial bags

The major WMSDs are:

Carpal tunnel syndrome (CTS) - One of the most common neuropathies that constitutes a peripheral nerve injury, caused by compression of the median nerve in the carpal tunnel lying on the pulse (Figure 2.4) [34]. This pathology is caused by repeated and vigorous movements of the hand and wrist as well as the use of vibrating tools [35] and is more common in middle-aged individuals and women. The first symptoms that differentiate the syndrome are intermittent numbness or tingling and burning sensation in the fingers [36]. Patients with this disease in progression tend to have more symptoms, including progressive weakness, difficulty, suffering, palm or hand dry bright and lack of positioning of the upper limb [37]. It was carried out a study among industrial workers that stated a prevalence of CTS 9,4 cases per 100 employees [38].

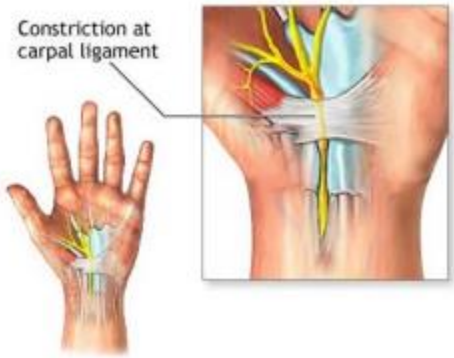


Figure 2.4 - Pressured at carpal ligament [34].

Tendonitis - Tendonitis is an inflammation of the joint area between the muscle and the tendon [2] and may occur in the hand, wrist, elbow or shoulder. When there is excessive carrying out work, such as repetitive flexion/extension of the wrist and fingers, the tendon tends to be excessively exerted, and that will cause swelling due to inflammation [29].Later tendinitis generates a local sensitivity in the flashpoint and when joint movements are affected it generates a sharp pain [36].

Tendonitis of the rotator cuff - Is the most common of shoulder disorders [38]. It appears as a result of the practice of activities that require high sustained or repeated UL at shoulder level or above it, circumduction movements with the arms high and static contraction of the muscles of the shoulders will also trigger this disease [29].

Epicondylitis – This disease is characterized as an elbow tendinitis that causes intermittent pain [39]. The epicondylitis can be side (if the pain is at the point of insertion of the wrist extensors), or median (if the pain is in the wrist flexors), and appears in response to the overload of the elbow or/and repetitive gestures and as a manifestation of poorly distributed excessive loads [40, 41].

In a study accomplished among industrial workers, it was found a prevalence rate of epicondylitis (average and lateral) of 5 cases per 100 [38].The lateral epicondylitis is an injury that occurs more frequently than the average and is the result of follows execution moves to tighten or hold with full flexion of the fingers repetitive sequence. The median epicondylitis may arise in the event of pronation of the wrist, the palmar flexion of fingers and wrists and palmar flexion with ulnar or radial tilt of the hand.

Rachialgia- According to the Direção Geral de Saúde (DGS), the Portuguese government institution for public health, the rachialgias are characterized by a severe pain in the spine that appears in consequence of an osteo-articular and/or muscle damage. This is one of the diseases that more often is associated with work, and its symptoms can vary because they depend on the affected area of the spine: cervical, lumbar or dorsal. The cervical and lumbar regions are more affected because they are the most mobile [29].

The more relevant MSIs among Workers in the industrial sector in Portugal, are the rachialgias with prevalence values for low spine pain of 2.3%, and for neck and spine pain 1.1% 0.8% [31].

Muscle Injury-The skeletal muscle, one of the most abundant tissues in the human body, is constantly exposed to various types of injuries [42]. Muscles are able to provide body balance, strength, flexibility and proprioception [43], they are specialized tissues formed by tiny protein structures (myosin actin), that grows in order to become larger and larger structures, microfibers, fibres, fasciculus and muscle group [44].

Muscle damage is very common, and usually happens because the muscle was stretched beyond its limits. (Figure 2.5). These lesions occur at high speed in load muscles and tendons, leg (quadriceps) and spine (the spine injuries are termed e.g. by rachialgias as mentioned previously) and biceps [1].

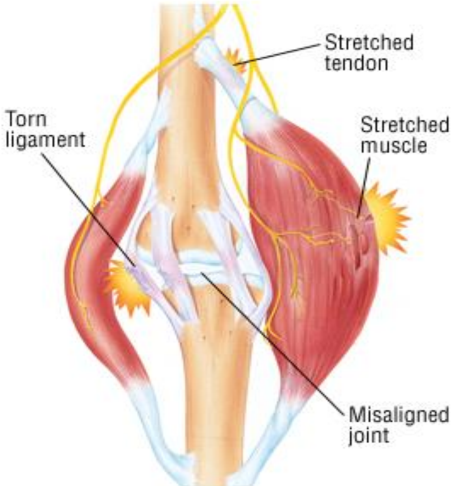


Figure 2.5 – Muscle Injury [45].

2.2.4- Risk Factors

A work that can cause the opposite effect on muscle is a risk factor (negative) [29] and increase the likelihood of developing a disease or injury [46].

There are several factors that contribute to the development of MSIs. Some examples are the manual handling of loads, repetitive movements, static or awkward postures, vibration, insufficient breaks, low temperatures, organizational factors, high demands and low job control [33]. According to a study by the European Survey on Working Conditions (ESWC) the stance of maintaining standing or in uncomfortable positions, repetitive work or with display screen equipment, and manual handling of loads, Figure 2.6, are strong reasons for the appearance of the disease [30].

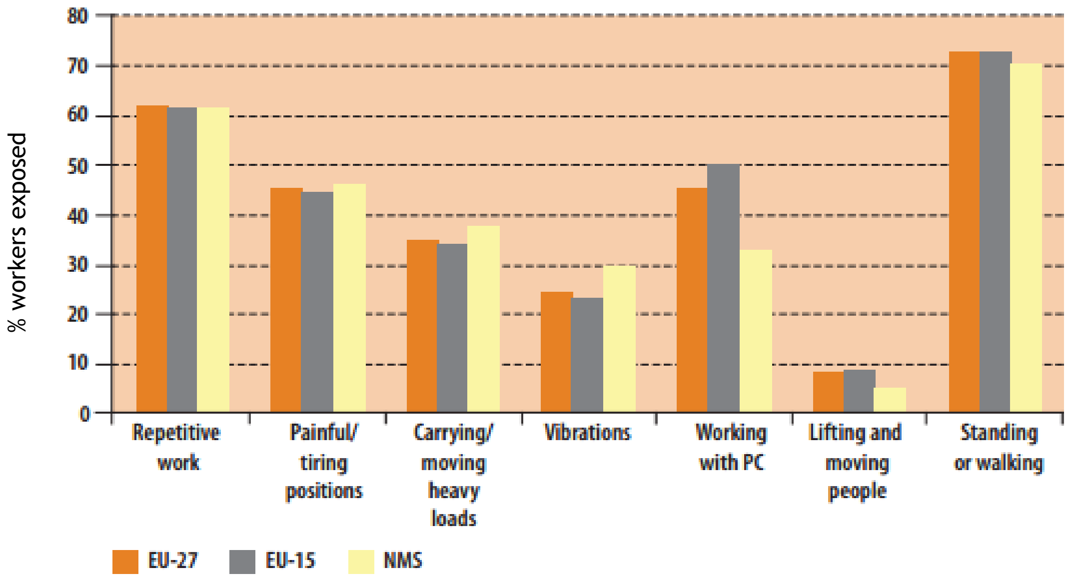


Figure 2.6 - Risk factors for MSIs [30].

These factors can be divided into 3 groups (Table 2.4): risk factors related to physical activity – These are risk factors emanating from the realization processes of work activity [4, 30]; risk factors organizational and psychosocial -These are risk factors related to work but without biomechanical nature. These factor is connected with the subjective perception that employees have on aspects related to the organization of work [3]. The third group is related to individual factors, constituting a subgroup not work-related that includes personal characteristics [46].

Table 2.4 - Risk factors for the occurrence of MSIs [3].

Classification	**Risk factors**
Related factors with the work activity or Physical	Force application, such as lifting, carrying, pulling, pushing or using tools.
	Repetitive movements
	Forced postures or static, for example, hands above the level of the shoulders or sitting or standing for a long period of time.
	Located compression exerted by tools and surfaces.
	Vibes
	Cold or Excessive Heat
	Lighting
	High noise levels
Psychosocial and Organizational Factors	Demanding work
	Lack of support from colleagues, supervisors and managers
	Low levels of job satisfaction

	Monotonous, repetitive and with a fast paced work.
Individual factors	Age
	Obesity
	Smoking
	Physical Ability

2.3- Thermography

Thermography is a non-invasive technology that measures the variations in Tsk across the surface of the body through infrared (IR) and thermal imaging [47], a technology that stands in the principle that an object with a temperature above absolute zero emits IR radiation or thermal radiation.

The IR image or thermography is a method that captures and measures radiation emitted by the body, thus allowing an image of the thermal distribution on the skin surface. This radiation is detected by an IR camera, and the emitted radiation intensity is converted to a temperature measurement. From the thermographic inspection, the observed temperature distribution differentials, provides information related to a process that is occurring inside the organism.

According to the International Academy of Clinical Thermology (IACT), thermography is a comfortable and safe procedure [48].It is a promptly, painless exam, that doesn't involve radiation or contrast substances [49].

The thermographic technique lends itself to countless applications in biology, thanks to its versatility, lack of invasiveness and high sensitivity. It is widely used in medical, chiropractic and veterinary areas [47, 50]. An example of its application is the assessment of the vascularization of solid organs and pathologies in soft tissues, thus establishing, a diagnostic aid component. It can identify thermal and vascular abnormalities, and is very suitable for studies relating to pain, which can be measured following therapeutic procedures for immediate review or long-term treatments [48].

The ease of use of the high thermal resolution (few centimes of Celsius degree depending on detector used), together with the fact of being non-invasive in terms os opportunities of use, have made thermography a technique widely used as a diagnostic tool [50]. Clinically, thermography can be used as a diagnostic tool, as an enhancer of the physical examination (because the camera is at least 10 times more sensitive than the clinician's hand), or as a method to detect inflammatory situations [51].

Despite all the mentioned advantages this is an unfit technique to provide information about the ethology of diseases and cannot give any anatomical details on deeper organs and structures because of the general difficulty of heat diffusion through the fatty tissue and bones. However, it provides information on the location of pathological changes and physiological temperature.

Thermography is particularly useful on diseases that lead to alterations of the normal control of the body temperature, such as changes in the microcirculation, inflammation, trauma, metabolism and efficiency of the thermoregulatory systems [48]. It can identify and locate the anatomical region affected by lesions by pointing out a temperature difference of 1 °C (Figure 2.7) [52, 53].

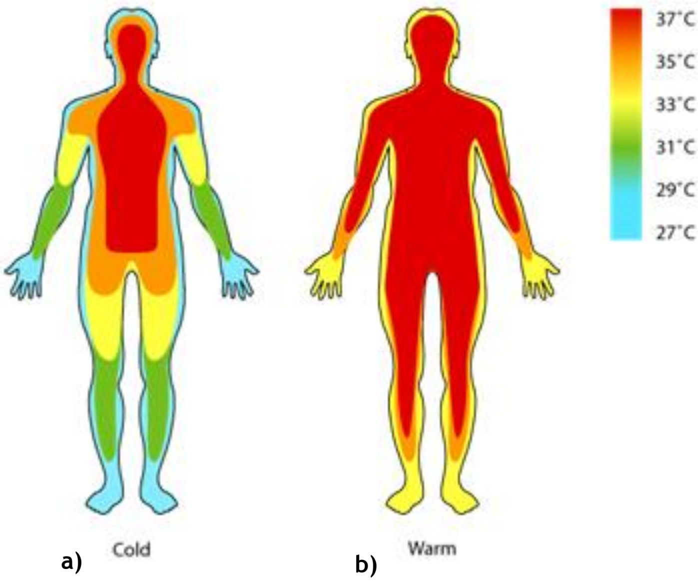


Figure 2.7 - Body temperature in: a) a cold environment; b) in the warm [54].

Thermography has been applied in some studies, as cancer diagnosis, muscle damage diagnosis, diagnosis of ischemia, in diabetic patients and evaluation of muscle recovery [55].

Clinical thermography has been in use since the 1960s and detects temperature variation on the surface of the skin. In the case of in breast cancer, thermography involves using a thermal imaging device to detect and record the heat pattern of the breast surface. Thermography does not provide information on the morphological characteristics of the breast, rather it provides functional information on thermal and vascular conditions of the tissue. The role of thermography is considered to be a complement to other techniques, as it is a test of physiology, this alone is not sufficient for medical practitioners to make or confirm a diagnosis [56].

This technique may not always provide specific pathology detail.

However, it assists in defining the localization of increased inflammation and/or injury area. The inflammatory response is characterized by the increase of the permeability of the blood vessels which results in the raise of the blood flow that alters the heat pattern. Therefore, variation in superficial thermal patterns resulting from changes in blood flow will alter the amount of radiated heat that may be identified without difficulty by thermography and may relate to inflammation of tissues underlying the appearance of changes in the metabolic activity [57].

As already mentioned before, this is a method used to record patterns of thermal gradients in the body and can be used to measure the thermal radiation (heat) emitted by the body. Considering this characteristics it may, therefore, be used in the process of diagnosing lesions caused by physical exercise. The thermography has been used, among other things, for example, to determine injuries of the musculoskeletal system [58].

It can be repeated as often as necessary because there is no risk or pain to the patient. The skin contains a thermal symmetry indicative of normalcy (Figure 2.8), when it is detected an asymmetric it means that there is a change in the organism. An increase in temperature indicates an increase of blood circulation, which is usually a process associated to pain, inflammation or other causes [59]. Figure 2.8 represents an example of a symmetrical temperature distribution of the knees from a healthy subject. In Figure 2.8a is represented the anterior view, where 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 (Figure 2.8b) shows high temperature in the popliteal fossa because of the popliteal arteries and veins [60].

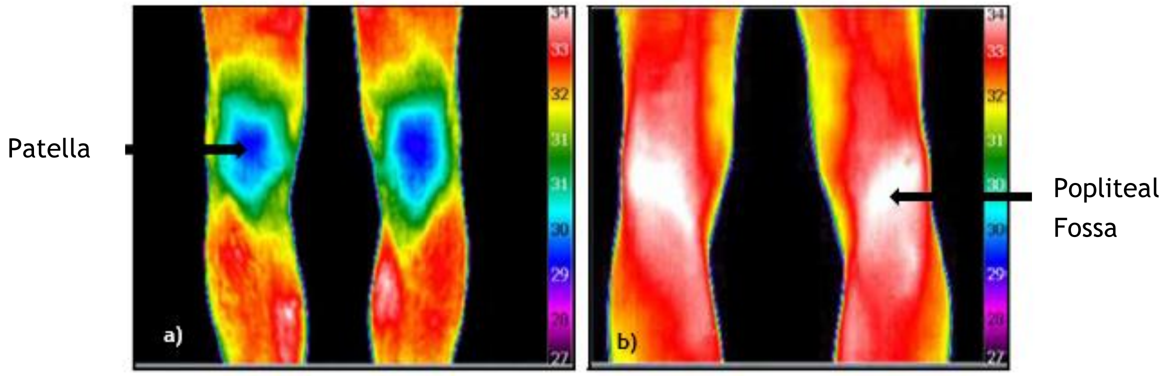


Figure 2.8 - IR image of healthy knee: a) anterior aspect; b) posterior aspect [60].

Thermography is a process in which temperature differences can be mapped in a two-dimensional image. The process detects electromagnetic radiation emitted by a body or liquids that are at a higher temperature and takes advantage of Stefan-Boltzmann's law, which states that the thermal radiation emitted by a body is proportional to the difference between the fourth power of the body and the fourth power of its surroundings [59].

$$W = \varepsilon \sigma T^4 , \qquad (2.1)$$

where W is the radiant energy flux emitted by a surface area W / cm^2, ε emissivity, 0,978, σ Stephan-Boltzmann constant, $5{,}673 \times 10^{-12}$ $W/Kx\ cm^{-2}$, and T cutaneous absolute temperature, K (Kelvin) [61].

This makes thermography a powerful tool to detect even the smallest differences in temperature.

There are three types of thermography: LCT; IRT and MWT, which will be discussed in detail later. While LCT on takes advantage of the fact that certain organic compounds are optically anisotropic in the liquid phase and a colour change is associated with a change in temperature, IRT and MWT, on the other hand, allow observation and detection of light emitted from warm objects in the IR and microwave regions of the electromagnetic spectrum [59].

The main advantage of using thermography is that non-invasive and accurate measurements on many subjects can be taken in rapid succession [57]. However, thermography has more very significant advantages, as the absence of ionizing radiation, the safety and the low cost. The patient has no pain, there is no physical contact, the ability to provide temperatures of a real-time image surface, non-intrusiveness, possibility of locating the lesion, ability to demonstrate metabolic and physiological changes in a functional examination and lastly, it can be used a portable device [62].

2.4- Types of Thermography

Thermography is a non-invasive technique in which temperatures are monitored, recorded and displayed in a two-dimensional image, allowing visualization of both thermal equilibrium and transient heating patterns. LCT and IRT are used to map surface temperatures, whereas MWT can map subcutaneous temperatures [61]. IRT and MWT, on the other hand, allow observation and detection of light emitted from warm objects in the IR and microwave regions of the electromagnetic spectrum, respectively. This makes IRT most suitable to record the temperature differences in clinical practice [59].

2.4.1- Liquid Crystal Thermography

Liquid Crystal Thermography (LCT) is a type of thermography relatively recent and widely used for clinical evaluation because is inexpensive, semi quantitative, and represents a contact method using liquid crystals [63, 64].

This thermal imaging method is a method of contact, as shown above, that allows the measurement of temperatures on skin surface [64].

The term “liquid crystal” denotes a state of aggregation of molecules that is intermediate between the crystalline solid and the amorphous liquid. In this state, a substance is strongly anisotropic in some of its properties, yet, at the same time, it exhibits a certain degree of fluidity, comparable, in many cases, to that of an ordinary liquid. An essential requirement that substances must fulfil to achieve a mesomorphic state (state of matter intermediate between a solid and liquid) is that their molecules must be highly anisotropic in their geometrical shape, (i.e. rod or disk shapes) [65].

Liquid crystals are applied to the area of interest and after placement, the crystal changes its neutral colour at room temperature, in response to the temperature of the body surface with which they come into contact. The resulting colour display is then photographed using Polaroid photography, giving a hard copy of the snapshot. It is this photography that shapes the thermogram, which is then used for the diagnostic assessment [64].

The liquid crystals used for thermal imaging are organic compounds that reflect the visible light in a narrow range, temperature-dependent wavelengths. The LCT system is simple, portable, commercially available and inexpensive. Biomedical applications include breast cancer detection and imaging of spinal root compression syndromes [61].

2.4.2- Microwave Thermography

MWT is the detection of microwave radiation from the human body. This procedure measures the emission of natural radiation in the microwave region of the electromagnetic spectrum [66, 67]. It can be repeated as many times as desired, without detrimental effects. Initial clinical assessments of MWT have been performed in breast cancer detection [66].

The technique was first described in 1975, being, at that time, used in joint disease. Some studies in the area of joint disease show that is easy to use this technique, and that it does not require a temperature controlled environment [67].

Unlike IRT and LCT, MWT enables reception of signals arising from thermal subsurface tissue [61]. There are some important and fundamental differences between IRT and MWT. The first technique uses wavelengths of 10 cm while the MWT uses longer wavelengths, typically 1-20 cm.

The microwave radiation can penetrate human tissue, therefore the emission will provide information relating to conditions within the subcutaneous body. The IR radiation is incapable of such penetration and thus, refers to conditions primarily at the surface.

Regarding the emission intensity of microwave, it is linearly proportional to the temperature transmitter. A measure of the emission can be easily connected with the emitter temperature. In a less direct manner IR intensity measurements can also be related to temperature.

The spatial resolution is also different in the two techniques: for microwaves it is around 1 cm, whereas the IRT typically conceived spatial resolutions of the order of 1 mm [66].

MWT attempts to directly observe the thermal radiation due to internal sources of the body, minimizing skin tissue contribution. The technique is, therefore, much less dependent on the measurement environment, and, in practice, it has been found possible to do entirely satisfactory measurements in normal clinical environment without the need for special facilities.

Thermography systems consists of a radiation receiving antenna that may be placed in contact with the surface, and a microwave radiometer receiver with is used for measuring the power of the thermal signal. To provide useful information in medicine, the MWT equipment must have a temperature resolution of about 0.1 ° C and a stability measurement order of some tenths of Celsius degree. The equipment is portable, easy to use and suitable for routine use in a wide variety of clinical applications. This equipment was used to demonstrate that the MWT (Figure 2.9) can, simply and safely, provide clinically valuable information about disease activity by measuring the internal body temperature patterns. Both the detector LCT and the microwave require contact with the skin, which can change the thermal conditions of its surface [68].

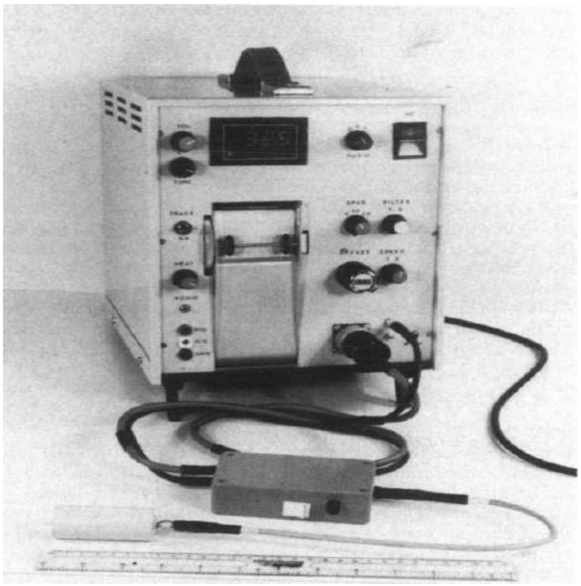


Figure 2.9 - Prototype clinical MWT equipment [68].

2.4.3- Infrared Thermography

IRT is a simple technique, also non-invasive and inexpensive, that provides valuable information to determine whether to continue with more specific studies. The IRT measures emitted IR radiation and displays the information as a pictorial representation, called thermogram, the surface temperature of an object [8, 9]. The spectral bands 3-5 µm and 8-12 µm are used for IRT, because this minimizes absorption in air (Figure 2.10) [61].

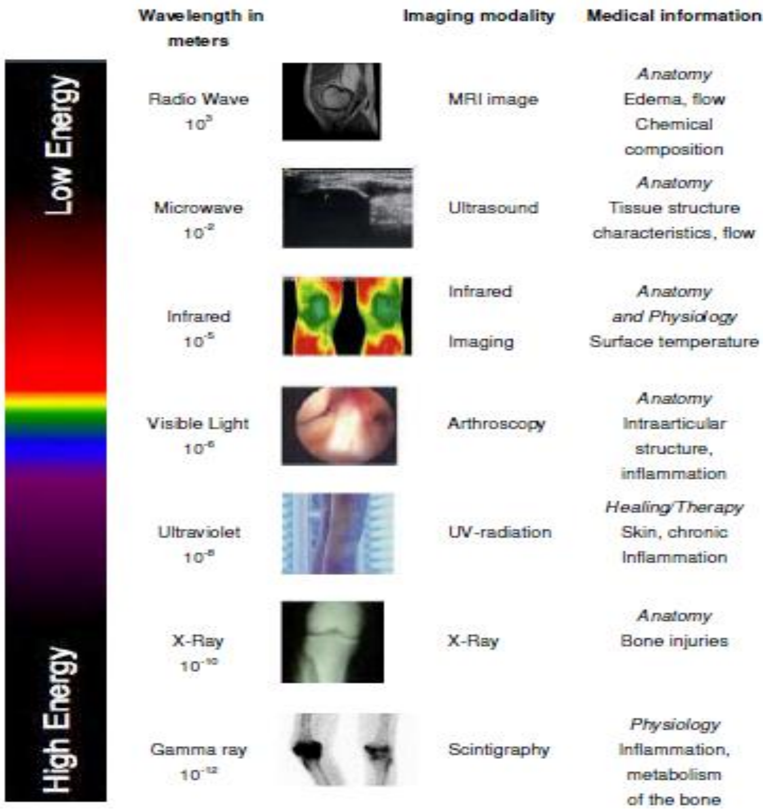


Figure 2.10 - Medical imaging techniques within the electromagnetic spectrum [60].

This technique does not use extra radiation of any kind, so it can be used in children and pregnant women without any risk. In addition, it can be repeated as often as necessary, with assurances in what regards to the repeatability of the results. This is a complementary technique that provides a more functional professional information regarding the disease or injuries suffered by patients.

IRT allows, with a simple gesture of taking a picture or video, the saving of energy when it comes to register the radiating of the human body. This technique was first used in the medical field in the 60s, but, due to a poor performance as a diagnostic tool, the lack of standardized protocols, and the appearance of more accurate diagnostic techniques it ceased to be used.

In order to describe the performance of this technique is important to state that IR radiation emitted by the bodies under temperature is captured and quantified by sensors that detect this type of radiation and convert it into electronic images that can be viewed, scanned and recorded.

A thermographic camera is a device that, without contact with the object detects IR energy and convert it into an electrical signal which is then processed in a thermal image on a monitor for analysis of different temperatures (Figure 2.11). The image obtained in the IRT can be considered as a heat map of the studied area, revealing the pathophysiological conditions associated with different disorders. Its medical use is based on human thermal physiology and the pathophysiology of skin thermoregulation [69].

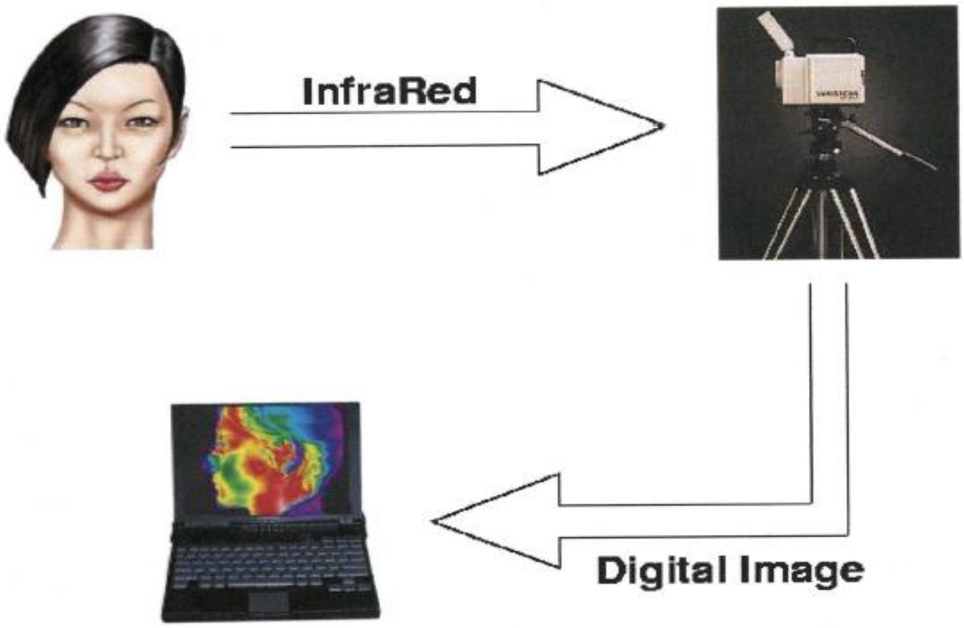


Figure 2.11 - The thermal detector in an IR camera converts photon energy from a target surface into a thermal image that can be displayed on a computer monitor. Each colour hue on the thermal image corresponds to a certain temperature interval [69].

Two aspects may be assessed: qualitative and quantitative variations in physiological thermal patterns. Qualitative variations are thermal symmetry changes that characterize the physiological thermal pattern; quantitative variations requires the determination of the temperature of the studied area and the existence of a temperature exceed 0.2-0.3 ºC over the thermal area around the location under observation.

The IRT differs from radiographic studies because this last one is used to show structural abnormalities, while IRT allows for the physical expression of functional changes that justify the patient's symptoms. The type of thermal change depends on the intensity of the biological phenomenon that is occurring, also depending on the size and depth of the tissue involved [8].

As mentioned above, the IRT measures the emitted IR radiation and displays the information as a pictorial representation of the temperature on the surface of the object through the thermogram. Each pixel in the thermogram represents the measured temperature surface of an object. The information can be displayed in colour scale (Figure 2.12a), in colour scale of strong-contrast (Figure 2.12b) and or as grey tones (Figure 2.12c). The colour scale contains the hotter and cooler areas in which the warmer areas are exposed in white or red and colder areas are displayed in blue or black [70].

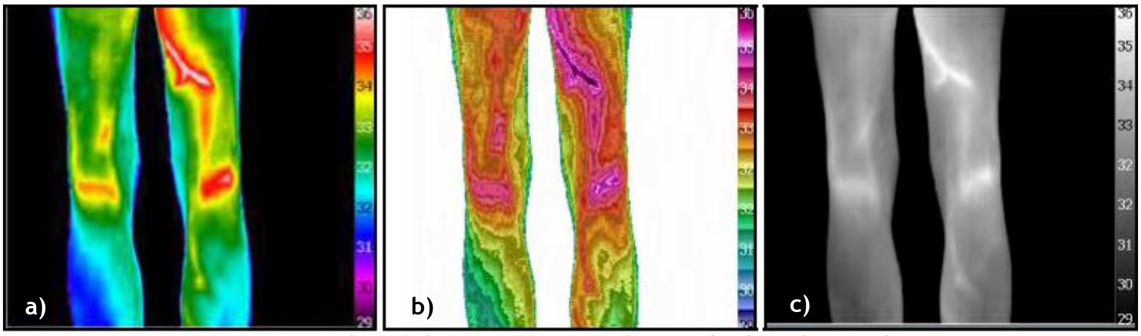


Figure 2.12 - Temperature scales of thermograms: a) colour scale; b) colour scale strong-contrast; c) grey tones [70].

Sometimes there are changes in skin temperature. They occur in there is a registration of variations in the thermal pattern (colour) that reflect thermal gradients. Patient conditions may not always be analysed in depth by thermography, however, this system helps to set the location of the area of inflammation and / or injury [57].

The infectious or inflammatory response is characterized by increased permeability of blood vessels, resulting in increased blood flow, which leads to a localized increase of the surface of the affected areas that changes the heat pattern of the area [57, 71]. Therefore, variation in superficial thermal patterns, resulting from changes in blood flow, will alter the amount of radiated heat that may be easily identified by thermography and may relate to inflammation on the tissues underlying that point or alterations in the metabolic activity [57].

The advantage of using IRT technique, compared to alternative methods that requires a contact between the object and the sensor, lies in the fact that the Tsk is not influenced by the presence of any probes that could modify the temperature variation of the surface through conduction (through direct contact between objects, molecular transference of heat energy) or through radiation (heat generated from within the body is given-off to the surrounding atmosphere) (Figure 2.13) [72].

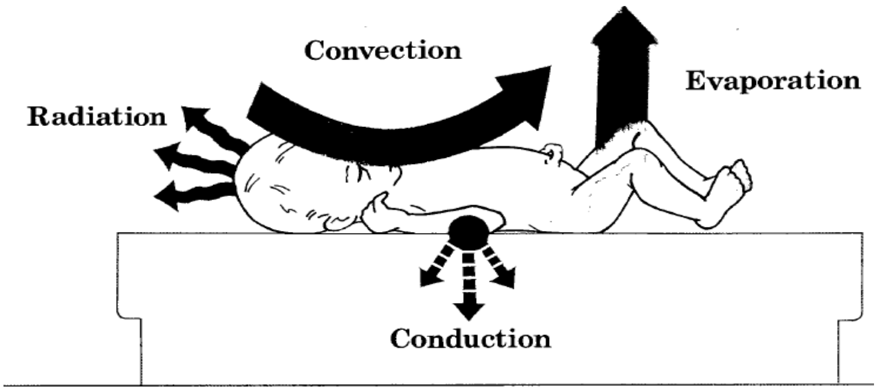


Figure 2.13 - Thermal Transfer Processes [73].

IRT was originally developed for military purposes, about 50 years ago, but is currently used, with widely expression, for engineering applications and as a medical imaging technique.

A thermal imager is used for IRT to measure the heat pattern of the object surface or human skin and to detect the IR radiation [10].

Thermography has some very important advantages. Such as being a non-contact process, and, therefore, a hygienic reliable procedure that presents no risk to the patient, it is also applicable in real-time and dynamically, thanks to the advanced image processing software that exists nowadays. Another advantage is the fact that this technique is able to track evolutionary processes and as a high portability profile [8, 10].

Several studies concerning IRT special characteristics state that we can get additional information about the skin's thermal aspect and about the complex thermoregulatory process, The IRT is very useful in sporting activity because it allows to detect the possible injury or dysfunction, measuring the temperature of the skin over the inflamed joints: lesions or dysfunctions often impossible to been shown by conventional methods. IRT can be a new, e.g. diagnostic tool for detecting knee pathology, because it shows physiological changes, rather than anatomical changes [10].

A review of the literature on this topic demonstrated that IRT can be very important, because it is a particularly useful assessment tool for physicians who manage MSIs (i.e., physical therapists, physiatrists, and doctors of chiropractic). IRT is also useful in the diagnosis of pediatric MSIs in order to reduce the use of X-rays emitting ionizing radiation as much as possible [71].

Bone fractures often trigger an inflammatory response, and as it was mentioned earlier, when there is this type of response that there is a significant increase in Tsk in the affected area. The IRT is a useful addition to the diagnostic tools available to the physician since it can detect localized temperature variations such as occur when there is a fracture [9].

IRT is not the only technique that can be used to measure the Tsk, there are also thermal contact sensors (such as thermistors and thermocouples) which are an equally promising technique. However, the thermal interaction between the sensor and the atmosphere can reduce the reliability of the measurement. In case of wireless sensors, they provide great mobility and it does not interfere with physical activity. These sensors provide a continuous record of temperature in situations of high-dynamic or below or between layers of clothing [74].

IRT has been successfully applied for many clinical purposes (Figure 2.14). It has become more popular in recent years in research about sports physiology due to its non-contact and non-invasive nature (Figure 2.15) [75, 76].

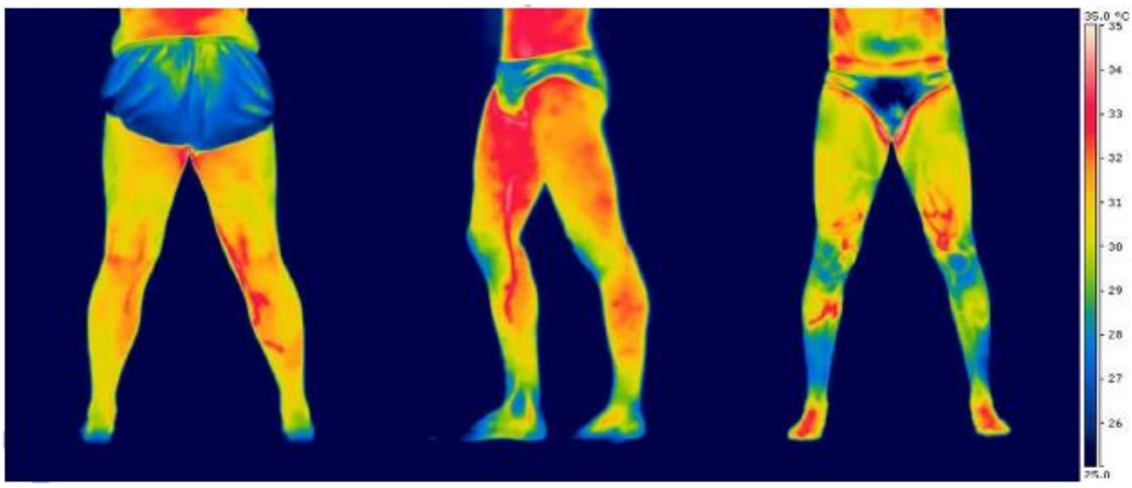


Figure 2.14 - IRT images showing examples of varicose and superficial veins [75].

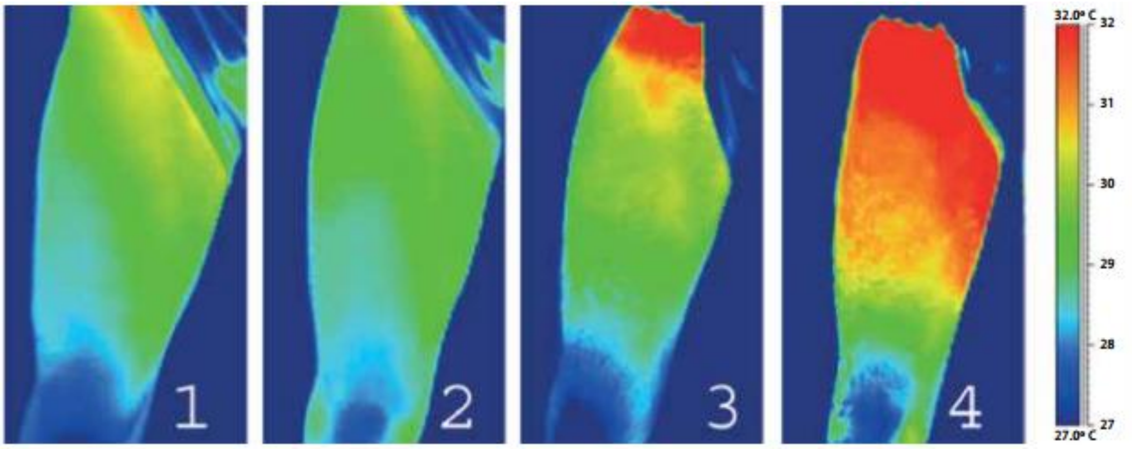


Figure 2.15 - Comparison of the pre-training and 24h post-training thermal image. (1) Subject of the control group, pre-training; (2) subject of the control group, 24h post-training; (3) subject of the experimental group, pre-training; and (4) subject of the experience.

To obtain a correct value of Tsk by quantifying the emitted radiation, the emissivity of the measured surface must be known. Scientific studies that determine the emissivity of the human skin, mostly agreed that the emissivity was 0.978 [10].

2.4.3.1 - Factors Influencing Infrared Thermography

When working with the IRT we have to take into account certain factors, that can influence the assessment or interpretation of thermal images.

These factors will be divided into three main groups (Figure 2.16): Environmental factors, individual factors and technical factors. Individual factors, in its turn, are divided into intrinsic factors and extrinsic factors.

Environmental factors are those related to the location (natural features of the environment) in which the assessment is held. Some examples of these factors are: compartment size and room temperature, which is very important for most IRT applications. After a review of the literature, it was found that the ideal temperature stands between 18 ° C to 25 ° C and if the temperature is lower the patient may begin to tremble and becoming sweaty ever since the opposite occurs, that is, the temperature becomes high.

The ideal temperature is 21 ° C since it is the temperature to which the skin IR emission values are higher; with relative humidity; correct atmospheric pressure. In this case, is given more emphasis to the temperature, because it is easier to control factor.

Individual factors are those that are related to the subject being evaluated and the personal characteristics that could influence Tsk. They are the most controllable and are divided into intrinsic factors - related to the biological and anatomical parameters, and extrinsic factors - those that affect the temperature of the human skin for a certain period of time. Intrinsic factors are: gender, age, anthropometry, height, weight, heart rate, hair density, emissivity of the skin, medical history, metabolic rate, skin blood flow, genetics and emotions. Extrinsic factors, are considered to be the admission factors affecting the Tsk or emissivity due to consumption or intake of medicinal products, beverages or other products that could temporarily influence the temperature of the skin, and also the application factors which are the products applied directly to the skin that affect the flow of blood or emissivity of the skin, including cosmetics, ointments and radiation.

The last group of factors, the technical ones, are connected to the equipment used during the evaluation of IRT. The validity, reliability, protocol, camera characteristics, and statistical analysis programs are examples of such factors.

We can see that there are a large number of factors affecting the Tsk in humans, and is very complicated to control all them, but the fact that we have knowledge about these factors can help to prevent their influence or, at least, help in the recognition of their importance, thus ensuring the correct use of IRT [75].

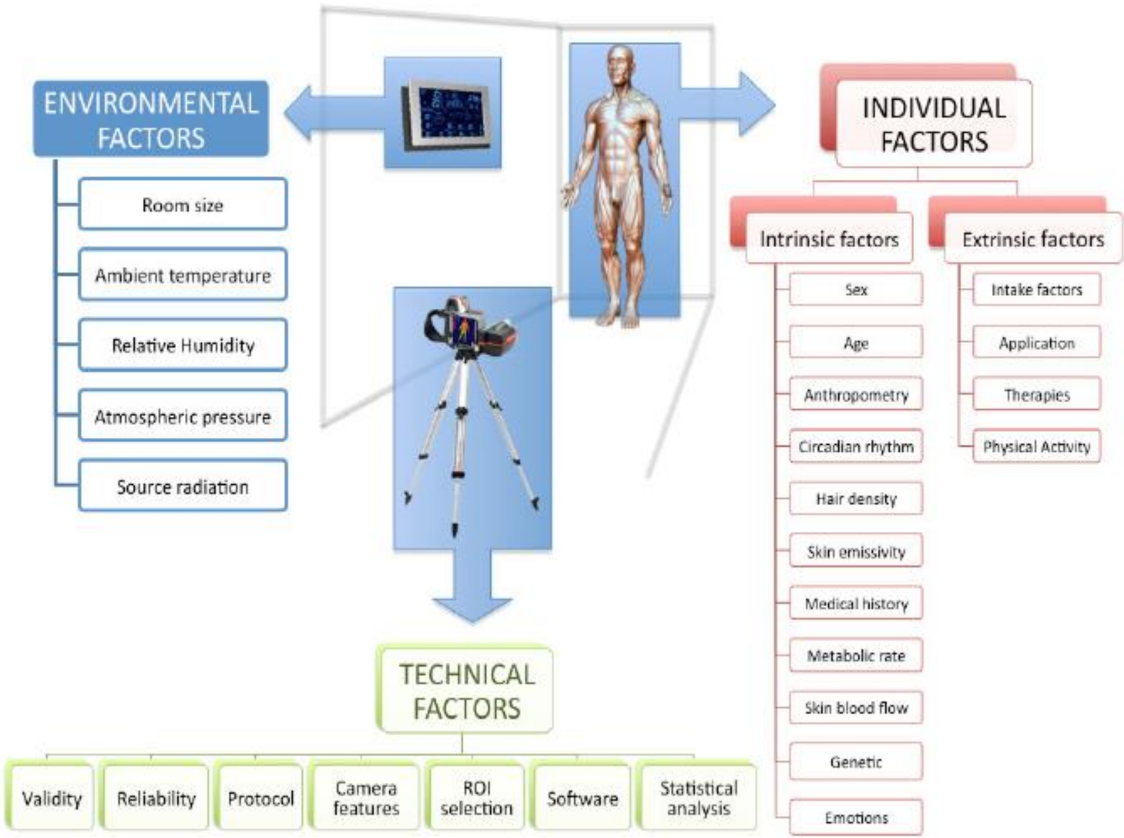


Figure 2.16 - Representation of the classification of IRT-related factors in humans [75].

2.4.3.2 - Infrared Radiation

IR Radiation were discovered in 1790 by M. Pitke and in the very beginning of the XIX century (1800) the English astronomer Sir William Herschel, reminisced it while trying to figure out which colours were responsible for heating the objects. This astronomer believed that there are two kinds of radiation, light and heat radiation, sustaining that below the visible, red found exists a very powerful invisible radiation of calorific levels, that became known as IR radiation [77].

IR radiation is the region of the electromagnetic spectrum between visible light and microwaves, containing radiation with wavelengths ranging from 0.75 to 10 mm [78].

All objects in the universe, including human beings, produce IR radiation, but the human body is not only a source of such radiation, it also absorbs it very easily. IR has strong penetrability and is readily absorbed by objects, in which it is transformed into internal energy [80]. The human eye detects only a small part of the electromagnetic spectrum, the eye only detect a wavelength that stands between 0.4 µm and 0.7 µm (Figure 2.17) [80].

In the next picture, we can see some parts of the electromagnetic spectrum, the wavelengths and their respective frequencies.

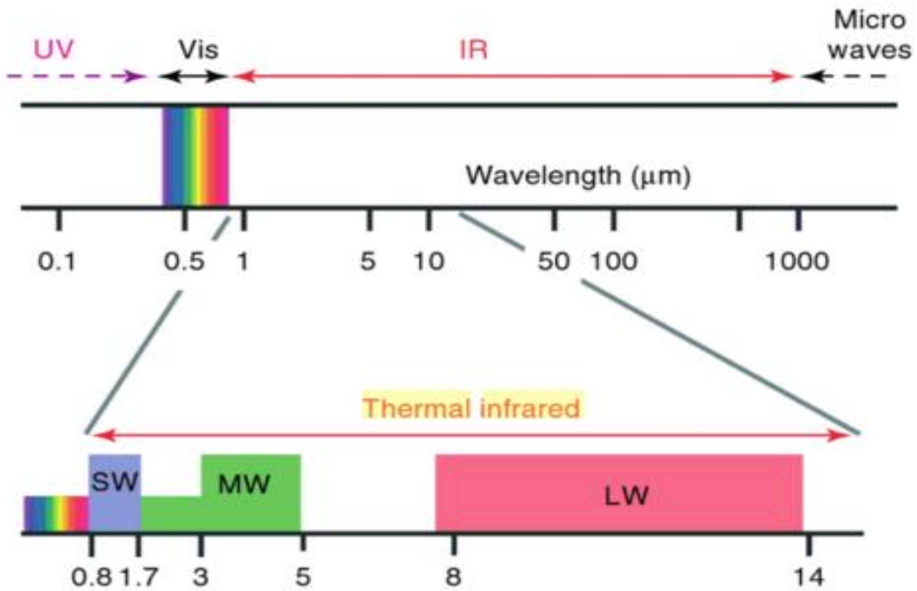


Figure 2.17 - IR and adjacent spectral regions and expanded view of the so-called thermal IR. This is the region where IR imaging systems for shortwave (SW), midwave (MW), or long-wave (LW) cameras exist. Special systems have extended MW or SW ranges [81].

By doing an analysis of the figure, we observe that the IR wavelength is between 0.8 µm and 100 µm, visible light between 0.4 and 0.8 an ultraviolet 0.001 and 0.4 [82].

IR rays may be divided into three types of wave, SW (0.9-1.7 µm), MW (3-5 µm) and LW (7,5 -14 µm).

Through the Planck's law, we find that the human body has IR emissivity 0,978, thereby achieving the maximum wavelength of 9 to 10 µm. By looking at the figure we can ascertain that these values fall within the far-infrared. A black body in thermal equilibrium, at a given temperature, emits electromagnetic radiation according to the Planck's law:

$$B(\nu,T) = \frac{2h\nu^3}{c^2} * \frac{1}{e^{\frac{h\nu}{kT}} - 1} \quad , \qquad (2.2)$$

where B (in watts per steradian per square meter) is the spectral radiance, T is the absolute temperature of the black body, k is the Boltzmann constant (1.381×10^{-23} J/K), h is the Planck constant (6.626×10^{-34}Js) , and c is the speed of light (2.998×10^{8} m/s).

In IRT is common use to refer to the wavelength λ of the emitted radiation instead of its frequency ν [83, 84].

Through the Planck curve, demonstrate in the next figure 2.18, we can see that for human skin, a temperature range from 30 to 34ºC, the region will emit radiation at wavelengths between 7.5 to 14 micrometre (more precisely between 9.57 to 9.41 µm).

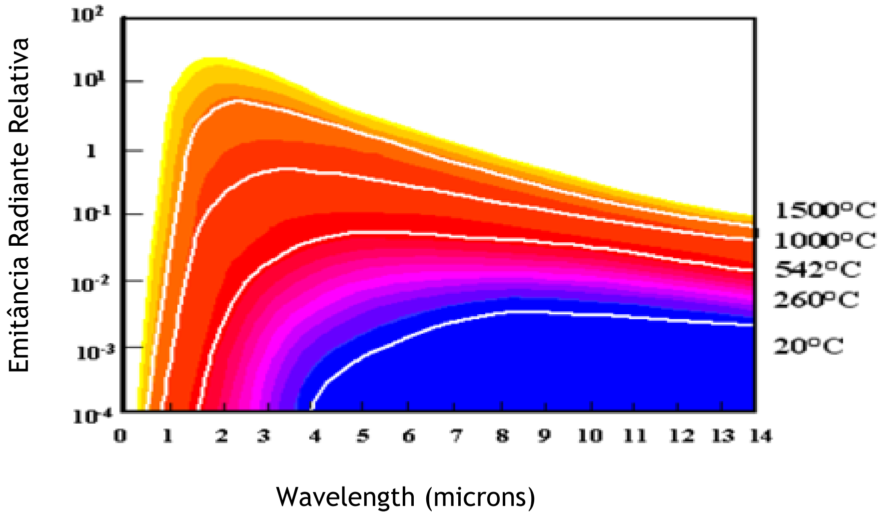


Figure 2.18 - Planck Curve [85].

Wavelengths 3-5 µm would be more suitable for bodies at temperatures above 100ºC and not to study the human body [85].

IR radiation emitted by a surface depends on the experimental conditions such as moisture, airflow and surrounding temperature [60].

2.4.3.3 - Infrared Camera

IR cameras utilize a sensor responsive to the IR range in order to convert the thermal radiation emitted by the skin surface into electrical signals, which are processed and digitized. These signs will be quantized at an appropriate levels scale of grey and then presented in a digital medical image. In that image, there are the hotter regions and colder regions, where the bright regions are represented in clear shades of grey, and the colder regions are represented in dark shades of grey. The grey scale is somewhat difficult to interpret, to facilitate this pseudo-colour interpretation it was attributed to this scale a colour image [7].

There are two general types of IRT systems, scanning systems and staring systems. Scanning systems are used to measure surface radiation point by point. Staring systems use IR sensor arrays or focal-plane arrays. With this arrangement, every element of the object is transferred to a corresponding sensor of the focal plane.

IR camera systems generally operate over one of three different wavelength regions or bands of the IR wavelength band, as it exists as a part of the electromagnetic spectrum [86].

Before the 90s, the IR cameras contained a comparatively small number of photosensitives detectors i.e., from 1 to 180 individual detectors. Cameras were heavy and consumed a lot of energy in its manufacture process, being extremely expensive. In order to overcome this hurdle more efficient and less expensive IR cameras were developed into a chamber focal plane arrays type (FPA).

An IR camera is a device that converts infrared radiation emitted by the body surface into electrical impulses. The basic components of an IR camera are: optics, electronic systems, image viewer, alimentation and accessories [87].

There are various models of IR cameras. In the next figure we present one example that has proven to be ultra-portable and that can obtain detailed picture and one optimal performance (Figure 2.19).

Figure 2.19 – Procedure for the production of a thermal image: a) Object; b) IR Camera Flir; c) Thermal image [88,89].

2.5- Thermography and Work-Related Musculoskeletal Disorders

The main functions of the musculoskeletal system, constituted by many organs and tissues, in the human body movement and mobility.

The MSIs are often associated with temperature changes on the skin surface, manifested by warmth, pain, redness, swelling and abnormal function [22]. Temperature is usually the main signal, due to metabolic rate increased and vasodilation, since that occurrences are able to alter the temperature gradient between the body and its environment [90]. This temperature variation is visible with the use of IRT and the vision listed consists of a medical imaging method that detects thermal radiation (IR radiation) emitted from the surface of objects.

The concepts mentioned in the present line have already been explore in the curse of our investigation but we intend to deepen their conceptualization taking in account articles and scientific publications that took this technology in order to perform medical diagnostics, as an summarized systematic review, compiled in a spread sheet (tables 2.5 and 2.6).

2.5.1- Thermography as a Diagnostic Tool

Thermography can be used as a diagnostic tool, being non-invasive, non-ionizing, fast, objective and able to monitoring a large area of interest in real time [91, 92].

IRT has been widely used since the early 1960s in different areas. During the first decades after its development, research into the use of IRT in humans was mainly focused on its applications as a diagnostic tool [78].

Studies published to the present date indicate that, IRT can be successfully used for diagnosis of breast cancer, diabetes, dentistry, diabetic neuropathy, and so on. This is a technology that also allows the diagnosis of problems related to tendons, ligaments, joints, muscles and bones, even if covered by thin musculature [93].

Table 2.5 - Some studies that was used as thermography as a diagnostic tool [94-96].

Paper	Objective	Conclusion
Assessment of Piano-Related Injuries using Infrared Imaging	In this paper, we used statistical analysis to examine the difference in hand and arm temperatures of pianists with pain and pianists without pain related to piano-playing.	They found that there was a correlation between heat and pain due to piano playing, which showed in the difference in the mean temperature of the hands between pianists with pain and pianists without pain. IR imaging would be a good way to detect these problems early on and prevent serious pain or injuries in the future.
Skin temperature in the dorsal hand of office workers and severity of upper extremity musculoskeletal disorders	This study aimed to examine the suitability of using mean dorsal (hand) skin temperature (MDT) before and after a short typing task as an indicator of upper extremity musculoskeletal disorder (UEMSD) severity.	This study has demonstrated a reliable physiologic method of determining UEMSD severity in office workers through the measurement of dorsal hand temperature using IRT under a controlled ambient environment (18–22°C recommended).
Infrared Thermography for examination of skin temperature in the dorsal hand of office workers	The study objective was to characterize potential differences in cutaneous temperature, among three groups of office workers assessed by dynamic thermography following a 9-min typing challenge.	Post-typing differences in Tsk in response to a 9-min typing challenge were detectable through IRT in three groups of office workers. IRT appears to distinguish between the three groups of subjects, with keyboard-induced cold hand symptoms presumably due, at least partially, to reduce blood flow.

2.5.2- Thermography as an Evaluation Tool of Exposure to Risk Factors for Development of Work-Related Musculoskeletal Disorders

Recent research on thermography had illustrated that it is an effective diagnostic and, potentially, evaluative tool for assessment of task demands on physiological responses believed to be directly related to WMSD development [97].

Table 2.6 - Some studies in which the thermography was used as an evaluation tool of exposure to risk factors for development of MSIs [98-101].

Paper	**Objective**	**Conclusion**
Skin temperature and muscle blood volume changes in the hand after typing	Examine the correlation between mean skin temperature (THand), and relative blood volume (RBV) in the first dorsal interosseous muscle as measured through near infrared spectroscopy in the hand after a 9-min typing task in healthy subjects and the effect of typing speed on the physiological measures was determined.	THand and RBV in the first dorsal interosseous (FDI) appear to be moderately correlated after a typing task of 9-min in asymptomatic office workers. This suggests that Tsk may be indicative of underlying muscle perfusion. With regard to industry, in this case, we conclude that the reduced blood flow has been implicated in MSI pathophysiology.
Analysis of Temperature on the Surface of the Wrist in Individuals Emulating an Operation with Highly Repetitive Movements Using Sensory Thermography	This study focuses on the application of sensory thermography, as a non-invasive method to evaluate the MSIs that industry operators performing Highly Repetitive Movements (HRM) may acquire, which could enhance the pathological understanding of the Cumulative Trauma Disorder (CTD).	The sensory thermography offers the early detection of cumulative trauma disorders and with it, it would be possible to prevent further injuries, and perhaps prevent Cumulative Trauma Disorder CTD's from occurring. Disorders like the Carpal tunnel disorder or tendinitis could be avoided by using an early monitoring system like the sensory thermography.
Infrared imaging of the anterior deltoid during overhead static exertions	The objective of this study was to quantify surface temperature changes over the anterior deltoid and evaluate efficacy of thermography as an assessment tool.	Infrared imaging has been used to detect the presence of neuromuscular disorders of the cervical spine and upper extremities. Thermography was sensitive to changes in task loadings, illustrating its potential use for risk assessment.
Efficacy of using thermography to assess shoulder loads during overhead intermittent work	This study was designed to evaluate the effects of task parameters on middle deltoid and trapezius thermal images during simulated work tasks.	Results showed that thermography readings are sensitive to task demands on the musculature during dynamic tasks. Thermography was found to be sensitive to changes in task parameters, providing preliminary evidence that thermography may be useful in quantifying work task demands.

2.5.3 – Applications of Infrared Thermography

The applications of IRT have been growing over the years. It is a technique widely used by the military, aviation, transportation, construction and manufacturing industries, research and the medical and veterinary professions. One example of its use is the fact that it is very useful for firefighters because it allows them to see throughout smoke-filled rooms.

In regard to the area of human medicine, thermal imaging has some advantages over other imaging techniques because it is non-invasive and very fast. The IRT does not expose the patient to harmful x-ray radiation.

Some anomalies cause an increase in temperature and shows hot spots as standards or as an asymmetric IR thermogram, these abnormalities are malignant diseases, inflammations and infections located [60]. Even if the anomaly is not specific, IRT will be able to detect it, because this technique is a very powerful detector of problems that affect the physiology of the patient [93].

IRT has also been used as an adjunctive assessment method in several cases: WMSDs [11], muscle damage induced by exercise [12], ulcer prevention study by pressure, prevention, detection and tracking of injury gymnasts [13]. It is necessary to take in to account some procedures before starting an IR images diagnosis process such as the adjustment of the room temperature and room humidity [102,103].

As said before thermography can be widely used and, this vast set also includes the WMSDs and the possibility of beem taken during physical exercise, as we are going to see hereafter.

In concern to exercise, the thermal interaction of human body and the environment during running activity is an important mechanism that may affect the athletic performance. In the figure presented next, the Tsk response to running exercise has been tested by IR thermographic imaging, a highly reliable method for diagnoses performed in real time. In this image are represented typical examples of Tsk modifications, on the previous body regions, during the graded and constant load treadmill exercises [104].

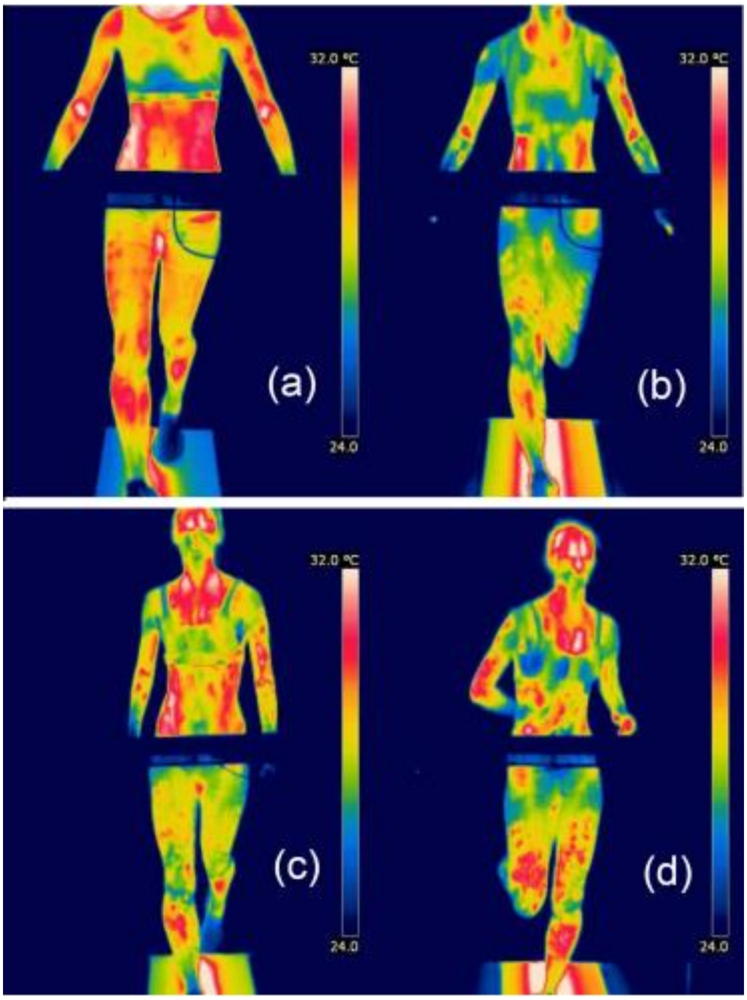


Figure 2.20 - Tsk measurements by IRT during running exercise [104].

When comparing Figure 2.20a and 2.20b, corresponding to different speed steps, we find that further reductions occur the exercise progresses. In the images 2.20c and 2.20d load keeps always constant, and, as this happens, the temperature distribution over the skin surface is still uneven. Anyways mages taken at different intervals from the start of the exercise only show minor differences in temperature levels over the body surface [104].

Humans throughout the day participate in various activities, due to this fact the knee is susceptible to many diseases and injuries such as osteoarthritis (OA) that is a degeneration of a particular cartilage without infection or inflammation can lead to a more or less rapid destruction of cartilage. With IRT is possible to detect trauma or disorders that cannot be displayed by conventional methods. This technology can measure the temperature of the skin over the inflamed joints and, for that reason, it might be consider a plus tool in the diagnose of knee pathology that present physiological changes, rather than anatomical changes. The objective is to evaluate the utility of the IRT in knee OA detection (Figure 2.21) and to assess the relationship between the intensity of pain and the measurement of Tsk.

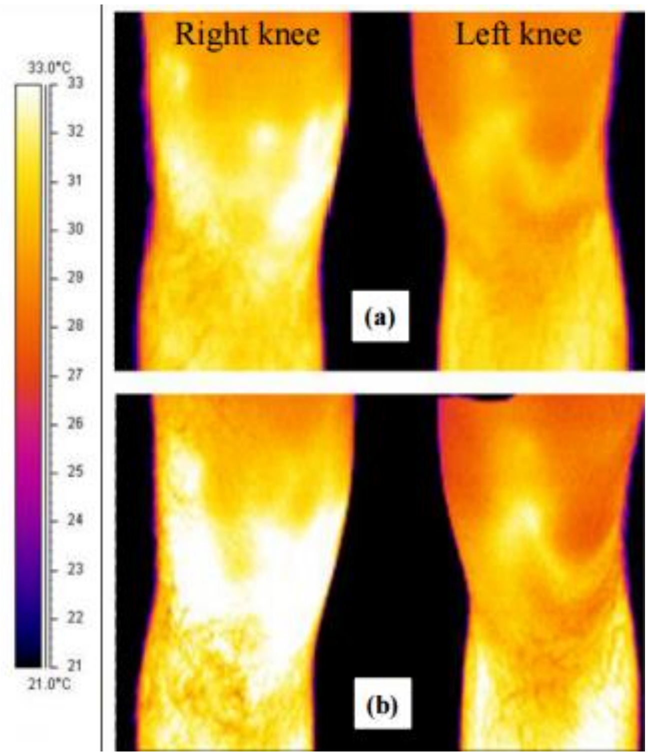


Figure 2.21 - IRT of right and left knees: a) before; b) after race for the participant with right knee OA [74].

Comparing figure 2.21a to figure 2.21b, it is seen that the load on the knee, over the thermal zone is increased. This happens due to excessive use of the knee and repetitive stress injury during vibration exercise that has been increasing in popularity both in leisure, sport and clinical settings.

In this way, a survey was conducted with the aim to study the impact of acute exposure to whole body vibration in the Tsk and thermal symmetry of the lower extremities in healthy subjects (Figure 2.22) [105].

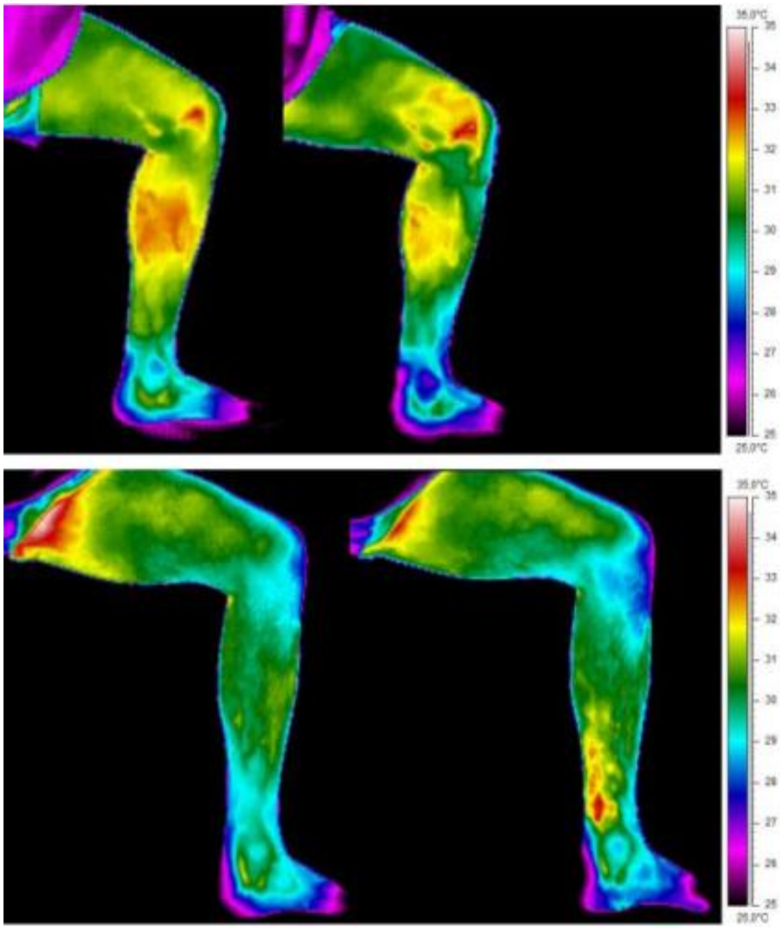


Figure 2.22 - Medial aspect of the left leg in the control (above) and experimental (below) groups, before (left) and after (right) whole body vibration [105].

Looking at the picture above, it can concluded that isometrically maintaince of the position of 45 º of knee flexion for 5 minutes is enough to significantly decrease Tsk in the previous aspect of the knee, anterior aspect of the lower leg, anterior aspect of the ankle, dorsal aspect of the thighs, dorsal aspect of the lower legs and medial and lateral aspects of the ankles. However, it is still necessary to deepen the research to reinforce the results obtained.

Concerning to thermography and MSIs in concret we are now presenting some studies, with the respective images of some types of MSIs where thermography is applied.

Starting with muscle injuries, a type of musculoskeletal injury, we performed a study in which we assessed the muscle injuries in musicians. Musicians, especially those using instruments like the violin and the flute, often suffer from health problems due to inadequate body positions. To detect the most critical zones, it was used IRT. It is anticipated that the warmer areas, i.e. more active and more vascularized, are the region's most exposure to risk of overuse and pain.

These areas are highlighted in Figure 2.23 with a darker colour [106].

Figure 2.23 - The image is represented 2 and 3 a guy after fiddling with the shoulder at rest and images 4 and 5 without shoulder be at rest [106].

Another case of MSIs is to hand-arm vibration syndrome, which remains a major problem in occupational health. In some circulatory disturbances, such as Raynaud's phenomenon, or hand arm vibration syndrome (Figure 2.24), damage to small blood vessels, from exposure to vibrating machinery and the effect of the local blood circulation on Tsk, can be assessed by thermal imaging. The hand-arm vibration syndrome is caused by repeated and frequent use of vibrating tools like, drills, saws, jackhammers, among others. It can also be caused by exploration or operating machinery that vibrates.

The nerves are affected first, leading to changes in sensitivity. This can be followed by Raynaud's phenomenon, resulting from changes in the blood vessels, ensuing in a white finger. Raynaud's phenomenon comes in crisis or attacks that are trigger by cold weather or touching a cold object [107,108].

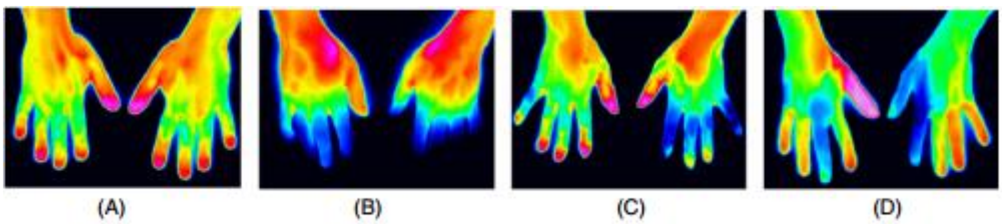


Figure 2.24 - The effects of stress on hand thermogram (A) 10 min full recovery from the normal 1 min immersion in water at 20 ◦C; (B) in a patient with Raynaud's phenomenon after 10 min. (C); (D) Examples of hand arm vibration injury to certain fingers, showing delayed recovery after vibration and thermal stress have been applied. The affected fingers are cooler [107].

In the figure 2.25, it is described the process that was used.

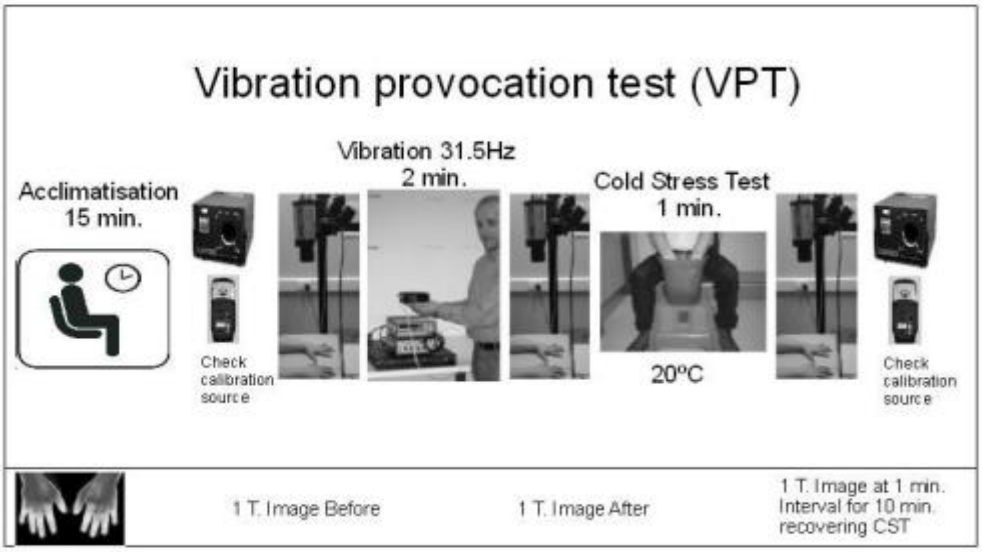


Figure 2.25 - The Vibration Provocation Test (VPT) diagram [108].

2.6 - Conclusions

WMSDs take place in people who are exposed to repetitive and continuous activities during their work. As a result of this practices pain becomes a constant complaint. These workplace injuries are considered to affect workers of all countries. Besides affecting workers, the company is also affected by the reducing of productivity and the increase of absenteeism.

These lesions can be of various types, since tendonitis, epicondylitis and muscle injury.

The thermography has been widely used for clinical purposes, for example, in the diagnosis of musculoskeletal injury. There are three types of thermography, namely LCT, IRT and MWT, the most relevant for this project is IRT.

IRT technique is a simple, non-invasive and low cost diagnosis technique that also doesn't use any type of radiation, and, therefore, may be used in pregnant women and in children. This technique shows physiological changes instead of anatomical changes, hence may be a novel diagnostic tool in, for example, detecting pathologies of the knee. In MSIs caused by work or in sports, this technique has also been applied very successfully.

Over the years, various studies have been conducted where the application of thermography has been essential.

Chapter 3

Processing and Image Analysis

The image use in medicine is currently considered an important resource in the development of medical diagnostics. The processing and image analysis focuses on developing procedures for extracting information from an image using computer processing [14].

In recent years, the techniques responsible for processing and image analysis have had a tremendous growth. Medicine is one of the areas that has most benefited from the interaction with the computer, especially on analyzing and processing images, mainly for diagnostic analysis.

The image analysis area is a field of study that aims to develop techniques that allow the extraction of information from images, and allows people and machines to acquire a greater power of analysis, resulting in greater support diagnosis [109].

Analysis techniques aided by computer have been proposed in order to offer better parameters for the development of a more careful diagnosis, indicating suspicious areas [14].

In the present chapter the prominent issue is the processing and image analysis. Morphological operations used in this project are presented in Section 3.1 and in Section 3.2 the findings are mentioned.

3.1 - Morphological Operations

Morphological operations are used in MATLAB provide a systematic geometric change of image content while maintaining stability of the important geometric features.

Generally, morphological operators transform the original image into a smaller image size and certain forms, is known as the structuring element. The geometric characteristics of the image that are similar in shape and size to the structuring element are preserved, while other features are suppressed. Morphological operations can simplify the image data, preserving their characteristic forms and eliminating irrelevancies. Morphological operations can be used for many purposes, including the detection of edge, segmentation, enhancement of images, reconstruction and others [110].

3.1.1- Function bwmorph

The bwmorph is an Image Processing Toolbox (IPT) function that can perform a variety of practical morphological tasks, implements a variety of useful operations based on combinations of dilations, erosions, and lookup table operations. Its calling syntax is

g= bwmorph (f, operation, n) (3.1)

where f is an input binary image, operation is a string specifying the desired operation, and n is a positive integer specifying the number of times the operation is to be repeated. Input argument n is optional and can be omitted, in which case the operation is performed onlyonce. Table 3.1 describes the set of valid operations for bwmorph.

Table 3.1 – Operations supported by function bwmorph [110].

Operation	**Description**
Bothat	"Bottom-hat" operation using a 3 x 3 structuring element; use imbothat for other structuring elements.
Bridge	Connect pixels separated by single-pixel gaps.
clean	Remove isolated foreground pixels.
close	Closing using a 3 x 3 structuring element; use imclose for other structuring elements.
diag	Fill in around diagonally connected foreground pixels.
dilate	Dilation using a 3 x 3 structuring element; use imdilate for other structuring elements.
erode	Erosion using a 3 x 3 structuring element; use imerode for other structuring elements.
fill	Fill in single-pixel "holes": use imfill to fill in larger holes.
hbreak	Remove H-connected foreground pixels.
majority	Make pixel *p* a foreground pixel if at least five pixels in N_8 (p) are foreground pixels; otherwise make *p* a background pixel.
open	Opening using a 3 x 3 structuring element-, use function imopen for other structuring elements.
remove	Remove "interior" pixels.
shrink	Shrink objects with to holes to points; shrink objects with holes to rings.
skel	Skeletonize an image.
spur	Remove spur pixels.
thicken	Thicken objects without joining disconnected 1s.
thin	Thin objects without holes to minimally connected strokes; thin objects with holes to rings.
tophat	"Top-hat" operation using a 3 x 3 structuring element; use imtophat for other structuring elements.

In the rest of the present section we concentrate on two of these: thinning and skeletonization. Thinning means reducing binary objects or shapes in to an image to strokes that are a single pixel wide. Each application of bwmorphs thinning operation removes one or two pixels from the thickness of binary image objects. The following commands, for example, display the results of applying the tinning operation one and two times.

```
>> f = imread ('fingerprint_cleaned.tif');
>> g1 = bwmorph (f, 'thin', 2);
>> imshow (g1), figure, imshow (g2)
```

Figures 3.2 is a fingerprint image from Figure 3.1, figure 3.2(a) and 3.2(b), respectively, show the results.

Figure 3.1 - Noisy fingerprint image. Opening followed by closing [110].

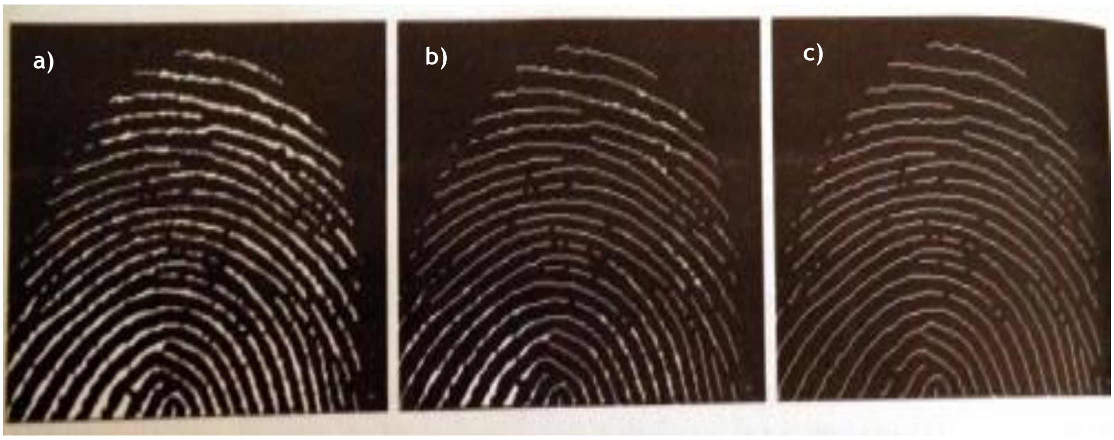


Figure 3.2 – Fingerprint image from Figure 3.1 thinned once. (b) Image thinned twice. (c) Image thinned until stability [110].

Skeletonization is another way to reduce binary objects image to a set of thin strokes that retain important information about the shapes of the original objects. Function bwmorph performs skeletonization when operation is set to 'skel'. Let f denote the image of the boonelike object as in Figure 3.3 (a). To compute its skeleton, we call bwmorph, with n=Inf:

```
>> fs = bwmorph(f, 'skel', Inf);
>> imshow(f), figure, imshow(fs)
```

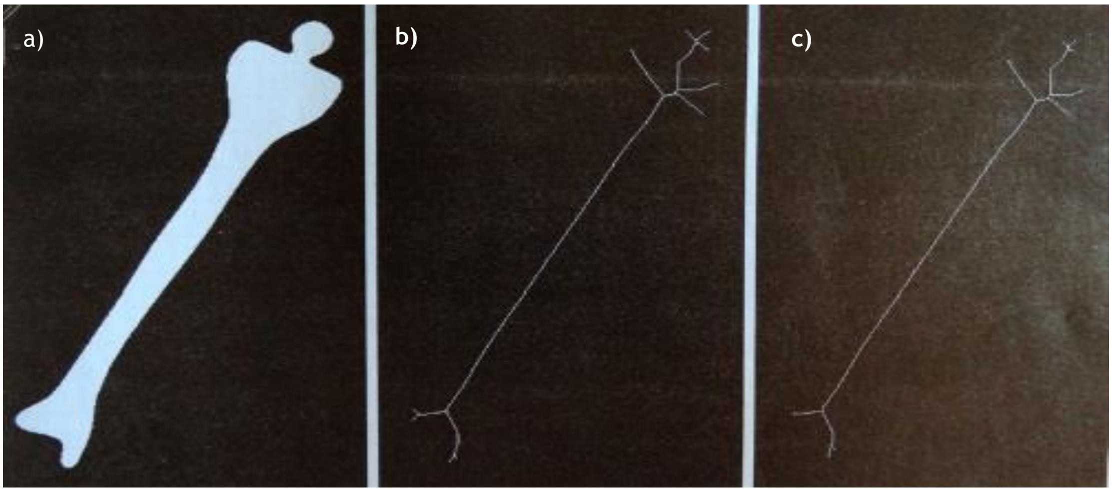


Figure 3.3 – (a) Bone image. (b) Skeleton obtained using function bwmorph. (c) Resulting skeleton after pruning with function endpoints [110].

Skeletonization and thinning often produce short extraneous spurs, sometimes called parasitic components. The process of cleaning up (or removing) these spurs is called pruning. Function endpoints can be used for this purpose. The method is to iteratively identify and remove endpoints. The following simple commands, for example, port processes the skeleton image fs through five iterations of endpoint removals:

```
>> for k = 1:5
>> Fs = fs & ~endpoints(fs);
>> End
```

3.1.2 – Edge Detection using Function Edge

Edge detection is the process of localizing pixel intensity transitions. The edge detection has been used by object recognition, target tracking, segmentation, and so on. Therefore, the edge detection is one important parts of image processing.

There is a several range of edge detection methods (Sobel, Prewitt, Roberts, Canny). These methods have been proposed for detecting transitions in images. Early methods determined the best gradient operator to detect sharp intensity variations.

Edge detection is an important concept, both in the area of image processing and in the area of object recognition. Without being able to determine where the edges of an object fall a machine would be unable to determine many things about an object such as shape, volume, area and so forth.

The goal of edge detection is to mark the points in a digital image at which the luminous intensity changes sharply. Edge detection of an image reduces significantly the amount of data and filters out information that may be regarded as less relevant, preserving the important structural properties of an image.

Although point and line detection certainly are important in any discussion about image segmentation, edge detection is by far the most common approach for detecting meaningful discontinuities in intensity values. Such discontinuities are detected by using first- and second-order derivatives. The first-order derivative of choice in image processing is the gradient. We repeat the pertinent equations here for convenience. The gradient of a 2-D function, f (x,y), is defined as the vector

$$\nabla f = \begin{bmatrix} G_x \\ G_y \end{bmatrix} = \begin{bmatrix} \frac{\partial f}{\partial x} \\ \frac{\partial f}{\partial y} \end{bmatrix} , \tag{3.2}$$

the magnitude of this vector is

$$\nabla f = mag(\nabla f) = [\,G_x^2 + G_y^2]^{1/2}$$
$$= [(\partial f/\partial x)^2 + (\partial f/\partial y)^2]^{\frac{1}{2}} , \tag{3.3}$$

To simplify computation, this quantity is approximated sometimes by omitting the square-root operation,

$$\nabla f \approx G_x^2 + G_y^2 , \tag{3.4}$$

or by using absolute values,

$$\nabla f \approx |G_x| + |G_y| , \tag{3.5}$$

These approximations still perform the role of derivatives; that is, they are zero in areas of constant intensity and their values are proportional to the degree of intensity change in areas whose pixels values are variable. It is a common practice to refer to the magnitude of the gradient or its approximations simply as "the gradient."

A fundamental property of the gradient vector is that it points in the direction of the maximum rate of change of its coordinates (x,y). The angle at which this maximum rate of change occurs is

$$\propto (x, y) = \tan^{-1}(\tfrac{G_y}{G_x}) , \tag{3.6}$$

One of the key issues is how to estimate the derivatives Gx and Gy digitally. The various approaches used by function edge are discussed later in this section.

Second-order derivatives in image processing are generally computed using the Laplacian. That is, the Laplacian of a 2-D function f(x,y) is formed from second-order derivatives, as follows:

$$\nabla^2 f(x, y) = \frac{\partial^2 f(x,y)}{\partial x^2} + \frac{\partial^2 f(x,y)}{\partial y^2} , \tag{3.7}$$

There are two important general criteria used in the idea behind edge detection that is to find places in an image where the intensity changes rapidly:

1. Find places where the first derivative of the intensity is greater in magnitude than a specified threshold.
2. Find places where the second derivative of the intensity has a zero crossing.

The general syntax for this function is

[g, t] = edge(f, ‘method’, parameters) (3.8)

where f is the input image, this method is one of the approaches listed in Table 10.1, and parameters are additional parameters explained in the following discussion. In the output, g is a logical array with 1s at the locations where edge points were detected in f and 0s elsewhere. Parameter t is optional; it gives the threshold used by edge to determine which gradient values are strong enough to be called edge points [110].

3.1.2.1 - Edge Detection Algorithms

Edge detection is the process of determining where the boundaries of objects fall within an image. There are several algorithms that exist to date that are able to detect edges (table 3.2). Roberts Cross was the first technique used and is thus the fasted and simplest to implement. Lastly, there is the Canny edge detection algorithm. This uses several steps to detect edges in an image. However, sometimes this algorithm can be slow due to its higher degree of complexity.

Table 3.2 - Edge detectors available in function edge [110].

Edge Detector	Basic Properties
Sobel	Finds edges using the Sobel approximation to the derivatives.
Prewitt	Finds edges using the Prewitt approximation to the derivatives.
Roberts	Finds edges the Roberts approximation to the derivatives.
Laplacian of a Gaussian (LoG)	Finds edges by looking for zero crossings after filtering f (x,y) with a Gaussian filter.
Zero crossings	Finds edges by looking for zero crossings after filtering f(x,y) with a user-specified filter.
Canny	Finds edges by looking for local maxima of the gradient of f (x,y). The gradient is calculated using the derivative of a Gaussian filter. The method uses two thresholds to detect strong and weak edges, and includes the weak edges in the output only if they are connected to strong edges. Therefore, this method is more likely to detect true weak edges.

Roberts Edge Detector

Roberts operator makes the cross gradient, that is, instead of calculating the differences in brightness values in the vertical and horizontal direction, do it in a direction rotated 45 º [110]. The Roberts edge detector uses the masks in Figure 3.3 to approximate digitally the first derivatives Gx and Gy [110].

$$G_x = \begin{bmatrix} 1 & 0 \\ 0 & -1 \end{bmatrix} \qquad G_y = \begin{bmatrix} 0 & -1 \\ 1 & 0 \end{bmatrix} \tag{3.9}$$

Its general calling syntax is

[g, t] = edge(f, ‘roberts’, T, dir) (3.10)

The parameters of this function are identical to the Sobel parameters. The Roberts detector is one of the oldest edge detectors in digital image processing, and as Figure 3.4 shows, it is also the simplest [110].

Prewitt Edge Detector

The Prewitt operator, and differentiate, softens the image, reducing the negative effects of noise [111] and the masks in Figure 3.4 to approximate digitally the first derivatives Gx and Gy [110].

$$G_x = \begin{bmatrix} -1 & 0 & 1 \\ -1 & 0 & 1 \\ -1 & 0 & 1 \end{bmatrix} \qquad G_y = \begin{bmatrix} 1 & 1 & 1 \\ 0 & 0 & 0 \\ -1 & -1 & -1 \end{bmatrix} \tag{3.11}$$

Its general calling syntax is

[g, t] = edge(f, ‘prewitt’, T, dir) (3.12)

The parameters of this function are identical to the Sobel parameters. The Prewitt detector is slightly simpler to implement computationally than the Sobel detector, but it tends to produce somewhat noisier results [110].

Sobel Edge Detector

The Sobel operator is very similar to Prewitt differing from it only because it gives more weight to the nearest central pixel points and because it produces diagonal edges less attenuated. The Sobel operator performs a 2-D spatial gradient measurement on an image [111] and uses the masks in Figure 3.5 to approximate digitally the first derivatives Gx and Gy [110].

$$G_x = \begin{bmatrix} -1 & 0 & 1 \\ -2 & 0 & 2 \\ -1 & 0 & 1 \end{bmatrix} \qquad G_y = \begin{bmatrix} 1 & 2 & 1 \\ 0 & 0 & 0 \\ -1 & -2 & -1 \end{bmatrix} \tag{3.13}$$

In other words, the gradient at the center point in a neighborhood is computed as follows by the Sobel detector:

$$\begin{aligned} g &= [G_x^2 + G_y^2]^{1/2} \\ &= \{[(z_7 + 2z_8 + z_9) - (z_1 + 2z_2 + z_3)]^2 \\ &\quad + [(z_3 + 2z_6 + z_9) - (z_1 + 2z_4 + z_7)^2\}^{1/2} \quad , \end{aligned} \tag{3.14}$$

The general calling syntax for the Sobel detector is

[g, t] = edge(f, ‘sobel’, T, dir) (3.15)

where f is the input image, T is a specified threshold, and dir specifies the preferred direction of the edges detected : 'horizontal', 'vertical', or 'both' (the default). As noted earlier, g is a logical image containing 1s at locations where edges were detected and 0s elsewhere. Parameter t in the output is optional. It is the threshold value used bye the edge. If T is specified, then t=T. Otherwise, if T is not specified (or is empty, []), edge sets t equal to a threshold it determines automatically and then uses for edge detection. One of the principal reason for including t in the output argument is to get an initial value for the threshold. Function edge uses the Sobel detector as a default if the syntax g=edge, or [g, t] = edge(f), is used [110].

Laplacian of a Gaussian (LoG) Detector

Consider the Gaussian Function

$$h(r) = -e^{-\frac{r^2}{2\sigma^2}} \quad , \tag{3.16}$$

where $r^2 = x^2 + y^2$ and σ is the standard deviation. This is a smoothing function which, if convolved with an image, will blur it. The degree of blurring is determined by the value of σ. The Laplacian of this function (the second derivative with respect to r) is

$$\nabla^2 h(r) = -\left[\frac{r^2 - \sigma^2}{\sigma^4}\right] e^{\frac{r^2}{2\sigma^2}} \quad , \tag{3.17}$$

We convolve the image with $\nabla^2 h(r)$, knowing that it has two effects: it smoothes the image (thus reducing noise), and it computes the Laplacian, which yields a double-edge image. Locating edges then consists of finding the zero crossings between the double edges.

The general calling syntax for the LoG detector is

[g, t] = edge(f, ‘log’, T, sigma) (3.18)

where sigma is the standard deviation and the other parameters are as explained previously. The default value for sigma is 2. As before, edge ignores any edges that are not stronger than T. If T is not provided, or it is empty, [], edge chooses the value automatically. Setting T to 0 produces edges that are closed contours, a familiar characteristics of the LoG method [110].

Zero-Crossings Detector

This detector is based on the same concept as the LoG method, but the convolution is carried out using a specified filter function, H. The calling syntax is

[g, t] = edge(f, ‘zerocross’, T, H) (3.19)

The order parameters are as explained for the LoG detector [110].

Canny Edge Detector

The Canny is an operator that is little affected by noise and allows the detection of contours by maximizing the signal ratio / noise gradient contour location factor which ensures that the detected contour is the most suitable possible and minimizing the number of responses to a single contour [112]. In this method, initially is applyed a Gaussian filter, and then applies the Canny operator gradient.

The Canny detector is the most powerful edge detector provided by function edge. The method can be summarized as follows:

1. The image is smoothed using a Gaussian filter with a specified standard deviation, σ, to reduce noise.

2. The loal gradient, $g(x,y) = [G_x^2 + G_y^2]^{1/2}$, and edge direction, $\alpha(x,y) = \tan^{-1}(G_y/G_x)$, are computed at each point. Any of the first three techniques in TABLE 10.1 can be used to compute G_x and G_y. An edge point is defined to be a point whose strength is locally maximum in the direction of the gradient.

3. The edge points determined in (2) give rise to ridges in the gradient magnitude image. The algorithm then tracks along the top of these ridges and sets to zero all pixels that are not actually on the ridge top so as to give a thin line in the output, a process known as nonmaximal suppression. The ridge pixels are then thresholded using two thresholds, T1 and T2, with T1<T2. Ridge pixels with values greater than T2 are said to be "strong" edge pixels. Ridge pixels with values between T1 and T2 are said to be "weak" edge pixels.

4. Finally, the algorithm performs edge linking by incorporating the weak ixels that are 8-connected to the strong pixels.

The syntax for the Canny edge detector is

[g, t] = edge(f, ‘canny’, T, sigma) (3.20)

where T is a vector, T=[T1, T2], containing the two thresholds explained in step 3 of the preceding procedure, and sigma is the standard deviation of the smoothing filter. If t is included in the output argument, it is a two-element vector containing the two threshold values used by the algorithm. The rest of the syntax is as explained for the other methods, including the automatic computation of thresholds if T is not supplied. The default value for sigma is 1 [110].

3.1.3- Function Regionprops

Function regionprops is IPTs principal tool for computing region descriptors. This function has the syntax

D = regionprops(L, properties) (3.21)

where L is a label matrix and D is a structure array of length max (L(:)). The fields of the structure denote different measurements for each region, as specified by properties. Argument properties can be a comma-separated list of strings, a cell array containing strings, the single string 'all', or the string 'basic'. Table 11.1 lists the set of valid property strings.

If properties is the string 'all', then all the descriptors in Table 3.3 are computed. If properties is not specified or if it is the string 'basic', then the descriptors computed are 'Area', 'Centroid', and 'BoundingBox'. Keep in mind that IPT uses x and y to indicate horizontal and vertical coordinates, respectively, with the origin being located in the top, left. Coordinates x and y increase to the right and downward from the origin, respectively. For the purposes of our discussion, on pixels are valued 1 while off pixels are valued 0 [110].

Table 3.3 – Regional descriptors computed by function regionprops [110].

Valid Strings for properties	Explanation
'Area'	The number of pixels in a region.
'BoundingBox'	1 x 4 vector defining the smallest rectangle containing a region. BoundingBox is defined by [ul_corner width], where ul_corner is in the form [x y] and specifies the upper-left corner of the bounding box, and width is in the form [x_width y_width] and specifies the width of the bounding box along each dimension.
'Centroid'	1 x 2 vector; the center of mass of the region.
'ConvexArea'	Scalar; the number of pixels in 'ConvexImage'.
'ConvexHull'	P x 2 matrix; the smallest convex polygon that can contain the region.
'ConvexImage'	Binary image; the convex hull, with all pixels within the hull filled in (i.e., set to on). The image is the size of the bounding box of the region.
'Eccentricity'	Scalar; the eccentricity of the ellipse that has the same second moments as the region. The eccentricity is the ratio of the distance between the foci of the ellipse and its major axis length. The value is between 0 and 1, with 0 and 1 being degenerate cases (an ellipse whose eccentricity is 0 is a circle, while an ellipse with an eccentricity of 1 is a line segment).
'EquivDiameter'	Scalar; the diameter of a circle with the same areas as the region. Computed as sqrt (4*Area/pi).
'EulerNumber'	Scalar; equal to the number of objects in the region minus the number of holes in those objects.
'Extent'	Scalar; the proportion of the pixels in the bounding box that are also in the region. Computed as Area divided by the area of the bounding box.
'Extrema'	8 x 2 matrix; the extremal points in the region. Each row of the matrix countains the x- and y-coordinates of one of the points.
'FilledArea'	The number of on pixels in FilledImage.
'FilledImage'	Binary image of the same size as the bounding box of the region. The on pixels correspond to the region, with all holes filled.
'Image'	Binary image of the same size as the bounding box of the region; the on pixels correspond to the region, and all other pixels are off.
'MajorAxisLength'	The length (in pixels) of the major axis of the ellipse that has the same second moments as the region.
'MinorAxisLength'	The length (in pixels) of the minor axis of the ellipse that has the same second moments as the region.
'Orientation'	The angle (in degrees) between the x-axis and the major axis of the ellipse that has the same second moments as the region.
'PixelList'	A matrix whose roes are the [x , y] coordinates of the actual pixels in the region.
'Solidity'	Scalar; the proportion of the pixels in the convex hull that are also in the region.

3.2 - Conclusions

The image processing focuses on developing procedures to extract information from an image appropriately for computational processing. The image analysis area is a field of study that aims to develop techniques that allow you to extract information from images, and allows people and machines to acquire greater power analysis, resulting in a greater support diagnosis.

The concepts and techniques presented in this chapter constitute a powerful set of tools from which we can extract features of an image, as is the function of the case bwmorph that implements a variety of useful operations based on combinations of dilations, erosions, and table lookup operations.

The edge detection algorithms, is based on a drastic change in value from one spot to the next in either an image or in one's own eyes. There are several algorithms that are able to detect edges and in this chapter they were presented. However, only one of these algorithms has used in this project, the Sobel Edge Detector. Finally, regionprops function is also used, this function has several regional descriptors computed, but used was bweuler function which is the Euler's number, Area and PixelList.

Chapter 4

Methodological Procedures

In the present chapter it is presented the methodological procedures of this project. The chapter starts with the operational definition of Variables and followed is presented the materials and methods section 4.2, this same section divided into subsections 5.

4.1 - Operational Definition of Variables

Injuries Musculoskeletal - are disorders of muscles, tendons, fascia's (band of fibrous tissue that lines the muscles) and nerves in the upper limb caused by repetitive movements that result in pain, numbness, decreased range of motion, and, in consequence, temporary incapacitation, reaching the disability. Usually located in the upper limb and spine these kind of injuries may occur in other locations, such as the knees or ankles, depending on the area of the body affected. These are injuries that have a close relation to the activity developed by a worker, once its appearance and degree of intensity depends on it.

Thermography - is a non-invasive, simple and low cost technique that measures the amount of infrared radiation emitted by the body, providing the value of its surface temperature and, soon after, processing the results in a, display that appears in the form of images.

4.2 - Materials and Methods

To conduct a study of a scientific nature is necessary to opt for a particular research methodology that adapts to the reality to be studied. In this sense, there was a research study at a tire company, Continental Mabor, SA, in Vila Nova de Famalicão. This study was of qualitative and quantitative nature, through an exploratory process. Its implementation deepens the level of knowledge by description and / or interpretation of the data obtained, so that one can understand the phenomenon under study.

The present research project is of a cross observational descriptive comparison type, we are going to analyse and compare simultaneously the patient's exposure to hazardous situations and the results in terms of health, in two samples over a given period of time.

4.2.1- Population and Sample

The study universe corresponds to all workers of the production sector of the refferd company. All subjects of the sample are male.

All participants were informed concerning the objectives of the study and they where also told that all the information collected would be treated anonymously and confidentially.

The study sample comprises 52 male workers from the production area. All of them are more than18 years old. This sample contains 26 injured workers (experimental group) and 26 healthy workers (control group). Lesions considered in this project are mainly focused on the knee, feet, spine and UL, which are areas where the lesions were more prevalent.

The control group selection was easily accomplished, and all patients who appeared in clinical enterprise services for any reason not being musculoskeletal complaints lesions where also envited to be a part of our sample, as a member of the control group.

On the day of evaluation it was required to the participant to sign an informed consent form (Appendix A), and to complete a questionnaire (Appendix B), followed by a period of thermal acclimation to the examination room and image acquisition. It is important to note that this research was completely safe and painless, did not present any risk to the individual, and all data collected were confidential.

4.2.2- Methods for Collection of Data

The instruments used in data collection were a questionnaire (Appendix B) for assemblage of information on musculoskeletal symptoms reported by workers.

This questionnaire (Appendix B) consisted in 8 questions and for their preparation, we had taken into account the objectives of the study and the existing research on the subject.

The questionnaire is provided by the Nordic Questionnaire Musculoskeletal (QNM) in the version translated and validated for the Portuguese population [113], to assess health aspects.

The questionnaire was organized in three thematic groups: sociodemographic questions; questions on health issues and about the job itself. The answers to the questions where dichotomous (yes / no), polychotomous, or presented in an ordinal scale (Likert).

The questionnaire had good internal consistency and high repeatability and was considered valid, reliable and moderately sensitive method for assessment of musculoskeletal symptoms [114].

The initial questions were of more personal origin, enquiring the worker's sex, age and shift. Then it where made questions about the job, about laterality, and about physical activity. In another group of the questionnaire questions where made in relation to MSIs. It was asked if there where a recent musculoskeletal injury of any kind suffered inside or outside the workplace.

There are some factors that can influence the temperature of the body, so it was asked to the employee if he had, smoked, drinked alcohol, tea / coffee, if he practiced a physical activity or used some cosmetic / ointment on his skin, the last two hours. Finally the respondent was asked to signalize the injury point looking for a figure on paper and indicating the intensity of his pain. A numerical scale was included for rating pain intensity in the different regions, measured on an ordinal scale from 0 to 5 values, where 0 represented no pain and 5 represented maximum pain.

During this project were acquired thermal images in two different ways, in workers with MSIs (experimental group) and workers without any lesions (comparative group). This images that captures the division was performed in order to be able to make the comparison and see if in fact if there are differences in the images of a patient with lesion and the one without injury.

4.2.3- Environmental Preparation Protocol and Patient

There are some factors that can influence the examination of thermography as this requires some specific conditions, as the place where the examination will be performed. The environment must be controlled, the room temperature should be maintained between 18ºC to 23ºC, being 21 º C the ideal, and the relative humidity is also a factor to be controlled.

Before the examination be performed, the patient should strip the area where the affected zone is located and wait for 15 minutes for your body to adapt to room temperature. This should not contain drafts and heat sources such as sunlight and incandescent bulbs.

The patient fill out a questionnaire where he was asked if he smoked, drank coffee / tea / alcohol, if he used lotion or moisturizing cream in the precedent two hours because all these types of behaviours are factors that can influence the temperature of the skin. Artefacts resulting from thermal clothes or the external environment have been eliminated because temperature change will occur on the body surface very slowly and evenly.

Images can be viewed through a computer, so the doctor can acquire images from different regions, and identified them if they are cold or hot (hyperthermic - high blood flow zone). A professional in this field will be able to identify various diseases, in this case MSIs.

4.2.4- Materials Used

In this research the materials used were as follows:

- Informed consent
- Quiz
- Camera

The Sony camera (figure 4.1) was used to get a photo of the exact location where the patient feelt pain.

Figure 4.1 – Camera Sony [115].

- Pen and paper
- Hygrometer and tape measure (Figure 4.2)

Figure 4.2 – Hygrometer and tape measure [116].

- Tripod
- Thermal camera Gobi-384 Industrial (Xenics)

Thermal images were recorded with a thermal camera (figure 4.3). The main features of this thermal camera are showned in table 4.1.

Figure 4.3 – Thermal Camera Gobi-384 Industrial (Xenics) [117].

Table 4.1 – Characteristics of thermal camera Gobi-384 Industrial (Xenics) [117].

Camera Specifications	**Gobi-384**
Focal length	18 mm f/1,HFOV 38º, standard manual focus
Window of interest	Minimum size 160 x 80
Power consumption	3.6 W
Power supply	12 V DC
Ambient operating temperature	0º C to 50º C
Weight camera head	<500 g (Lens not included)
Spectral band	8 μm to 14 μm
Pixels	384 x 288

- Thermal camera Fluke Ti25

Access to this chamber was scarcer, it was only used to calibrate the camera described above (figure 4.4). The main features of this thermal camera are shown in table 4.2.

Figure 4.4 - Thermal Camera Fluke Ti25 [118].

Table 4.2 - Characteristics of thermal camera Fluke Ti25 [118].

Camera specifications	**Fluke Ti25**
Range of temperature measurement (Uncalibrated below -10º C)	-20 º C to + 350º C (two ranges)
Precision	± 2º C or 2 % (whichever is greater)
Emissivity correction on the screen	Yes
Window of interest	25º x 17º
Spectral band of infrared	7,5 μm to 14 μm
Camera visual images	Resolution 640 x 480
Pallets	Reddish tones, Blue-red, High contrast, Amber, Hot metal, Gray
Operating temperature	10º C to 50º C (14º F to 122º F)
Storage temperature	-20º C to +50º C
Weight	1,2 Kg (2,65 lb)

- Computer

4.2.5- Acquisition and Processing of Thermal Images

The thermal images were acquired at Continental Mabor SA - Tire Industry. The acquisition of thermal images requires accuracy, and so the examination room should be prepared in accordance with the rules and the patient must follow the necessary procedures in order to obtain an accurate diagnosis, as already indicated above.

The test room was maintained closed throughout the realization of the data collection and was maintained at a constant temperature of 21ºC, with a variation of + - 1 º C and relative humidity between 50% and 70%. The focal distance was 1 meter and the emissivity of the patient was set to 0.98.

As stated above, the patient had to remove the garment in the affected region and stand about 15 minutes to allow thermal equilibrium with the ambient room temperature before starting the examination. After 15 minutes it was captured an image with the photographic camera only of the area that the patient indicates as a pain zone, so we can compare it and gage to see if it coincides with the heat zone that thermal camera indicates. The time to acquire thermal images was about 2 minutes as they were taken 4 images for each patient, thus giving an interval of about 30 seconds per image. The images were acquired by a thermal camera fixed to a tripod and the patients were positioned at 1 meter of distance from it and in different positions according to MSIs. The capture of thermal imaging was performed through a Gobi-384 of Infaimon Camara. A sotware Xeneth 2.5 - Xenics Graphical User Interface was used to transfer the images to the computer. The software was also used to convert temperature pixels in Digital 16 bits Numbers.

Calibration of Gobi-384 camera it could be performed through the use the Fluke Ti25 thermal camera, this camera provides a calibrated image.

The following table 4.3 are the features of all tested images represented that is the 26 actual cases of patients with injury and 26 real cases of patients without injury.

Table 4.3 - Characteristics of the 52 tested images.

	Characteristics			
Images	Width	Height	Bits	Colour Type
All tested images	384	288	8	RGB

4.2.6- Software Features

For this study, the operating system was Microsoft Windows XP / 2007. It was also used the Xeneth 2.5 software - Xenics Graphical User Interface for transfers images of the thermal camera to the computer. It was also used Matlab (The MathWorks, Inc.), with the toolbox image processing. Matlab is used to preprocessing the images, in order to highlight the areas of potential lesions based on the surface body temperature. For statistical analysis we used the SPSS software.

Chapter 5

Results

In this chapter it is presented a description of the different methodologies implemented in study and its results. The techniques were implemented in MATLAB with 26 actual cases of thermal images with MSIs (experimental group) and 26 real thermal imaging cases without any injury (control group). These 26 injuries cases are variable, although all patients had their MSIs in key areas of the body with increased risk (UL, spine and lower limbs). All images were acquired through the Gobi-384 thermal camera and always in a controlled environment of 21° C.

At first we present the results of the Patient Diagnosis, that was mad by a health professional (nurse Continental Mabor - Industry S.A. tires).

In a second step, we present the thermal image of the experimental group and the control group. At this time it will also be presented the results from processed images.

Lastly, automatic processing achieved for all thermal images using morphological algorithms. The statistical analysis was also evaluated.

5.1 - Patient Diagnosis

There are many MSIs, but some of them are key injuries in the context of the present study such as lumbago, omalgias, contractures, tendinitis, among others. These lesions are, sometimes, difficult to detect, and, therefore also difficult to be diagnosed in a more specific and detailed way. The injuries we focused have in common the fact of occurring very frequently during industrial operations because workers are continuously exposed to very demanding efforts and repetitive movements. These is a very common scenario in Continental Company as we can see in Figure 5.1 where are represented the main complaints of workers MSIs of the last year (2015).

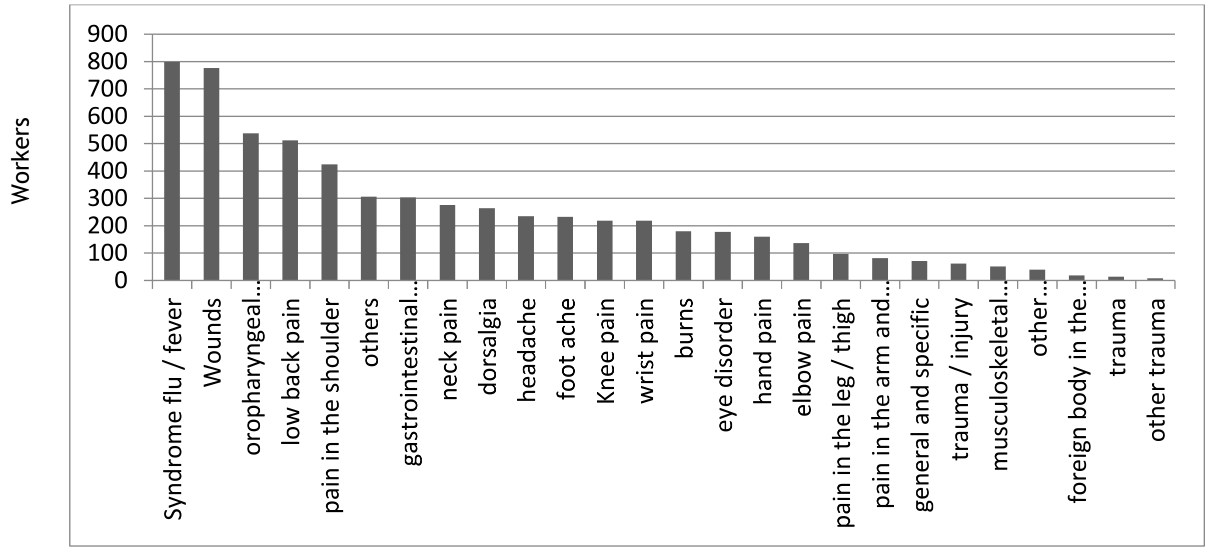


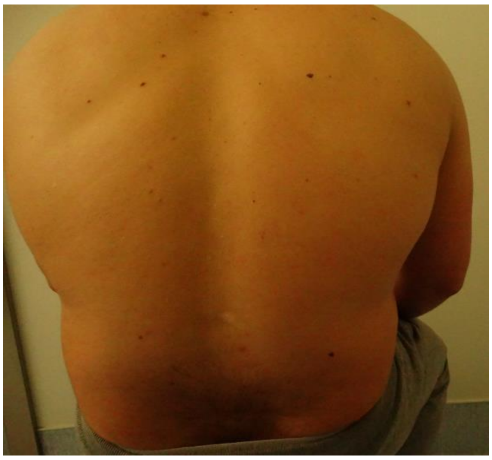
Figure 5.1 - Main complaints in 2015 at Continental Mabor [119].

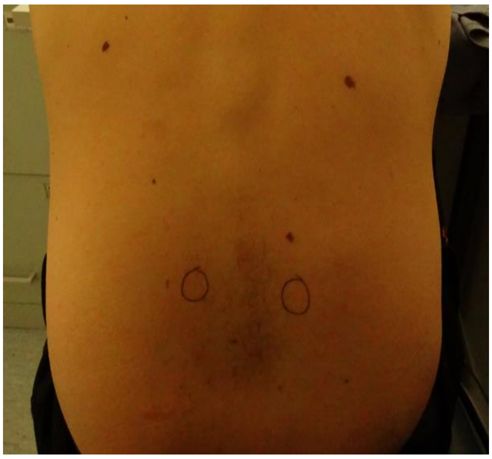
Health professionals had a crucial participation in our study because they did the appreciation and pointed the correct diagnosis of each patient.

Next, in Table 5.1, will be presented the diagnose of each worker, or an indication of the musculoskeletal injury and a photo of the area where the patient felt pain. It is important to underline that we don't have pictures of all the patients because some of the subjects of the study didn't felt free to take pictures.

Table 5.1 – Patient Diagnosis.

Reference Image	Diagnosis
Trapezius – 21/04/2016	Trapezius muscle contracture - right side
Shoulder – 29/04/2016	Tendinosis of the above-espinhal- left side
Foot – 02/05/2016	Bruising traumatic foot - right side
Fist – 02/015/2016	Ulnar Tendinitis - left side
Fist – 04/05/2016	Wrist strain - right side
Back – 04/05/2016	Muscle contracture in the back / lower back - center
Foot 1 – 05/05/2016	Fracture of the 5th finger - left side
Back – 05/05/2016	Muscle contracture in the back / lower back - right side

	
Foot 2 – 05/05/2016 	Plantar fasciitis - right side
Back 1 – 06/05/2016 	Non-specific low back stress (patient with degenerative diseases background) - center

Back 2 – 06/05/2016 	Non-specific low back stress - center
Back – 10/05/2016 	Non-specific low back pain (pyramidal muscles) - center
Knee – 13/05/2016 	Tendinitis tendon above - left front

Shoulder – 13/05/2016 	Tendonitis of the rotators of the hood - left side
Trunk – 17/05/2016 	Diffuse pain in the trunk - right side
Back – 18/05/2016	Low back pain - left side

	
Knee – 24/05/2016 	Traumatic knee pain - right side
Back – 31/05/2016 	Distension of the muscle of the lower back - right side
Foot – 31/05/2016	Big finger - right side

Trapezius – 31/05/2016 	Contracture of the upper trapezius muscle - right side
Shoulder – 01/06/2016	Omalgia by inflammation of the rotator of the hood - left side
Foot – 01/06/2016	Sprain tibio-tarsal - right side
Trapezius – 15/06/2016	Trapezius muscle contracture - left side
Back – 16/06/2016	Non-specific low back pain - center
Shoulder – 28/06/2016 	Omalgia by inflammation of the rotator of the hood - left side
Back – 20/07/2016	Non-specific low back pain - right side

5.2 - Human Intervention

Human intervention in this section is the main objective, the images of the two groups were randomly mixed and displayed one by one by the company's nurse so that these professional could indicated what he could see in every picture, that is, if there was visible injury or not, simply looking at the pictures and identifying the color difference.

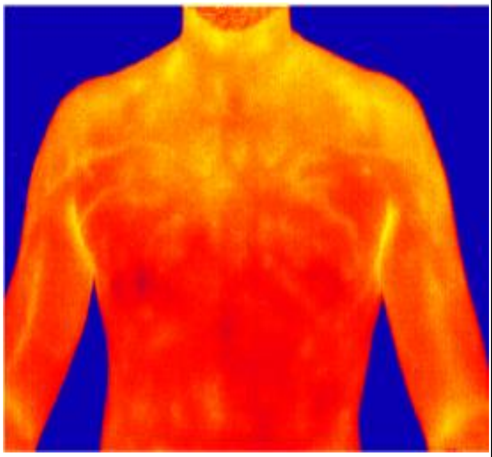
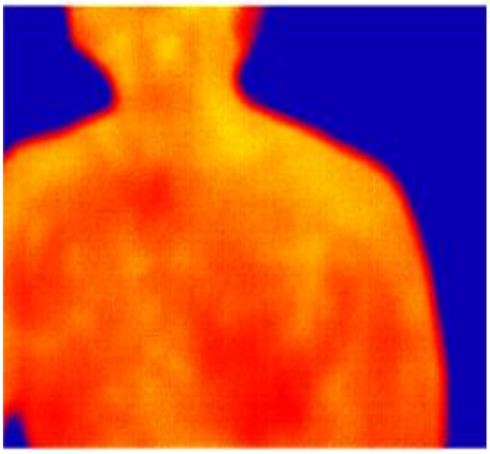
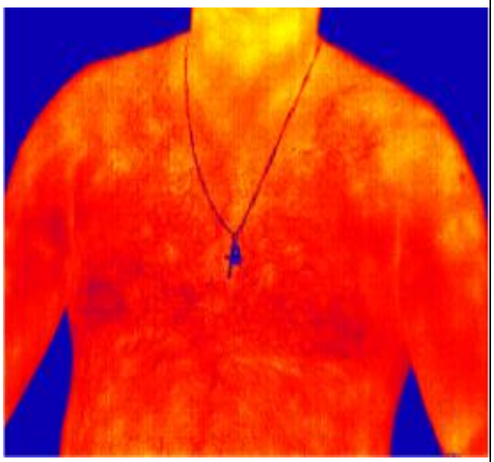
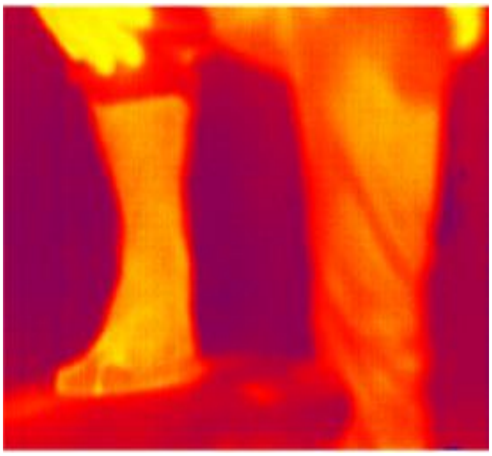
5.2.1- Images Unprocessed

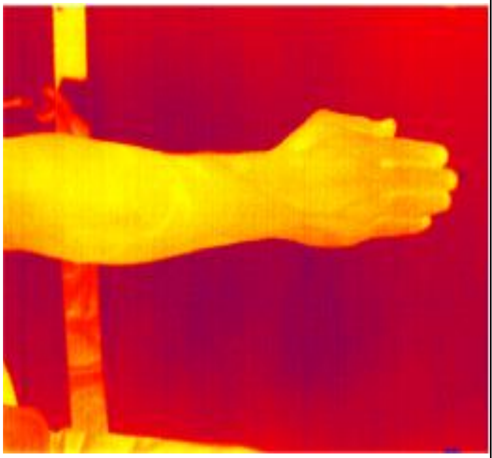
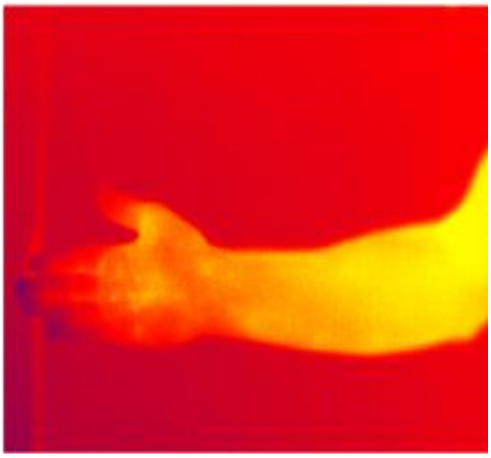
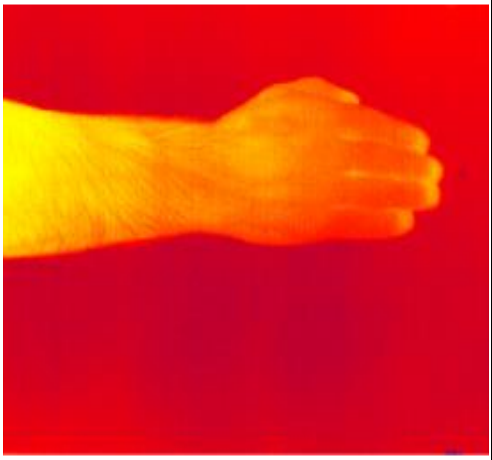
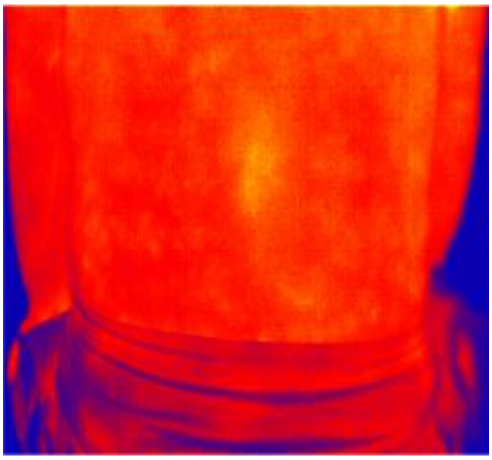
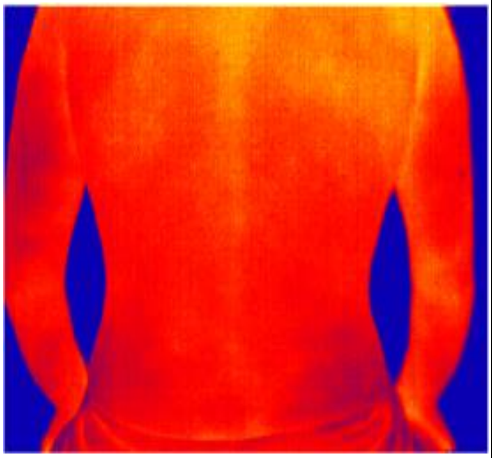
In this subsection the unprocessed images, those that were obtained simply from the camera without any kind of processing, will be presented. In addition to the presentation of images, also have the appreciation of the nurse to each of them. These appreciation will be presented on Table 5.2.

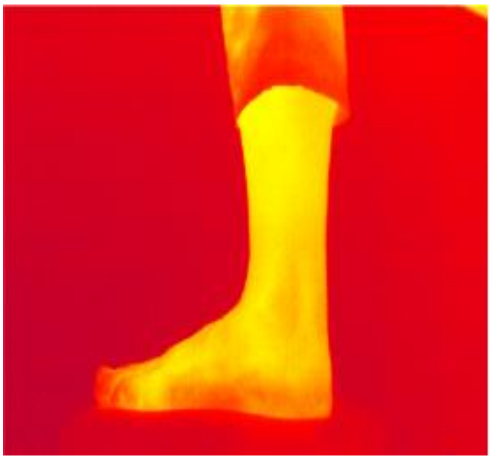
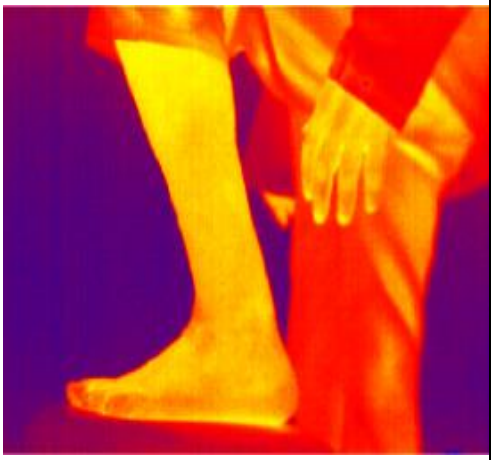
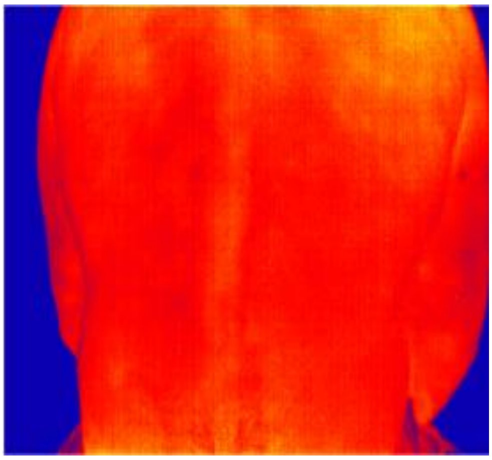
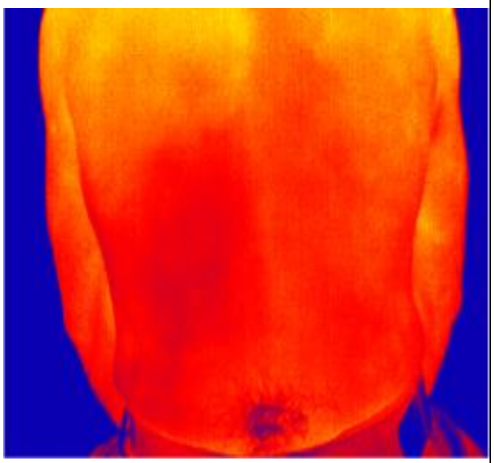
The main objective of this task is to see if there are noticeable differences to the human eye on the images with and without injury, that is, if by only watching the images is possible find some atypical area. The yellow areas are the hottest areas and the blue areas are the coldest ones.

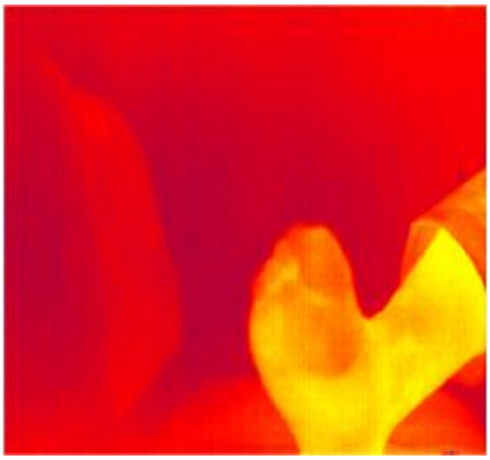
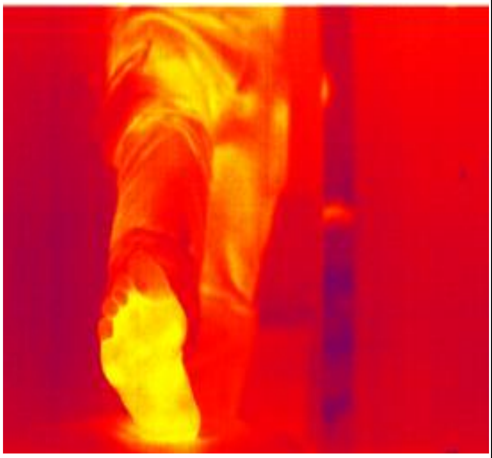
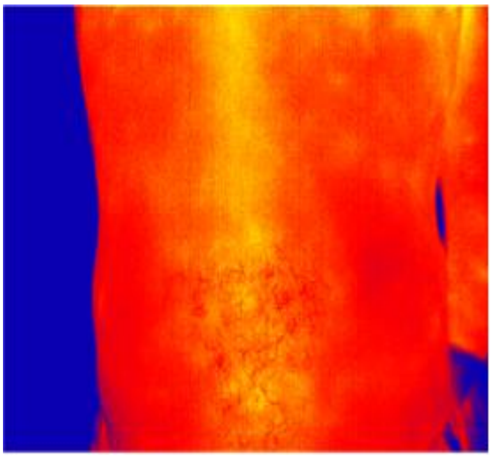
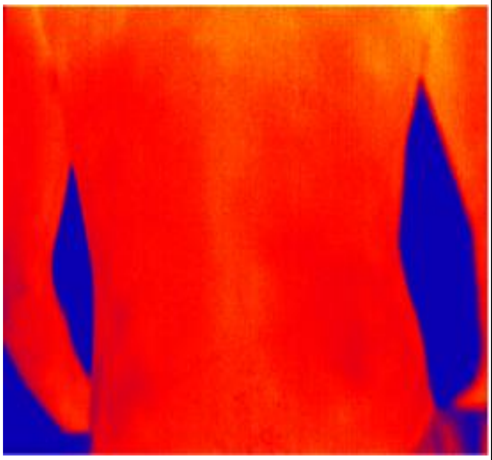
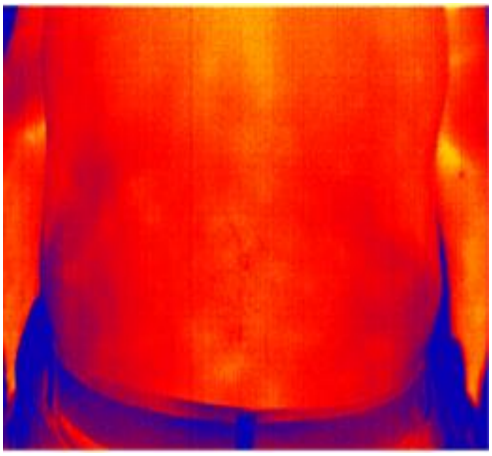
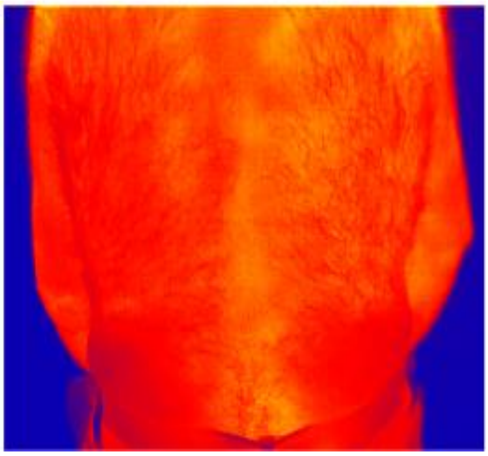
Table 5.2 – Imagens unprocessed with injury and uninjured.

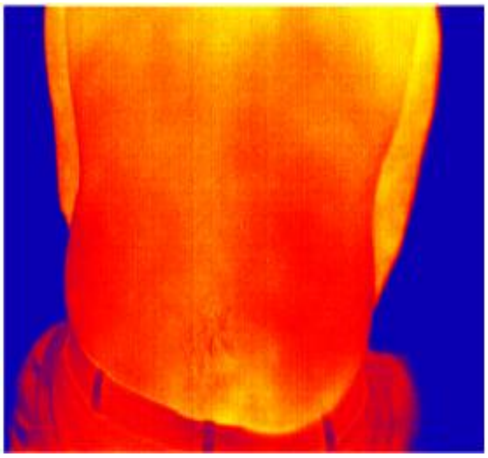
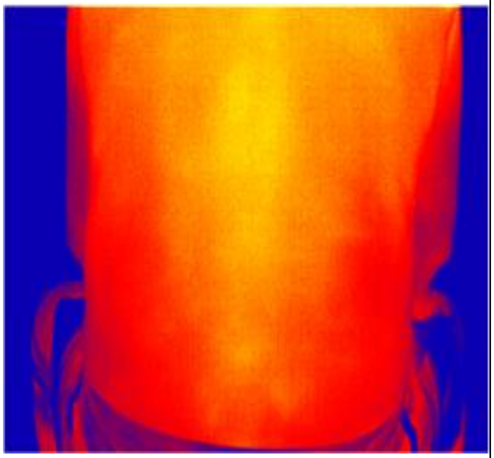
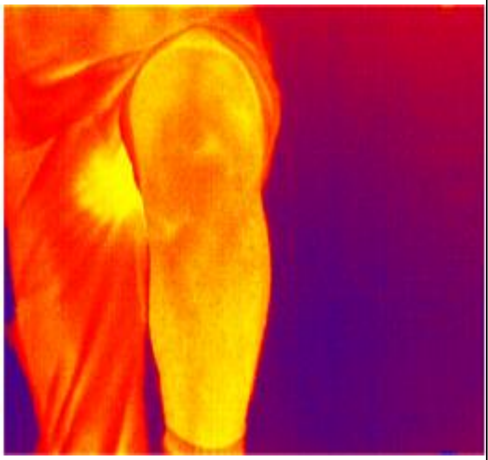
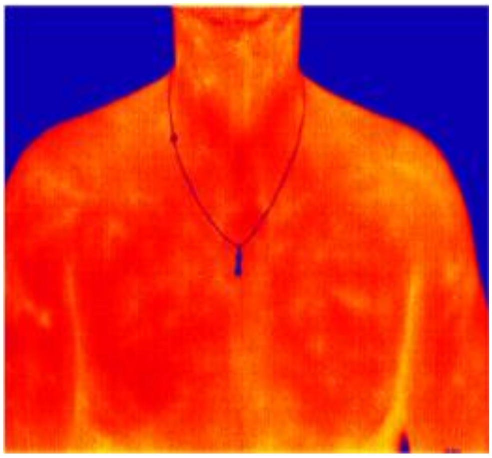
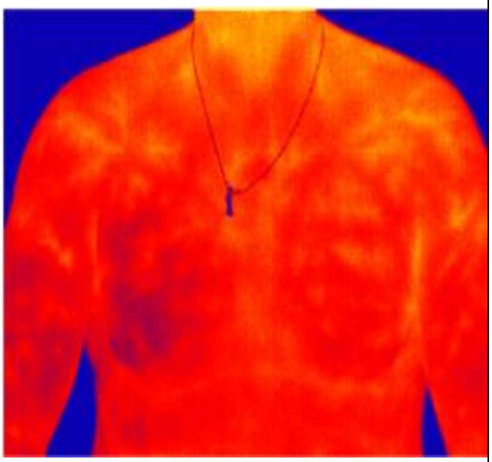
Image		**Test assessment (Yes / No)**
With injury (Test)	Uninjured (Control)	

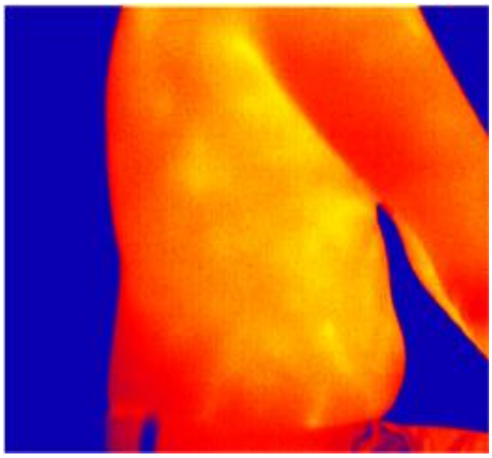
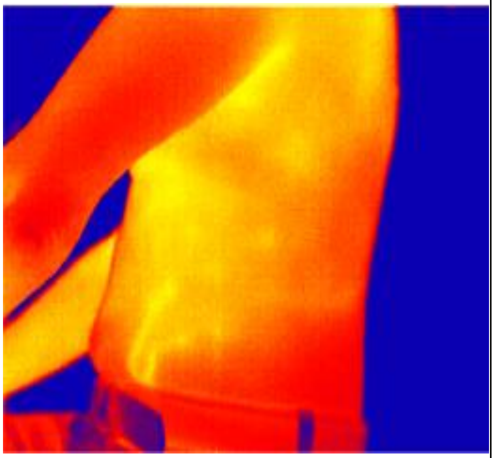
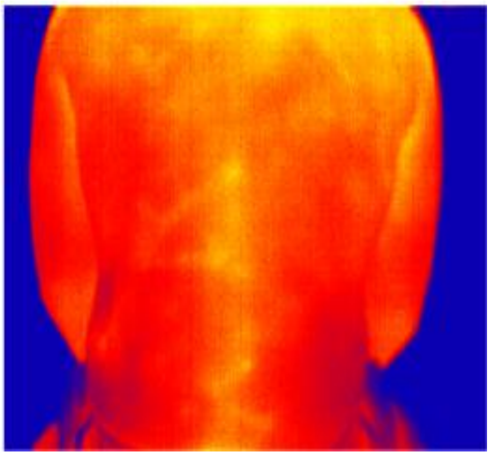
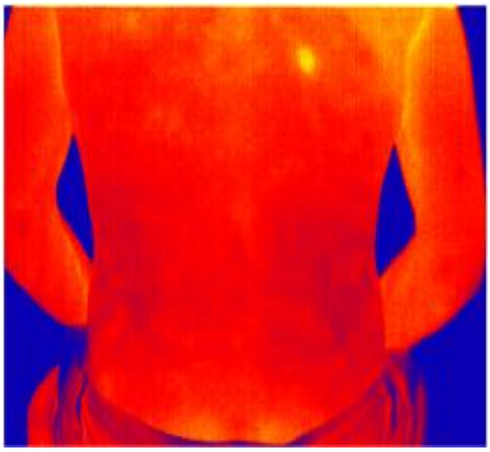
Trapezius – 21/04/2016 	06/06/2016 	Yes
Shoulder – 29/04/2016 	25/05/2016 	No
Foot – 02/05/2016 	1 – 29/07/2016 	No

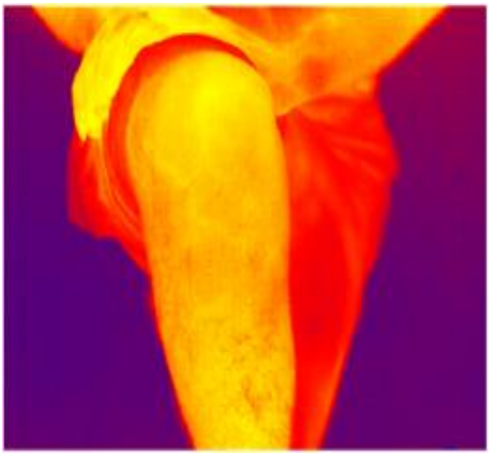
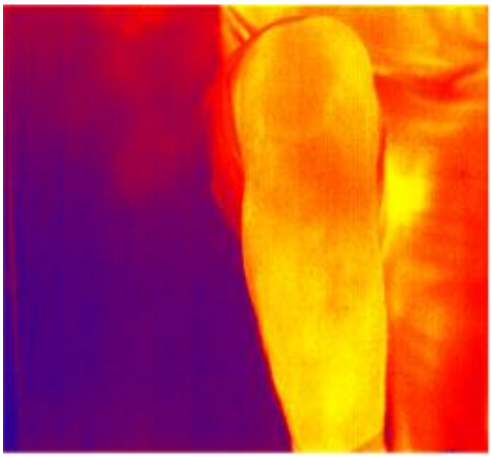
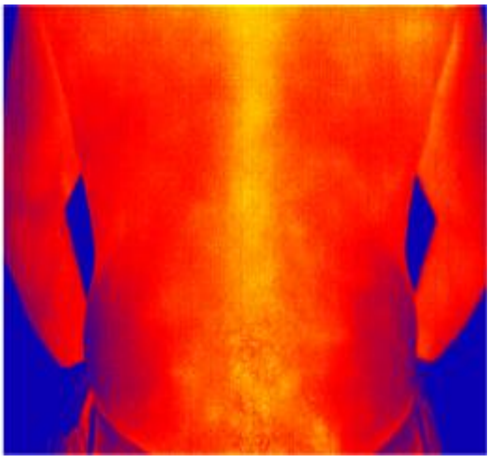
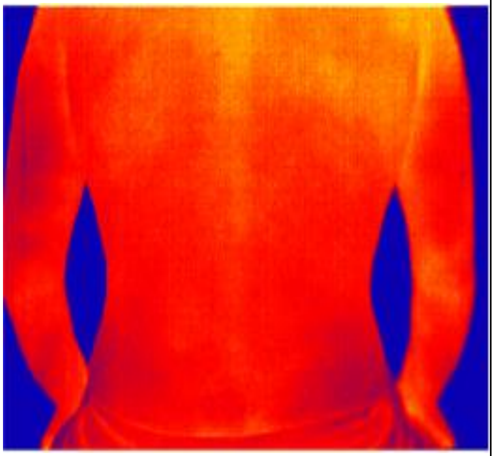
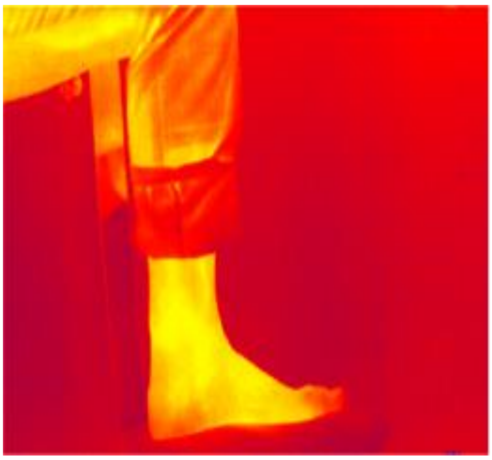
Fist – 02/05/2016 	06/06/2016 	No
Fist – 04/05/2016 	25/05/2016 	No
Back – 04/05/2016 	31/05/2016 	Yes

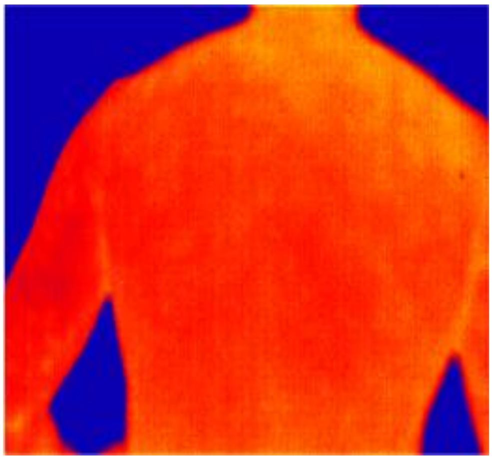
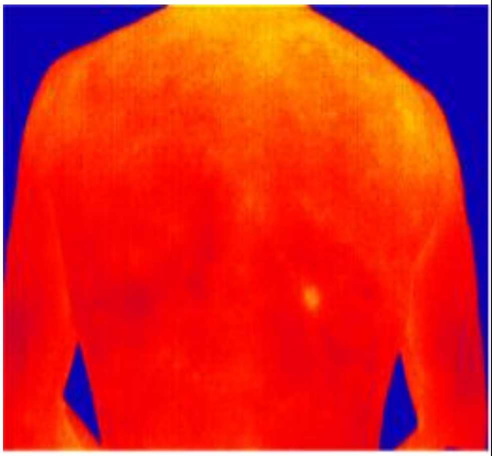
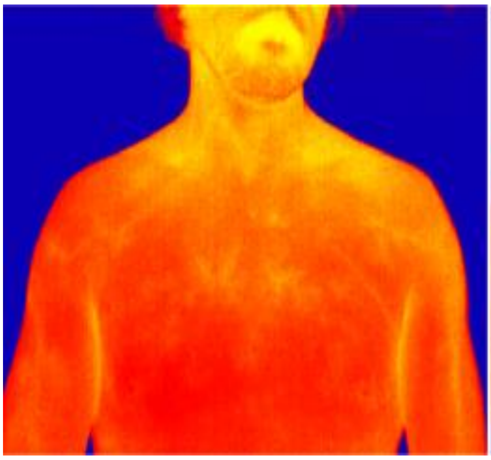
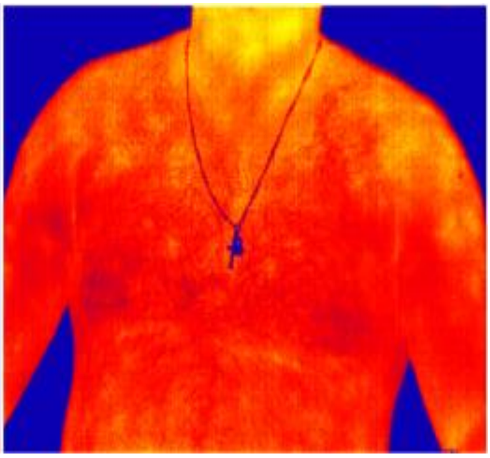
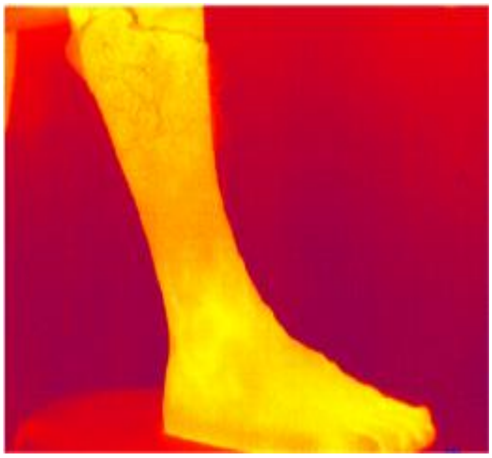
Foot 1 – 05/05/2016 25/05/2016  	Yes
Back – 05/05/2016 1 – 08/06/2016  	No
Foot 2 – 05/05/2016 29/07/2016	Yes

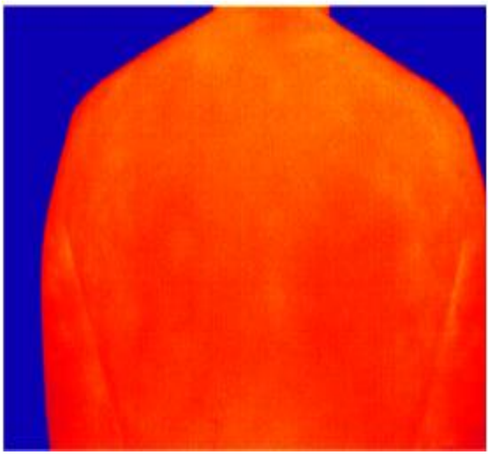
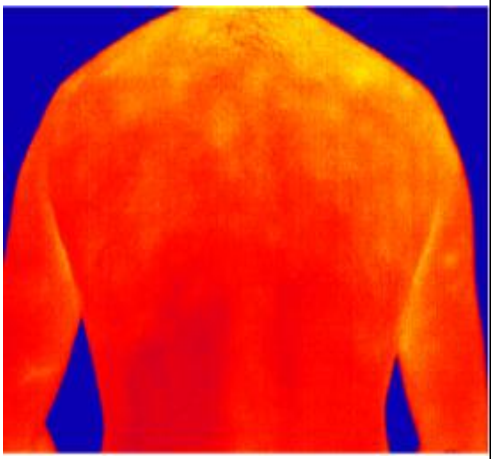
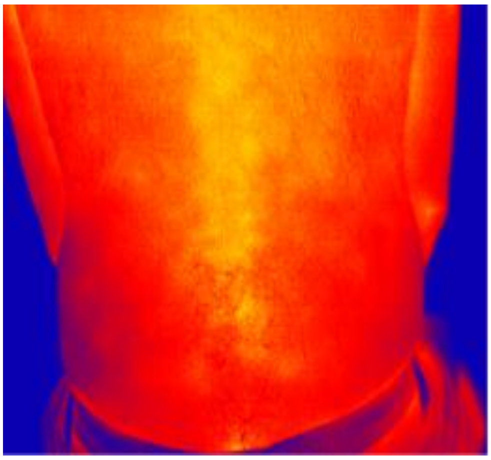
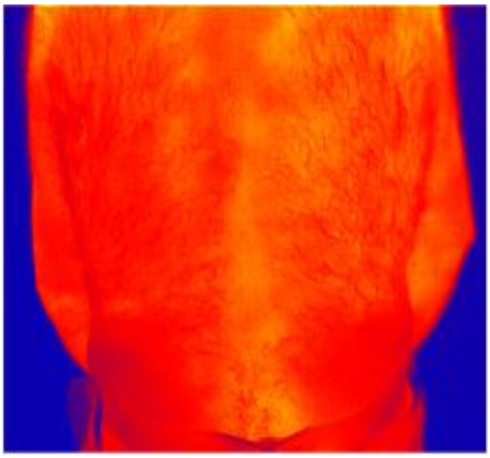
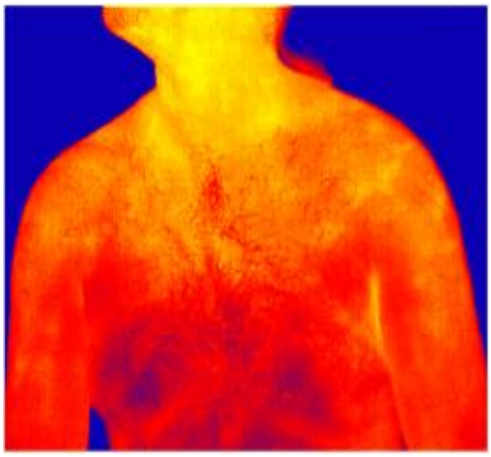
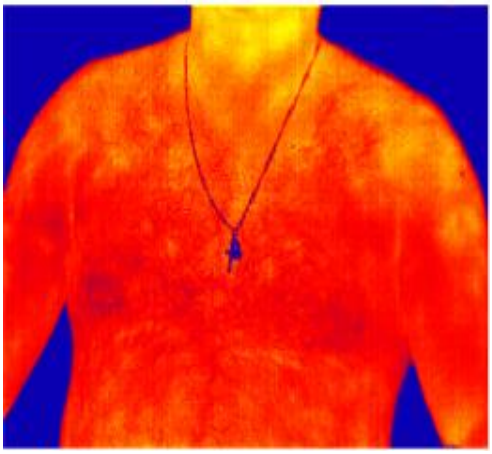
		
Back 1 – 06/05/2016 	2 – 08/06/2016 	Yes
Back 2 – 06/05/2016 	17/06/2016 	No

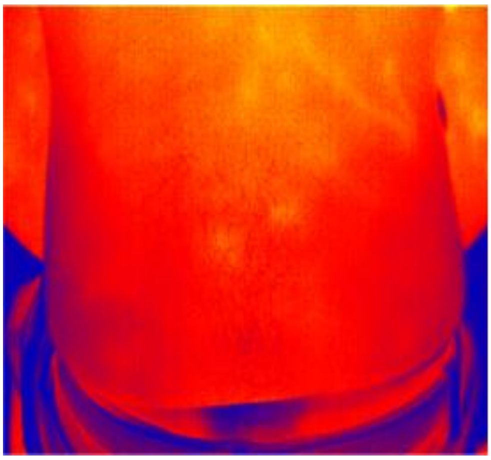
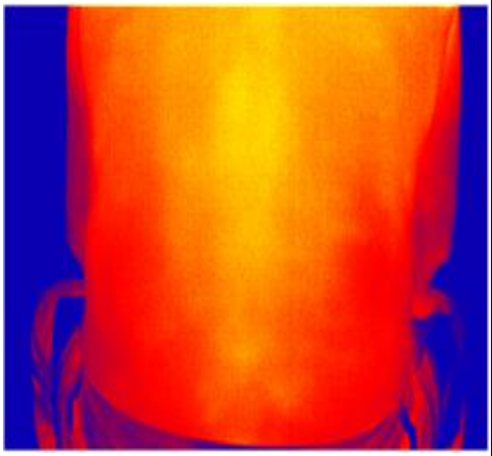
Back – 10/05/2016 	25/05/2016 	Yes
Knee – 13/05/2016 	08/06/2016 	No
Shoulder – 13/05/2016 	Temperatura 	Yes

Trunk – 17/05/2016 	29/06/2016 	Yes
Back – 18/05/2016 	2 – 31/05/2016 	No
Knee – 24/05/2016	08/06/2016	Yes

 	
Back – 31/05/2016 1 – 31/05/2016  	Yes
Foot – 31/05/2016 2 – 29/07/2016  	Yes

Trapezius – 31/05/2016 	2 – 31/05/2016 	Yes
Shoulder – 01/06/2016 	25/05/2016 	Yes
Foot – 01/06/2016 	1 – 29/07/2016 	Yes

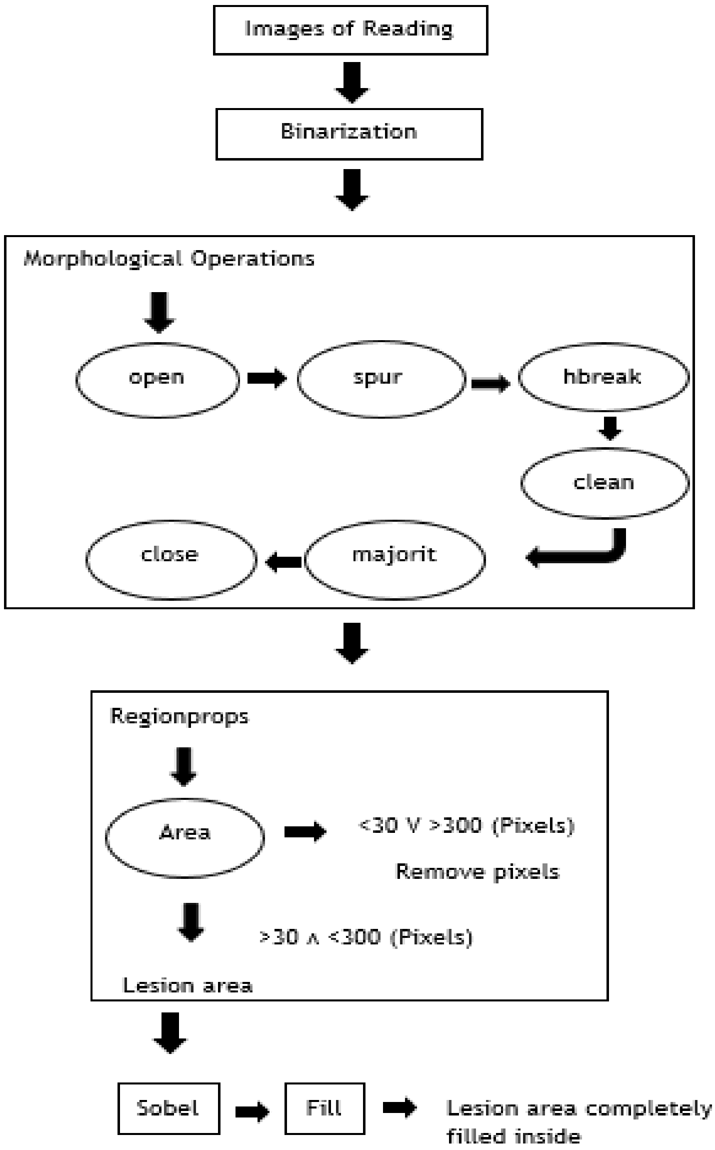
Trapezius – 15/06/2016 	06/06/2016 	No
Back – 16/06/2016 	17/06/2016 	Yes
Shoulder – 28/06/2016 	25/05/2016 	No

Back – 20/07/2016 27/05/2016  	No

5.3 - Automatic Processing

As in the previous subsection, here presented thermal images acquired by the same way: the experimental group and the control group. The white areas are the possible injuries.

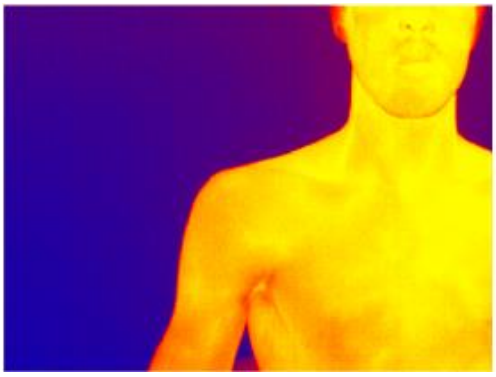
The processing and image analysis was performed using morphological algorithms, such as the bwmorph and edge detection algorithms Sobel and regionprops. This is accompanied by other MATLAB functions, such as Area, EulerNumber and PixelList. The morphological operators were used to determine the region of interest in which the lesion is found. The developed algorithm follows the following structure:



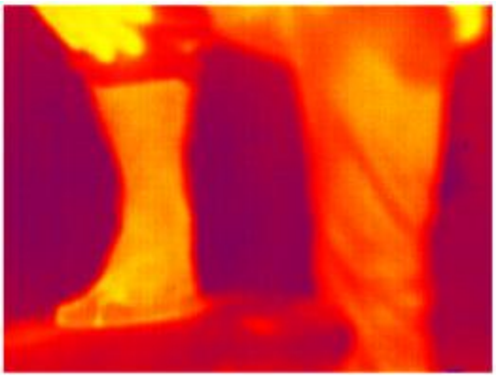
5.3.1- Experimental Group

In this subsection, thermal images was showed in Figure 5.2 with injury and their respective processed images. Nevertheless, only 20 images are presented within the 26 real cases, because in 6 images the program has not identified any injury.

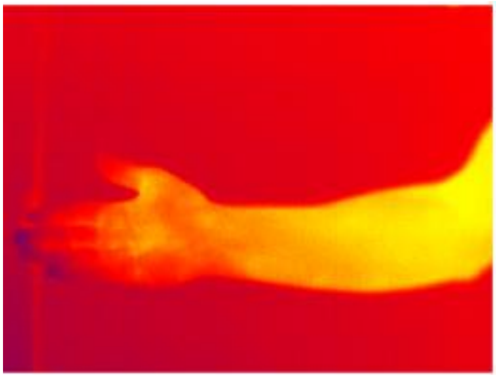
Trapezius – 21/04/2016

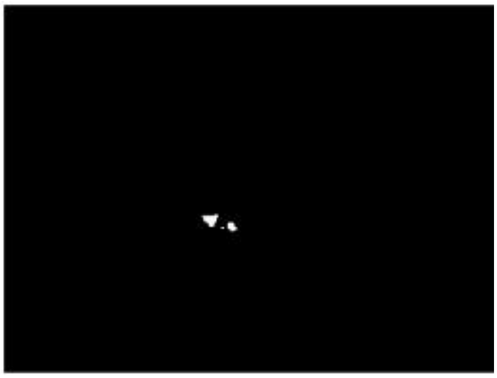


Foot – 02/05/2016

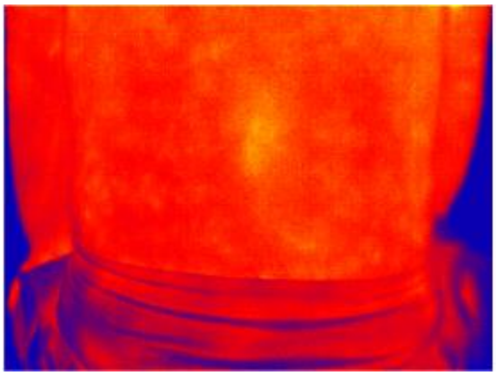


Fist – 04/05/2016



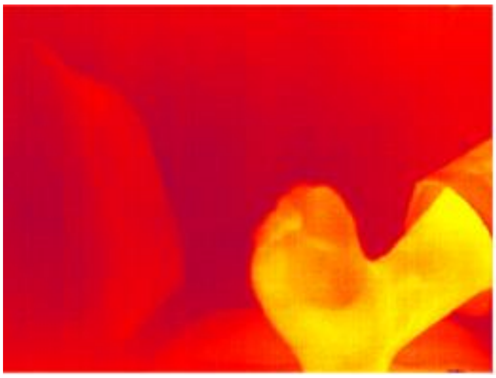


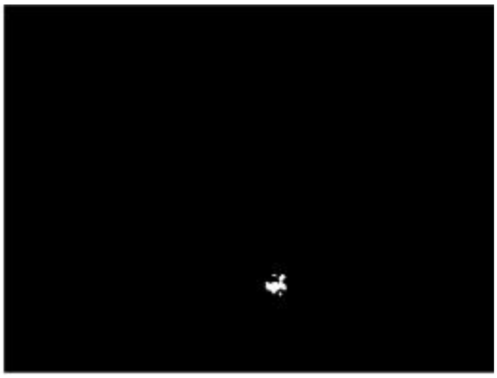
Back – 04/05/2016



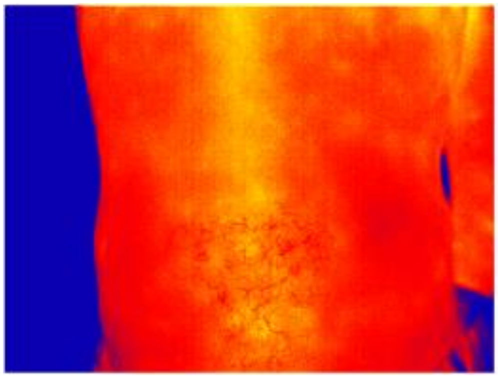
Foot 1 – 05/05/2016

Foot 2 – 05/05/2016

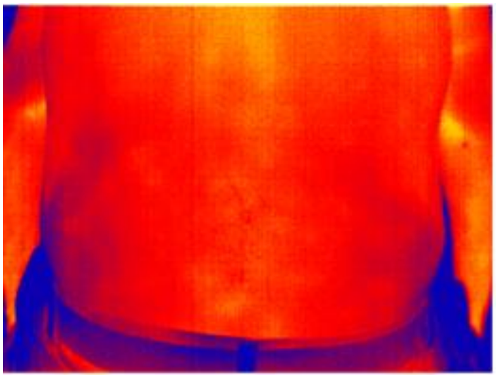




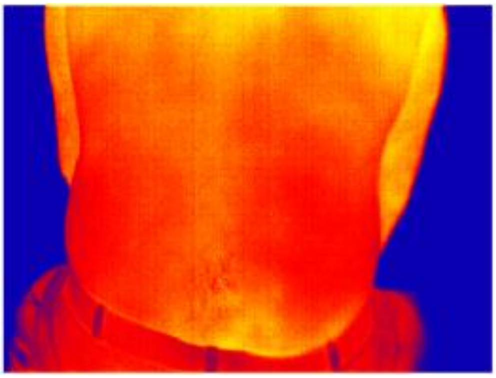
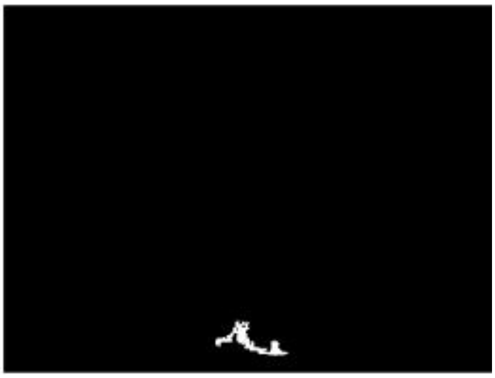
Back 1 – 06/05/2016



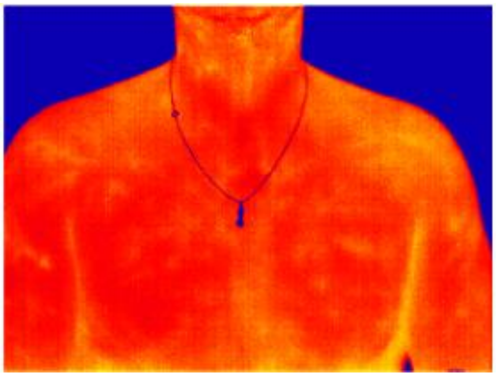

Back 2 – 06/05/2016



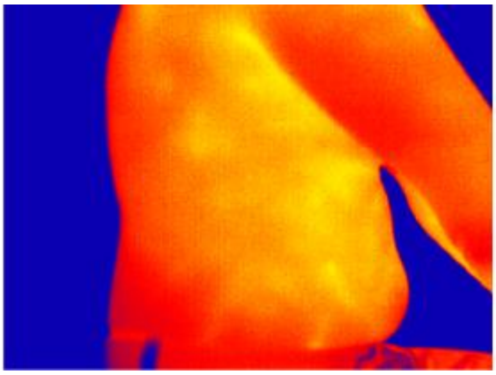

Back – 10/05/2016

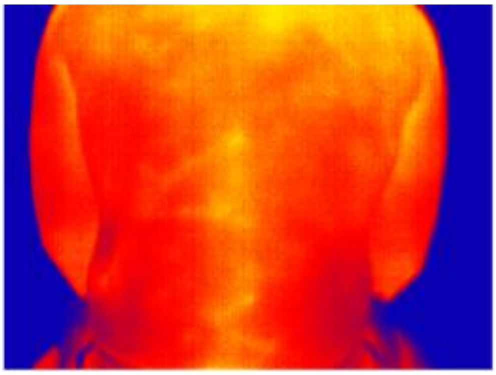
Shoulder – 13/05/2016

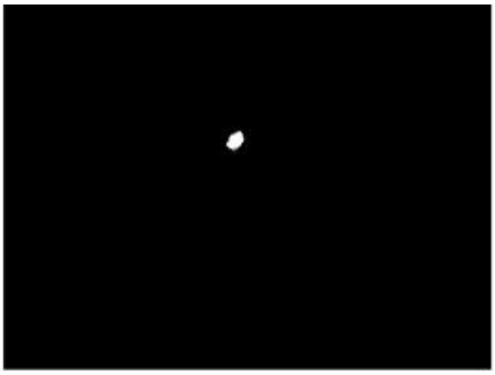


Trunk – 17/05/2016

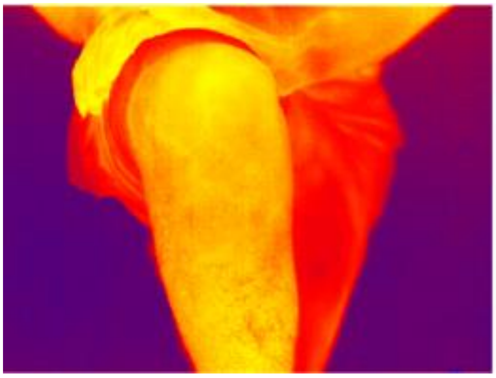


Back – 18/05/2016

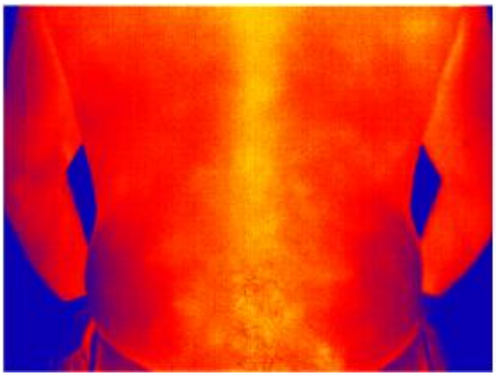




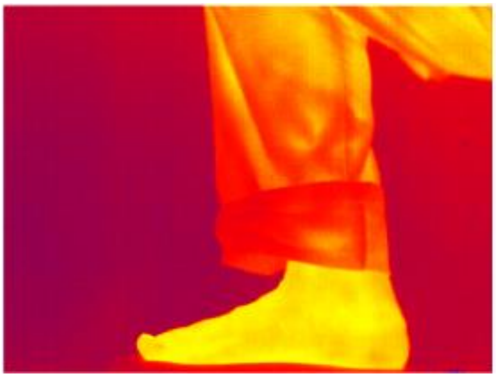
Knee – 24/05/2016

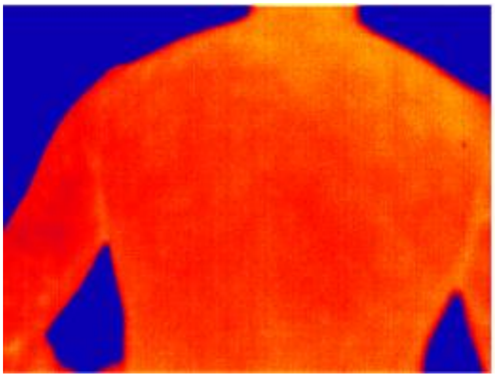
Back – 31/05/2016

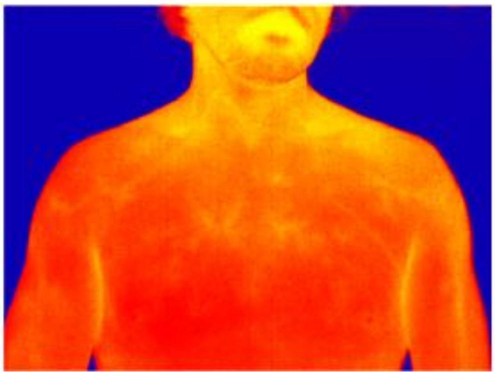
Foot – 31/05/2016

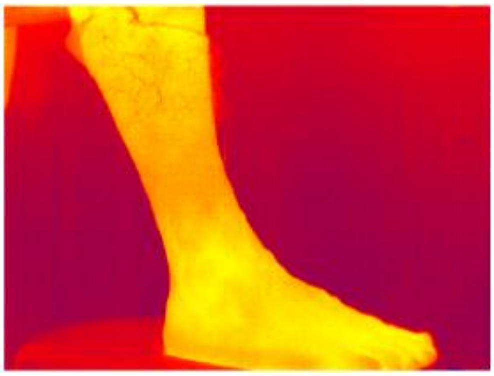
Trapezius – 31/05/2016



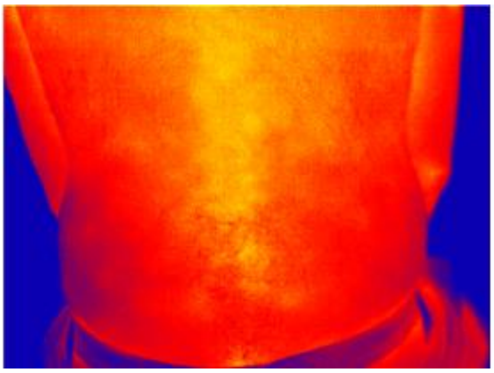
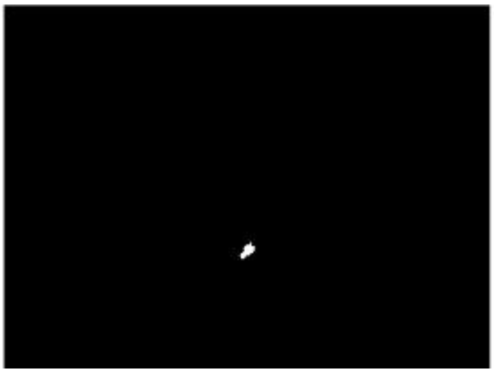
Shoulder – 01/06/2016



Foot – 01/06/2016



Back – 16/06/2016

Shoulder – 28/06/2016

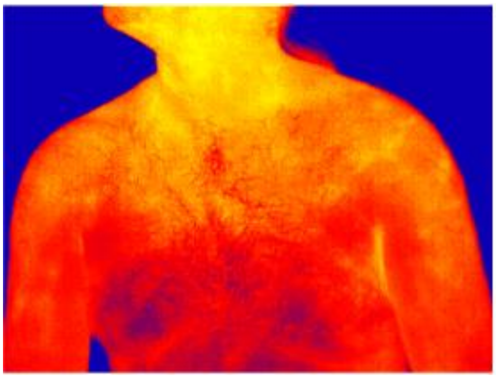
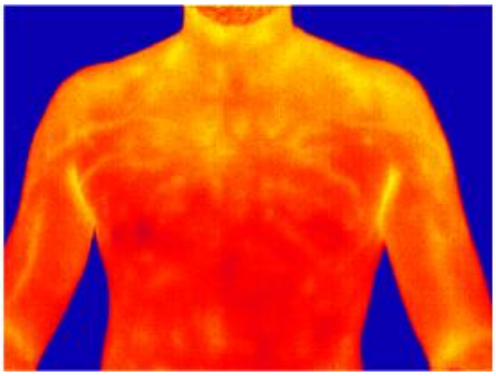



Figure 5.2- Processed images the experimental group.

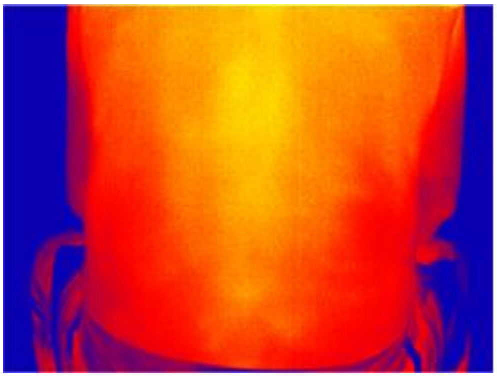
5.3.2- Control Group

The images of the control group, are images of participants that did not (supposedly) contain any kind of injury. However, after the images are subject to the program, 4 potential injuries in 4 patients have been identified. In this section, these images are displayed (Figure 5.3) and the respective processed image.

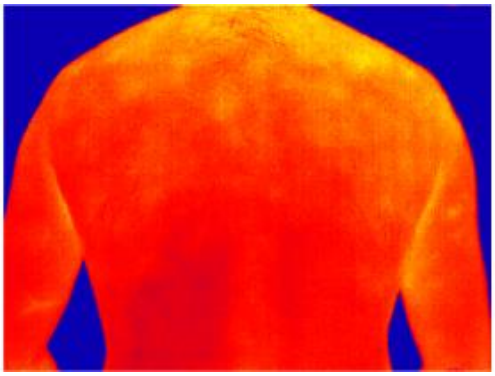
Trapezius - 06/06/2016




Back - 25/05/2016



Trapezius - 06/06/2016



Foot 1 – 29/07/2016

Figure 5.3 - Processed images the control group.

5.4 - Statistical Analysis

This section will display the statistical analysis of this project, where McNemar test was used. This test is executed to analyze the difference between two paired variables of nominal type. In present analysis three sets of paired variables were used: (1) Diagnosis & Diagnosis Based on Thermal Images; (2) Diagnosis and Thermal Imaging Processed; (3) Diagnosis Based on Thermal Images & Thermal Imaging Proceeded. Each variable contain the result (positive or negative) from diagnosis (Table 5.3). The test statistic results are presented in Table 5.4.

Table 5.3 Results of Diagnosis.

Diagnosis	**Diagnosis Based on Thermal Images**	**Diagnosis of Thermal Imaging Processed**
Injury	Injury	Injury
Injury	Without injury	Without injury
Injury	Without injury	Without injury
Injury	Without injury	Without injury
Injury	Without injury	Without injury
Injury	Injury	Injury
Injury	Injury	Injury
Injury	Without injury	Without injury
Injury	Injury	Injury

Injury	Injury	Injury
Injury	Without injury	Without injury
Injury	Injury	Injury
Injury	Without injury	Injury
Injury	Injury	Injury
Injury	Injury	Injury
Injury	Without injury	Injury
Injury	Injury	Injury
Injury	Injury	Injury
Injury	Injury	Injury
Injury	Injury	Injury
Injury	Injury	Injury
Injury	Injury	Injury
Injury	Without injury	Injury
Injury	Injury	Injury
Injury	Without injury	Injury
Injury	Without injury	Injury

Table 5.4 - Test Statistics McNemar.

	Diagnosis and Diagnosis Based on Thermal Images	Diagnosis and Thermal Imaging Processed	Diagnosis based on thermal images and Thermal Imaging Processed
N	26	26	26
Exact Significance (2-tailed)	0,001[a]	0,031[a]	0,063[a]

a. Binomial distribution used.

5.5 - Discussion of Results

In this chapter, it is presented a discussion regarding the results described in Chapter 5.

In first place, it will be made an analysis to the intervention of the health professional to whom fell the task of identifying in every image the existence of a musculoskeletal injury.

In the first column of table 5.1 there's a representation of images with lesion (experimental group) and, in the second column of the same table was presented images that resulted from control group that, as we know didn't have any kind of musculoskeletal injury. The third column represents the nurse appreciation regarding the obtained image with lesion.

As we observed all the images from first column have a lesion according to the subject complaint and in acquiescence of the health professional.

To each thermal image with injury was associated a control image where in the body region was the same but in different patients. These association was made in order to facilitate the nurse visualization task of the images. The images were shown to the nurse side by side, one with the lesion and the other one without it, so the professional could indicate is expert input at a naked eye. In short the nurse had the task of identifying, or not, a lesion, simple based on colour differences. It was possible for the nurse to identify the images prevenient from the workers with lesions and the control images.

These professional did not knew which of the images contained the injury but still he managed to assess the patient's image and the control ones. From his evaluation it can be stated that, according to the provided appreciation, not all the thermal images have lesions and that founding came to be a contradiction to the worker complaint and even to the diagnosis presented in section 5.1.

Yet, based on the results arising from the questionnaires there are very factors to be taken in account as if the worker had a smoke in the previous two hours, drank alcohol, or a tea, or coffee, if he practiced a physical activity or used some cosmetic / ointment on his skin in the same period of time. After verifying that the nurse couldn’t identify lesions through the direct observational process of the images, the relation of the images to the questioners was made. Then it is found in the group of images where nurse said there were no injuries, the worker had done some of the described activities that, as is know from literature, have influence on body temperature.

From the appliance of all the procedures of our study we found an exceptional case that was named the “back – 18/05/2016” case. In the image correspondent to this case it was found a lesion but not in the region the worker had indicated and the nurse made the diagnose. The situation seems to be related to the fact of treatment of the injury had been made before the image was taken. In that treatment it was used a medical spray that is able to lower the body temperature of the affected region. As the main characteristic of the camera is the detection of body heat, and since affected regions are the warmer ones, the equipment couldn´t detect anything, and so, instead of having an image with yellow colour, an image with purple colour was collected.

All pictures in the experimental group were processed using Matlab software to verify whether the processing is useful in these cases, these results are given in section 5.3 of the previous section. The bwmorph function was used in order to determine the skeleton of the image obtained at the end, which gave us an approximate outline of the original image using the Sobel method. At last we use the regionprops algorithm that is accompanied by other Matlab functions. The goal is to detect polygon whose area (in pixels - number of pixels defined by nodes) is greater than 30 pixels.

As mentioned before this algorithm is accompanied by other Matlab functions as shown in the table 3.3, but we only used some as the Area function because this is the one that lets us know the number of pixels of a region, the EulerNumber that identifies the number of objects that exist and subtracts those in the middle, and the PixelList whose function is to extract the coordinates of an image of a particular region.

In section 5.3 it was shown the original and processed images as well as the images that resulted from the preceding processing. From these task we came to the conclusion that the use of thermal imaging could be useful to support the identification of injuries.

Regarding the control images there were 4 cases of workers that drew our attention. From these cases we verified that, despite the fact that there was no pain or injury complain in the beginning of the process, we were able to detect injuries from the evaluation of the obtained images. From the analysis of the thermal image we verify that may exist an injury in the body region the camera point to be hotter. In order to test these findings we made, in section 5.4, the processing of the images of these 4 patients, always applying the algorithms previously referenced. The same procedures were taken in the control images but we couldn't identify anything so we gave up presenting the images, considering they were completed black.

Despite the fact that we came to prove efficient in the studied method it is not possible to firm the exact conviction that the worker as, in fact, an injury, and, for the scientific establishment of that it is necessary to made a clinical exam in a credentialed hospital.

For the statistical analysis of the results obtained through the image processing are according to the assessment made by the nurse based on thermal imaging. By the same analysis verifies that the diagnosis is different from the diagnosis based on the images and also the results of the processed images, that is there is a difference in the first group (diagnosis and diagnosis based on thermal images) and second group (Diagnostic and processed thermal imaging). This difference may be due to the fact that the nurse did not have access to any confirmation tool or support the development donates patient diagnosis.

Thus, thermal imaging can contribute in order to bridge an existing fault, requiring extra exams.

5.6 - Conclusions

In this work was presented the nursing diagnosis for each patient as well as the picture of the spot of the lesion. All 52 cases of thermal images were exposed and processed yet not every one of them were showed in the study because they didn´t had any lesion to show and, for that reason, the program developed the image in black. Therefor only 26 images were used and processed being that 20 of them are images that correspond to the experimental group and 4 correspond to the control group. In all pictures the procedure was carried out through several morphological algorithms. In these study it were used the functions bwmorph and edge, that many algorithms, the Sobel algorithm came to be the most effective one in relation to the objective of our study. Lastly is necessary to mention that algorithm regionprops also was used. Specifically, the used function were Area, EulerNumber and PixelList.

All techniques were implemented in MATLAB as a computational tool in order to test its effectiveness.

Chapter 6

Conclusions

The job environment should helps prevent fatigue and the occurrence of musculoskeletal injuries thus preventing excessive overloading, repetitive motion and stress in the workplace.

Work related musculoskeletal injuries are one of the main causes of absenteeism at work, and the most common problem of occupational health in Europe. These lesions affect different regions of the human body, particularly the spine and upper limbs due to repeatability, overloading and improper postures at work.

Infrared thermography can be used as an adjuvant evaluation method in many cases, as is the case of MSIs related to work.

So, in this presented a study of thermography and musculoskeletal injuries and the relationship between them, to try to make thermography a diagnostic tool musculoskeletal injuries in an industrial activity sector in which the work is very demanding. The fact that infrared thermography is a non-invasive technology and has no risk for the patient, makes possible the conduction of multiple exams and leads us to the conclusion that in regarding the MSIs problem a very efficient solution seems to be the use of thermography.

A set of thermal images with and without injuries, acquired through a thermal camera which detects the heat produced by the human body, were user used to diagnose the presence and location of muscular lesions either through a human expert and some image processing.

These cameras have some limitations like in the case “back– 18/05/2016” where a spray for the treatment of the lesion was previously used serving as an external disturbance factor for the diagnosis.

The evaluation to all the 52 cases analysed can sustain that the results were very satisfying since it has possible to show that improved images through algorithms became an added value not only for health professionals but also for patients, allowing a faster medical or therapeutic intervention.

For some cases there are differences in the diagnosis of nurses and diagnosis based on the images and also the results of the processed images. However this diagnostic difference may be due to the technical fact contain no confirmation tool or support the preparation of the patient's diagnosis.

6.1 - Proposal for Future Research

For future work it is intended the use any other diagnostic test (for example radiography) beyond thermography in order to be able to identify exactly if there is damage in the muscular system of a worker. These proposal is sustained in the fact that, as it was found, thermography by itself, and even with nurse diagnosis, can, sometimes fail. One limitation that was found is that, it’s important to have in mind that these process requires specific conditions, like a thermal chamber, that many company’s may not have, so it was important to find other methods of diagnosing muscular injuries. More test cases is intended to improve monitoring of the conditions of purchase, and track clinical cases recording a history that might give more clues to the diagnostics.

Appendix

Appendix A – Informed Consent

Continental Mabor
Indústria de Pneus, S.A.

Imagens Térmicas

18 de abril de 2016

CONSENTIMENTO INFORMADO, LIVRE E ESCLARECIDO PARA PARTICIPAÇÃO NA RECOLHA DE IMAGENS TÉRMICAS

Confirmo que expliquei ao trabalhador, ou seu representante, de forma adequada e inteligível, os procedimentos necessários ao ATO acima referido.
Em qualquer caso, é garantido que a presente autorização pode ser retirada, em qualquer altura, sem que isso cause qualquer prejuízo ou afete os cuidados a prestar à pessoa.

Nome legível do profissional responsável pela proposta:

Selma Pinho

Data ....../....../.......... Assinatura ....

Por favor, leia com atenção todo o conteúdo deste documento. Não hesite em solicitar mais informações ao médico se não estiver completamente esclarecido. Verifique se todas as informações estão corretas. Se entender que tudo está em conformidade e se estiver de acordo com a proposta que lhe é feita, então assine este documento.

Declaro ter compreendido os objetivos de quanto me foi proposto e explicado pelo profissional que assina este documento, ter-me sido dada oportunidade de fazer todas as perguntas sobre o assunto e para todas elas ter obtido resposta esclarecedora, ter-me sido garantido que não haverá prejuízo para os meus direitos assistenciais se eu recusar esta solicitação, e ter-me sido dado tempo suficiente para refletir sobre esta proposta. Autorizo a realização do ato indicado nas condições em que me foram explicadas.

Lousado, .../... .../... ... (data)

Nº mecanográfico... ... ... Nome legível... ... ...

Assinatura ... ...

Appendix B – Nordic Musculoskeletal Questionnaire

U.PORTO
FEUP FACULDADE DE ENGENHARIA
UNIVERSIDADE DO PORTO

Mestrado em Engenharia Biomédica

Este questionário é anónimo e pretende recolher informações sobre a sua sintomatologia músculo-esquelética relacionada com o trabalho.

Data: __/__/__ Turno:

Sexo: Feminino ☐ Masculino ☐ Idade: ___ anos

Posto de trabalho:

Qual é a sua lateralidade? Dextro ☐ Esquerdino (canhoto) ☐ Ambidextro ☐

Pratica atividade física com regularidade? Sim ☐ Qual? ____________ Não ☐

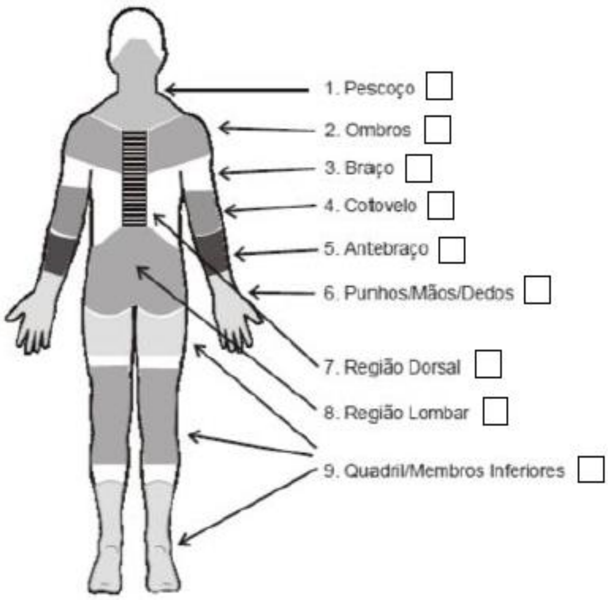
Recentemente sofreu alguma lesão de natureza músculo-esquelética, fora do local de trabalho? Sim ☐ Qual? ____________ Não ☐

Recentemente sofreu alguma lesão de natureza músculo-esquelética, no local de trabalho? Sim ☐ Qual? ____________ Não ☐

Nas últimas 2 horas:

Fumou: Sim ☐ Não ☐
Bebeu álcool: Sim ☐ Não ☐
Bebeu chá/café: Sim ☐ Não ☐
Praticou atividade física: Sim ☐ Não ☐
Utilizou algum cosmético/pomada na pele: Sim ☐ Não ☐

Observando a figura, identifique por favor qual a região do corpo onde se encontra a sua lesão.



Assinale com um círculo o número (corresponde à intensidade de dor) por favor.

1	2	3	4	5
Muito ligeiro	Ligeiro	Moderado	Intenso	Muito Intenso

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