MEDICAL THERMOGRAPHY AND ITS APPLICATION IN REHABILITATION OF SPINAL CORD INJURED INDIVIDUALS

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Abstract: Exercise induces muscle contraction, and in interactivity with cardiovascular and respiratory system produces heat, which dilates by conduction through the tissue to body surface. In individuals with spinal cord injury (SCI) autonomic disruption, immobility and inactivity play critical roles in affecting peripheral vascular circulation. It is even more important to monitor temperature changes during the physical activity (rehabilitation process) in mentioned group of patients. One of the possible ways how to provide thermometric measurements and evaluation is the use of the infrared (IR) thermography. It is very important to use suitable methodology of measurement. IR imaging can produce reliable and valid results only if the technique follows established standards. Initial thermographic measurements in SCI individuals and able-bodied (AB) during the rehabilitation process were performed.

Introduction

The IR radiation discovering starts with reporting of Herschel's experiment 200 years ago. He built a crude monochromator that used a thermometer as a detector so that he could measure the distribution of energy in sunlight. His work was followed by many scientists during the next years. These efforts resulted in the formulation of well-known Planck's law [9].

IR technologies were connected mostly with controlling functions and night vision problems. Modern IR techniques originated during the Second World War. Due to the development of high-performance RI detectors, the IR technology is successfully applied to remote sensing problems. Although, the most of applications were developed for military needs, there have been continuously increased also applications for medical purposes. These include thermography in which IR scans of the body allows medical diagnostics. For example, it can detect cancers or other trauma, which raise the body surface temperature [7, 9].

The IR range covers al electromagnetic radiation longer than the visible, but shorter than millimetre waves. Wavelength 1μm is a sensitivity limit of popular Si detectors; wavelength 3μm is a long wavelength sensitivity of PbS and InGaAs detectors; wavelength 6μm is a sensitivity limit of InSb, PbSe, PtSi detectors and HgCdTe detectors optimised for 3-5μm atmospheric window; and wavelength 15μm is a long wavelength sensitivity limit of HgCdTe detectors optimised for 8-14μm atmospheric window. Table 1summarizes distribution of infrared radiation regions.

Table 1: Dividing of IR radiation regions.

Region	Wavelength range (μm)
Near infrared	0.78-1
Short wavelength IR	1-3
Medium wavelength IR	3-6
Long wavelength IR	6-15
Very long wavelength IR	15-1000

Medical applications of thermography, we are interested in, is based thermal emission. It is based on fact that al object are composed of continually vibrating atoms, with higher energy atoms vibrating more frequently. The vibration of all charged atoms generates electromagnetic waves. The higher temperature of an object causes faster vibration, and thus the higher spectral radiant energy. As a result, all objects are continually emitting radiation at a rate with a wavelength distribution that depends upon the temperature of the object and its special emissivity.

Radiant emission is usually treated in terms of the concept of a blackbody which is an object that absorbs all incident radiation. The energy emitted by a blackbody is the maximum theoretically possible for a given temperature. The ratiative power and its wavelength distribution are given by the Planck radiation law:

$$W(\lambda,T)=\frac{2\pi hc^2}{\lambda^5}\left[\exp\left(\frac{hc}{\lambda kT}\right)-1\right]^{-1} \quad W/\left(cm^2\mu m\right), \qquad (1)$$

$$P(\lambda,T)=\frac{2\pi c}{\lambda^4}\left[\exp\left(\frac{hc}{\lambda kT}\right)-1\right]^{-1} \quad photons/\left(scm^2\mu m\right), \qquad (2)$$

where λ is the wavelength, T is the temperature, h is the Planck's constant, c is the velocity of light, and k is the Boltzmann's constant [9].

According to this law, it is evident, that as the temperature increases, the amount of energy emitted at any wavelength increases too, and the wavelength of peak emission decreases. Note that for an object (people) at an ambient temperature (14 °C), we need detectors operating near 10 μm. For hotter objects such as engines, maximum emission occurs at shorter wavelengths.

The total radiation received from any object is the sum of the emitted, reflected and transmitted radiation.

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Objects that are not blackbodies emit only the fraction of blackbody radiation, and the remaining fraction is either transmitted or reflected. When the scene is composed of objects and backgrounds of similar temperatures, reflected radiation tends to reduce the available contrast which is one of the important parameters for IR image devices. We should realize that fact when taking thermal image from the scene with temperature variations.

The choice of IR band is important parameter. The 8-14 μm band is preferred for high performance thermal imaging because of it higher sensitivity to ambient temperature objects and its better transmission through mist and smoke. On the other hand, the 3-5 μm band may be more appropriate for hotter objects.

To get got results it is necessary to use proper detector. Progress in infrared detector technology is connected mainly to semiconductor IR detectors. They are included in the class of photon detectors in which the radiation is absorbed within the material by interaction with electrons. The observed electrical output signal results from the changed electronic energy distribution. The second class of IR detectors is composed of thermal detectors. In these detectors, the incident radiation is absorbed to change the temperature of material, and the resultant change in some physical properties is used to generate an electrical output. Thermal detectors have been less exploited in commercial and military systems as photon detectors.

Because thermography detects alterations or variations in skin temperature, any disease process or injury affecting directly or indirectly the microcirculation of the skin becomes a candidate for thermal evaluation. There are a wide variety of such conditions and vascular alterations are one of them.

Muscle motorics and sensitivity of lower and upper extremities are specific physiological manifestations which are in SCI individuals (paraplegics and quadriplegics) limited or completely absent [5]. Progress in physical condition (increasing muscle motorics), metabolic changes and other effects relate to exercise affect skin surface temperature. Mentioned changes are possible to measure by means of infrared thermography.

Factors determining the temperature distributions on body surface are the following: temperature of internal organs, heat conductivity of muscular and adipose tissue and heat emissivity of the skin. Thus, temperature on skin surface is function of temperature of internal organ and heat properties of tissue separating this organ from body surface.

Skin is the largest organ of body and plays important role in maintaining thermal equilibrium through heat exchange at skin surface by radiation, conduction, convection and evaporation [1, 3, 7].

With exercise, skin temperature can elevate up to or > 40°C without any ill effects due to the excessive heat generated by the exercising muscles [6].

Thus, rehabilitation is one of the factors, which are disturbing the balance between thermal production in the organism (thermal performance) and expenditure (thermal loss) into the external environment.

In individuals with spinal cord injury (SCI) autonomic disruption, immobility and inactivity play critical roles in affecting peripheral vascular circulation [4].

Studies of the mechanisms of thermal energy exchange from deeper tissue to skin and then environment can tell much about physiological mechanisms in health and disease.

Thermography is a diagnostic method that measures physiological functions by recording thermal heat emission. This provides a territorial analysis of the surface temperature with specific quantitative and qualitative measurements. Observed radiation wave length is at the infrared end of light spectrum and is considered non-invasive [1, 3].

Nowadays, the primary thermography utilizations in medical diagnostic relate to tumor changes, inflammation changes, function or farmacological conditioned changes in peripheral blood circulation and hormone and neural changes in human organism.

Methodology of ir-imaging in sci individuals

There are four main options of thermographic measurements necessary to follow up:

- location for thermal imaging (ambient temperature, atmospheric (air) temperature, distance, relative humidity of the air)
- the imaging system (technical parameters, mounting, field of view, etc.)
- the patient (skin emissivity, pre-imaging equilibration, positions for imaging report generation (evaluating and analyzing)

Location For Thermal Imaging

At the location for thermal imaging we are watching room parameters and ambient and room temperature.

The room used for thermal imaging has to meet certain basic requirements: adequate size for working and adequate space for locating the image processing equipment (IR camera, computer).

In SCI individuals measurements are performed mostly in hospital patient's rooms, where it is impossible to keep the necessary distance between the patient and the IR camera sometimes, because of [14]:

- post traumatic or post surgery condition of the patient (depends on accident severity, level of spinal cord injury, other associated complications)
- room parameters (accessibility to the patient, distance regulation possibility)
- room equipment (comfort, motivation and psycho-ergonomic assurance)
- other effects

Consequently, the patient can't be often moved and positioned and the operator can't move either (it is not possible to keep required distance).

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A rough indicator for the least distance in one direction can be derived from the optical features of the lens (to take an image of upper or lower part of the human body or of an object of 1.2 meters height). Therefore, variability of optical modules can be a solution for getting an appropriate measurement area.

Ambient temperature control is a primary requirement for most clinical applications of thermal imaging. A range of temperatures from 18°C to 25°C should be attained and held for at least one hour to better then 1°C. The type of used examination will determine the ideal ambient temperature. Many clinical examinations are performed with partial disrobing of the patient. When larger areas of the body are unclothed and exposed to the air for longer periods, the lower ambient temperatures will cause discomfort [9] and may result in reflex vasoconstriction.

Indication of the air temperature is important; a large digital display which is visible anywhere in the room should be used. Air temperature is affected not only by heat generated by electronic equipment, by also by the human body.

Room temperature maintenance in SCI patients is even more important, because of poikilotherm behaviour of this group (having body temperature that varies with the environment). They are inclined not only to undercooling, but also to overheating.

The Imaging System

The latest generation of focal plane array cameras can be used without cooling, providing almost maintenance free technology. Almost all systems now use image processing techniques and provide basic quantitation of the image [9]. In some cases this may be operated from a chip within the camera, or may be carried out through an on-line or offline computer.

Earlier reports stipulate the requirement for a separate (external) thermal reference source for calibration checks on the camera, however many systems now include an internal reference temperature.

An external reference (purchased or constructed) can be switched on with the equipment, and left running throughout the day. This allows the operator to make checks on the camera (hardware and software), which may be the only satisfactory way of providing the reliability of temperature measurements made from the thermogram.

The proper mounting of the imager using a camera stands (photographic tripod, studio camera stand) is very important for medical thermography. IR camera stands should be vertically and angularly adjustable (available stands are usually vertically adjustable from minimum 0.1 meters to 2.5 meters).

Stands used in small hospital patient's rooms should be adjustable to the highest position as possible, because of measurements of the patients lying on the bed in the horizontal position. Thus, patient-camera distance is set by vertical movement of the stand [9].

Software packages for thermal imaging are provided by some manufactures, few of which are specifically designed for medical applications [9].

According our experiences, it is necessary to estimate the way of images analysis, using software package tools at the beginning of the measurement to better comparison evaluation of all measurement subjects (SCI patients) [14].

The Patient

At the patient management we should inform patients about thermographic examination procedure and ask to avoid some controllable influences. Important are also pre-imaging equilibration, positions for imaging and field of view.

Human skin temperature is the product of heat dissipated from the vessels and organs within the body, and the effect of environmental factors on heat loss or gain. There are a number of further influences which are controllable, such as cosmetics, alcohol intake, smoking and physiotherapy methods (electrotherapy, ultrasound, heat treatment, cryotherapy, massage, hydrotherapy) because of their thermal effects, which can last for 4-6 hours under certain conditions. Heat production by muscular exercise is a well documented phenomenon. Drug treatment can also affect the skin temperature.

SCI individuals in subacute treatment phase are measured usually in their hospital rooms and they are mostly fully controllable, including meals and liquids intake [9, 13, 14].

The time required to achieving adequate stability in blood pressure and skin temperature is generally considered to be 15 minutes, with 10 minutes as a minimum. If the lower extremities are to be examined, a stool or leg rest should be provided to avoid direct contact with the floor. During the examination paper or linen towels may be required to avoid overcooling of the feet.

It should be noted, that SCI individuals in the post surgery phase are not able to exercise longer than several minutes. Consequently, it is not possible to compare results among more patients together sometimes (different levels of SCI, different physical condition, different drugs treatment, etc.). It means that it is often time-consuming to get appropriate subjects (SCI individuals) and these kinds of IR thermographic measurements are necessary to be organized for longer time period.

Positions for imaging are not less important than other adjustments. As in radiology, it is preferable to standardise on a series of standard views for each body region. The EAT Locomotor Disease Group recommendations include a triangular marker system to indicate anterior, posterior, lateral and angled views [9]. It should be noted that the position of the patient for scanning and in preparation must be constant. Standing, sitting or lying down affect the surface area of the body exposed to environment, therefore an image recorded with the patient in a sitting position may not be comparable with one recorded on a separate occasion in a standing position.

Figure 1: Picture of the measurement approach at verticalisation by means of verticalisation bed.

SCI subjects at the post surgery rehabilitation phase are mostly lying on the clinical bed. Muscle motorics and sensitivity loss in lower extremities (paraplegia) and in both, upper and lower extremities (quadriplegia) requires fixation during the rehabilitation process (see Fig. 1). A lot of attention should be given to the selection of the appropriate body and extremities fixation, according to requirements including:

- size (designed to cover smallest skin surface)
- material (without thermal effects to the skin surface)
- safety and reliability
- comfort, psycho-ergonomics [5, 14]

Image size is dependent on the distance between the camera and the patient and the focal length of the infrared camera lens. The lens is generally fixed on most medical systems, so it is good practice to maintain a constant distance from the patient for each view, in order to acquire a reproducible field of view for the image. If different thermograms of different field of view of the same subject are compared, the variable resolution can lead to false temperature readings [9].

Report Generation

Clinical report made after thermographic examination consists of the images, the demographic data and measurements made from image processing. Every image or block of images must carry the indication of temperature range, with colour code/temperature scale. Industrial software frequently provides a greyscale picture and one or more colour scale (sometimes medical scale including).

Background temperature which can obscure the clinical image should be avoided, and cleaning the image by processing e.g. squeezing the temperature range or overwriting the lower temperatures with a background of white, grey or black will improve the visual presentation. The use of hardboard or cold towels arranged just prior to image recording will often improve the image clarity.

Materials and methods

We measured 20 individuals. Measurements in 10 SCI individuals were realized in clinical environment.
According to a post-injury or post–surgery condition of the patients or their physical condition we selected appropriate rehabilitation method and rehabilitation device (verticalisation bed, CPM (Continuous Passive Motion) device, orbitrack or unweighing lift system (ULS)).

AB (able-bodied) group exercised according to a formula: 2x5 minutes (5 minutes Orbitrack, 5 minutes upright exercise bike).
Measurements were performed by means of FLIR IR-Thermocamera Thermacam PM 693, with thermal sensitivity 0, 08°C at 30°C and accuracy ± 2%.

Early verticalisation in SCI Individuals is a necessary phase of rehabilitation process. Its realization depends on total condition of the patient, which narrowly relates to his physical condition and post-injury or post-surgery condition.

We evaluated the effect of verticalisation on surface skin temperature by sensing of the surface skin temperature variations, which depend on several physiological factors, affected by exercise. We assumed, that the most significant factors affecting the skin surface temperature are muscle work, vascular system performance and metabolism of the rehabilitated person. Percentage representation of single factors is not known, and can be determined by future specific measurements.

Conclusions

Temperature in SCI individuals verticalisation varied in the range from 34 to 36°C.
Disadvantage of IR – thermography is in complicated and specific evaluation of output sequences, where using the appropriate methodics significantly affect the results.

Initial measurements we realized in clinical practice in SCI group indicate some significant changes in the skin temperatures between verticalisation using verticalisation bed and ULS device. Results show also in some cases differences between temperatures at the beginning and at the end of verticalisation. In some cases, the temperature during 150 second of rehabilitation process remained without significant changes.

Rehabilitation approach is different from patient to patient because of SCI level, physical condition, secondary diseases or their impairments. In the present time, we are preparing additional measurements to obtain statistically significant files and to confirm our initial measurements.
The another way how to get appropriate results is to provide parallel measurements by using some of other suitable methods of rehabilitation process monitoring together with infrared thermography.
A lot of attention should be given to methodics of the measurements.

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