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Recent application of infrared thermography in work-related musculoskeletal disorders

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ABSTRACT: The burden of work-related musculoskeletal disorders is an important problem in the occupational setting. New techniques to quantify the exposure to risk factors are important to understand possible pathophysiological mechanisms that may lead to the development of these disorders. Existing methods have known limitations and new approaches are required. Work-related musculoskeletal disorders have been associated with blood flow impairments. Skin temperature is influenced by blood flow and might be an interesting parameter in their management. Thermography is a simple way to record skin temperature and produces a thermal map of the evaluated body part. A literature review was conducted in order to analyze the recent applications of thermal imaging in the management of work-related musculoskeletal disorders.

1 INTRODUCTION

Injuries affecting a structure of the musculoskeletal system are often called "Musculoskeletal Disorders". According to several authors these disorders may develop in a sudden or insidious onset and can be responsible for functional impairment and symptom provocation for short periods or the whole lifetime (Bernard, 1997, Sanders & Dillon, 2006, Sanders & Stricoff, 2006, Woolf & Pfleger, 2003, Mody & Brooks, 2012). If the musculoskeletal disorder has been induced or aggravated by work or its circumstances the term Work-Related Musculoskeletal Disorder (WRMD) is adequate (Schneider et al., 2010, Luttmann et al., 2003).

The functional capacity of the musculoskeletal system can be assessed through numerous methods in order to identify the risk leading to musculoskeletal disorders, to monitor the effects of occupational interventions and research. The most common used instruments are questionnaires, functional tests and observational methods. While using questionnaires data collection costs are low, several parameters of exposure can be determined simultaneously and all risk factors are assessed with a similar approach but these instruments require better validity testing research (Barrero et al., 2009). Wind et al. (2005) in a systematic review identified 13 questionnaires and 14 functional tests and concluded that only three questionnaires showed high levels of validity and reliability and that none of the functional tests had high level of validity and reliability. Observational methods may be useful but differences were found while using different observational methods on the same target (Takala et al., 2010).

WRMD have a high impact in either individuals and society, the burden associated has been extensively discussed in the literature. The need for research in new technologies that allow a better understanding of these disorders and objective outcomes is crucial to reduce the impact of WRMD.

2 INFRARED THERMAL IMAGING

Temperature is a physiological health status indicator as the presence of pathology may affect local thermal balance, increasing or decreasing skin temperature through blood flow regulation. This principle supports the use of thermography, a measurement tool applied to images of temperature distribution of the skin that is simple, non-invasive, non-ionizing and objective measurement. Several studies relate the appearance of musculoskeletal disorders with disturbances in blood flow, especially in repetitive strain injuries (Pritchard et al., 1999, Gold et al., 2010, Brunnekreef et al., 2006).

Thermal imaging has been used for research, to study diseases where skin temperature is an indicator of the underlying tissues status or where blood flow is increased or decreased and can be applied as a diagnostic procedure or as an outcome measure (Ring & Ammer, 2012).

2.1 *Equipment*

Several imaging modalities work within the electromagnetic spectrum but mainly allow access to anatomical information.

Thermal cameras are used in thermography to capture and monitor the amount of heat dissipated by infrared radiation and to produce infrared thermograms, which are images of temperature distribution of the target.

It was in the 1960s that the impact of temperature distribution measurements from thermograms began (Ring, 1995) however equipment and examination protocols have evolved significantly in the last decade (Ring & Ammer, 2012). The latest generation of high thermal and spatial resolution cameras improved the potential of thermography and small, but meaningful, variations in thermal patterns can be identified and assessed.

2.2 *Standardization requirements*

As a method to measure skin temperature, thermography must meet criteria of measurements like validity, reliability, sensitivity and responsiveness. In order to meet these criteria the examiner must be aware of the sources of variability of measurements performed. The object or subject being studied, the imaging system, the position of the subject or object during image capture and the environment conditions (temperature, humidity and air flow) are common sources of errors.

Plassmann et al. (2006) proposed a series of simple tests for quality assurance in thermal imaging. The use of external sources of reference temperatures is important for systematic calibration checks.

Thermal patterns are often represented in false colour scales where different colours represent different temperature values. In medicine, the use of a rainbow false colour scale has been recommended, since at human eye has better discrimination. The temperature colour scale used at acquisition should be displayed in the thermogram since its absence makes the image poorly defined as the range of temperatures is essential to correctly understand the image and to allow future comparisons (Ring & Ammer, 2012).

The concern with standardization procedures has been increasing in the literature and guidelines have emerged regarding equipment preparation, subject preparation, body positioning, examination environment conditions, image recording, region of interest definition and evaluation of thermograms (Ammer & Ring, 2008, Ammer, 2008, Schwartz, 2006).

3 RECENT APPLICATIONS OF THERMAL IMAGING IN THE MANAGEMENT OF WORK-RELATED MUSCULOSKELETAL DISORDERS

Thermal imaging has not been extensively used in occupational medicine in the management of WRMD but some studies have attempted to use the technology as diagnostic tool and as a means to study risk factor exposure in order to better understand the pathophysiological mechanisms leading to injury development.

3.1 *Thermal imaging as a diagnostic tool in the occupational setting*

Three studies were conducted to study the potential use of thermography to identify groups of patients with WRMD.

Gold et al. (2004) studied office workers with WRMD and healthy controls simulating a keyboard typing activity. The subjects with WRMD were distributed in two groups according to the presence of cold hands induced by keyboard use and thermograms of the dorsal hand skin temperature were obtained at baseline, 0–2 minutes, 3–5 minutes and 8–10 minutes after typing. The authors found three distinct temperature patterns during the 9 minutes typing activity followed by an observation period of 10 minutes and concluded that infrared thermography was able to discriminate between the three groups of subjects. The same group (Gold et al., 2009), in another study simulating a similar task aimed to establish the suitability of using dorsal hand skin temperature as an indicator of WRMSD in office workers and addressed the reproducibility of thermal measurements. Symptomatic and asymptomatic office workers and controls were evaluated the conclusions pointed skin temperature of the dorsal hands measured by infrared thermography as a reliable measurement to determine the severity of WRMD in office workers.

Mohamed et al. (2011) studied two groups of pianists, one with pain related to piano playing and one without associated pain, focusing in hand, forearm and arm skin temperatures. Thermograms were captured at baseline, immediately after each of the three piano-playing activities with increasing difficulties, 15 minutes after and 30 minutes after the last piano exercise. The authors found that the experimental design conduced to meaningful results and that the temperature of the hands, but not the temperature of the forearm and arm, was significantly higher in the group with pain related to piano playing.

More studies are needed in order to establish thermal imaging as a useful diagnostic tool but the literature that has been published on the subject is promising.

3.2 *Thermal imaging as a sensitive technique to assess risk factors and task demands on the musculoskeletal system*

Several studies have been recently published contributing to understand the pathophysiological mechanisms of injury development.

Gold et al. (2010) aimed to establish the correlation between the skin temperature of the dorsal hand of office works and relative blood flow measured by near infrared spectroscopy. Thermographic evaluation followed the methodology previously published by the research group (Gold et al., 2004, Gold et al., 2009). The authors found a moderate correlation between relative blood flow and the temperature of the hand during the 10 minutes following a typing task. Skin temperature and relative blood flow were influenced by the typing speed and despite reasonably correlated both parameters were found to be highly variable between subjects. Individuals typing more than 50 words per minute evidenced faster overall post-typing temperature decrease towards the baseline values.

Govindu and Babski-Reeves (2012) analyzed skin temperature over the muscles in the thenar eminence in 12 participants simulating a pipetting task. The effects of pipette volumes, solvent viscosity and gender on thermal parameters and subjective rating of discomfort of the thumb thenar muscles were analyzed. Thermal parameters were not sensitive to solvent viscosity and pipetting volume but were correlated with subjective ratings of discomfort. An increase in thermal parameters and discomfort ratings was observed. The rate of temperature change may be more adequate to describe the impact of task demands on muscles over time and may predict the amount and change in discomfort experienced during the task.

Camargo et al. (2012) simulated a textile industry activity with repetitive movements of the wrist. The activity was emulated for 3 hours and 30 minutes and involved movements like reaching, taking, dropping and others. Only two subjects were studied, and the behavior of wrist temperatures in both cases was similar, increasing during the first hour and a half of work and declining over the next 2 hours.

Barker et al. (2006) and Bertmaring et al. (2008) applied thermal imaging to assess shoulder overhead activities. Barker et al. (2006) evaluated the effects of task parameters on middle deltoid and trapezius. Thermography was a sensitive method to detect changes in task parameters, working at 33% duty cycle and lower work height resulted in higher temperatures and increased rates of temperature change. At the 50% work cycle the temperatures were lower. The temperatures at 67% work cycle were expected to be even lower but the opposite was true. The authors advanced the accumulation of waste products in the muscle and lower levels of blood flow due to exertion as possible explanations.

Another study (Bertmaring et al., 2008) proposed to quantify surface temperature changes in the anterior deltoid and evaluate the efficacy of thermography as an assessment tool. Two work loads and two shoulder angles were evaluated and surface temperature, discomfort ratings and endurance time were assessed during overhead static exertions until exhaustion. The work loads were 15% and 30% maximum voluntary contraction since blood flow has been cited to begin at 20% of maximum voluntary contraction and 90º and 115º shoulder angles were chosen as they represented overhead postures previously published. In this study, shoulder angle affected temperature rates of change. According to the authors, lower temperature slopes may present increased risk of injury due to lower blood flow levels. Working at a lower shoulder angle allows more blood to be distributed to working muscles resulting in faster rates of change. The results related to the exertion levels were unexpected since the deltoid thermal readings were not influenced by them, possibly because the exertion levels spanned the 20% cited in the literature as cut point to reduced blood flow.

Using infrared thermography as a diagnostic and/or assessment complementary tool has several advantages. Being a non-contact, non-invasive and fast method allows real time dynamic temperature monitoring without interfering with the subject being monitored, even when monitoring large areas. In opposition to other imaging modalities whose focus is anatomical information, the focus of infrared thermography is the physiology of the human being, associated with the microcirculation and autonomous nervous system. The use of false colour coded thermograms allows faster and easier subjective analysis. The fact that it is a non-ionizing method, recording the natural radiation emitted from the human body surface, makes it suitable for repeated and prolonged measurements. When assessing the microvascular system, the great advantage of thermography, compared with laser doppler, is that it is a faster method, able to measure a larger area, although more research is needed for reaching the same sensitivity.

Caution, however, is needed when using this imaging modality. Well controlled environment and evaluation protocols are needed since several sources of variability of thermal images may be present, arising from the subject being evaluated, the imaging system, the image capture protocol and/or the environmental conditions such as temperature, humidity and air flow.

4 CONCLUSION

Despite several limitations in the previously mentioned studies, attention should be placed in thermal imaging as an assessment tool in occupational setting.

Epidemiological studies are needed in large cohorts of workers to establish objective criteria of early development of WRMD, reducing the associated burden.

Longitudinal studies should be conducted in order to test the suitability of this physiological parameter in the workplace to evaluate the severity of WRMD. Workers at risk to develop musculoskeletal disorders, working with different exertion levels should be monitored regularly in order to understand the possible relationship between the rate of temperature changes and the onset and severity of WRMD. The correlation with subjective parameters like perceived pain, perceived effort and discomfort ratings should also be studied.

Some research has been done to understand the relation between thermal readings and other physiological parameters, like blood flow, but more studies are needed in order to fully understand this relation. Studies focusing on the relation between thermal readings and muscle activity, measured by surface electromyography, are highly demanded. Using the objective criteria of surface electromyography to establish the state of muscle fatigue, the thermal characterization of the process of muscle fatigue could be known and more information would be added about the effect of muscle activity on the rate of temperature change.

Research is still required in order to structure specific evaluation protocols and guidelines, allowing thermography to become an even more reliable diagnostic tool but, more importantly, a more reliable assessment tool to be used in the field.

Further research is needed in order to clarify the possible relationship between muscle activity, thermal readings and task demands.

The relationship between working experience and temperature is also to be fully understood. Different groups of workers with varying work experiences should be compared.

More studies focusing on the reliability of thermal imaging are highly required.

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