Abstracts

Session I: Thermal physiology

MEASUREMENT OF HUMAN BODY TEMPERATURE TECHNOLOGICAL AND METHODOLOGICAL ADVANCES

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The historical link between changes from the normal process of thermoregulation and disease is well documented. Even so it was the development of the thermometer that ultimately replaced the medical art of detecting fever by touching the patient. Galileo's simple thermoscope indicated the temperature of the water, but as an open system it was influenced by atmospheric pressure. Once this was realised and the tube was sealed, the glass thermometer became the standard instrument for measuring temperature to the present day. In medicine, a dramatic change in approach to temperature measurement of sick patients followed the thesis of a German physician Dr Carl Wunderlich. He systematically recorded the temperature of his patients at regular times throughout the day, and charted their progress. His main work sets out some forty different statements about the value of temperature measurement in medicine, the proof of fever by elevated temperatures, indication of worsening or improvement, and ultimately the decrease of temperature leading to death and post-mortem cooling. For 200 years, temperature charts have been a familiar record of hospitalised patients throughout the world. Of special, significance was his concept of the maximum or clinical thermometer, optimised to a narrow temperature range for clinical indication of fever.

The original mercury thermometers are now replaced by coloured fluid, for safety reasons. Electrical sensors, particularly thermocouples have been used in contact temperature sensors. Thermistors are not generally as rapid in response, but well suited to continuous monitoring have their place, especially in intensive care medicine.

Radiometric temperature detection of the naturally emitting infrared radiation has been a more recent development. In clinical medicine, simple radiometers are now used for aural temperature, and in some countries are replacing glass contact thermometers, mainly because they are considered to a lower risk for infection. When used in the ear, a disposable sheath is required, which can in itself be a source of temperature error. However, the presence of cerumen, the variable shape of the ear canal in individuals, and the sometimes poor quality of the instruments themselves, are liable to reduced accuracy overall. At the present time there are a variety of thermal sensors made for medical use. Some are provided with an algorithm for an estimate of core temperature, largely regarded as the "gold standard" in the diction of fever or hypothermia. However, core temperature is a loose concept, and often poorly defined. The current interest in mass fever screening in airports etc. is based on thermal imaging, but verified by clinical thermometry to relate to core temperature. Work to update the International Standard for these instruments is currently in progress.

Infrared thermal imaging systems have reached a significantly higher level of performance since 2000. Focal plane array detectors with high spatial and thermal resolution are available, at a relatively lower cost than in previous years. Criteria for their use in medical imaging have been described, and optimal conditions for a physiological recording of temperature should be a part of any thermal imaging routine. Most modern cameras claim to be fully in service within 10-15 minutes from start-up. This may not be valid for all cameras, and some will require much longer before they reach full radiometric specification. Furthermore the time to reach this required stability can change over time. It is therefore important that the user of each camera system is fully aware of the minimum time required before any images of the patient are made. Image capture requires as much standardisation as possible to ensure the ultimate repeatability of the images. Software can be used to help in the precise location of the target and of the regions of interest used for measurement. Improved resolution, stability and accuracy of temperature measurement are significant technical advances. However, critical technique and understanding of thermal physiology are also necessary to obtain clinical benefits from thermal imaging. The new interest in fever screening raises important challenges for the future.

REGIONAL HUMAN SKIN TEMPERATURES AFTER CAFFEINE INGESTION

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PURPOSE: This investigation examined the influence of a single dose of caffeine (120 mg) on regional skin temperature measures during standing rest, work (70% VO_2 max, 30 minute duration), and passive recovery periods in a warm environment (30°C, 40% rh).

METHODS: The participant's habituation to caffeine was not determined, but regular daily use of caffeine products was recorded. Subjects refrained from using a caffeine product on the experimental days. Work rates (m,ean =10.86 km/hr) for the ten physically active college males were determined from a treadmill test for maximal oxygen consumption(mean= 45.2 ml.kg.min^{-1}). During the four randomized double blind investigative trials, all participants either drank 20 ounces of Gatorade™ (G) or Gatorade™ plus caffeine (GC) prior to 60 minutes of passive standing performed at the same time of day and separated by at least 24 hours. During two trials the subjects were followed for an additional 30 minutes of standing, while the remaining two trials consisted of a 30 minute work bout followed by a 30 minute recovery test periods. Physiological measures consisted of thermographically determined skin temperatures, rectal core temperature, heart rate, Physiological Strain Index (PSI), Rating of Perceived Exertion (RPE), weight (sweat) loss, and thermal sensation. A caffeine effect was not observed until 30 minute post ingestion.

RESULTS: Core temperature was higher during the caffeine passive trials after 30 minutes (0.3°C) and exercise trials (0.4°C), and recovery (0.2°C). Post caffeine ingestion the subject's heart rates were slightly elevated, but no differences were observed in the subject's perception of thermal stress, PSI, RPE. Body weight changes indicate greater fluid retention in both the active and passive caffeine trials. Thermal imaging demonstrated slightly elevated temperatures in the chest and slightly cooler in the head with caffeine supplementation while standing in the heated climate. No difference in skin temperatures were observed for the arms and legs. During the caffeine exercise and recovery trials, the arms and legs were substantially cooler while no difference was observed for the chest region. In contrast, the head was cooler during exercise and then continued to rise in temperature during the recovery period.

CONCLUSION: The ingestion of caffeine (120 mg) in a heated environment increased core temperature, increased heart rate, altered skin temperature, but did not disturb the thermal patterns on the skin surface thermograms.

Research supported by Gatorade™

THE EFFECT OF EXERCISE ON BODY COOLING RATES DETERMINED BY THERMAL IMAGING

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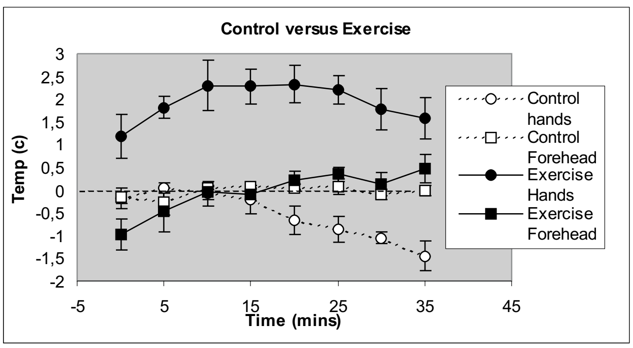
Modern thermal imaging technology provides new opportunities to study non-contact skin temperature in the evaluation of the effects of sport and exercise. In this simple study 8 Sport Science students were tested in a temperature-controlled laboratory before and after a standard exercise. The object was to observe the effects of exercise on the cooling of skin temperature in a constant ambient temperature. The subjects were lightly clothed in loose fitting shorts and shirt. A 20 minute period of stabilisation in the laboratory at 22ºC was allowed, prior to exercise, and baseline thermograms were taken of the face, palmar hands, posterior legs, at a standard positioning set by the use of image capture masks. Thermograms were recorded by a FLIR A40 digital IR camera connected by firewire to an image-processing computer with CTHERM software. Subjects were divided into 2 groups control and exercise. The exercise group undertook a standardised 10-minute step test while the control group rested. Subsequently images were captured at 5-minute intervals for the 35 minutes cooling period. The mean temperatures over the regions of interest were extracted from the thermal images and the baseline values were subtracted prior to analysis using a student t-test.

Results: After exercise hands were significantly warmer (p=0.00054, t=-5.87 one tailed) at 20 minutes compared to control subjects. On average hands were 2.3ºc above baseline in the exercise group compared to 0.2°C below baseline in the control group. In the control group the mean hand temperature dropped over the experimental period from 0.2°C below baseline at time 0 to 1.5°C below baseline at 35 minutes (p=0.0039, t=2.35, two tailed).

Immediately post exercise there was an observable decrease in forehead temperature, in the exercise group compared to controls, which was significant (p= 0.031, t=1.94, two tailed).In the exercised group the mean forehead temperature increased over the experimental period from 1.0°C below baseline at time 0 to 0.5°C above baseline at 35 minutes (p= 0.0036, t=3.18 two tailed). There was also a significant decrease in face temperature i



mmediately post exercise, in the exercise group compared to controls, (p= 0.026, t=2.44, two tailed). In exercised subjects the mean facial temperature increased over the experimental period from 1.6°C below baseline at time 0 to 0.2°C above baseline at 35 minutes (p= 0.0023,t=3.18, two tailed). No obvious changes were observed in the thigh and calf regions in the control group compared to the exercise group.

Houdas and Ring showed when moving from a cold to a neutral environment the extremities (including hands) showed a large change in temperature whereas the forehead temperature shows a much smaller change. One might expect to find similar results due to exercise, indeed the present results are comparable; the hands show a large change in temperature following exercise, whereas the forehead shows a much smaller temperature change. However in the present study the forehead temperature is initially lower following exercise but is higher 35 minutes after exercise cessation. This has implications for using forehead temperature as an indication of core temperature.

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RELATIONSHIP BETWEEN INTRAMUSCULAR TEMPERATURE AND SKIN SURFACE TEMPERATURE AS MEASURED BY THERMAL IMAGING CAMERA

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Introduction Cryotherapy is the application of cold to the skin to achieve therapeutic objective in deeper tissues (Knight 1995, Merrick et al 1999 and Merrick et al 2003). Superficial tissues transfer temperature change to deeper tissues, through conduction; deeper tissues therefore experience a smaller decrease in temperature (Hardy & Woodall 1998). Skin Surface (SS) and Intramuscular (IM) temperature during cryotherapy application have been investigated separately. However a relationship between the two parameters has not been directly investigated. It is evident that cooling at the surface has an effect on IM temperature during application of Crushed Ice (CI) (Merrick et al 2003), however the nature of the relationship between SS and IM temperature following cryotherapy application is currently unknown. Thermal Imaging (TI) is a valid and reliable measure of skin surface temperature (Sherman et al 1996, Owens 2004) its ability to measure temperature over a given area makes it an ideal tool for SS temperature measurement following cryotherapy. The aim of this paper is to investigate the relationship between SS and IM temperature in response to cryotherapy.

Methods Nine healthy male participants were recruited from the staff and student population of Manchester Metropolitan University, Manchester, England. Data collection was carried out in an environment chamber set at 22ºC. An Anatomical Marker System (AMS) was applied over the right quadriceps to define a precise region of interest (ROI). A baseline thermal image was taken. CI was applied to the right quadriceps for fifteen minutes. Upon removal of the CI, Thermal images were collected at a rate of 1 image min-1 for 40 minutes, IM temperature data were collected at 3cm sub-adipose, simultaneously. Differences and relationships between SS and IM temperature were examined

Results Significant ($p<0.01$) differences exist between mean baseline, SS (29.92ºC±0) and IM (35.75ºC±0.74) temperatures. Regression analysis revealed a highly significant ($p<.01$) quadratic relationship between mean SS and IM change in temperature from baseline (?T) during the 40 minute re-warming period ($r2 = .979$). Significant differences ($p<.05$) exist between SS and IM ?T up-to 30 minutes into the re-warming period.

Conclusion Fifteen minute cryotherapy application over the quadriceps has a clinically significant IM cooling effect at 3cm sub-adipose. The quadratic relationship between SS and IM ?T may be explained by the cooling of the surface area in relation to the dispersion in the underlying tissue volume. IM cooling continues for 35 minutes after removal of CI suggesting a time delay in cooling of deeper tissues.

Session II: Vascular: Blood flow studies

CO_2 REACTIVITY. APPLICATIONS IN INFRARED IMAGING

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Objective: To review literature and present potential applications for Infrared technology. CO_2 reactivity has been clinically utilized in children and adults safely to study headaches, panic disorder, pathophysiology of anxiety disorder, noctural panic, after superficial temporal artey- middle cerebral artery bypass in patients with transient ischemic attacks and watershed zone infarctions and in idiopathic environmental intolerance.

Harold G. Wolff postulated that migraine and vascular headaches (such as cluster headache) are caused by unstable neurogenic cerebrovascular control. Sakai and Meyer tested this theory in patients with vascular headache by measuring rCBF during inhalation of a mixture of 5% CO_2 in air and found it to be correct. Patients with migraine showed excessive cerebral vasodilator responsiveness to 5 % CO_2 inhalation, the increases being almost twice those measured in age- matched controls. Furthermore, during the headache interval CO_2 responsiveness was lessened or lost. In normal volunteers the CBF increase to hypercapnia was symmetrical throughout the brain, in patients with migraine the response was asymmetrical with greater vasomotor instability on the side of the most recent and frequent headaches. They used this excessive and asymmetrical cerebral vasodilator response to 5% CO_2 inhalation to investigate pharmacological responses of the cerebral circulation in migraine. Both intra and extracranial circulation are innervated by the trigeminovascualr system. Clinical case reports documenting altered extracranial vasomotor response to hypercarbia challenge has been reported from our laboratory in migraine and narcolepsy. Drugs used to treat migraine and narcolepsy improves vasomotor response to induced hypercarbia, stabilizing vasomotor capacitance in the microcirculation/ arteriovenous anastomoses.

Testing extracranial / facial vasomotor response to 5 % CO_2 in air inhalation for three minutes can be utilized in thermography laboratories to image trigeminal/facial microcirculatory vasomotor status and use it clinically.

A PRELIMINARY REPORT ON MAPPING OF VASCULAR PERFUSION PATTERNS IN ISOLATED HUMAN LOWER TRANSVERSE ABDOMINAL FLAPS USING DYNAMIC INFRARED THERMOGRAPHY (DIRT), INDOCYANINE GREEN (ICG) FLUORESCENCE VIDEO ANGIOGRAPHY AND 3-DIMENSIONAL CT SCANNING.

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Free tissue transfer is widely used in reconstructive surgery to restore contour and function in patients with soft tissue defects due to trauma, pressure sores and cancer treatment. During free tissue transfer, tissue is transferred from one part of the body to another part, and the so-called flap may be without perfusion for periods as long as two hours. After transfer to the recipient area, the blood supply to the flap is re-established by connecting (anastomosing) a single artery and a single vein of the flap to the vessels at the recipient site. Recently, DIRT has proven to be a reliable non-invasive technique to establish the patency of the anastomosis and the re-establisment of blood circulation in autologous breast reconstruction surgery (De Weerd et al, 2006).

However, a well-functioning anastomosis is not a guarantee that the whole flap will survive. Before the flap is transferred, it is perfused by many blood vessels; however, their number is reduced to one single artery and vein after transfer. Whether the selected artery can perfuse the whole flap depends on the vascular territory of the selected artery. Information on the vascular territory of this vessel helps to identify areas that are inadequately perfused. These areas will eventually result in partial flap loss causing significant morbidity to the patient. Intraoperative use of ICG video angiography can help to estimate areas in the flap that are poorly perfused allowing them to be resected before they cause partial flap loss. The invasive technique is relatively new and gives only semi-quantitative values. In this comparative study, an isolated lower transverse abdominal flap was used to examine the vascular perfusion patterns of selected arteries using ICG video angiography. These results were compared with the thermal patterns obtained after warm and cold perfusion of the same vessels in an isolated lower transverse abdominal flap. A 3-dimensional (3-D) CT scan was taken after selective perfusion of the isolated flap with a radio-opaque contrast medium. A significant overlap between the IR-thermal and video angiograpic images, as well as with the 3-D CT scan images would support the idea that intraoperative use of the non-invasive technique of dynamic infrared thermography technique, could be of help in free flap surgery to estimate areas with adequate perfusion. This would reduce postoperative morbidity for the patients. Preliminary results from these studies will be presented.

References

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ASSOCIATION OF PLANTAR FOOT TEMPERATURES AND SENSORY LOSS IN DIABETIC FOOT DISEASE

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Neuropathic foot ulcers are a major complication of type 2 diabetes mellitus. Progressive degeneration of sensory nerve pathways is thought to affect thermoreceptors and mechano-re ceptors equally. The neuropathic foot is characterised by heightened colouration and increased foot temperature. However, clinical evidence in the literature suggests that foot temperature and response of thermoreceptors is not assessed routinely. Thermological techniques such as infrared thermography, liquid crystal thermography (LCT) and electronic thermometry may be useful for screening the neuropathic foot. The choice depends on cost, spatial resolution, temperature resolution, practicality and clinical significance of results. Liquid crystal thermography (LCT) is used extensively in heat transfer studies. LCT is a non-invasive and high resolution technique used to measure surface temperatures. Liquid crystals reflect incident light producing colour as a function of temperature. Typically, the hue of the colour image is calibrated versus temperature. Recently, the authors have developed a novel thermochromic liquid crystal (TLC) calibration technique using neural networks. Use of LCT in diabetic foot assessment has the important advantage of providing quantitative measurements of response thresholds compared to qualitative measurements based on sensory perception.

A low cost LCT system has been developed which is capable of dynamically monitoring microvascular response to induced thermal stimulus. There are good physiological reasons to expect correlation between our technique and current techniques such as Semmes Weinstein monofilaments and vibration perception techniques (e.g. Biothesiometer). Evidence of correlation between impaired thermoregulatory responses and the degree of sensory neuropathy may indicate common degenerative mechanisms. System design and in vitro calibration has been independently validated for three physical forms of TLC materials. Three encapsulation technologies were evaluated: sprayable liquid crystal paint, thermochromic liquid crystal sheets (TLC) and liquid crystal on latex sheet. Results show that repeatable calibration can be obtained with sprayable paints and TLC sheets under similar lighting conditions. The hue versus temperature curve shifts towards higher hue values for identical temperatures producing a maximum of 15-20% change in hue when incident illumination is changed from minimum to maximum. A neural network training technique has been developed that can compensate for variations in the incident light intensity by merging the shifted hue curves into a single curve determined via the regression analysis of test data. TLC sheets offer higher stability and better colour response. Encapsulated liquid crystals on latex produce a poorer colour response due to a non-uniform spatial distribution of liquid crystals arising from the manufacturing process. This is evidenced by microscopic images obtained during the study of the three forms of liquid crystal. Preliminary results for pressure sensitivity show that TLC sheets are insensitive to vertical pressure in the physiologically relevant range (0-2 Kg/cm2). There is a shift in calibration curve during cooling (relative to heating) leading to temperature bias in both narrow band and wide band TLC sheets. It is envisaged that the LCT technique is sufficiently advanced to carry out a clinical study in order to compare. This paper describes development of the system, in vitro calibration and initial in vivo results from healthy subjects.

SNIFFING OUT RAYNAUD'S PHENOMENON

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Infra-Red Imaging is the accepted gold standard test for confirming or excluding Raynaud's Phenomenon, and is one of the most widely performed investigations in medical thermology. It can help differentiate between primary Raynaud's Disease and Raynaud's Phenomenon associated with connective tissue disorders such as systemic lupus erythematosis (SLE), scleroderma, Sjogren's syndrome and rheumatoid arthritis etc. A fresh approach to the investigation of Raynaud's Phenomenon will be described and discussed.

FOREHEAD - NOSE THERMAL RATIO AND PAIN RELIEF IN MIGRAINE.

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Objective: To evaluate Forehead - Nose Thermal ratio in migraine following vasomotor reactivity testing with hyperoxia and drug treatment and correlate with pain relief.

Materials and Methodology: 10 patients, all Caucasians 9 females and 1 male, ages 22 to 59 with mean age of 40.4 yrs. All were diagnosed as having migraine after physical and neurological exam, laboratory testing, Brain CT / MRI and EEG, and underwent Committee for the Protection of Human Subjects approved infrared imaging protocol for monitoring changes in facial perfusion under the regional control of trigeminovascular system. Extra cranial vasomotor status was imaged with induced hyperoxia using 100% oxygen inhalation for 5 minutes in all patients during headache. Thermograms were also doe in two during headache free period, in six before and after treatment. 3 with Imitrex® (sumitriptan succinate injection), 1 with Zomig®Nasal Spray (zolmitriptan), 1 with Migranol®Nasal Spray (dihydroergotamine mesylate) and 1 with Amerge® (naratriptan hydrochloride) tablet. Following treatment. Timing for imaging started after 15 minutes (the half life of CGRP-Calcitonin Gene Related Peptide, neurochemical involved in the pathophysiology of migraine) and at the recommended dosage timings specific to each drug and routes of administration.

Exclusion Criteria: Age below 18 yrs, pregnancy, headinjury 18 months prior to testing, uncontrolled hypertension, recent myocardial infraction, diabetes mellitus, recent chemotherapy or radiation and hemiplegic or basilar artery migraine.

Results: Nose was colder and forehead warmer during headache free period. Improvement in headache and Pain relief following drug treatment for migraine was associated with stabilization/ normalization of vasomotor response to heperoxia challenge (vasoconstriction following hyperoxia) and the nose being colder and forehead relatively warmer.

Conclusion: Forehead - Nose Thermal ratio appears to be sensitive to extracranial vasomotor reactivity and stabilization of the ratio correlates with pain relief following treatment. tissue volume. IM cooling continues for 35 minutes after removal of CI suggesting a time delay in cooling of deeper tissues.

Session III: Infrared Technology

INFRARED DETECTORS AND CAMERA SYSTEMS

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The use of Infrared Technology has developed significantly in recent years from the very cumbersome, sometimes unreliable, often liquid nitrogen cooled and extremely expensive infrared cameras prevalent in the later part of the twentieth century. Infrared detector technology has developed to an extent where re-

peatability, reliability and accuracy are now synonymous with modern systems.

Currently there is a proliferation of Infrared Cameras available worldwide representing a number of differing applications and challenges in choosing the appropriate camera (Runciman, 2000). Examples of applications are wide and include predictive machine condition monitoring (Tissot, 2005) which directly impacts on the efficiency of British Industry to the use of infrared thermography to improve efficacy during laser therapy on human tissue (Campbell, 2003).

Optimum IR camera specification is an important consideration especially when adopting quantitative thermography. Examples of key specifications are discussed.

Higher specification infrared cameras are emerging and able to satisfy the requirements of medical practice. These systems have high levels of thermal and spatial resolution ideal for diagnostic purposes. There currently remain one or two challenges regarding spatial uniformity and geometric distortion but these are already subject to experimentation and testing (Thomas, 2006). There are a growing number of medical examples of such work in Europe most notably at the University of Glamorgan in the UK.

An important aspect of any infrared programme is training (Snell, 2005). The success often pivots on training and that it is recognised, relevant and most importantly imparts the necessary skills for qualitative and quantitative thermography.

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QUALITY ASSURANCE OF THERMAL IMAGING SYSTEMS IN MEDICINE

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Standardisation is important for reliable use of infrared thermal imaging in medicine. Infrared camera systems are now of higher performance with improved reliability, which can lead the operator to assume that the system is continually giving optimal performance. This, however, is not the case.

We propose a series of simple experiments based on inexpensive and easy to acquire materials, which a thermographer can use under normal clinical conditions to monitor the performance of thermal imaging equipment in order to maintain confidence in the measurements made. The 5 tests proposed here are not intended to replace those performed by manufacturers or calibration laboratories, but can provide valuable information on both short and long-term camera performance. The proposed tests identify: a) offset drift after switching on, b) long-term offset drift, c) offset variation over the observed temperature range, d) image non-uniformity and e) the thermal 'flooding' effect.

Measurement results based on the above experiments will be presented which demonstrate that cameras may drift over several degrees centigrade in less than 2 hours after switching on. We will also show that imaging equipment can produce a varying amount of measurement error (up to 1.5 degrees centigrade), which depends on the temperature range observed. Results also show that equipment may be prone to non-linear errors (in the region of 1 degrees C), which are caused by deficiencies of the optical system and will manifest themselves if the equipment is not calibrated regularly.

Although the proposed tests will identify errors if present, due to the simplicity of the materials used, the tests are only of limited use for the quantification of these errors. We therefore present experimental results obtained using a new 3-point calibration blackbody source currently under development by the UK's National Physical Laboratory (NPL) specifically for use in medicine. The source exploits the stability of the melting/freezing point of certain chemicals which makes it extremely stable and when in use does not require a power source, cables or electronic stabilisation circuits. This source, once commercially available, will provide a highly reliable and practical tool not only for the quality control of thermal imaging equipment but by virtue of its inherent precision it will also enable cross-calibration for multi-centre trials.

COMPACT THERMAL IMAGER ON THE BASE OF 2X64 FOCAL PLANE ARRAY WITH TELEVISION FRAME FREQUENCY AND HIGH THERMAL RESOLUTION.

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The portable infrared imager is designed for detection of thermal (infrared) radiation, subsequent processing of the signal and its real-time visualization on the built-in LCD display or on an external computer monitor. The imager is supplied with the original software. Fast USB 2.0 interface is used for communication with a computer. The infrared sensor is a nitrogen-cooled 128-element HgCdTe photodetector array operating in the spectral range of 2 to 12 microns (or 8 12 mkm).

Application areas:
Medical diagnostics:: contactless and intrusionless detection of inflammations, blood circulation anomalies and other pathologies, particularly in oncology (breast cancer, thyroid gland cancer), traumatology, gynaecology, post-operation complications control, etc. The device is portable and easy in use, making it suitable for mobile diagnostic units. The imager has undergone several clinical tests and is certified by the Ministry of Health of Ukraine.

Ecological monitoring and nondestructive control: detection of thermal losses of buildings, pipelines, monitoring of moving engine parts, control of fire-risk areas, etc.

Technical specifications of the imager

FPA configuration	Monolithic HgCdTe detector
Spectral range	2-12 µm (8-12 µm)
Number of photodiode elements	128
Photosensitive element area	30x30 ìm
Size of image	160x120 pixels
Cooling method	By liquid nitrogen, 77 K
Instantaneous field of view: Horizontal Vertical	≤0.0015 radian ≤0.0015 radian
Field of view: Horizontal Vertical	>0.4 radian >0.4 radian
Temperature resolution of photodetector at 30N	< 80 mK
Distance from object	0.5-100 m
Frame frequency	50 Hz
Nitrogen refill cycle time	4 hours
Line supply	~220 (=12 DC) V
Dimensions	350õ125õ180 mm
Weight	3,5 kg

THERMAL IMAGE PROCESSING FOR MEDICAL APPLICATIONS - ADVANCED HARDWARE AND SOFTWARE DEVELOPMENTS

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This paper presents low-cost microbolometer IR camera based on 284x288 focal plane array (Fig.1). Read-out control circuit is presented with IEEE1394 interface to transmit image to the computer in real time (Fig. 2). Nonuniformity correction (NUC) is mentioned as an important problem which can reduce significantly the image quality (Fig. 3). For simplicity of the hardware implementation, NUC processing is performed at the host level using both 1 and 2-point method, and the new approach introduced by the authors.

The integrated software for thermal image processing both for static (passive) and dynamic (active, lock-in) thermography is presented. This software cooperates with hardware interfaces in COM environment, effectively using the IEEE 1394, or/and PCI image capturing devices. Additionally, it controls power generator used in lock-in thermal wave approach. New function of the software is also presented, such and statistical parameter calculation, windowed FFT analysis, time-domain image processing, filtering, calibration, etc.

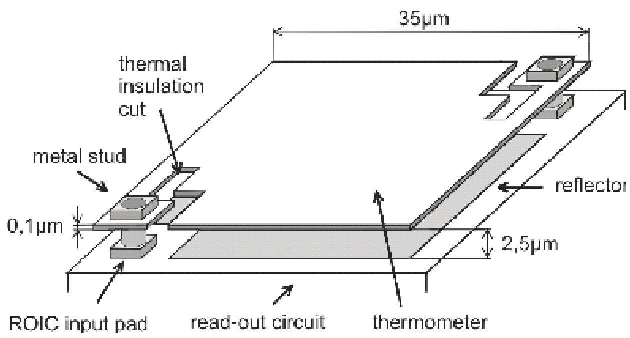

Fig. 1
Microbolometer cell in focal plane array

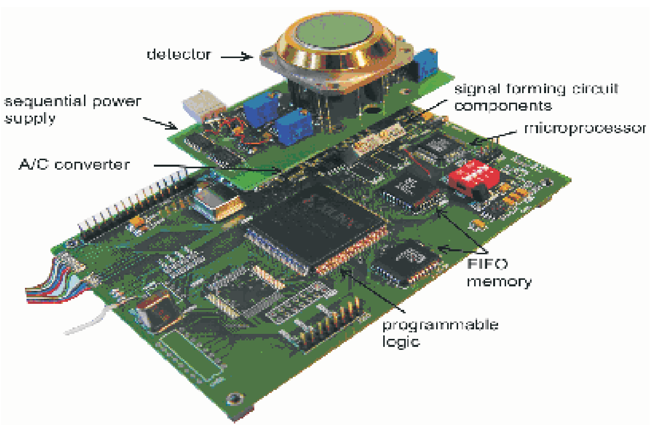

Fig. 2.
Readout circuit of microbolometr array

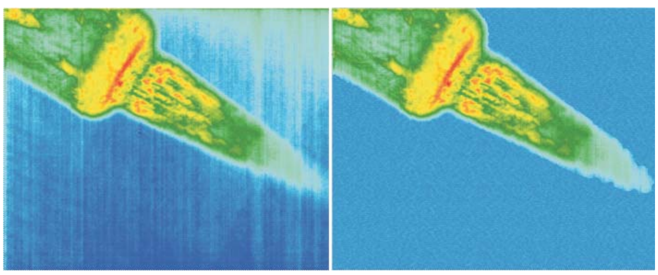

Fig. 3
Nonuniformity correction

PROCURING AND OPERATING THE RIGHT THERMAL IMAGER FOR MEDICAL THERMOGRAPHY

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At present, very few hospitals in the UK offer a thermographic imaging service. Thermography has not displaced other modalities in the diagnosis of deep vein thrombosis, and is no longer deemed appropriate for breast imaging (1), although a later review (2) suggested that thermal imaging was still of utility. However, thermography retains a niche role in rheumatology for the assessment of, inter alia, Raynaud's phenomeneon, morphoea and carpal tunnel syndrome.

The general utility of medical thermography may be reconsidered as recent advances in focal plane array (FPA) detector technology have brought rapid improvements in thermal imager performance. More are on the market than ever before and at increasingly competitive prices. The vast majority are still purchased for non-medical uses. The performance expectations placed on a thermal imager used for medical thermography are necessarily different from those placed on an imager utilised for engineering applications, but these differences are not universally recognised.

This paper will address the criteria to follow when acquiring a thermal imager for medical use, based on our vast experience in rheumatology.

·Cooled or uncooled FPA detector

·Array size and resolution

·Thermal accuracy and sensitivity

·Dynamic response

·Time to reach stability

Software for image capture and analysis

·Methods of storing, reporting and disseminating images to referring physicians

·Calibration and service – the "whole life cost" of the imager, and its lifetime

·Operating environment

·Risk assessment – (note thermal imagers are not typically CE-marked to the Medical Devices Directive 93/42 EEC).

If thermography is not to be misapplied in medicine, ultimate responsibility lies with the clinical thermographer to procure the best thermal imager for their applications. An ongoing programme of Quality Assurance (QA) is also vital to ensure that thermal detector performance is understood, and the imager continues to operate within the exacting criteria necessary for reliable medical thermography, especially in the context of longitudinal and multicentre studies. UK centres are involved in work to develop QA protocols that can be adopted by all medical thermographers (3,4). Annual calibration and service of the imager by the manufacturer should be in addition to, rather than in place of, these regular QA checks specific to medicine.

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Session IV: Imaging and Image Processing

THERMAL-VISUAL COMPOSITE IMAGE GENERATION

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Often visual and thermal images of the same patient are taken to relate inflamed areas to the human anatomy which is useful for medical diagnosis as well as for assessing the efficacy of any treatment. This process requires great expertise and is subject to the individual clinician's ability to mentally map the two distinctly different images.

We present a completely automatic approach to generating a composite thermal-visual medical image based on the two modalities which makes it possible to easily cross-reference regions with unusual temperature distributions to the human anatomy. Based on our earlier work we employ an image registration process to perform the actual overlay of the two images. However to prevent manual intervention in the form of hand-segmenting the visual image into patient and non-patient (i.e. background) areas, we apply a skin detection algorithm which is used to identify the outline of the patient and hence (following some morphological processing) to perform the segmentation step. After segmentation, intensity-based image registration (based on an affine transform model) is employed to align the two images and to generate the superimposed image that is then presented to the clinician. Experimental results based on a series of morphea (localised scleroderma) patients are presented.

REPEATABILITY OF THE IDENTIFICATION OF HOT SPOTS IN THERMAL IMAGES

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Hot spots are regarded as diagnostic signs in thermal images of patients suffering from tennis elbow or fibromyalgia. However, the reliability of the identification of hot spots is not well known and may be poor. The **aim of this study** to investigate how precisely hot spots can be identified from thermal images.

Methods 32 images recorded from fibromyalgia patients in the view upper back were reviewed. Hot spot were identified in two ways. Firstly, the colour scale of the thermal images was compressed in order to increase the contrast between cool and warm areas- Then hot spots were identified by eyes and the identified area was accepted as a hot spot when the temperature difference to the surrounding areas was greater than 0.5 degrees. Secondly, two isotherms were generated at temperature levels 1 degree apart. The mean temperature of hot areas within the isotherm at the higher temperature was determined and compared to the mean temperature of the surroundings of the hot spot. These temperature measurement procedures were repeated two days later. The findings were statistically analyzed with respect to method of hot spot identification and time of investigation.

Results: The number of hot spots per image varied between 1 and 8. Identification of hot spots by eye was impossible in two thirds of the images prior to the compression of the colour scale.

A higher reproducibility was obtained for the isotherm method than for the hot spot identification by eye.However, the isotherm method is time consuming and not fully reproducible.

PERIOPERATIVE PATIENT WARMING: A THERMOGRAPHIC EVALUATION OF TWO SYSTEMS

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Physiological mechanisms, including changes in blood flow and modifications of central thermoregulatory control, cause body temperature to fall during general and regional anaesthesia. Post-operatively, hypothermia results in longer stays in the recovery area and delayed discharge from hospital. The current "revolution" in the UK NHS has lead to an increase in the number of day-case procedures. Technology to maintain a patient's body temperature perioperatively should be employed optimally in order to sustain the throughput of day-case surgical patients, who should be fit for discharge within a short time.

Blood and fluid warmers together with patient warmers are used. The former are designed to ensure that the temperature of blood and fluids infused into a patient is close to body temperature. They must accommodate a wide range of infusion rates, extending to over 400 $mlmin^{-1}$, the inevitable heat loss between the warmer and the patient, and the absolute requirement not to heat the infusates much above 40 ^{o}C lest thermal degradation occurs.

Patient warmers fall into two categories: hot-air warming blankets and warming mattresses. Both actively warm the patient and reduce heat loss to the environment. They each have a role to play depending on the nature of the surgical procedure. Mattresses must have appropriate pressure relieving properties.

Warming blankets lie over the patient. They are disposable single patient use items connected, via a flexible tube, to a blower that warms filtered ambient air. The warmed air passes out of the blanket and onto the patient.

We have performed pilot work with one warming blanket system, using a thermal camera used clinically (Flir SC 500) which has shown that the system does not deliver air to the blanket at the expected temperature, and that the heat loss is variable depending on the configuration of the corrugated tube connecting the blower to the blanket.

The purpose of this work is to report the formal evaluation of the thermal performance of two hot-air warming blanket systems on the UK market. Whilst thermal performance is one factor in determining overall system performance it is also necessary to consider: ease of use; cost of use; and reliability.

We shall present results comparing the two systems and demonstrate that thermal imaging has applications in medicine that extend beyond clinical thermography.

DICOM FOR INFRARED IMAGING

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Recently, efforts have been made towards standardising the process of medical infrared imaging. Clearly, one aspect of such a standardisation procedures has to concern the actual file format of the digital thermograms. Currently, camera manufacturers typically employ their own proprietary formats which hinders exchange and communication of the images while in other medical fields, DICOM (Digital Imaging and Communication in Medicine) has emerged as a standard for storage and exchange of medical images. In our work we investigate if and how the DICOM standard can be adopted for thermal medical imaging.

The results of our study are encouraging. Virtually all information necessary can be embedded into DICOM based on the current version of the standard, including the actual image and temperature information (and the mapping of temperature values to false colours to be displayed), patient, study and clinician information and information on pre-defined regions of interest.

Based on the study, a conversion application capable of exporting CTHERM images to DICOM has been developed and will also be introduced.

DEVELOPMENT OF AN ANATOMICAL MARKER SYSTEM FOR THERMAL IMAGING DATA ANALYSIS FOR USE IN CRYOTHERAPY RESEARCH

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Introduction Cryotherapy is a well established treatment modality for the immediate care of acute soft tissue injury (Bleakley et al 2004). Currently, treatment protocols remain ambiguous. A skin surface temperature of 10 – 17ºC, is reported to reflect desirable underlying physiologic responses (Bugaj 1975, Knight 1976 and Zachariassen 1991), indicating the value of skin surface temperature data. Existing methods of TI data analysis lack standardisation and reliability. These methods are often dependent upon the opinion of the assessing reporter or incorporate irrelevant temperature data. The aim of this study was to develop an accurate and reliable method of TI data analysis based on an Anatomical Marker System (AMS) to define a precise region of interest (ROI). The focus is the Anterior Knee.

Methods Nine Patellofemoral Pain patients were recruited from Bolton PCT and Bolton Hospitals NHS Trust, England. Thermally inert markers were placed at specific anatomic locations, defining an area over the anterior knee. A baseline thermal image was taken. Patients underwent a 3 minute thermal washout of the affected knee, a technique developed specifically for this project using an Aircast cryo/cuff (Surrey, England) . Thermal images were collected at a rate of 1 image min-1 for a 20 minute rewarming period. A Matlab (version 7.0, The Mathworks Inc) program was written to digitise the marker positions and subsequently calculate the mean of the area over the anterior knee. Virtual markers formed an ellipse, defining an area representative of the patella shape. The mean value of the full pixels within the ellipse, determined the mean temperature of this region.

Results The ICC produced coefficients within acceptable bounds, ranging from 0.82 to 0.97 indicating clinically acceptable interrater reliability.

Conclusion The AMS provides an accurate, reliable and easily reproducible method for TI data analysis. The focus of this paper is the knee, however, principles of the AMS will be applicable at other anatomic locations, using a minimum of three markers to allow definition of an area.

HUMAN EXPERIMENTS IN A VACUUM-CHAMBER: TESTING PILOTS FOR EMERGENCY CASES

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The imagery of the thermal radiation of various objects in a defined range of the infra-red (IR) spectrum opens new vistas to researchers and practical specialists in the field of engineering and other sciences (medicine, biology, etc.). The devices creating IR-images, thermographs and thermogrammeters which convert the variation on the surface of objects' thermal radiation to visible image, i.e. thermogram, work in this principle.

The examination of the human organisms as a thermal system leads to various conclusions in the field of biology and medicine. The comparison of the IR-images to the results of medico- diagnostic examinations permits further conclusions or makes it possible to apply them as screening test. The paper presents an example on the possibilities of ergonomic-biologic examinations (the effect of changing ambient conditions) mainly from the aspect of thermal engineering.

Ergonomic personality test by means of IR-images. The different personality traits e.g. the way the individual reacts to various effect of the environment are well-known from psychology. However, this is not easy to determine such reactions without disturbing person by the use of instruments. In this cognitive process we can also avail ourselves of the information provided by IR-images. In case of emergency or simply when emergency is possible to occur, or in an less dramatic situation, e.g. when a question is put to someone in an examination, the reaction of individuals manifests itself in the change in the thermal state of the head, namely that of the face, forehead and/or in the eye-nook, as well as on the hands. The character and degree of the change in temperature is in connection with the reaction brought about in the course of solving the problem, or only by the state of preparedness, and it differs according to the individual, but it is characteristic of the person. However, the same symptoms are effected by the change of ambient temperature and pressure.

Pilot's test. In the case of an airliner's decompression the pilots have to tolerate some lack of oxygen (anoxia) at 0.5 bar pressure for approximately 15 minutes without any oxygen respiration. The temperature of the eye-nook and the forehead are adequate indicators of the human thermophysical condition. The pilots' reactions were tested in a vacuum-chamber. A figure shows the temperature change in the chamber vs. elapsed time from 'taking-off' to 'landing' without pressure equalizing. The model of decompression of an airliner's emergency case can be seen in function of altitude (chamber pressure) vs. time Pilot's thermal data (temperature of eye-nook and forehead) vs. process time serve as indicators of the pilot's adjustment to changing ambient parameters. The paper presents two series of IR-pictures taken of two pilots with different capability for adjusting to decompression.

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Session V: Clinical studies

INFRARED THERMAL IMAGING FOR THE DIAGNOSIS OF OSTEOARTHRITIS

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Osteoarthritis is the most prevalent rheumatic disease worldwide. It can be described as a pain syndrome based on degenerative changes of joints with episodic pain peaks due to inflammation. This combination may lead to deformity, muscle wasting, muscle weakness and to subsequent need of joint surgery.

What can infrared thermal imaging contribute to the diagnosis of osteoarthritis ? Firstly, the state of inflammation can easily be detected by the heat dissipated from the inflamed joint. Although osteoarthritis is not the sole cause of joint inflammation, temperature elevation seen in osteoarthritis is usually moderate, but rheumatoid arthritis, joint infection or gouty attacks present with a much higher temperature increase. Hot areas can easily detected over elbow, wrist, knee and ankle joints, but might be difficult to see over small finger joints, and are rare or nearly impossible to find over shoulder or hip joints or over the spine.

A cold water challenge can be useful in the identification of increased temperature over small finger joints as they show up very early in the recovery phase of finger temperature. Normally, fingers re-warm from the fingertips to the hand, but in case of inflammation this sequence is disturbed and the inflamed joints will appear at first.

In osteoarthritis of the shoulder or the hip, the area over the affected joint may appear colder than the contra-lateral side due to reduced muscular activity. Cold muscles may also be found adjacent to chronically inflamed knee or ankle joints which may therefore restricted in range of motion. In the first case the thigh may present with low surface temperature, in the other case the lower leg appears cold.

Thermal imaging is only helpful for diagnostic decisions, if the imaging and analysis of thermograms is performed under strict and standardised conditions. The protocol must include procedures and preparations for the object or subject to be imaged, the camera system and its calibration, the patients position for image capture and standards for image analysis. The protocol for image capture and image analysis that was developed at the School of Computing, University of Glamorgan, provides means to increase the reproducibility of measurements from thermal images. Thus applying strict protocols, increases the diagnostic utility of infrared thermography.

COMPARING THE RESULTS OF THERMOGRAPHIC, DERMATOSCOPIC, HISTOPATOLOGIC AND ELECTRON MICROSCOPY EXAMINATIONS OF SKIN MELANOCYTIC NEVI

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The aim of the study was to compare thermographic and histopathologic analyses of melanocytic skin nevi. In addition, the mitotic activity of cells was analysed by the expression of Ki-67 antigen in histopathological studies of few melanocytic nevi which showed temperature changes in the thermographic study.

Material and Methods: In total, 160 melanocytic nevi from 35 patients were studied. These included 22 patients with a diagnosis of atypical nevus syndrome. The thermographic analyses were performed using Therma CAM TM SC 500 thermographic camera. The thermograms were analysed using AGEMA Report 5.41 computer programme. The differences between maximal (Tmax) and minimal (Tmin) temperatures within each pigmented lesion were calculated: δT= Tmax-Tmin. In 20 control subjects healthy skin without melanocytic nevi was studied. In the total group of 160 melanocytic nevi, the values of δT coefficients were 1.41 °C. In total 47 melanocytic nevi showed signs of atypy in the clinical and dermatoscopic examination and were treated surgically in the Department of Dermatology and Venereology of Pomeranian Medical University. Subsequently histopathologic examinations of the excisions were performed. For the evaluation of the mitotic activity in 15 melanocytic nevi, the expression of the Ki-67 proliferative antigen was studied histochemically. Ten melanocytic nevi with δT>1.41°C and five melano- cytic nevi with δT < 1.0 °C were evaluated. Additionally, in five cases of skin melanoma the expression of Ki-67 antigen was investigated.

Results: Mean value of δT coefficient for control group was 0.74±0.128 °C, whereas for 141 melanocytic nevi δT < 1.41 °C and for remaining 19 nevi - δT>1.41 °C. The correlation between atypy in the histopathological examination and increased value of dT coefficients was noticed. For ten melanocytic nevi with δT > 1.41 °C, expression of Ki-67 was 1-9%, for 5 melanocytic nevi with δT < 1.0 °C the Ki-67 expression was 0-0.5%, whereas for 5 skin melanoma - 10-26%.

Conclusions: 1. Melanocytic nevi with δT >1.41 °C in thermo. graphic study shows frequently histopathological signs of cell atypy 2. The elevated values of δT could be caused by the increased mitotic activity of melanocytic skin nevi.

REGRESSION OF SKIN LESION IN PSORIASIS VULGARIS PATIENTS EVALUATED BY THERMAL IMAGING

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Psoriasis vulgaris is a chronic skin disease of inflammatory background involving about 2% of human population worldwide. The aim of the study was to evaluate usefulness of thermal imaging in psoriasis vulgaris lesion regression. Only in-patients with psoriasis vulgaris and negative history of join pain were included in the study. ThermaCam INFRAMETRICS 290E thermocamera with temperature resolution of 0.1 ^{o}C was employed. Both visual and thermal images of four body regions i.e. chest, back, upper and lower limbs of lesional and lesion-free areas were recorded and further analyzed. With the regression of skin lesions, a significant decrease in temperature was observed both over psoriatic skin lesions and lesion-free areas. What is more, a negative correlation between temperature and desquamation on the chest and between temperature and infiltration on the back were found. In conclusion, temperature monitoring in psoriasis vulgaris patients could serve as an early marker of remission or progression of psoriatic lesions on condition that proper patient preparation and equipment maintenance is continuously preserved.

THERMOVISION IN THE ASSESSMENT OF SUBARACHNOID ANESTHESIA EFFECTIVENESS

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(No abstract received)

COST-SENSITIVE CLASSIFICATION OF BREAST CANCER THERMOGRAMS

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In this paper we present an approach to cost-sensitive classification of breast cancer thermograms based on statistical image features and fuzzy logic. Thermography provides a real alternative to other methods such as mammography for diagnosing breast cancer as it is a non invasive technique that is able to detect physiological changes causes by early cancer growth.

In our approach we calculate several statistical features from the digital thermogram and use these in a classification stage to distinguish between benign and malignant cases. Image features including mean temperature, standard deviation, 90-percentile, temperature histograms, temperature co-occurrence histograms, entropy information and image moments, are calculated for both breast regions and bilateral differences between the two sides serve as features to be employed during the classification.

We use a fuzzy logic if-then rule based classifier to assign each thermogram as either benign or malignant. Crucially, the classifier we employ can be easily modified to provide a cost-sensitive approach to classification where the goal is not necessarily to maximise the overall classification rate but to minimise the overall cost. In cases such as cancer diagnosis clearly the associated costs for misdiagnosing benign and malignant cases should not be equal as falsely assigning a malignant case as benign will have more severe consequences than diagnosing a benign tumour as malignant.

Experimental results on a training set of about 140 patients give good classification rates of up to about 98%. Employing the cost-sensitive classifier gives similar classification performance but also provides greatly reduced overall costs on the same dataset.

INTERESTING CASE STUDIES USING INFRARED IMAGING FOR BREAST SCREENING

Gardner N.

San Rafael, California, USA

I will be presenting four case studies of interesting phenomena that will hopefully help to create a better understanding of what we are seeing in infrared imaging. My goal is to help create more uniform thermology reports as well as present my unusual patients. It is my feeling that in order for thermology to be accepted as an accompanying breast screening tool by the mainstream medical community, we need have a professional consensus of exactly what the different features that we are seeing in infrared imaging, represent. This presentation is an attempt to demonstrate my impressions of the data seen in thermology studies.

1.Paradoxical response to the autonomic challenge being a case of over stimulated sympathetic nervous system from exhausted adrenals.

2.Psydo-angiogenesis one of 72 case studies in the USA. This case study is presented with pathology report and medical description.

3.Hypo-metabolic thyroid seen in a thermography breast study where all of the hyperthermic features were extremely low approximately 31 C and the hypothermic features were approximately below 27 C.

4.Extreme case of hyper-metabolic lymphatic system indicated by the diffused hyperthermic features seen through out her entire body in a woman with extended exposure to environmental pollutions.

5.Case study monitoring a patient diagnosed with breast cancer over 20 years ago showing the natural progression of the disease with no medical intervention.

HYPER-METABOLIC LYMPHATIC SYSTEMS IMPAIRING VIEW OF VASCULAR FEATURES IN THERMAL BREAST SCREENING

Gardner N.

San Rafael, California, USA

I will be presenting five case studies of patients with varying ratings of breast thermology who have one thing in common, thermographic indications consistent with a hyper-metabolic lymphatic system. I will attempt to show two distinctive lessons that can be learned from comparison studies before and after a cellular detoxification protocol is adhered to: First of all, that a comprehensive cellular detoxification program, addressing the cleansing of all the organs of elimination, the lymphatic system and subsequent into intracellular tissue can and does strengthen the immune system and subsequently improve this hyper-metabolic condition of the lymphatic system. And secondly, by detoxifying the lymphatic system, thus eliminating excessive hyperthermic features seen in infrared imaging, it helps to distinguish what is truly characteristic of hyper-vascular features. The end results is a patient with a thermal study that is clearer and easier to read and thus easier to monitor improvement or advancement of the hyperthermic blood vessels.

ACTIVE DYNAMIC THERMOGRAPHY - A NEW QUANTITATIVE METHOD OF BURN DEPTH EVALUATION.

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Proper evaluation of the surface and depth of a burn wound especially in the case of a severe burn, enables an appropriate choice of treatment to be made. This choice decides subsequently about the success of the entire medical treatment. Clinical assessment is currently the most frequently applied method in burn depth evaluation. Unfortunately the use of this method results in a high number of false diagnoses. Numerous other methods have therefore been introduced, and none of them has been fully accepted by clinicians treating burns.

The goal of this work was to evaluate and compare the usefulness in burn depth assessment of selected modalities of infrared imaging (IRI), namely classical static thermography (ST) and active dynamic thermography (ADT), based on analysis of thermal transients after external tissue excitation using pulse optical heating. Commonly used clinical methods and histopathological assessment were taken as reference methods. To achieve the goal set an objective quantitative criterion for burn depth evaluation has been elaborated, so that the proper mode of burn treatment may be selected.

In this work the following methods have been employed: two clinical methods - the first according to clinical degrees of I, IIa, IIb and III and the second according to the criterion "Wound healing within 3 weeks after burn", histopathological assessment, ST and ADT. The methods presented were employed in in vivo animal experiments on 3 six-week-old white Polish landrace

domestic pigs, each weighing approximately 20 kg. Analysis was made of 23 burn wound inflicted according to the modification of Singer's procedure and 6 areas of unburned skin. The analysis also made use of bacteriological methods.

The animal experiment results obtained were subjected to statistical analysis by means of the Anova variance analysis method and by comparing the average post hoc values with Tukey's RIR test. The accuracy, sensitivity and specificity of the methods tested with reference to the characteristic sought, namely healing of the wound within 3 weeks of the burn, have been quantitatively calculated.

When the clinical method of discriminating grades of depth of burn wound was applied and a prognosis of healing result based on this, the calculated accuracy and sensitivity were low, at 62.5% and 44.2% respectively, but the specificity, at 100% was incommensurably high. These properties betray the limited usefulness of the method. When histopathological assessment was employed, the total number of accurate prognoses (the measure of the accuracy of the method) rose to 89.1% and sensitivity to 97.7% while specificity decreased to 71.4%. from these results it may be concluded that usefulness of the histopsthological assessment of burn depth is considerably greater than that of the clinical method.

One the basis of the bacteriological results the possibility of the thermographic results being influenced by the micro-organisms has been excluded.

The values obtained for the ST parameter, T, for both the groups involved when histopathological assessment was used, different at the level of statistical significance, ($p<0.001$). this demonstrates the high classificatory power both methods (ST and histopathological evaluation). The best results were obtained by correlating the ST method with the ex post classification into wound that did heal within 3 weeks following infliction and those that did not heal spontaneously during this period. The threshold value of the T parameter obtained T=0.3oC, enabled a "prognostic" classification to be made of the burn wounds into those that would heal within 3 weeks of burning and those that would not heal spontaneously in this time and, in consequence, also enabled a proper choice to be made of method of treatment.

The mean values calculated for the synthetic ATD parameter did not differentiate the burn wounds classified into clinical groups at the level of statistical significance. In contrast, however, they did differentiate in this way the groups established according to the histopathological criterion (shallower or deeper than 60% of dtms). When the ADT method is employed, the results of classification based on the histopathological criterion (60% of dtms) are identical to these based on the clinical criterion "healing within 3 weeks". The calculated threshold value of the time constant =10.125s and the quality of the method are as follows: accuracy - 100%, sensitivity - 100% and specificity - 100%. In the interpretation of these unusually advantageous results necessary caution should be maintained because of the relatively small number of cases.

In the conclusion it is stated that the clinical method in common use for dividing burns into degrees of I, IIa, IIb and III does not allow for an objective classification which is based on a quantitative criterion. Introduction of the IRI modalities as complementary methods does not improve the diagnostic value of the clinical assessment. In contrast, when the criterion of healing of the burn wound within 3 weeks of burning it does enable burn wound depth to be evaluated and, in consequence, a proper mode of treatment to be selected.

The histopathological assessment also discriminates the burn wound depth objectively and thoroughly. However, this method has many shortcomings which cause that is remains a reference for newly introduced methods but has marked limitations in routine application in clinical practice. Of the IRI modalities, ST allows for the objective discrimination of burn depth based on a quantitative criterion. The quantitative interpretation of the method is based on the difference between the mean values of skin area temperature for the burn wound area and the unaffected reference skin area (T), a parameter which depends closed on the influence of the environment. This should be regarded as a drawback of the method.

ADT as the single method of choice does allows for the objective classification of burn depth on the basis of a quantitative criterion. The optimal time for the investigation is the second day after the burn. The statistical analysis applied demonstrates the priority of ADT among all the methods investigated in this work. The quantitative synthetic parameter of ADT, the time constant measured in [s], supplies information about the basic physical thermal parameters of the tissue. Possessing all the advantages of ST, ADT is much less subject to the limitations of ST. when all this is taken into consideration it may be claimed that ADT meets to the highest degree the requirements of a modern diagnostic method which will evaluate burn depth and, in consequence, prove useful in the proper choice of treatment. It is concluded that IRI in its complex modern scope is of great use in the assessment of burn wound depth, especially in the face of the difficult and clinically crucial problem of making the appropriate choice of treatment.

Session VI: Fever screening, SARS / Avian Flu

THERMOGRAPHY FOR HUMAN TEMPERATURE SCREENING- INTERNATIONAL STANDARDS ORGANISATION PROJECT.

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Following the SARS outbreak in S.E. Asia, and the use of thermal imaging used to screen travelling populations for fever, a full report has been published by the Singapore Standards Organisation (SPRING). This report highlights the essentials for quantitative use of thermal imaging, and defines some of the standards required to discriminate febrile subjects from normals, based on elevated facial temperatures.

An international committee has been called to investigate the possibility of defining critical standards for both suitable thermal imaging cameras, and their method of employment, particularly in airports and ports. The threat of an avian influenza pandemic has given urgency to this working group.

Many different aspects of the SPRING report have been examined to adapt, where necessary, to an international standard applied to infrared imaging employed for fever screening. The improved performance and reducing costs of thermal imagers, increases their potential for more widespread use. However, many low cost systems are non-radiometric, and are therefore unsuitable for sale to airport and public health authorities for temperature measurement. It is also recognised that cooled detector systems, while giving excellent thermal and spatial resolution, suffer from the limited number of hours that the cooling system can operate, before expensive replacement. Un-cooled camera systems are more suited for continuous use, but may need to be used in conjunction with an external temperature reference source.

A further problem is the limited amount of published data on facial temperatures in fever, and any relationship between temperatures measured at the cranial face, compared to body core temperature. Some recent studies have been conducted in this area in the light of the current problem of febrile screening in humans.

Instrumentation tests have also been highlighted. If a large number of thermal cameras are in use, as could be the case in a busy airport, it will be essential to have a regular quality assurance programme for every camera system, and for replacements to be substituted in the event of failure to perform to specification at any point in time.

Large numbers of thermograms will be recorded every hour in this application, raising issues of data storage and retrieval. Possible legal action arising from passengers who experience delays caused by failure to pass the fever test, mean that very critical measurements are essential. To date, data is needed to establish that the observable differences in facial temperatures between normal and febrile subjects are actually measurable with radiometric cameras of high and stable performance, and the results will be of statistical significance. The standard draft document ISO/TC121/SC3 – IEC TC/SC62D JWG8 will be available for comment by experts in due course, probably during late 2006.

Plassmann P. Ring EFJ. Jones CD. Quality Assurance of Thermal Imaging Systems in Medicine. Thermology Int. 16.1.10-15.2006

FLIR SYSTEMS EXPERIENCE WITH SARS DISEASE

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(No abstract received)

FACIAL TEMPERATURE MEASUREMENT IN CHILDREN

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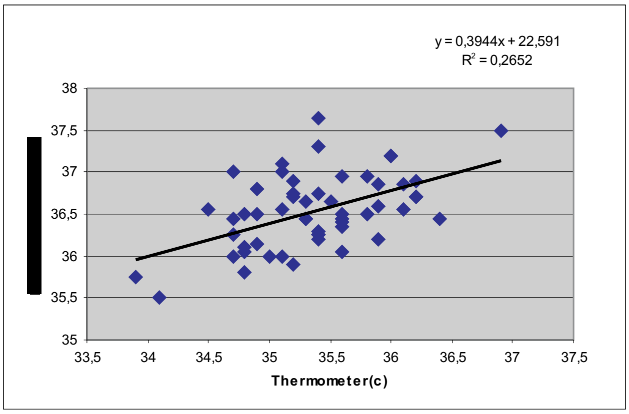
Recording of fever has traditionally been achieved by use of a clinical thermometer, either placed sublingually in the mouth, or by axillary placement under the armpit, to achieve as far as possible a closed cavity. Infrared thermal imaging offers rapid imaging of the human body surface. Recent SARS studies in South East Asia indicate that raised temperature over the face, particularly the forehead had been used in a screening operation to identify humans who may have a raaised temperature, and therefore potential sufferes of the acute resiratory syndrome.

We investigated the facial temperatures of 50 children aged who were in, or outpatients at the Pediatric Clinic in the Military Academy of Medicine in Warsaw. There were 25 female and 25 male children, age range from I month to 17 years, mean age 8 yrs 1 month. 2 neonates were not inlcuded in the calculation.

Facial thermograms were recorded in a stable room temperature at 22°C using a FLIR 350 small thermal imager. The camera was mounted on a table top tripod and the subjects were seated on a chair facing the camera lens. Axilla temperatures were recorded with a standard clinical glass thermometer for a full 3 minutes. Date of birth was recoded in all subjects.

Results. The mean inner canthi temperatures of all subjects were averaged between left and right eye. The mean eye temperature recorded was 35.36°C, and the mean of the axilla or underarm temperature was 36.54C, showing a mean tem,perature difference between the two measuremnts of 1.18°C. Two children were repeated after 2 hours, because they had raised eye temperatures, and had both been crying. This resulted in raised eye temperatures to over 37.0°C, although the axilla tempertures were normal. This could imply that a child subjected to thermal facial screening who had been crying would probably show a higher canthus temperature, close to 38°C. The results plotted in the figure show a poor correlation $R^2 = 0.265$ between the inner canthi and axilla temperatures in these children, none of which recorded as febrile during this short study.



A THERMAL IMAGE VALIDATION SYSTEM FOR MEDICAL INFRARED THERMOGRAPHY

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In medicine, body temperature measurements are expected to have an absolute accuracy of 0,2 oC; however, manufactures of thermal cameras quote an absolute accuracy of 0,2 oC near ambient temperatures. This is a problem for applications such as the detection, assessment and monitoring of localized scleroderma (LS) in children [1]. The changes caused by LS can potentially result in irreversible structural deformities, thus making it important to diagnose and stop development of the disease in its early stages.

Children with LS may be imaged over a period of years, placing particular demands an the reproducibility an reliability of the thermal imaging equipment. It is extremely important to be able to compare images, which have been taken at different times, accurately and to a common standard. This is even more important if images have been taken at different centers. To provide an acceptable level of measurement uncertainty the UK National Physical Laboratory (NPL) have developed and constructed a prototype 3-point blackbody references system to provide a calibration check of thermal imagers across the temperature range of 25oC to 40oC.

The system is being evaluated at various centers across the UK, including the Royal Free Hospital. One experiment to determine the utility of the system is presented. Figure 1 shows an image (Flir SC500) of normal hands held horizontally immediately after cold challenge (water at 15oC for 1 minute). The three temperature standards can be seen running vertically between the hands. Figure 2 shows the mean re-warming curve of the subject's hands after the cold challenge and the three reference temperatures (temperatures extracted using Flir Thermacam Researcher software). The dip at 9 minutes was caused by the subject's hair partly occluding the image. It can be seen that, even for a relatively straight forward medical application such as cold challenge test, the presence of the three calibration temperatures validates the data and makes it transferable between sites.

The system has proven to be sufficiently accurate, reproducible and robust for medical use. It should reduce the uncertainty of medical temperature measurement using existing infrared imaging technology to approximately 0.6oC or better within the 25oC to 40oC range. By adopting this equipment (once available commercially) it is hoped that the system will provide an exceptional in-house calibration method to help improve the reliability of thermal imaging in medicine.

Reference

G Martini et al, "Juvenile-onset localized scleroderma activity detection by infrared thermography." Rheumatology 41:1178-1182.2002

Session VII: Animal studies

RESEARCH REVIEW OF THERMOLOGY IN VETERINARY MEDICINE

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After 30 years of experience and use of thermology in veterinary medicine, we have chosen this opportunity to reflect upon the research questions that need further investigative studies. These studies must adhere to the highest standards of scientific inquiry, while meeting the scrutiny and requirements for publication in appropriate referred journals.

In addition to the already recognized, normal thermographic patterns in horses, we need to establish thermal patterns and dermatome patterns for the various animal species. This will be a challenge due to the potential use of pharmacological agents that can alter thermal patterns. The thermal variation among animal species, as well as within different breeds of animals, would provide significant contributions to the field of thermology. We have not developed suitable standards for various animals. Indoor thermal imaging standards for environmental control are well known, but we lack meaningful guidelines and standards for outdoor imaging. Skin thickness and hair coat in some animal species has been an extensively debated issue. There are some parts of the body where meaningful diagnostic thermography can be obtained, where there is a lack of hair coat, such as scrotal and perineal areas. In other cases hair clipping may be desirable to obtain diagnostic thermograms. Some animals are not calm and quite or easily controlled during clinical examination. This requires the use of sedatives and tranquilizers to make it easy to handle them. As we know, that same tranquilizer and sedative may alter thermal patterns and temperature gradients. Thus, we need to research appropriate sedatives and tranquilizers which can be used to calm the animal but does not have adverse effects on diagnostic value of the thermograms. We know that exercise, heating, cooling, and the use of tranquilizers before and after thermal examination has been efficacious for diagnosis of various neurovascular and inflammatory conditions. What are the additional challenges of testing that we can use to enhance thermographic examination?

In conclusion, as advanced portable equipment is now becoming available for use in veterinary medicine, do we have a need for standardization of this equipment, and if so, what can we do to make it easier for the practicing veterinarian to use them?

THERMOGRAPHIC EVALUATION OF CERVICAL DERMATOME IN THE BULL

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Neck injuries are not uncommon in some rodeo bulls. A bull was presented to the Large Animal Teaching Hospital with head carriage and slight head tilt after bucking. There were no changes in head tilt and carriage after 2 to 3 weeks post injury. The bull was in good physical condition other than the problem associated with the head carriage. Physical examination and history indicated some cervical neuropathy.

Thermographic evaluation was done using a Computerized Thermal Imaging Processor system. Facial views, along with right and left views of the neck and shoulder were obtained. Lower shoulder thermographic images left and right were similar in temperature and pattern. The left side cervical region (C1-C4) demonstrated warmer skin temperatures and a different thermal pattern when compared to the right cervical region.

Abnormal thermal patterns similar to cervical (neck) injury were observed. The bull had his head tilted more to the left and it seems that he was trying to relieve the pressure and pain presentation associated with the neck injury. In conclusion, both clinical findings and thermographic evaluation indicated neck and cervical area injury. Radiographic examination was postponed because bull weighed about 750 kg, obnoxious behavior, and it would require bull to be under general anesthesia. The bull was put on an anti-inflammatory drug and the owner was advised if condition persisted to return to the clinic in 90 days.

STANDARDIZATION FOR THE USE OF INFRARED THERMAL IMAGING IN VETERINARY MEDICINE

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In most mammalian species the body temperature is normally well controlled by its own metabolic state. The skin temperature is normally lower than that of internal tissues and depends not only on the metabolic state of the animal, but also various factors such as thermal conduction from heat sources within the body's vascular activity and just beneath the surface, heat losses due to evaporation, convection by air currents, or exchange of infrared radiation energy to the surroundings. Heat lost from the body by the exchanges of IR radiation with the surroundings is the basis of thermography. For this to occur, there must be a temperature gradient. The following criteria should be a minimum requirement for obtaining diagnostic thermograms:

1.The environmental factors which interfere with the quality of thermography should be minimized. The room temperature should be maintained between 21 to 26^0 C. Slight variations in some cases may be acceptable, but room temperature should always be cooler than body temperature and free from air drafts.

2.Thermograms obtained outdoors under conditions of direct air drafts, sunlight, and extreme variations in temperatures provide unreliable thermograms in which thermal patterns can be altered. Such observations may provide false information.

3.When an animal is brought into a temperature controlled room it should be equilibrated at least 20 minutes or more, depending on the external temperature from which the animal was transported. Animals transported from extreme hot or cold environments may require up to 60 minutes of equilibration time.

4.Other factors should also be evaluated so as not to effect the quality of the thermograms obtained such as hair coat, exercise, sweating, body position and angle, body covering, systemic or topical medications, regional and local blocks, sedatives, tranquilizers and anesthetics, vasoactive drugs, skin lesions such as scars, surgically altered areas, etc.

The value of thermography is its extreme sensitivity to chan- ges in heat, and its ability to detect changes. Therefore, it is important to have well documented, normal thermal patterns and gradients in a species prior to making any claims or detecting pathological conditions.

Session VIII: Final

STANDARDISATION OF THERMAL IMAGING- THE ANGLO POLISH REFERENCE DATABASE

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Despite the availability of infrared thermal imaging for medical investigation for 45 years, there is a notable lack of reference data for normal subjects. Human body temperature is known to be self regulating (homeothermic) and to remain within narrow range of temperatures in a healthy subject. Inflammation, reduced blood perfusion and a number of defined clinical conditions can affect skin temperature to a significant degree. Nevertheless, to use thermal imaging to study body surface temperature, strict protocols must be followed; to obtain the thermal sensitivity required for measuring the changes in the limited thermal range. Thermal imaging equipment has iIncreased thermal and spatial resolution, now attainable at lower cost than in the past. Even with the improved technical performance, there are a number of pitfalls to be avoided in order to obtain reproducible and reliable thermal data from medical thermography.

The Anglo Polish Project to investigate sources of error in order to develop a useful reference database of normal thermograms began in 2001 with funding from the British Council in Warsaw.

Over a three-year period eight stages for potential errors or artefacts have been identified.

1.Patient information and preparation for examination.

2. IR Camera systems and calibration.

3. Patient positioning & Image Capture.

4. Thermal image analysis.

5. Image storage.

6. Elec-tronic image exchange (radiometric)

7. Image presentation.

8. Information on protocols and learning resources.

Details of patient preparation are more widely known and published, but a number of issues arise in the choice of thermal camera and its reliable performance. Calibration procedures are usually well undertaken by the manufacturer, but unless a regular maintenance contract is held, most cameras drift over time, and may produce significant variability in performance and temperature measurement. Comparability between cameras is essential in any multicentre study, especially in the collection of a reference database of thermograms. Even the use of a pillar stand rather than a tripod can improve reproducibility for image capture.

Many variables occur in image capture, due to the position of the patient and the distance from the camera. The ambient temperature control is also important before and during the recording of thermograms. We have developed image masks in the software for each of the 27 standard views selected for the database. This also allows the standard regions of interest to be pre-selected, with reduction in reproducibility errors, and faster measurement.

In response to the final issue, we are publishing books and papers on the outcome of our study, relating to protocols and standardisation of technique. A regular training course in the UK (University of Glamorgan) also includes these protocols and information.

Of special importance is the need for the operator to carry out regular checks on the camera, since we have shown significant differences between cameras even of the same model, and major offset calibration differences over time. Time from switch on is also important and many operators assume that the image is stable and accurate very quickly. Some of these issues can be found on the website www.medimaging.org

EUROPEAN CONGRESS OF THERMOLOGY 1974-2006: A HISTORICAL REVIEW

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The **aim of this presentation** is to give a historical survey on the European Congress of Thermology, which was organized for the very first time in Amsterdam in 1974 and occurred then in a cycle of 4 years until 1994. The interval between congresses was changed to 3 years after the 6th Congress in Bath1994 and in this year 2006 the 10th congress takes place in Zakopane.

Methods: The presentations schedules of all the conferences, the lists of delegates, the books of abstracts, conference proceedings and photographs of congress participants were reviewed. Descriptive statistics were performed with respect to the origin of participants, number of participants and presentations per conference and topics of presentations.

Results: In total 9645presentations have been given at the first 10 European Congresses of Thermology. The congresses in Brescia in 2000 and this year in Zakopane had the smallest attendance, but the conferences in 1974, 1978, 1982 and 1986 attracted in each meeting 250 to 400 participants The conference delegates came from 30 different countries and 5 continents (Europe, North- and South-America, Asia and Australia). A wide range of topics was discussed including thermal physiology, thermal physics, methods of temperature measurement, clinical application of thermal imaging for diagnosis and as an outcome measure in breast disease, urology, neurology, rheumatology, pediatrics, dermatology, angiology and dentistry. Thermotherapy, hyperthermia treatment and use of microwaves as a diagnostic tool were other issues. Prof Francis Ring seems to be the only one who attended all 10 conferences.

Conclusion: Similar as the scientific literature on thermology, the history of the European Congress of Thermology reflects the ups-and downs of this discipline.