SATURDAY 18TH MAY 2002.
MEDICAL INFRARED THERMOGRAPHY

9.00-9.25 Registration and Coffee, Sheila Sherlock Centre Common Room

9.25 WELCOME
from KJ Howell, meeting organiser

9.30 KEY NOTE ADDRESS

The historical development of infra red thermal imaging in medicine
EFJ Ring

SESSION 1: INSTRUMENTATION AND CALIBRATION

Chair: G Machin

10.00 **Temperature traceability issues in medical thermography**
B Chu

SESSION 2: THERMAL IMAGING OF THE BREAST

Chair: KJ Howell

10.20 **Breast tumour detection using functional parametric thermographic imaging**
DK Harrison

10.40-11.00 Coffee and exhibitors: Common room

11.00 KEY NOTE ADDRESS

Thermography in surgery
Professor Sir Alfred Cuschieri

SESSION 3: THERMOGRAPHY IN RHEUMATOLOGY

Chair: EFJ Ring, JM Engel

11.30 **The relaxation thermogram after cold challenge test - graphical representation of relaxation velocities**
JM Engel

11.50 **The role of thermography in the diagnosis of reflex sympathetic dystrophy in clinical & forensic rheumatology**
AG White

SESSION 4: THERMOGRAPHY IN NEUROLOGY

Chair: PA Campbell

12.10 **Thermography in nerve root diseases**
P Dub

12.30– 1.30 Buffet lunch and exhibitors: Common room

1.30 KEY NOTE ADDRESS

The detection of human deception using thermal imaging.
JA Levine

SESSION 5: THERMAL PHYSIOLOGY

Chair: K Ammer, JR Harding

2.00 **A database of normal thermal images of healthy subjects**
K Ammer

2.20 **The effect of somatotype on thermograhic imaging of the back and whole body**
AI Heusch

2.40 **IRT - a valuable tool for evaluation of infrared radiation therapy (water filtered IR-A, broad band IR and low dose IR)**
JM Engel

3.00 – 3.20 Tea and exhibitors: Common room

SESSION 6: THERMOGRAPHY IN VASCULAR DISEASE

Chair: DK Harrison, KJ Howell

3.20 **Thermal imaging in the investigation of deep vein thrombosis**
JR Harding

3.40 **Thermographic imaging and skin oxygen saturation measurements applied to routine clinical prediction of amputation level viability**
DK Harrison

4.00 **Thermal imaging in diabetic foot ulceration**
JR Harding

SESSION 7: THERMOGRAPHY IN DERMATOLOGY

Chair: EFJ Ring

4.20 **The cold provocation test and Epidermolysis Bullosa Simplex**
AI Heusch

4.40 CLOSING ADDRESS

Future prospects for medical infrared thermography
KJ Howell

4.50 – 5.00 Update and discussion forum for UKTA Medical Section members

THE HISTORICAL DEVELOPMENT OF INFRA RED THERMAL IMAGING IN MEDICINE

EFJ Ring

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The observation of human body temperature and its relation to disease is as old as medicine itself. However, thermometry did not develop much before the 16th Century, and remained imprecise for over a hundred years. The first major progress to be made in the systematic study of body temperature was made by Carl Wunderlich in Leipzig. His treatise documented the basis of the clinical use of temperature recordings, and many hundreds of case studies were reported which were supported by charts of temperature changes from the patients studied, during onset, and progression of disease. Wunderlich also proposed the well-known clinical thermometer, which was designed to operate around 37°C with a constriction to act as a maximum thermometer.

Electrical sensors, thermocouples, thermistors and thermopiles were developed later. Many early physiological studies in the late 19th and early 20th century were made with multiple thermo-electric devices and multi-channel pen recorders to make a record.

Non-contact measurement became possible through the discovery and development of infrared radiation. In 1800 the heating part of the spectrum was identified, and in 1840 the first thermogram recorded using solar radiation. In the late 1950s indium antimonide detectors for remote sensing became available to industry and medicine. The Smith's Pyroscan was the first British camera to be manufactured for medical applications in 1960. Later developments brought faster scan times, and oscilloscope displays. Other infrared detectors including cadmium mercury telluride were introduced. More recently, uncooled and cooled focal plane array systems have been introduced which offer high speed and high-resolution imaging. Computer image processing has transformed the practical use of thermal imaging, with reliable facilities for temperature measurement.

Improved infra red optics and advanced processing for image manipulation have brought this technology to a high standard in under 50 years, and more improvements and miniaturization can be expected.

TEMPERATURE TRACEABILITY ISSUES IN MEDICAL THERMOGRAPHY

Brian Chu, Graham Machin.

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Manufacturers generally supply thermal imaging cameras in a calibrated state. Their performance is usually checked by the users either with their own in-house reference sources or by returning the imager to the manufacturer for re-calibration. This approach can have several drawbacks (a) If regular re-calibration isn't performed it is not possible to have confidence in the measurements performed by the imagers. (b) In-house calibration sources are not always traceable to the International Temperature Scale of 1990 (ITS-90), leading to a multiplicity of temperatures scales based upon the per- formance of the local standard. (c) Returning the imager to the manufacturer is no guarantee that rigorous traceability to ITS-90 has been achieved unless manufacturers calibration services are ISO 17025* accredited. In response to this issue, the UK Department of Trade and Industry (DTI) has funded a project to develop a blackbody reference source whose specifications are optimised for the calibration and traceability requirements of the medical thermography user community.

This paper consists of three parts. First an outline of the project is given. The second part contains the results of a survey, which was sent out to various medical thermography users both within and outside of the UK. The purpose of this survey was to identify current and future requirements for a reference source. Finally a proposed design for a suitable reference source is given. Once the source is constructed it will be circulated to two user groups within the UK who will test and evaluate the source to ensure it meets the functional and traceability requirements of the majority of the medical thermography user community.

* ISO 17025 is the recognised International Standard for demonstrating that a laboratory has the requisite competence and equipment to undertake traceable calibrations.

BREAST TUMOUR DETECTION USING FUNCTIONAL PARAMETRIC THERMOGRAPHIC IMAGING

DK Harrison, AIM Cook†

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Statistics show that 150,000 women die of breast cancer worldwide each year. According to the American Cancer Society, mammography misses 10 to 15% of breast cancers, but about 50% of diagnostic surgical open biopsies find non-malignant tumours. This combination of false positive and negative results, together with the desire to detect very small tumours (less than 1cm if possible) means that there is a need for improved non-invasive methods for breast cancer detection.

Medical infrared thermographic imaging has been applied in the past to the detection of breast tumours but the technique resulted in an unacceptable number of false positive results and failed to gain wide acceptance.

In the present study, thermographic images were recorded dynamically during the reheating of skin following cooling to 25°C. Pixel-by-pixel component analysis of the images was carried out offline in order to construct the functional parametric images. Normal volunteers were investigated using dynamic thermographic imaging of the left volar forearm skin under different experimental conditions. In a further pilot study 6 patients with known tumours were studied in order to investigate whether the lesions could be characterised by abnormalities in the parametric images.

The resultant parametric images display information on the heterogeneity of skin blood flow in the areas examined. The heterogeneities observed are very much greater than those obtained with static thermographic images and characteristic patterns appear to emerge under the different experimental conditions. In particular, the early parametric images of breast tumours indicate clear characteristic patterns.

DYNAMIC THERMOGRAPHY AS AN ADJUNCT TO ENERGISED SURGERY

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We have used dynamic infrared thermography in two distinct surgical contexts, (i) the laboratory based optimisation of energised instrument/device performance, and (ii) the real time in-vivo observation of energised [electro- and ultrasonic based] surgical instrumentation. The goal of both studies was to ensure that collateral damage induced by prolonged tissue heating is minimised, and therefore that the incidence of any subsequent complications is reduced.

The focus of the first study relates to our use of shape memory alloy (SMA) staples as an alternative to conventional suture line for minimally invasive [keyhole] procedures. This application is attractive as suturing in a keyhole environment is a particularly laborious and time consuming procedure. We will illustrate the principle of operation via infrared movies of the activation process, and highlight the method whereby quantitative dynamic thermography can aid instrument design and optimisation for in-vivo procedures. Computational finite element based analyses will also be illustrated

In the second part of the presentation, we will show the results of two large scale in-vivo case studies where thermography was used to monitor, in real time, the extent of thermal spread during activation of energised surgical devices. Subsequent histological analysis is compared with the recorded thermograms in order to correlate the thermal exposure with actual damage. We found that ultrasonic based devices can produce thermal collateral damage over wide areas of several centimeters or greater. However, with bipolar electrosurgical devices incorporating an intelligent feedback system, thermal spread can be as low as 0.65mm on certain vessels, and not greater than 1.8mm on vessels with diameters of up to 5mm.

We will illustrate the vessel dependent performance of one particular device (Ligasure), together with a thermographic based guide to best handling for optimum results.

THE ROLE OF THERMOGRAPHY IN THE DIAGNOSIS OF REFLEX SYMPATHETIC DYSTROPHY IN CLINICAL & FORENSIC RHEUMATOLOGY

AG White & KJ Howell

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Reflex Sympathetic Dystrophy (RSD), otherwise termed algodystrophy or complex regional pain syndrome I, is highly variable in both its presentation and severity. It involves most commonly upper or lower limb extremities and may follow trivial injury or major trauma, presents to many different specialties and is frequently diagnosed late, due to lack of sufficiently characteristic clinical signs.

In severe cases a careful history and meticulous examination will secure the diagnosis. When few physical signs are present yet pain is severe, investigations may fail to confirm the diagnosis as abnormalities present on radio-isotope scintiscan may have other causes. However the combination of the demonstration of increased deep blood flow in such a scan with evidence of reduced skin blood flow in an adjacent area of the same limb, provides much more convincing support for the diagnosis. Examples of this will be presented.

Owing to the freedom from ionizing radiation, thermography is attractive for follow-up investigation of RSD as the presentation will show, and offers an underused method of evaluating treatment modalities over which there is much dispute at present.

In recent years thermography has found wider applications in strengthening the evidence in support of the diagnosis of RSD in medico-legal medicine, with significant benefits to successful claimants.

THERMOGRAPHY IN NERVE ROOT DISEASES

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We performed an initial study, which should prove the usefulness of thermography in nerve root diseases. Unlike Xray-CT and MRI, thermography does not show anatomical changes of vertebrae or discs, but it may show the result—the involved nerve root can be seen as a colder area at the corresponding dermatome. The precise mechanism of this effect is still unknown, but our experience with 22 patients (and 17 students as a control group) shows that this effect is present.

At the beginning of our research we have concentrated on the problems related to herniated discs at the lower part of the back (mostly L4/L5 and L5/S1). Since corresponding dermatomes are situated on the patient's legs, we have used our ThermaCAM PM575 digital infrared camera to measure temperature changes in this area. The selection of legs is intentional, because corresponding dermatomes are larger than in other parts of the human body. Nineteen of the patients underwent surgical treatment of their disease and we made another measurement one week after the operation. Fourteen of them also underwent a control examination five weeks later. Our first results show that the area of decreased temperature is topologically correlated with dermatomes and therefore could replace EMG in diagnosis. This can be useful especially with patients who have AIDS, hepatitis or other infectious diseases.

We have made also a single long-term study. This 59-year-old male had nerve root disease, which could be seen by neither Xray-CT nor MRI, but was diagnosed by EMG. This patient was treated clinically. We have already made 58 measurements of this patient and the results show that the temperature difference of over 1°C has dropped to 0.4°C during the ten-month-long study. The temperature difference can be evaluated from any area in the given dermatome—it is independent of size of the area and position inside the dermatome, but the bigger the area is, the more precise (statistically) result we obtain. The overall changes of thermal pattern are in correlation with the patient's subjective feelings.

THE DETECTION OF HUMAN DECEPTION USING THERMAL IMAGING

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An instrument for automated, rapid mass screening for deceitfulness has obvious applications, but such an instrument does not exist. We explored high definition thermal imaging of the face by detecting deceptiveness because we had demonstrated in previous studies a specific, quantifiable, "thermal signature" in the face that accompanied fright. Were the same thermal signature to accompany lying, it might represent an opportunity to perform automated, instantaneous lie detection without physical contact and even without the subjects' awareness.

To examine whether thermal imaging of the face could be used to detect lying, we had volunteers commit a mock crime and then assert innocence under experimental conditions at the Department of Defense Polygraph Institute, US Army. Twenty volunteers were randomly assigned to commit a mock crime, whereby they stabbed a mannequin, stole $20 from it and then asserted innocence. Control, "innocent" subjects, had no knowledge of the crime or crime scene. The thermal imaging system correctly categorized 83% of these subjects; 6 of 8 guilty subjects were correctly identified as guilty and 11 of 12 innocent individuals were correctly characterized as innocent. Traditional polygraphs were performed by experts on the same subjects. The polygraphs correctly characterized 70% of the subjects; 6 of 8 subjects were correctly identified as guilty and 8 of 12 were correctly identified as innocent.

In this experiment, high definition thermal imaging of the face exhibited compatible precision to the traditional polygraph and warrants further investigation for detecting deceitfulness and lying.

Support:
NIH/RR00585, DK56650, US Army, Mayo Foundation, Honeywell Corporation.

A DATABASE OF NORMAL THERMAL IMAGES OF HEALTHY SUBJECTS

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The literature does not provide enough information on reference values of temperature distribution on the human body surface. Standardized positions of the body for image capturing and definition of reproducible placement of regions of interest (ROI) for temperature measurements can reduce systematic errors. Images captured and analyzed in a clearly defined protocol will show mainly the individual variations of temperature distribution, and deviations from these standard images would be suggestive for a physical dysfunction.

We established a protocol for capturing a series of images that covered the whole body of a healthy subject. The protocol defined a healthy subject as someone who had no problems with mobility, no difficulty in caring for himself, no restrictions in performing normal activities, experienced no pain or discomfort and was not suffering from anxiety or depression. A total of 24 views of the body were specified and within these views, a total of 87 regions of interest (ROI) were defined. The repeatability of some standard views by different investigators and the inter- and intrarater reliability of temperature readings from selected regions of interest was investigated.

The repeatability of standard views varies by the body regions investigated. However, standard views can be reproduced within a narrow range by different investigators. Interrater reliability coefficient alpha and intraclass correlation coefficient of the ROI "Lower Arm", and the hourglass shaped ROI at the anterior knee confirmed excellent repeatability of ROI placement. Reference values for the surface temperature of body regions based on images captured according to our protocol will reflect mainly the individual temperature variation.

THE EFFECT OF SOMATOTYPE ON THERMOGRApHIC IMAGING OF THE BACK AND WHOLE BODY

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The recent improvements in infrared camera technology and computer software have improved its reliability. We are currently involved in compiling a reference bank of standard thermal images of 'normal' people. We therefore decided to investigate the influence of Body Mass Index and somatotype upon the thermal image within 'normal' people.

Ethical approval was obtained from the University's ethics committee. The subjects were asked to refrain from exercise for twelve hours prior to imaging and the following modalities: Manipulation, electrotherapy, ultrasound, heat treatment, cryo-therapy, massage, acupuncture and hydrotherapy. They were also asked not to shower, bathe, sauna, shave, drink alcohol, or eat a large meal within four hours of their scheduled thermogram.

Thirty-four male volunteers (age range 19 - 45 years old) were imaged. The subject disrobed and equilibrated for twenty minutes within a stable environment (23.0 ± 0.5°C), without folding their arms or leaning against a surface. The whole body was imaged (ventral, dorsal and laterally) and the average mean temperature calculated. Also the standard image of the dorsal surface of the lower torso was taken and the average temperature for the paraspinal lumbar region calculated.

There was a significant relationship between Body Mass Index and lumbar paraspinal temperature (Kruskal-Wallis $p<0.03$). Therefore, consideration of body size is important in interpreting standard images.

THERMAL IMAGING IN THE INVESTIGATION OF DEEP VEIN THROMBOSIS

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Thermal imaging can have a useful role to play in the investigation of clinically suspected deep venous thrombosis (DVT).

When a patient presents with DVT, in addition to having a painful swollen lower limb, the patient is at significant risk of the serious, and frequently fatal, complication of pulmonary embolism (PE).

Effective treatment by anticoagulation dramatically reduces the risk of PE, but the treatment has risks of its own and is expensive and time consuming. Treatment, therefore, should not be undertaken without a confirmed diagnosis, particularly as there are a number of conditions which are clinically indistinguishable from DVT. Indeed, clinical diagnosis of DVT is notoriously unreliable, hence the need for accurate clinical tests to confirm or exclude DVT.

The most commonly utilised conventional imaging investigations for DVT, venography and Doppler ultrasound have disadvantages of their own.

Venography is invasive and exposes the patient to ionising radiation and risks of contrast allergy, dislodging of an embolus, cardiac failure, and development of DVT if not already present.

Doppler ultrasound avoids the risks of venography, but is operator dependent and can be very time consuming. This is where thermal imaging with its very high sensitivity for detection of DVT (approaching 100%) can have a place, by avoiding the need for conventional investigation in over one third of cases.

A negative thermogram effectively excludes DVT and no further investigation is needed. In addition to the clinical benefits to the patient, this can result in substantial savings in time and revenue.

THERMOGRAPHIC IMAGING AND SKIN OXYGEN SATURATION MEASUREMENTS APPLIED TO ROUTINE CLINICAL PREDICTION OF AMPUTATION LEVEL VIABILITY

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About 5% of British males over 50 years of age contract peripheral arterial occlusive disease. Of these about 2% ultimately require lower limb amputation. In 1995 we proposed a new technique using lightguide spectrophotometry to measure the oxygen saturation level of haemoglobin (SO_2) in the skin as a method for predicting tissue viability. This technique, in combination with thermographic imaging, was compared with skin blood flow measurements using the (I_{125}) 4-Iodoantipyrine (IAP) clearance technique. The techniques gave a sensitivity and selectivity of 1.0 for the prediction of successful outcome of a below knee amputation compared with a specificity of 93% using the "traditional" IAP technique at a below knee to above knee amputation ratio (BKA:AKA) of 75%.

The present study assesses the routine clinical application of these two techniques. The study is ongoing, but the data to date comprises 22 patients. 4 patients were recommended for above knee amputation (AKA) and 18 patients for below knee amputation on the basis of thermographic and tissue SO_2 measurements. All but one of the predicted BKA amputations healed. The study to date produces evidence of 94% healing rate (specificity) for a BKA: AKA ratio of 82%. This compares favourably with the previous figures given above.

THERMAL IMAGING IN DIABETIC FOOT ULCERATION

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3 Wound Healing Research Unit, University of Wales College Of Medicine, Cardiff, South Glamorgan.

Diabetic foot ulcers present a difficult problem in clinical management, promotion of healing not being easy because of increased risk of soft-tissue infection in diabetes plus impaired local blood supply due to diabetic vascular disease.

Infection of diabetic foot ulcers have particular risk of involvement of the adjacent bone resulting in the serious complication of osteomyelitis. This needs early aggressive antibiotic therapy to avoid even more serious secondary long term complications, but unfortunately clinical diagnosis and 'marker' blood tests such as ESR and C-reactive protein may be negative in early osteomyelitis, when antibiotic therapy is most likely to be effective.

The large number of patients plus the chronic and recurrent nature of diabetic foot ulceration precludes routine investigation for early osteomyelitis by x-ray, isotope bone scanning, or MRI in cases in the absence of positive markers, for logistic radiation protection and cost reasons. There is significantly increased temperature on infra-red imaging not only around the ulcer, but in the entire sole of the foot in patients subsequently confirmed radiologically as having early osteomyelitis.

Quantitative infra-red imaging in diabetic foot ulceration defines objectively whether or not early osteomyelitis is likely to be present, reducing morbidity and mortality by selecting those patients who will benefit from appropriate aggressive antibiotic therapy.

THE COLD PROVOCATION TEST AND EPIDERMOLYSIS BULLOSA SIMPLEX

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Epidermolysis Bullosa Simplex (EBS) is a skin disorder, where mechanical trauma can lead to blister formation. The blister occurs in the basal epidermal layer because of an autosomal mutation of epithelial keratins (K5 & K14). Diagnosis involves a biopsy of the blister. We therefore undertook a pilot study to investigate the potential use of thermography protocols in diagnosis.

Ethical approval was obtained from the University's ethics committee. Volunteers with confirmed EBS and age-matched controls (age range 23 - 76 years old) were imaged. On entering the stable environment of the thermography laboratory (22.0 ± 0.5ºC), the subjects sat and removed their shoes and socks. Their feet and lower limbs equilibrated for twenty minutes before imaging was commenced. Standard images of the plantar surface were taken. The feet were placed individually in plastic bags before immersing them in 'cold' water (20°C) for sixty seconds. The feet were then removed from the water and plastic bags before plantar surface images were taken every minute for fifteen minutes.

The average temperature for the balls and toes together (BT) and heels were calculated. The final temperatures for analysis were derived from deducting H from BT (BT-H) for pre and post- provocation test (5, 10 and 15 minutes). Subjects were then thermographically classified according to their feet's average temperature difference (post 5 - pre). Class 1 non-EBS, non heat stressed; class 2 EBS, non heat stressed and class 3 heat stressed feet. There was a significant difference between the classes (Kruskal-Wallis p = 0.007).

DEVELOPING MEDICAL INFRARED THERMOGRAPHY IN THE UK, EUROPE AND THE WORLD

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Today's varied meeting programme has demonstrated that thermography is now an established imaging technique in medicine. The availability in recent years of high-resolution infrared imagers at competitive prices has encouraged a wider adoption of medical thermography.

To accommodate this growing interest, an infrastructure exists for the dissemination of thermographic research. The International College of Thermology stages regular meetings, which are hosted in rotation by the American, Asian, and European associations. Intra-continental meetings are held more frequently, and a number of national associations also run regional meetings.

The international journal of medical infrared imaging, "Thermology International," is now an Embase-listed journal. An extensive archive of papers published in earlier journals (all now out of print) is available on CD-ROM.

Researchers in the UK have played a leading role in the development of medical thermography throughout its 40-year history. The Medical Section of the UK Thermography Association is affiliated to the European Association of Thermology. It exists to promote medical thermography in the UK, and currently has about 15 members. This does not reflect the current number of active medical thermographers in the UK, and we would hope to increase membership in the coming months.

Opportunities now exist in both the UK and continental Europe for formal training in medical thermography, so whilst the quantity of medical thermographers increases, the quality of their knowledge also improves.

Today's meeting has showcased the development of medical thermography worldwide, and highlighted a potentially bright future for the discipline in the UK.