2004 UK Symposium on Medical Infrared Thermography, 3rd November, Bushy House, NPL, Teddington, Middlesex, UK.

UK Thermography Association, National Physical Laboratory (NPL)

10.00 Registration, coffee and welcome

Session 1 Clinical applications of thermography

10.30 Cooling curves: is time important? *A Heusch*

10.50 Combined thermal imaging and colour duplex ultrasound assessments in renal fistula patients. *J Allen*

11.10 Thermography, photography, laser Doppler flowmetry and 20 MHz B-scan ultrasound for the assessment of morphoea activity: a pilot protocol. *K Howell*

11.30 Infrared thermal imaging and autologus breast reconstruction surgery. *J Mercer*

Session 2 Quality assurance and calibration

11.50 Reliability of quantitative measurements in medical thermography. *P Plassmann*

12.10 Quality assurance in medical thermography: is it necessary? *F Ring*

12.30 Medical infrared radiation thermometry – traceability and calibration. *R Simpson*

12.50 Lunch and tour of NPL radiation thermometry facilities

Session 3 Techniques, technology and resources

14.30 Trends in infrared detector and camera systems. *R Thomas*

14.50 Microwave radiometry technique for medical and industrial thermometry. *D Land*

15.10 Publications on medical infrared imaging from European countries. *K Ammer*

Session 4 Infrared image processing and computing

15.30 Compressing thermal medical images. *G Schaefer*

15.50 Registration of clinical photography and infrared thermograms. *C Jones*

16.10 Thermal medical image retrieval by moment functions. *S Y Zhu*

16.30 Open forum discussion / close

COOLING CURVES: IS TIME IMPORTANT?

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The time required for the body to equilibrate with its surrounding temperature is an accepted factor in the production of a standardised thermogram. If the environment is at a different temperature to that of the body, the body will try to compensate. This means that there will either be no change, an increase or a decrease in radiated heat from the body. At present, neither the time required nor the factors which might affect this have been scientifically determined, however, it is often stated that one should wait at least 15 minutes before imaging.

Sixteen volunteers gave their written consent before participating in this ethically approved project (School of Applied Sciences Ethics Committee). The subjects disrobed to the required level and thermal images were taken every five minutes for an hour (laboratory temperature 22.1°±1.2°C, outside temperature 9° ±2°C). A standard protocol was used to minimise non-biological variance.

The neck was found to increase in temperature over the time of assessment, yet the difference (comparing right side to the left) for the majority of the subjects was 0±0.3°C, irrespective of the cooling time allowed. The thoracic region showed a slight cooling effect, whereas the lumbar was variable. Between 15 and 30 minutes appears to be relatively stable period.

We conclude that the 3 gross anatomical regions of the back appear to vary in their reaction to being disrobed in a controlled environment. Although this data suggests that separate regions of the body might require different standardisation protocols, as yet there is not enough data for use to propose a region specific cooling time.

COMBINED THERMAL IMAGING AND COLOUR DUPLEX ULTRASOUND ASSESSMENTS OF RENAL FISTULA PATIENTS

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Vascular and clinical assessments of fistula function are important in patients undergoing or preparing to undergo renal dialysis. Objective assessments at Freeman Hospital now include combined colour duplex ultrasound and medical thermography. For example, these modalities can help study problems relating to high fistula flow and vascular steal, where digital blood flow (and hence skin temperature) can be impaired. The aims of this pilot study were a) to determine if fistula region skin temperature was related to fistula region blood flow and b) to compare simple differences in mean hand temperature against the clinical steal grading.

Renal patients were clinically assessed for vascular steal by the transplant surgeon (either steal or no steal). Patients also underwent objective vascular measurements which comprised thermal imaging of the hands and fistula region followed by fistula blood flow estimation using colour duplex ultrasound at the brachial artery. Differences in hand temperature and mean fistula region temperature were determined using dedicated image processing software (FLIR SC300 thermal imaging system with ThermaCam Researcher image processing software, skin emissivity 0.97). These temperatures were then compared with fistula flow and steal grading.

Twelve patients were studied (mean age 59 years), with five classed as having some degree of steal. Ultrasound measurements also identified the presence of stenosis in three patients. Estimated fistula flows ranged from 30 - 1950 ml min (mean [standard deviation] of 1100 [640] ml min) and were correlated with mean fistula region skin temperature ($R = +0.6$, $p<0.05$). Thermography usually clearly highlighted the warmer superficial blood vessels in the region of the fistula (33.7 [1] °C). Hand (non-fistula – fistula side) temperature differences with a cut-off of +1 °C were found to separate steal from non-steal patients with an accuracy of 92% (specificity 100%, sensitivity 80%). In this study the maximum difference between mean hand temperatures for a patient with steal was close to 5 °C.

We have demonstrated an association between fistula region skin temperature and estimated fistula blood flow. We have also shown that a bilateral hand temperature difference cut-off of +1 °C separates steal from non-steal patients with an accuracy of greater than 90%. Further work is now needed to explore the clinical utility of these findings, to identify which patients subsequently needed surgery, and also to examine the detailed characteristics of the fistula thermal profiles.

THERMOGRAPHY, PHOTOGRAPHY, LASER DOPPLER FLOWMETRY AND 20 MHZ B-SCAN ULTRASOUND FOR THE ASSESSMENT OF LOCALISED SCLERODERMA ACTIVITY: A PILOT PROTOCOL

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Background Localised scleroderma (LS) is a rare skin disorder characterised by an initial phase of inflammation, followed by progressive fibrosis (which can affect both the skin and underlying tissues), and ultimately atrophy. Infrared thermography (IRT) has been shown to be of value in the detection of active LS lesions in children. Plaques with a temperature >0.5°C warmer than adjacent or contralateral uninvolved skin can be considered "thermography +ve." On this basis, a positive thermogram detects clinically active LS lesions with a sensitivity of 92% and a specificity of 68% (*Martini et al, 2002). Skin surface temperature is influenced not just by dermal blood flow, but also by the morphological skin changes that can occur in LS. Increased heat transfer through the skin in older, clinically quiescent lesions associated with fat and muscle atrophy has been thought to be the reason for "false-positive" thermograms.

Method We have evaluated a new protocol for the assessment of LS in children. This combines IRT with laser Doppler flowmetry (LDF, a measure of microvascular skin erythrocyte flow), 20 MHz B-scan ultrasound (US, a technique for imaging skin structure), and digital photography (to record the extent of the clinically visible lesion). The digital images are superimposed on the infrared thermograms to assist the physician in relating the anatomy to the extent of skin involvement.

We re-assessed 15 clinically quiescent LS patients who were found to have "false-positive" thermograms on previous assessment by IRT (11F, 4M,). Up to 3 involved skin sites from each patient were selected for assessment by IRT, LDF and US. Equivalent measurements were also made from contralateral or adjacent uninvolved skin. Each involved site was re-assessed by two experienced clinicians to confirm that the area had remained clinically quiescent. Only data from such quiescent sites was included in our analysis. We calculated temperature data from the infrared thermograms at each skin site, and also LDF flux data from each site. All involved LS sites were then grouped into those that remained "thermography +ve" and those that were reclassified "thermography -ve."

Results The difference in LDF red cell flux between involved LS skin and contralateral/adjacent uninvolved skin was expressed as a percentage of the flux in the uninvolved skin. The mean (± standard deviation) flow difference for the "thermography +ve" group was 131 ± 153% versus 11 ± 51% for the "thermography -ve" group (p<0.004, t-test)

Conclusions Microvascular skin blood flow is increased in thermographically warm LS plaques that are considered to be clinically quiescent. This may suggest residual disease activity and could have implications for the length of medical treatment. Our protocol shows promise for the assessment of skin structural changes and blood flow in LS. Overlay of clinical photography onto thermograms improves the utility of thermography for monitoring LS plaque extension. Further work is in progress to refine our imaging techniques in order to define whether the increase in blood flow observed is related to inflammation or to structural changes.

*Martini et al, Rheumatology 2002;41:1178-1182

INFRARED THERMAL IMAGING AND AUTOLOGUS BREAST RECONSTRUCTION SURGERY

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Background and purpose

Autologus breast reconstruction has become an integrated part in the overall treatment for breast cancer patients who have had a mastectomy. Many studies have demonstrated the psychological, cosmetic, and sexual benefits of post-mastectomy breast reconstruction. One of the standard methods is to reconstruct a new breast using tissue removed from the patient's own abdominal wall (skin and underlying fat). Two different procedures may be used with regards to the preparation of the abdominal skin flap: (a) a free transverse rectus abdominis musculocutaneous (TRAM) or (b) a deep inferior epigastric perforator (DIEP) flap. In both cases patients are specifically pleased with the natural shape, soft consistency and permanency of the end result. However, there is a recognised incidence of partial flap necrosis in both the TRAM flap and the DIEP flap: this is more likely in smokers and the obese. A critical period during the operative procedure occurs during the re-connection (anastomosing) of the harvested flap. Blood circulation to the newly reconstructed breast is dependent on the viability of the microvascular anastomosis. Having an efficient non-invasive technique to monitor the blood flow status of the flaps used in autologus breast re-construction would provide invaluable information during such a procedure and may well help to reduce the incidence of post-operative complications. We wished to find out whether Infared (IR) thermal imaging (IR-thermography) could provide this possibility.

Method

Infra-red thermal images of selected skin areas in patients undergoing autologus breast reconstruction surgery using the DIEP flap method were taken prior to, during (to check circulation in the stomach flap when the blood supply is reconnected to the mammary artery) and in the days, weeks and months following surgery (to monitor blood flow status in the newly constructed breast). All IR-images were taken using a Nikon Laird S270 (Tokyo, Japan) IR-camera. This camera is a so-called 2 generation IR-camera that is capable of producing high-definition digital infrared thermal images. The images were stored electronically. For processing of the IR digital images we used image analysis software PicWin-IRIS (EBS system technik GmbH, München, Germany), which could produce measurements of skin surface temperatures to an accuracy of 0.1ºC. IR-images were taken under both steady state conditions as well as following a mild cold challenge. This latter procedure called dynamic IR-thermography, basically consists of activating the sympathetic nervous system by challenging the body with a cold stimulus (e.g. short period of fan cooling) and taking a series of images during the spontaneous recovery (re-warming) period. This technique allows one, for example, to more easily identify so-called perforatoring vessels of the medial and lateral branches of the deep inferior epigastric artery, one or more of which will be selected for re-connection to the internal mammary artery (the usual recipient vessel) during surgery. IR-thermography during surgery was used to indirectly monitor the blood flow status of the DIEP flap following re-connection of its blood supply to the internal mammary artery and associated veins. Dynamic IR-thermography was also performed during the post-operative period to monitor blood flow status in the newly constructed breast.

Results

In the pre-operative situation the use of IR-thermography to identify perforating vessels in the abdominal tissue was found to be helpful to the surgeons. The number and distribution of the perforating vessels varied greatly from patient to patient. During the operation the dissected flap cools down during the period it is not receiving a blood supply (ca. 50 min.) The rate and pattern of the re-warming in the flap after anastomoses to the recipient vessels gives a very clear indication as to how good blood circulation is in the DIEP flap. With a successful and adequate outcome of the anastomosis process the re-warming response was found to be rapid and well distributed. A poor re-warming response often resulted in anastomosing an extra vein to improve venous drainage (the most common problem). In the days following surgery IR-thermography of the new breast was found to be a quick and easy way to monitor its blood flow status, especially in the peripheral areas of the implanted flap, where reduced blood circulation often occurs. The easily understandable visualization of blood flow in the newly constructed breast using IR-thermography was also found to be comforting for the patients during the post-operative period.

Conclusions

During surgery IR-thermography was found to be particularly useful for monitoring blood flow status of the DIEP flap immediately after re-connection of its blood supply to its recipient vessels. The use of IR-thermography as a non-invasive indirect method of monitoring blood flow status in autologus breast reconstruction surgery is clearly beneficial, both to the surgeon as well as to the patients

RELIABILITY OF QUANTITATIVE MEASUREMENTS IN MEDICAL THERMOGRAPHY

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This paper describes two experiments designed to establish the measurement accuracy (bias, offset) of 4 thermal imagers after switching on and over a temperature range between 22 ºC and 42 ºC. A highly accurate Thermal Imaging Black Body (TIBB) reference source developed at NPL was used to test the imagers. Results demonstrate that imagers may drift considerably during the first 2 hours after switching on (up to 5 ºC). Results also show that over the normal human range of temperatures the offset error of the 4 systems under test is not necessarily constant or even linear. This means that absolute inter-image or multi centre measurements can not be made reliably. It also demonstrates that precise intra-image measurements can also be unreliable in spite of the fact that the imagers under test were within their respective manufacturer's specification.

The authors therefore recommend the use of external calibration sources in order to achieve repeatable results where high accuracy is required. A simple 3-point source based on the triple point of chemical compounds is suggested.

QUALITY ASSURANCE FOR MEDICAL THERMOGRAPHY, IS IT NECESSARY?

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Imaging systems for infra red thermography are able to provide two dimensional temperature maps. In medicine, it is possible to simultaneously record a large number of temperature measurements and their distribution over the human body surface. Most clinical thermographers are aware of the complexities of imaging curved surfaces, and of the need to examine the patient in a stabilised thermal environment.

Infra red imaging systems have advanced to a remarkable degree in the last decade. Focal plane array detectors are able to produce high resolution images at high speed. However, the size of the detector array and the stability of the camera system vary according to manufacturer and cost. Furthermore, not all systems are designed to provide radiometric measurements, even though the visual image may appear to be of good quality.

An early study performed in 1977 with a heated spatial resolution chart showed how the earlier scanning systems were dependent on distance from the object. Small fields of view 20x20cms often resolved a 2 mm bar on the target, while increasing the distance to image a 30x30 target area of the same area resulted in a marked loss of spatial resolution, which may be biased vertically, horizontally or both. Linearity of field was also tested by the same system.

More recently Ring and Dicks (1999) demonstrated the variability in spatial resolution using a smaller heated target. The focal plane array cameras were compared with an older scanning single element detector camera.

A current study with this thermal target has been used to identify a developing fault in a focal plane array camera, and to compare performance with a low cost low resolution camera using external calibration sources.

These results highlight the need for external monitoring of thermal imagers, which may drift in performance over time, and are undetected until a major fault is evident.

For collaborative studies, such as the Anglo Polish normals atlas project, it is clearly essential to carry out regular calibration to a single traceable temperature reference, and to monitor stability of the system before thermograms captured at different centres can be amalgamated for processing.

References.

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2. Spatial Resolution of New Thermal Imaging Systems Ring EFJ Dicks JM. Thermology international 9 1, 7-14 1999

MEDICAL INFRARED RADIATION THERMOMETRY – TRACEABILITY AND CALIBRATION

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Infrared radiation (IR) thermometry offers a rapid and non-contact means of measuring patient temperature. In the clinical environment IR ear thermometer devices help to reduce time-scales and cross contamination and provide good diagnostic information; for example, an ear thermometer measurement takes ~ 5 seconds and uses disposable caps, whereas a mercury-in-glass thermometer needs a measurement time of ~ 5-10 minutes and requires sterilisation. In addition thermal imagers are increasingly being used to help diagnose a number of physiological conditions (for example, Raynaud's syndrome) following advances in technology and reductions in imager cost. With the devices being used in critical monitoring and measurement applications good measurement practice is very important.

The accredited calibration of IR thermometers and thermal imagers used within the clinical environment is key to ensuring that a traceable, accurate temperature is provided. With this in mind the NPL has produced three blackbody sources to provide calibration facilities for medical IR thermometry. The first is a novel fixed-point blackbody source operating at 36.3 °C, designed for rapid in-field ear thermometer validation. This source is backed up by a variable temperature blackbody source meeting the CEN requirements for the calibration of ear thermometers and having a range of 15 to 45 °C with an uncertainty of 0.04 °C (k =2). The third source is a variable temperature blackbody for the assessment and calibration of thermal imaging cameras, with a temperature range of 0 to 80 °C and an uncertainty of 0.03 °C (k = 2).

MICROWAVE RADIOMETRY TECHNIQUE FOR MEDICAL AND INDUSTRIAL THERMOMETRY

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Microwave radiometry provides a non-invasive, non-destructive and inherently safe method of temperature measurement for a range of medical and industrial applications. The radiometric temperature of a volume of material is measured by coupling to its microwave thermal radiation field using antenna or cavity type structures, and measuring the equivalent temperature of the coupled signal with a microwave radiometer receiver. At frequencies below about 6 GHz body tissues and many natural materials are partially transparent to electromagnetic radiation. The dielectric properties of these materials at the lower microwave frequencies are such that generation and transmission of microwave thermal radiation occurs over distances of about the radiation wavelength in the material allowing tight coupling to temperature patterns over depths of up to several centimetres in human tissues. This strong coupling of measuring radiometer to source material distinguishes microwave radiometric measurements from surface radiant or contact thermometric techniques.

For microwave radiometric temperatures to be compared between different measurement systems or compared with other thermometry measurements it is essential that the matched-impedance maximum power transfer temperature is measured. The electromagnetic impedance of the source material region usually differs significantly from that of the coupling antenna or cavity structure and may vary during the measurement process. The radiometer must be capable of measuring a true matched-impedance signal temperature in the presence of a significant and variable source impedance mis-match. Since the receiver measures a thermal radiation signal there must always be a natural fluctuation of the measured temperature value. This imposes the natural Gabor limit on the temperature resolution that can be achieved and for efficient measurement the receiver must be designed to operate close to this limit.

The radiometric temperature of a source volume is determined by a convolution of the material temperature pattern with a coupling spatial response or weighting function within the material. The form of this weighting function depends on both the radiation coupling structure and on the geometry and dielectric properties of the coupled material. Through the reciprocity principle the weighting function is identical to the normalised power dissipation distribution in the material when the coupling structure is actively excited. The weighting function can thus be found by analytical or computational modeling or by measurement. When known it can be applied at one or several frequencies or combined with thermal modeling to interpret measured radiometric temperatures in terms of estimated material temperature patterns.

PUBLICATIONS ON MEDICAL INFRARED IMAGING FROM EUROPEAN COUNTRIES

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A literature search was performed in the section" 1996 to 2004 week 28" of the database Embase using the key words "thermography" or "thermal imaging" or "infrared imaging". 589 publications were found betweeen 1999 and week 28 of 2004. The resulting list of publications was matched with the field "institution" showing one of the following European countries (hits in brackets): Austria (22), Belarus (0), Belgium (11), Bulgaria (1), Croatia (2), Cyprus (0), Czech Republic (4) Denmark (5), Estonia (0), Finland (5), France (19), Germany (52), Greece (14), Hungary (3), Ireland (0), Italy (21), Latvia (0), Lithuania(0), Malta (0), Netherlands (9), Norway (4), Poland (24), Romania (0), Russia (0), Slovenia (0), Slovak Republik (0), Spain (13), Sweden (2), Turkey (7), Ukraine (0) and United Kingdom (47). In addition, all issues of the journal Thermology international from 1999 on were searched for full length articles written by European authors.

265 of 589 publication found in Embase were of European origin and 55 of 66 articles in Thermology International were submitted by authors from Europe. The main applications of thermal imaging in clinical medicine were angiology, locomotor diseases, paediatrics and surgery. Physiology, infrared equipment and other methods than infrared were the topics of the remaining publications. In the reviewed period of 5 years, Thermology International did not attract authors from France, Spain or the Netherlands, but was well accepted by thermographers from Poland, United Kingdom and Austria. A total of 39 papers were published from these three countries. The main topics were similar to the papers found in Embase.

COMPRESSING THERMAL MEDICAL IMAGES

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In recent years, there has been a resurgence of interest in the application of infrared thermal imaging in medicine due to improvements in camera technology and the promise of reduced costs. Due to this increased use factors concerning the storing of thermal medical images have become an issue with one of the most prominent of these factors being the storage space used by the images. Hence, in order to reduce the demands on hardware resources compression of the data seems necessary. For images there are two categories of compression algorithms: lossless techniques which preserve all information and lossy algorithms which sacrifice some of the visual quality to gain in terms of compression rate. For medical images typically lossless techniques are employed so as to make sure no image features are remove or distorted. However, lossless image compression achieves only a compression ratio of about 1:2 which is in stark contrast to lossy techniques which provides compression with ratios up to 1:100.

In this paper we apply the recently released JPEG2000 compression standard to thermal medical images. We utilise the lossy mode of JPEG2000 together with its ability of Region of Interest (ROI) coding which allows certain parts of an image to be coded at a different (higher) quality than the rest. The ROIs are obtained following recent work conducted at the University of Glamorgan which defines a set of standard views for thermal medical imaging together with a series of interest regions within each of the views. Coupling these with JPEG2000 allows high quality coding of thermal images with compression rates far beyond the ability of lossless algorithms.

REGISTRATION OF CLINICAL PHOTOGRAPHY AND INFRARED THERMOGRAMS

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Here we describe an application designed for registration of clinical photography and infrared thermograms. For direct comparison of images, registration is necessary to account for differences in camera positions, lens types and resolution. The infrared image is geometrically transformed so that it can be directly overlaid on the clinical photograph. The transformation is computed from reference points present in both images selected manually by a clinician. Three transformation types (Rigid, Affine and Projective) are compared and the merits of each are discussed along with the limitations.

THERMAL MEDICAL IMAGE RETRIEVAL BY MOMENT FUNCTIONS

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Past efforts on the automated processing on medical infrared images has typically focused on specialized applications like the detection of breast cancer. We propose the application of content-based image retrieval (CBIR) to medical thermal images. One main advantage of using this concept is that it represents a generic approach to the automatic processing of such images. Rather than employing specialised techniques which will capture only one kind of disease or defect image retrieval when supported by a sufficiently large medical image database of both 'good' and 'bad' examples will provide those cases that are most similar to a given one. CBIR allows the retrieval of similar images based on features directly extracted from the image data. Hence, image retrieval for a thermal image that shows symptoms of a certain disease will provide visually similar cases which will usually also represent similarities in medical terms. The features we propose to store as an index for each thermal image are a set of combinations of moments of an image which are invariant to common factors and operations such as scale, translation, and rotation. Each thermal image is characterized by such a set of moment functions. Image retrieval is performed by finding those images whose moment descriptors are closest to the ones calculated for a given query image.