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Quality assurance for
a multi-centre thermography study

EAT 2018-Introductory Thermography Course Syllabus

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CARE (Consensus-based Clinical CAse Reporting Guideline Development) for case or care reports [6]

SPIRIT (Standard Protocol Items: Recommendations for Interventional Trials) for study protocols [7]
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In general, manuscripts hould be organized as follows: Introduction, methods, results, discussion, acknowledgements, references. A short abstract in English and, if possible, German (translation will be offered) should head the manuscript. Following the abstract, up to 5 key-words should characterize the paper.

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Chapter in a book
Gautherie M, HaehnelP, Walter JM, Keith L. Long-Term assessment of Breast Cancer Risk by Liquid Crystal Thermal Imaging. In: Gautherie M, Albert E, editors. Biomedical Thermology. New York Alan R.Liss Publ; 1982. p. 279-301.

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[2] www.consort-statement.org

[3]www.strobe-statement.org

[4]www.prisma-statement.org

[5] www.stard-statement.org

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[7] www.spirit-statement.org

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Current Trends in Medical Thermography: Quality Assurance and Data Mining

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The international guidelines for the evaluation of measurement data states "*When reporting the result of a measurement of a physical quantity, it is obligatory that some quantitative indication of the quality of the result be given so that those who use it can assess its reliability. Without such an indication, measurement results cannot be compared, either among themselves or with reference values given in a specification or standard*" [1]. The uncertainty of measurement depends in its widest sense on many conditions. Quality assurance procedures are employed to describe the uncertainties of defined measurement conditions. This is an important prerequisite for the credibility of temperature readings from thermal images in medicine particularly when they contribute to diagnostic or therapeutic decisions.

In this issue Howell and colleagues report the results of quality assurance targeted to the performance of infrared cameras employed in a multi-centre study for assessing Raynaud´s phenomenon [2]. This study confirmed a start-up drift in 5 of 6 evaluated cameras and found the bias of repeated temperature measurements within the limits of manufacturer´s specifications in 5 of 6 imaging systems. In the repeatability experiment it was also observed that the mean of the differences was not constant indicating a likelihood that the overall limits of agreement are somewhat too wide for low temperatures, and too narrow for higher temperatures. Different offsets in the tested temperature bands might reflect different algorithm used inside the camera types. The authors emphasise that the camera performance is not the only source of uncertainty of temperature readings.

This condition is not recognised in paper which reported the reliability of temperature measurements on the plantar foot of diabetics recorded with infrared thermal images [3]. Whilst biographic data of patients, their preparation prior to and foot position during image capture, camera specifications and condition of blinding observers during image analysis are almost completely reported, the procedure of temperature extraction from thermograms is not sufficiently described. Although a map with the location of temperature measurement is provided and the software named, the way of temperature measurement remains unclear. Spot temperature measurement might have been performed, however, the size of the measurement area is not reported. It might have been a circular measurement area of sufficient size to allow extraction mean, minimum and maximum temperature. There is also no information on placement of measurement areas within the regions of interest, and no rules are described how the exactly same position of the region of interest can be achieved in repeated evaluations. Without controlling the location of measurements, it remains uncertain whether the observed level of reliability is true or occurred just by chance.

Gatt et al. reported foot temperatures of diabetics with and without arteriopathy. Automatic segmentation was employed for the definition of measurement areas [4]. However, the authors concealed the success rate of the segmentation algorithm in the investigated sample. In a previous study by the same authors, the failure rate of foot segmentation was 10%. In addition, automatic definition of measurement areas cannot compensate the influence of foot deformities on the plantar temperature profile. In a case with higher temperature of ischaemic than the well perfused foot, the silhouette of the non-ischaemic foot is very similar to the appearance of a pes cavus. The different geometry between the rather flat ischaemic foot on the right and the pes cavus on the left affects with high probability the thermal image of the feet.

Another trend in medical thermography is represented by software packages designed for automatic analysis of thermal images, often combined with methods for data mining [5]. However, computer assisted evaluation of infrared thermal images developed in the late seventies and early eighties of the 29th century, when the pioneers in medical thermography developed their own software solutions for clinical applications, independent from commercial software packages offered by camera manufacturers. The heat distribution index can be regarded as an early example of analysing temperature distribution in thermograms recorded in humans [6,7]. Clark et al developed software for the analysis of temperature distribution on the human back [8,9]. Edge detection technique was employed to visualise subcutaneous veins [10]. High rates of image capture in a new generation of detectors required new algorithms for evaluation. M. Anbar collected thousands of images within a short period from small skin area, which was divided into small squares of 4 pixel each. From the time series in each square the variation in amplitude underwent fast Fourier transformation (FFT) and selected sequences of frequencies were characterized after attenuation of neuronal control. The derived parameter AMT (= attenuation monotonicity transfer) proved to be an effective discriminator between

cancerous and non-cancerous breasts [11]. Anbar was convinced that further developments will allow localization of cancerous lesions by purely computational means.

Several centres in Europe, US, and East Asia contributed to Computer Aided Diagnosis (CAD) employing various techniques such as neural networks, fuzzy logic, machine learning, non-linear features and high order spectral analysis [12]. The latter approach was applied in automatic analysis of dry eyes [13] and recently in evaluation of thermograms of feet of diabetics [14]. Whilst in Anbar's original approach movement artefacts and body posture have not much influence on the temperature readings in a unique investigation, variation in camera and body position as well as the selection of region of interest are an important source of error in repeated examinations.

A thermal image is a 2-dimensional map of the intensity of heat radiation from the surface of a 3-dimensional object. Consequently, any change in the position of the object in relation to the camera will affect the intensity registered in the projection plane. Considering the small temperature difference which can be theoretically detected by modern detectors, and their much poorer performance in clinical measurements, the validity and credibility of all high order spectral features can be questioned, particularly in the case of diabetics´ feet. A recent study showed that temperatures differences greater than 2.2°C can be detected between corresponding sites on the feet of healthy subjects [15]. A submission to the EAT 2018 conference clearly demonstrated, that a local increase of temperature was a poor predictor of ulcer formation in diabetic patients at high risk for foot ulcers [16].

The efforts in quality assurance for thermal imaging must be strengthened to reduce as many sources of uncertainty in temperature measurements as possible. Data mining methods have not yet proven that transformation of flawed signals into sharp signals is possible. A temperature signal does not tell whether it results from a change in blood flow rate or an increase of metabolic heat [17]. It is also impossible to identify heat sources in deep tissues that correspond to cumulations of temperature in the skin of living beings.

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Quality assurance for a multi-centre thermography study

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SUMMARY

In this study we describe the quality assurance programme developed to evaluate the performance of six thermal imaging devices in the VALIDS study, a project set up by a United Kingdom (UK) group to investigate the reliability of thermography for the assessment of Raynaud's phenomenon secondary to systemic sclerosis. At each of the six centres the start-up drift, accuracy and repeatability of the thermal cameras was assessed by imaging an Isotech 988 blackbody source. All of the thermal cameras, except one (FLIR A35SC) had stable measurements within a 30 minute warm-up period. All of the thermal cameras, except the FLIR A35SC had accurate measurements within ±2°C of the blackbody temperature. Repeatability, as demonstrated by the calculation of the within-subject standard deviation, was less than 0.5°C for 5 of the 6 cameras; the exception being the FLIR Agema Thermovision 570 thermal camera. In conclusion the results confirmed that the thermal imaging device with less exacting accuracy specifications (FLIR A35SC) did not match the performance of the higher-specification devices, and it is questionable if it is fit for purpose when being used clinically. All the other devices demonstrated acceptable accuracy and repeatability for clinical use. These quality assurance methods, when employed along with rigorous patient preparation, image capture and analysis protocols, provide essential confidence in valid and reliable temperature measurements across multiple clinical centres.

KEY WORDS: Thermal camera, quality assurance, medical thermography

QUALITÄTSSICHERUNG EINER MULTIZENTRISCHEN THERMOGRAPHIE-STUDIE

In dieser Studie wird ein Qualitätssicherungsprogramm beschrieben, das für die Leistungsbewertung von sechs Wärmebildkameras in der VALIDS Studie entwickelt worden war. Dies ist ein Projekt, das von einer Gruppe im Vereinigten Königreichs (UK) gegründet wurde, um die Zuverlässigkeit der Thermographie für die Beurteilung des sekundären Raynaud-Phänomen bei systemischer Sklerose zu untersuchen. In jedem der sechs Zentren wurde mittels des Schwarzkörperstrahlers Isotech 988 die Stabilität der Messung nach dem Einschalten, sowie Genauigkeit und Wiederholbarkeit der Messung der Wärmebildkamera beurteilt. Alle Wärmekameras mit Ausnahme Einer (FLIR A35SC) boten innerhalb einer 30-minütigen Aufwärmphase stabile Messungen. Alle Wärmebildkameras mit Ausnahme der FLIR A35SC zeigten akkurate Messungen innerhalb von ± 2 °C der Temperatur des Schwarzkörpers. Die Standardabweichung von wiederholten Messungen wurde als Maß der Wiederholbarkeit verwendet und ihr Wert lag bei 5 der 6 Kameras unterhalb von 0,5°C; ausgenommen hiervon ist die Wärmekamera FLIR Agema Thermovision 570. Abschließend bestätigten die Ergebnisse, dass das Wärmebildgerät mit weniger exakten Spezifikationen (FLIR A35SC) nicht die Leistung der Geräte mit höherer Spezifikation erzielte, und es fraglich ist, ob es für eine Verwendung in der klinischen Temperaturmessung geeignet ist. Alle anderen Geräte zeigten eine für den klinischen Einsatz akzeptable Genauigkeit und Wiederholbarkeit der Temperaturmessung. Gemeinsam mit dem strengen Befolgen von Anleitungen für die Vorbereitung der Patienten sowie der Erfassung- und Analyse von Wärmebildern, fördern diese qualitätssichernden Methoden wesentlich das Vertrauen, dass Temperaturmessungen aus mehreren klinischen Zentren valide und zuverlässig sind.

SCHLÜSSELWÖRTER: Wärmebildkamera, Qualitätssicherung, Medizinische Thermographie

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Introduction

Infrared thermography is a well-established imaging method for skin temperature measurement in biomedical research (1), but a requirement for better quality assurance of the technique has been identified (2). All temperature measurements should be traceable to the International Temperature Scale of 1990 (ITS-90) (3), and to ensure reliable outcomes the performance of thermal imagers should be regularly checked against an accredited reference standard. It is therefore important that all thermal imaging cameras used in clinical studies are subject to a rigorous and standardised quality assurance programme to ensure consistency of camera performance.

Howell and Smith (4) have described a protocol for the procurement and quality assurance of thermal imagers in medical use, and detailed standards for the application of thermography in fever screening have been published by the International Standards Organization (5).

Simpson et al (6) investigated the performance of several thermal imagers in routine medical use, finding considerable variation in camera stability and agreement with blackbody reference temperature. Uncontrolled, these differences in performance represent a potentially significant source of error in multi-centre studies where many thermal

imagers are used to collect temperature data across several sites.

The VALIDS study (7) was a project set up by a United Kingdom (UK) group to investigate the reliability of thermography with repeated hand cold challenge for the assessment of Raynaud's phenomenon secondary to systemic sclerosis across six UK tertiary referral centres. Herein we describe the quality assurance programme developed to ensure traceable temperature measurements at all sites, and present the performance results of the six different thermal imaging devices at each of the centres employed for the VALIDS data collection.

The aim of the study presented was to compare the performance of six thermal imaging cameras at different sites using a series of simple quality assurance measurements. Some of the measurements were also undertaken at the end of the VALIDS study to assess any changes in the operating parameters of the thermal cameras.

Method

Thermal cameras

Each of the thermal cameras put forward for the VALIDS study (7) was routinely used as part of the clinical service in each of the centres except for Centre 6, where the camera was loaned from FLIR (West Malling, UK). All the other thermal cameras were manufactured by FLIR and utilised uncooled focal plane array (FPA) sensors. The models of the cameras used were as follows; Centre 1- FLIR Agema Thermovision 570; Centre 2- FLIR SC305; Centre 3- FLIR A320G; Centre 4- FLIR A40; Centre 5- FLIR A305SC and Centre 6- FLIR A35SC. The spatial resolution of each of the cameras was 320*240 pixels, except for the FLIR A35SC which had a resolution of 320*256. The noise equivalent temperature difference (NETD) for each of the cameras was approximately 50mK. The accuracy range given by the manufacturer for the cameras in Centres 1-5 was ±2°C (or ±2%), whereas for Centre 6 (FLIR A35SC) it was stated as ±5°C (or ±5%). The receiver bandwidth of the detector for all cameras was 7 - 13 microns. Each thermal camera was fitted with a standard 25° x 18.8° lens, where the focus can be altered from 40-100cm from the front of the camera. ThermaCamResearcher software version 2.11, supplied by FLIR, was used to capture the images over a cross-over ethernet connection between a laptop and the thermal cameras at each of the centres.

Figure 1:
Picture of the set up used when imaging the blackbody source

Set-up

To examine thermal camera performance an Isotech 988 blackbody source (Isothermal Technology Limited, Pine Grove, Southport, Merseyside, England), which had been calibrated against a primary standard at the National Physical Laboratory (Hampton Rd, Teddington), was imaged at each of the six centres at the beginning and end of the study period. The measurements were performed with the blackbody positioned on a table approximately one metre from the thermal camera, with the room temperature set to approximately 23°C at each centre. The thermal camera emissivity was set to 0.98. A picture of the blackbody source being imaged by the thermal camera is shown in Figure 1.

Warm-up stability

Measurement of start up drift is important as it provides information on the amount of time required before a thermal imaging camera can be used optimally, and before clinical images can be acquired. To examine the stability of each imager during its warm-up period, the blackbody was set to 30°C and left to stabilise for 15 minutes. The thermal camera was then switched on, and images were acquired every five minutes for half an hour. An example of an image acquired by one of the cameras is shown in Figure 2. The warm-up data was only acquired at the beginning of the VALIDS study.

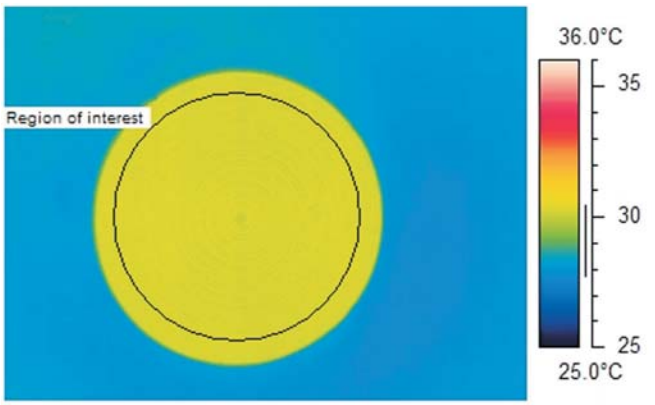


Figure 2:
Image of black body source acquired using a FLIR SC305 Thermal Imaging camera acquired at the start of the warm up stability test. The black body source was set to 30°C and the camera was measuring an average over the region of interest of 30.3°C. The region of interest made up 75% of the total area of the image of the black body source.

Accuracy and repeatability

To examine thermal camera accuracy and repeatability, the thermal camera and blackbody were switched on for a minimum of 30 minutes prior to image acquisition. The blackbody was then set to a temperature of 18°C and an image was acquired; the temperature of the blackbody was then increased in 2°C steps and further images acquired up to 40°C. These measurements were obtained before (baseline) and after or near the completion of the VALIDS study (follow-up) approximately 3 months later. In this experiment the blackbody source was taken as the reference temperature or "gold standard," and the performance accuracy of the cameras in measuring temperature was assessed against this device.

Analysis

Analysis of the blackbody images was performed using FLIR ThermaCam Researcher software version 2.11. For each image, a circular region of interest that encompassed approximately 75% of the area of the blackbody cavity was positioned in the centre of the image, and the mean pixel value was calculated.

The data was analysed using IBM SPSS Statistics version 22 (IBM Corporation, Armonk, N.Y. USA).

The repeatability of the thermal imaging measures was examined by calculating the within-subject-standard deviation of the data acquired from the blackbody source at all temperature points before (baseline) and after the completion of the VALIDS study (follow-up) approximately 3 months later. The within-subject standard deviation was calculated by dividing the sum of squares by its degrees of freedom to get the estimate of variance. The square root of this is the estimate of the within-subject standard deviation. This method is described in more detail by Bland & Altman in their paper on measurement error (8).

The agreement of the camera measurements against blackbody reading was examined by using Bland and Altman analysis (9). Bland and Altman analysis plots the mean of the thermal imaging camera and blackbody readings against the difference between the readings. The systematic "bias" is calculated as the mean difference of the measurements and the "limits of agreement" are given by ±1.96 standard deviations either side of the bias.

Results

Thermal camera warm-up

Figure 3 shows the temperature recorded by each thermal camera in 5 minute intervals from switch on. All of the thermal camera temperature measurements were within 2°C of the actual blackbody temperature (30°C), and all camera measurements tended towards 30°C by 30 minutes, with the exception of the measurements obtained by the camera in Centre 6. It was also observed that the temperature measurements for cameras in centres 3, 4 and 5 were not quite stable after 30 minutes, but the variations were less than 1°C. This is probably caused by small temporal and spatial temperature variations within the room, which are very difficult to control. However, collective opinion between the participating centres is that this is unlikely to have a major impact on the clinical results acquired.

Figure 3:
Temperature reading variation as the thermal cameras warm up from switch-on (blackbody source temperature 30°C)

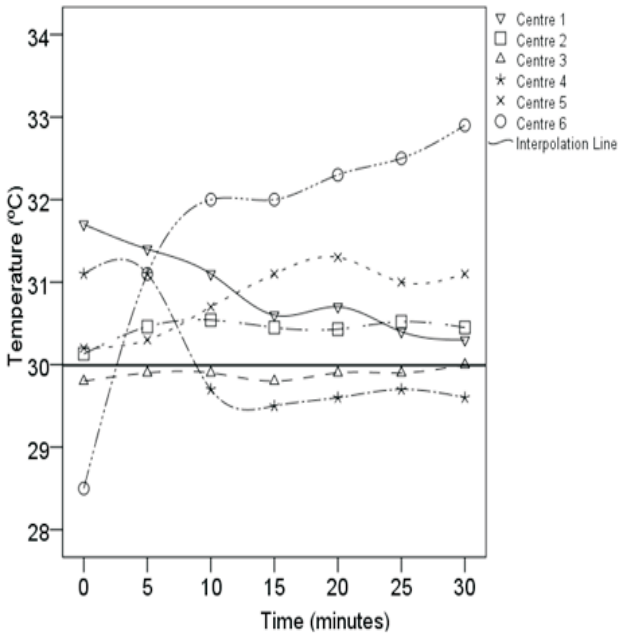


Table 1
Within-subject standard deviation for the baseline and follow-up thermal camera measurements acquired before and after the study period (across all blackbody temperature points).

Centre	Within-subject-standard deviation (°C)
1	0.71
2	0.22
3	0.06
4	0.34
5	0.12
6	0.22

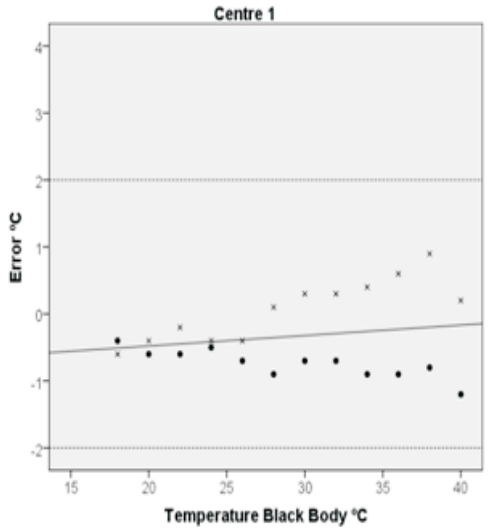
Accuracy and repeatability

Repeatability

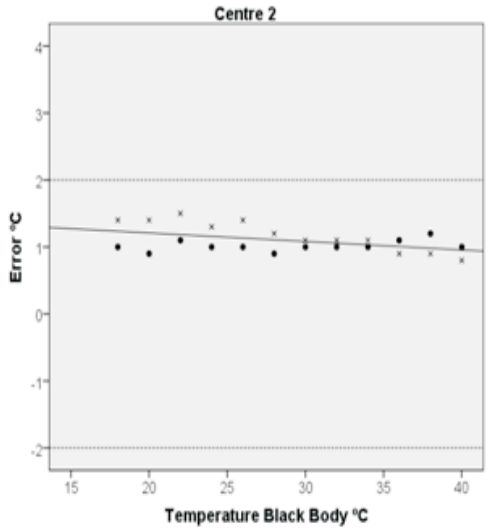
Figures 4a-f show the repeatability of each of the cameras in measuring the temperature of the blackbody source between 18°C and 40°C at baseline and at follow-up. Five of the six cameras behaved similarly at baseline and follow-up. At centre 1, however, the camera showed some variability in the readings taken above 25°C: there was a tendency to under-read the blackbody at baseline, and yet over-read it at

Figure 4a-f:
Measurement error (difference between thermal camera and blackbody reading) at baseline (•) and follow-up (x), plotted against blackbody reading. Maximum permissible error specified by the manufacturer (----) is also included (not shown for centre 6: ± 5°C)

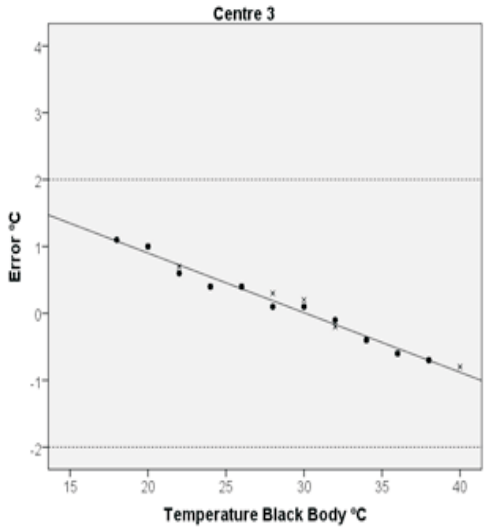
4a Measurement error acquired at centre 1



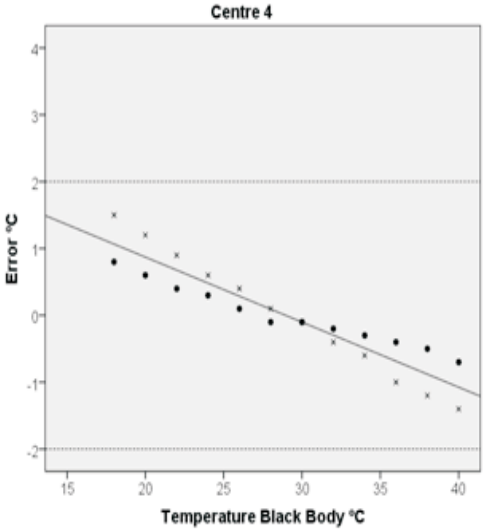
4b Measurement error acquired at centre 2



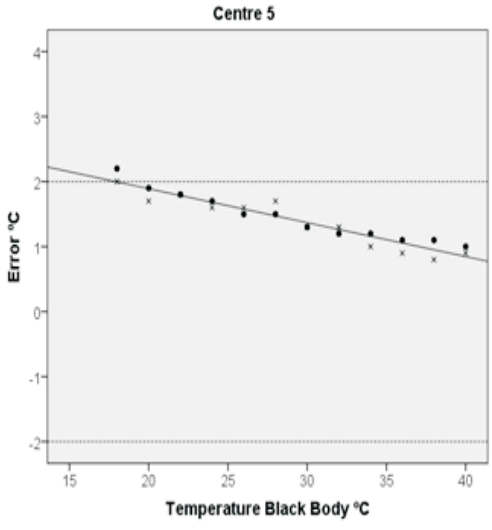
4c Measurement error acquired at centre 3



4d Measurement error acquired at centre 4



4e Measurement error acquired at centre 5



4f Measurement error acquired at centre 6

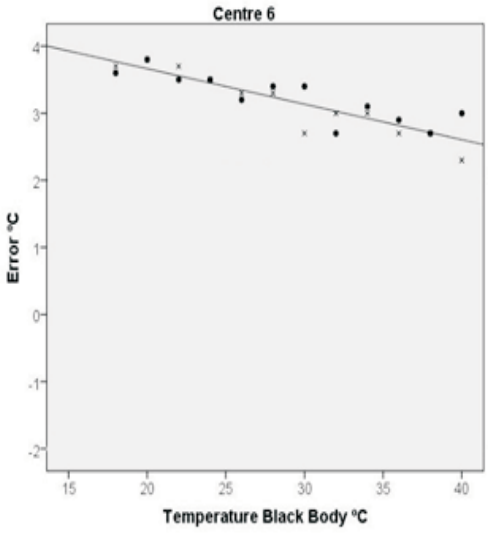


Figure 5
Bland and Altman plot of the mean of the thermal imaging camera and blackbody readings against the difference

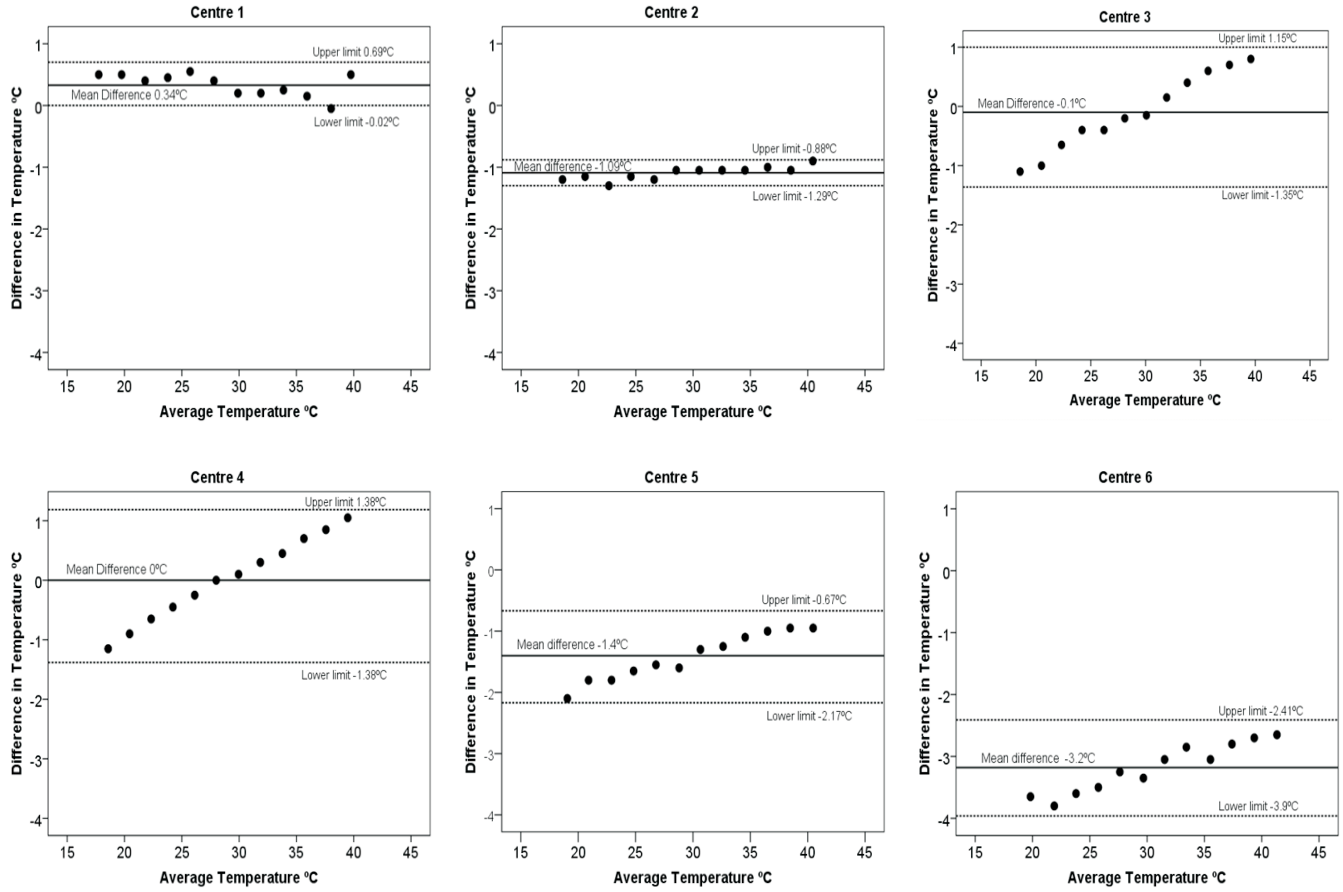


Table 2
Mean bias between blackbody and thermal camera

Centre	Mean bias (°C)	Limits of agreement (±1.96*SD (°C)
1	0.34	0.36 (-0.02 to 0.69)
2	-1.09	0.21 (-1.29 to -0.88)
3	-0.10	1.25 (-1.35 to 1.15)
4	0.00	1.38 (-1.38 to 1.38)
5	-1.42	0.75 (-2.17 to -0.67)
6	-3.18	0.77 (-3.95 to -2.41)

follow-up. Table 1 shows the repeatability (within-subject standard deviation) between the baseline and follow-up thermal imaging camera measurements.

Accuracy

Figure 5 shows the Bland and Altman plot of the mean of the thermal imaging camera and blackbody readings against the difference. For centres 1 and 2 the plots showed no relation between average temperature and the differences, but in the other four centres (which all employed FLIR "A" series cameras) the differences changed quite steadily with increasing average temperature. Table 2 shows the mean bias between the thermal camera and blackbody readings, with limits of agreements.

Discussion

In order to achieve reproducible results in thermal imaging investigations, one of the core requirements is to have equipment that is both reliable and repeatable. Up until quite recently cooled thermal imaging cameras were seen as the only option for acquiring reproducible high quality data. The cost of these devices meant that these were out of reach for most departments. However since the emergence of relatively low-cost, uncooled focal plane array thermal imager technology, a number of UK centres have now invested in such devices for investigating Raynaud's phenomenon, but there have always been questions about the reliability of the equipment being used. Validation of uncooled thermal imaging devices for assessing skin temperature therefore requires a traceable and simple-to-implement quality assurance protocol.

This is the first quality assurance study where a calibrated and externally verified blackbody source has been used to assess the performance of different thermal imaging cameras across a wide geographical region within the UK. In total six centres participated and results were acquired prior to, and following, a three-month clinical study (7) investigating reproducibility of a cold challenge in patients with Raynaud's phenomenon secondary to scleroderma.

The results from the warm-up tests showed that five of the six cameras were performing within the manufacturer's specifications of an accuracy of ±2°C when compared to a temperature setting of 30°C on the blackbody source. The thermal camera at Centre 6 was the only camera where the accuracy specification given by the manufacturer was ±5°C, and therefore this camera was within tolerance, even from switch-on. However, this camera showed by far the greatest variation in temperature reading during the warm-up period, and it was the only device where readings were continuing to change markedly at the end of the 30-minute evaluation. The thermal cameras at Centres 1-5 were all observed to be essentially stable at 30 minutes, and any systematic errors could be taken into account when analysing the results from clinical studies.

The repeatability experiment, examining the difference between the baseline and follow-up measurements, showed that for Centres 2 to 6 the within-subjects standard deviation was below 0.5°C. Only Centre 1 was outside this limit, and this may be related to the age of this thermal imaging camera (approximately 10 years old) whereas all the other devices were 6 years or younger. This is a reassuring result, as it confirms that there was insignificant drift in camera performance over the 3-month period of the VALIDS study, and therefore any limitations in clinical measurement repeatability could not be attributed to instrument factors.

The accuracy of the thermal imaging cameras as shown by Table 2 and the Bland and Altman plots shows that for Centres 1 to 5 the bias was well within ±2°C, which is acceptable for clinical imaging and within the manufacturers' specification. Indeed, amongst these five imagers, only one individual reading was found to be outside of the specification limit (for the camera at Centre 5 at a blackbody reading of 18°C). The thermal imaging camera at Centre 6 had a poorer bias of -3.2°C, which is however within the manufacturer's specification for this specific device. However, it is questionable if this is satisfactory for clinical use in a peripheral vascular setting, where the skin temperatures encountered only range across approximately 20°C.

All of the measurement errors were systematic and therefore could be taken into account and corrected when acquiring clinical imaging data. It is noted from the Bland Altman plots that the four FLIR cameras from the "A" range of devices all exhibited steadily rising biases across the range of blackbody temperatures studied, but with varying amounts of "offset" from the true blackbody value. The "SC" and "Agema" models showed a "flatter" response across the temperature range. These interesting findings probably reflect different approaches to the algorithm that calculates temperature from the detected infrared intensity signal within the collection of imagers evaluated.

A limitation of our Bland and Altman approach to analysing the agreement of the four "A" series cameras with the blackbody is that the mean of the differences is not constant throughout the temperature range: hence there is a likelihood that the overall limits of agreement are somewhat too wide for low temperatures, and too narrow for higher temperatures. A more robust approach for devices exhibiting varying means of the differences across the measurement range could be to analyse the logarithm of the measurements, or to find the 95% limits for the difference as a percentage of the mean (10).

Conclusion

In conclusion, we have demonstrated the practical application of a quality assurance programme for thermal imagers in medical use. This programme successfully validated thermography for a multi-centre clinical trial into cold-challenge reliability for Raynaud's phenomenon assessment.

Overall, the findings on the performance of modern uncooled focal plane array imagers were reassuring, but our results did confirm that the thermal imagers with less exacting accuracy specifications (as provided to Centre 6) do not match the performance of higher-specification devices.

It should be noted that an understanding of instrument performance is not the only prerequisite for reliable and repeatable clinical thermography. Rigorous adherence to patient preparation, image capture and analysis protocols is also vital, and guidelines on these topics are areas of ongoing international research (11).

Nonetheless, quality assurance based around a room-temperature blackbody device is vital to validate medical thermography, and we recommend a protocol similar to that which we have described for all clinical studies. The protocol outlined in this document could be used as part of acceptance testing for new thermal imaging cameras, monitoring the performance of these devices as they become older, and providing evidence to support the financial costs of replacement.

Acknowledgements

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EAT 2018-Introductory Thermography Course Syllabus

Introductory Thermography Course Structure

Date: 4th July 2018

9:00 Registration

Theory

9:10 Opening of the course (Kevin Howell)

9:15 Physical principles of heat transfer (Ricardo Vardasca)

9:45 Principles of thermal physiology/skin blood perfusion (James Mercer)

10:45 Coffee break

11:00 Standardization of thermal imaging, recording and analysis (Kurt Ammer)

12:00 Quality assurance for thermal imaging systems (Rob Simpson)

12:30 Producing a thermographic report (Kurt Ammer)

13:00 Lunch

Practical Session

13:45 Provocation tests (James Mercer and Manuel Sillero)

14:45 Image analysis (Kurt Ammer and Ricardo Vardasca)

15:15 Coffee break

15:30 Hands-on supervised practice (all course teachers)

16:30 Educational resources (Adérito Seixas)

16:45 Closing

Physical principles of heat transfer

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Thermodynamic temperature is one of seven base quantities in physics. A physical property of a system that does not depend on the system size or the amount of material in the system, is called intensive. The base quantity temperature is an intensive quantity of heat energy and represents the mean kinetic energy of atoms or molecules in a substance.

Energy can be defined as the ability to do work and is expressed by the same equation as work. It exists in many forms, such as mechanical, electrical, nuclear, and thermal. Transformation of one form of energy into another is possible, for example a thermally powered generating station can produce electricity. The transformation of all other forms of energy into heat can be total, but the contrary, i.e., the transformation of heat into one of the other forms, is never 100 percent efficient. Heat thus appears to be a special form of energy. The SI unit of energy is the Joule. For thermal energy, 1 Joule is the energy dissipated as heat when an electric current of one ampere passes through a resistance of one ohm for one second. In relation to temperature, 1 Joule is expressed as the 1/4.184 part of heat energy required to raise the temperature of a unit weight (1 g) of water from 0oC to 1oC. 4.184 Joules are equal to the traditional unit of 1 calorie [1].

In any closed system with an outer membrane (diathermal wall) permissive to energetic, but not to material exchange, energy is transferred from the high level to the low level. Thermal energy can be transferred without or with change of state of matter. Heat transfer without change of state can occur by either conduction, convection, or radiation. During heat exchange, the temperature at the high level of thermal energy falls, whilst the temperature at the low-level rises, until equilibration is achieved. [1].

In heat transfer with change of state, the temperature of the phase changing matter is constant. Since change of the state either requires or releases thermal energy, the system in which the phase change occurs gains or loses heat. Changing liquid water into vapour requires thermal energy. In a condition in which a thin film of water is evaporating from a surface, the temperature of the surface is decreasing. [1].

The minimal thermodynamic temperature is absolute zero, where the thermal motion of all fundamental particles in matter reaches a minimum. Temperature can be expressed in several scales. The International System of Units (SI) scale is the Kelvin (K), which has as its null point absolute zero, and is defined as the fraction (1?273.16) of the thermodynamic temperature of the triple point of water. The triple point of a substance is described by the temperature and pressure at which the three phases (gas, liquid, and solid) of that substance coexist in thermodynamic equilibrium. Other commonly used scales are the Celsius scale (°C), informally known as degrees centigrade and originally defined by the freezing (0°C) and boiling (100°C) points of water at a pressure of 1 atmosphere, and the Fahrenheit scale (°F), in which the null point is defined as the temperature of a solution of brine made from equal parts of ice, water and salt, and there are 180°F of separation between the freezing and boiling points of water [2-5].

In conduction, thermal energy is transmitted through a medium from one particle to another, requiring direct contact. With convection, it is transferred by fluid motion (gas or liquid), which may be caused by density differences (natural) or external mechanical forces (forced). Radiation transmits thermal energy through electromagnetic waves, the movement of heat of the charged particles inside the atoms is converted into electromagnetic radiation [3-5].

The electromagnetic spectrum describes the range of frequencies (the spectrum) of the electromagnetic radiation and their respective wavelengths and photon energies, and it can be used to characterise existing bodies and materials. This frequency range is divided into separate bands called by different names. It begins at the low frequency (long wavelength) end of the spectrum: radio waves, microwaves, infrared, visible light, ultraviolet, X-rays, and ends with gamma rays at the high-frequency region (short wavelength). The spectral range from gamma rays to high ultraviolet are classified as ionizing radiation, since their photons have enough energy to ionize atoms, causing chemical reactions which are harmful for humans. The infrared spectrum is located at the left of the visible region, ranging from 0.7 μm to 1000 μm in wavelength, and it is divided into three parts: near-infrared, medium-infrared and far-infrared [2-6].

Infrared radiation is invisible to the human eye, lower in energy than visible red light, and is naturally emitted by any object with a temperature above absolute zero. Blackbody radiation is thermal electromagnetic radiation within or surrounding a body in thermodynamic equilibrium with its environment, or emitted by a blackbody (an idealized object which absorbs all radiation falling on it at all wavelengths). It has a specific spectrum and intensity that depends only on the body's temperature, which is assumed to be uniform and constant [2-10]. The physics of radiation

follow the laws of optics and thermodynamics including absorption, diffraction, emission, reflection, refraction, scattering and transmission. For measurements of infrared radiation in medicine and related health, it is recommended to acquire only emitted radiation [7, 8].

Emissivity is the ratio between the radiant emittance produced by an object to that of a blackbody at a specific temperature, being dependent of its surface fine structure. This factor affects the accuracy of a remote temperature measurement. Its value can vary between 0 and 1, with 1 being the emissivity value of a blackbody [2]. The value of the emissivity of human skin is 0.98 [11].

The thermal radiation emitted across all wavelengths by a blackbody (ideal emitter) at any temperature can be calculated by Planck's law. Planck's law expresses the spectral radiance as a function of wavelength and temperature of the blackbody. The dominant frequency interval increases proportionally with the temperature. The rate of electromagnetic radiation emitted at a given frequency is proportional to the total value absorbed by the body at the same frequency. Wien's displacement law describes the relationship between the spectrum of blackbody radiation at any two temperatures. The emission of radiation of a blackbody has a spectral distribution that depends only on temperature, and the wavelength at which maximal radiation is emitted is inversely proportional to the temperature of the blackbody. According to the Stefan-Boltzmann law, the total amount of radiation, across all frequencies increases with the fourth power of the temperature, and it is with modified versions of this law that an infrared camera can determine the temperature from a perceived radiation source, comparing with an internal calibration source [1-12].

Consequences for temperature measurements in medicine

To promote thermal equilibrium between the body and the surrounding environment there are environmental factors that must be considered such as the environment temperature and the relative humidity, and the period of acclimatization to this before performing temperature recordings [12]. The dew point is a given temperature at which air containing a specific amount of water becomes saturated (condensation). Given a constant dew point in the air, if the ambient temperature rises, relative humidity falls and vice-versa. Other factors such as air flow, incident lighting and examination room size, have also to be considered.

Equipment available to assess temperature can be chemical, electrical or mechanical in operation. Examples of mechanical devices are: mercury in glass thermometers, bimetallic thermometers and pressure spring thermometers; chemical instruments include: liquid crystal sheets; and electrical examples are: thermocouples, resistance temperature detectors, infrared pyrometers and infrared cameras. Only the last two examples allow remote temperature recording, and both are based on the principle of infrared radiation [13].

The main characteristics of an infrared camera are the type of detector (which can be cooled or uncooled), the wavelength (which normally is medium or long wavelength), the focal plane array sensor size, the noise-equivalent temperature difference and the measurement uncertainty. When performing an examination with an infrared camera it is important to know the time required to stabilize the electronics, the image uniformity and the image focus. Appropriate camera settings such as emissivity, environmental temperature, relative humidity, distance to the target and temperature range are also recommended [12, 14-16].

The infrared sensors of a camera perceive an incident thermal radiation, which is then transformed into a voltage and, depending on the thermal resolution (bits), it is then coded into a radiometric value that is recorded into the camera proprietary file format. This, along with other parameters such as the emissivity and reflected temperature, along with the Planck constants, allows through the altered Stefan-Boltzmann law the calculation of a temperature value in Kelvin, and by the translation formula to degrees Celsius [6].

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Principles of thermal physiology & skin blood perfusion

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Infrared Thermal imaging (IRT) in medicine is used to image (thermogram) and accurately measure the surface temperature distribution of the human skin. The temperature distribution of the skin in healthy subjects varies according to a wide range of factors that not only depend on the body part being imaged but also on a large range of intrinsic and extrinsic factors, ranging from physiological control to environmental conditions. In fact, the number of factors that can affect the skin temperature in humans is very large and the infeasibility of controlling for all of them is one of the major challenges we have in performing IRT [1]. Thus, a general knowledge of these factors is important for medical thermographers.

In addition, there are many pathological conditions that can affect skin blood perfusion and thereby skin surface temperature. Knowledge of changes in skin blood perfusion due to pathological conditions is perhaps one of the most important aspects in using IRT. These changes are often used, not only to help a medical practitioner in making a diagnosis, but also, for example, to follow the effect of a medical treatment or surgical intervention. Thus, in order to be able interpret a thermal image a thorough knowledge of thermal physiology in general and the control of skin blood flow in particular as well as some knowledge of vascular anatomy in normal healthy individuals is necessary.

In this part of the introductory course, we will start with a brief overview of the main principles of thermal physiology, including the physiological control of skin blood perfusion. We will then go into more detail on factors effecting skin blood perfusion, including an introduction to some relevant aspects of vascular anatomy. We will briefly describe the dynamic aspects of skin blood perfusion, which is important in medical thermal imaging, particularly in connection with thermal and other provocation tests. The latter topic will be covered in more detail in another section of the course. To illustrate central points a variety of thermal images and videos in normal healthy subjects will be shown. Some examples of pathological abnormalities will be also shown to further help our understanding.

It is beyond the scope of this introductory course to give a detailed instruction in thermal physiology and skin blood perfusion. These topics are well covered in the scientific literature as well as in most medical textbooks in physiology. For the interested reader I would like to recommend the following textbooks/review articles [2, 3, 4 & 5]. References [2 & 3] are book chapters that covers many points related to thermal physiology and cutaneous circulation. Both books also contain other chapters covering a wide range of relevant topics in medical thermography. Reference [4] is a user-friendly monograph designed for medical students as well as graduate students and postdoctoral trainees in medicine and other health-related sciences who need a comprehensive overview of thermoregulation. It presents the bases of the modern concepts in thermal physiology and pathophysiology, bringing together the disciplines encompassed by this highly integrative field (physiology, anatomy, biophysics, molecular and cellular biology, pharmacology, neuroscience, pathology, medicine, and others) into a clear and concise form. Reference [5] is a recent scientific review article on the physiology and function of arteriovenous anastomosis (AVA´s). AVA´s are direct short circuits between an artery and a vein and knowledge of their physiological function is important for interpreting thermal images from many body areas, especially the hands, feet and face.

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Standardization of thermal imaging, recording and analysis

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Thermal imaging is defined as imaging based on the detection of weak infrared radiation from objects. Applications include the mapping of the Earth´s surface from the air, weather mapping and medical thermography (thermal contours on the surface of the human body) [1].

A common definition of a thermogram (thermal image) is "a map of temperature distribution on the surface of the object imaged". Consequently, thermal imaging is often regarded as a technique for 2-dimensional temperature measurements [2].

Definition of a medical infrared thermal image or infrared thermogram: An infrared thermal image showing the surface temperature distribution of either the total human body or of defined body parts or anatomical regions respectively.

Important terms used in metrology will be provided such as measurement trueness, accuracy, precision, repeatability, reproducibility [3].

Standards define the minimal requirements in structure and processes which contribute to the constant quality level of a product. Following a standard protocol will lead to valid and reliable temperature measurements in medical thermal imaging. However, quality assurance procedures must not be restricted to temperature measurements, because conditions of image recordings, position and posture of the imaged subject, image composition and method of extracting temperature from thermograms affect temperature readings. Detection of temperature changes caused by physiological and pathophysiological mechanism is only possible, when all other courses of temperature alterations are very well controlled.

Most of the procedures for controlling the conditions of medical thermography have been developed by Prof Francis Ring since 1970.

They can be classified into 5 main factors [4, 5].

1. Subject or object
2. Camera Systems, Standards, and Calibration
    a. The imaging system
    b. Temperature reference
    c. Mounting the imager
    d. Camera initialisation
3. Patient Position and Image Capture
    a. Location for Thermal Imaging
    b. Ambient temperature control
    c. Pre-Imaging Equilibration
    d. Positions for Imaging - Glamorgan protocol [6].
    e. Field of View - Glamorgan protocol [6].
4. Information Protocols and Resources
    a. Patient preparation
5. Image related factors
    a. Image processing
    b. Image analysis - Glamorgan protocol [6].
    c. Image exchange
    d. Image presentation

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Quality assurance for thermal imaging systems

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This overview is an introduction to basic concepts in temperature measurement [1-3]. Its purpose is to provide background knowledge about temperature measurement, calibration and traceability. The instruments will also be considered: technical features; practical issues; application; and sources of error. Although it does not require any background in temperature measurement, it assumes that the reader has a good level of scientific knowledge.

Thermal imaging (thermography) has become widely exploited in clinical medicine, with uses ranging from general healthcare and screening, to detecting circulatory ailments and tumours. The exploitation of this qualitative imaging modality for quantitative assessment is reliant upon a robust metrology (measurement) framework, regular calibration, good measurement practice and educated users.

This is an overview that aims to introduce users to temperature measurement and take them beyond what they may have picked up in school, university or everyday life. It is hoped that, after this introduction the user will have increased measurement confidence and will expand their understanding further with the accessible literature.

We open with some background about temperature, its measurement, instrumentation calibration and traceability, and conclude with examples of some of the measurement difficulties that may be encountered in use.

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Producing a thermographic report

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A request for a thermographic investigation is the starting point and the guideline to what thermal images should be recorded. The report may vary depending on the request, and the set-up of the unit that conducts the investigation.

In the case of a clinical imaging service for physicians, the use of a referral form is recommended. In the case of studies or trials in medicine, physiology or sports science, the request is defined in the study protocol. For reporting studies in journals, books or at conferences, a checklist based on a Delphi consensus clearly defined the required content of a thermographic report [1].

For the report of an imaging service the following required information is proposed

1. Name of the referring physician

Personal information of the patient including the health problem leading to the referral. All this information is available from the referral form, which may be copied and pasted to build the first section of the report.

2. Imaging conditions

All environmental conditions such as model of the thermal imager, room temperature, time for acclimatisation, patient´s position and clothing during the acclimatisation period must be reported. Any provocation test such as exposure to a cold challenge or particular positions of imaged body parts must be described in detail.

3.Captured images

All images recorded must be displayed in the report. All images should be labelled with date, room temperature, abbreviation of body view and/or provocation test. All images must be presented together with the applied regions of interest.

4.Temperature readings

A minimal requirement is to report mean temperature ± standard deviation of each region of interest; maximum and minimum temperatures are optional. The difference in mean temperature of corresponding regions of interest must be calculated. Presentation of temperature values in a table is recommended

References

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Provocation tests

James B. Mercer[1], Manuel Sillero [2, 3]

1 Professor Emeritus, Faculty of Health Sciences, UiT, The Arctic University of Norway, Tromsø, Norway and Medical Imaging Research Group, Department of Radiology, University Hospital of North Norway
2 European Association of Thermology, Vienna, Austria
3 Sports Department, Faculty of Sciences for Physical Activity and Sport (INEF), Technical University of Madrid, Madrid, Spain

Dynamic infrared thermography (DIRT) is based on the relationship between dermal perfusion and the rate of change of skin surface temperature (Tsk) following the application of a transient local provocation test, usually but not always, as described below, by a thermal challenge. Thus, while traditional thermography involves taking a single thermal image (thermogram), DIRT is based on the interpretation of a predetermined number of thermograms taken over a fixed period [1].

To perform DIRT, the regions of interest (ROI) being imaged are subjected to a provocation test and then single images are recorded and stored at pre-determined time intervals, for example 1 image every second. Ideally the camera position relative to the object being imaged should be kept constant. In most cases DIRT involves comparing the thermograms before, during, and at different selected time points during the recovery from the provocation (or stress), where the speed and changing thermal patterns during recovery are usually of interest [2].

In the practical part of the course this process will be examined with relation to:

1.Location of the stress

Local versus whole body)

2. Sources of stress

2.1. Heat stress [3]

2.2. Cold stress

Cold provocation tests are commonly used in order to provoke a temporary vasoconstrictor response where the rate and pattern of the spontaneous rewarming following the cold stress test is examined. A cold stress test may be invoked in several ways including cold stress provided by cold climatic chamber, water immersion, forced convection, alcohol cooling, or the cooling of a distal area (reflex cooling) [3, 4].

2.3. Pharmacological or chemical stress

For example, by caffeine ingestion, intake of nicotine, topically applied ointments or aerosol sprays [5].

2.4. Exercise stress

The effect that various forms of physical exercise has on skin temperature is commonly used, especially by those interested in thermoregulation in sports medicine [6, 7].

An introduction will be given into the effect that moderate and intense exercise during various types of sport activities has on skin temperature.

2.5. Rehabilitation techniques

The use of rehabilitation techniques such as TENS, acupuncture or pressure cuffs [8-10].

Other considerations

Age, body size, fitness level and health condition [2].

Asymmetrical differences - that is comparing left/right differences and why this is sometimes of interest and sometimes not. Also, comparisons between the dorsal and ventral aspect of a body part, for example the dorsal and palmar aspects of the hands [11].

No matter what provocation protocol one uses, it is recommended to always take normal digital photographs of the body part being imaged by the IR camera (approximately same distance and angle as the IR camera). This is done to document anomalies such as scars, skin growths such as warts and other skin injuries that may affect a thermogram

Finally, a short introduction in the uses of DIRT during surgical interventions, pre-, intra- and post-operatively will be presented.

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Image analysis

Kurt Ammer [1,2], Ricardo Vardasca [1,2,3]

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[2] Medical Imaging Research Unit, University of South Wales, Pontypridd, United Kingdom
[3] LABIOMEP, INEGI-LAETA, Faculdade de Engenharia, Universidade do Porto, Porto, Portugal

These 2 short lectures will instruct the students in using the provided software package for image analysis.

Ricardo Vardasca will show the retrieval of thermal images, the definition of circular, rectangular and polygonal measurement areas and their positioning in the region of interest of the retrieved thermal image. He will also demonstrate the extraction of temperature values from the thermogram.

Kurt Ammer will present regions of interest on the lower extremity as defined in the Glamorgan protocol [1]. Similarity of mean temperatures of corresponding anatomical regions and comparison to reference values will be discussed [2].

References

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Hands-on supervised practice

All course teachers

Two sets of images of the calf of the same subject in the view "lower leg posterior" and in the view "total body posterior" taken by two instructors will be distributed to course students.

That results in 4 images:

Image 1 (view: lower leg posterior, Operator 1)

Image 2 (view: total body posterior, Operator 1)

Image 3 (view: lower leg posterior, Operator 2)

Image 4 (view: total body posterior, Operator 2)

On each students' computer with the analysis software installed, the students will retrieve the recorded images and practice to define a rectangular and a polygonal region of interest on Image 1. After feeling competent in defining and positioning regions of interest, the students will define the region of interest "lower leg posterior" in each of the four images. Median, minimum, maximum, mean and standard deviation of temperature and the size of the ROI in the number of pixels must be recorded.

The results must be transferred to a prepared Excel spreadsheet, which will automatically calculate the mean value of all measurements and use it as reference value. Individual errors (individual value minus reference value) will also be generated. For each image one Excel sheet will be provided. If the students already have experience with the software and manage the task quickly, the definition of regions of interest must be repeated on a set of images, free of ROIs. Another set of Excel sheets will be provided for documentation.

Such a setting allows to assess in individual students:

- the agreement of temperature readings in different views
- the agreement of temperature readings in thermal images recorded by different camera operators
- the agreement of temperature readings in repeated evaluation (when a second evaluation was performed)
- the agreement of the size of ROI in the views "lower leg posterior" and "total body posterior"
- the agreement of the size of ROI in thermal images recorded by different camera operators
- the agreement of the size of ROI in repeated evaluation (when a second evaluation was performed)

And between students:

- the agreement of the size of ROI in each view
- the agreement of the size of ROI in repeated evaluation (when a second evaluation was performed)
- the agreement of temperature readings in defined ROIs
- the agreement of temperature readings in repeated evaluation (when a second evaluation was performed)

Educational resources

Adérito Seixas

European Association of Thermology, Vienna, Austria
Escola Superior de Saúde, Universidade Fernando Pessoa, Porto, Portugal
LABIOMEP, INEGI-LAETA, Faculdade de Desporto, Universidade do Porto, Porto, Portugal

Many instructional courses have been organized under the banner of the European Association of Thermology (EAT), covering different topics and devoting different amounts of time depending on the venue of the course and available instructors [1]. The EAT decided to move from that format and after intensive and constructive discussion the Board approved an introductory course structure covering all topics required to start using thermography in daily practice or research. From basic physical and physiological principles, to imaging technique, analysis and reporting guidelines, not forgetting quality assurance for thermal imaging systems, all required topics were covered.

Thermology International is the publication organ of the European Association of Thermology (EAT) and other thermology societies. It is an international scientific journal that publishes articles related to temperature measurement in all scopes of science and is indexed in Scopus, EMBASE and Medline with full text (EBSCO), and since 2013 it is published exclusively online [2]. One of its aims is to provide a means of dissemination of knowledge in the field of thermology, acting as an educational platform for all those interested in temperature measurements, endorsing all major reporting guidelines for main study types [3] to increase transparency in the publishing process. Throughout the years many articles have been published, related to the topics covered in the course, and this is an overview of a collection of papers that were selected to be distributed among the course students.

Due to its short duration, the historical developments of thermal imaging will not be addressed in the course. However, several hallmarks should not be forgotten [4, 5]. Skin temperature has been used extensively as an outcome measure [6], but objectively assessing thermal images can be a challenging task and thermal findings must be interpreted carefully [7, 8]. Thermal images are representations in false colour scale of the temperature distribution of the surface of the imaged object, from which emissivity must be known [9], and it is important to note that false colouring may affect image resolution and distort the anatomy of the imaged body part [10]. The conversion from camera signal to temperature values is not straightforward [11].

To avoid bias in image recording, standardization is the key. The repeatability of standard views of the dorsal aspect of both hands [12], the repeatability of temperature measurements at the forehead [13] and the influence of the field of view on temperature readings of the face and upper back [14] have been studied in three papers, published with data collected during instructional courses at the University of Glamorgan. Room temperature appears to have a stronger influence on temperature readings than the number of pixels of the measurement area [15], and recently a paper was published documenting the influence of angle and distance on temperature readings of the inner-canthi [16]. Guidelines for thermographic assessment have been published [eg. 17, 18] aiming to highlight the need for a standardized technique of image recording and analysis. In 2008, Ammer [19] published the Glamorgan Protocol for recording and evaluation of thermal images of the human body, defining 24 body views and 90 regions of interest, demonstrating high reproducibility of recorded images and temperature readings.

Reporting is also a source of bias in published studies. Standardization is required, not only during image recording, but also for reporting of thermographic findings. There are clear deficits in the reporting of primary studies but also in literature reviews [20], which led to the development of a checklist - the final product of a Delphi study - that should be used by researchers planning a research study, reporting research results and/or assessing the methodological quality of thermographic studies [21].

Quality assurance of thermal imaging systems has also been a focus of publication in Thermology International [22]. Simple procedures have been described and can be used by thermographers to monitor the performance of imaging systems [23] and guidelines for specifying and testing thermal cameras for medical applications are also available [24]. It is important to understand that technical characteristics of infrared cameras influence their performance and that regular assessment of the performance of the system is required [25].

The cited references were selected from the papers published in Thermology International and are important educational resources that will be available online to download at the time of the course.

The amount of published information about thermology is constantly increasing. Ammer [26-30] has compiled reference lists of all published papers on the topic "Thermology" from 1989 to 2016 and these resources are available freely from the archives of Thermology International.

Several scientific journals can be named as examples of good sources of information. One of the most read papers

in Physiological Measurement is a topical review on the use of infrared imaging in medicine [31]. Another journal - Infrared Physics & Technology - has published a similar topical review but focusing on different aspects of the applica-t ion of infrared imaging in medicine [32]. The same journal has a very in-depth review about the factors that can influence the use of infrared imaging in humans [33]. The Journal of Thermal Biology recently published a Delphi study and consensus statement regarding the information that should be reported in thermographic studies [34] and the Quantitative InfraRed Thermography Journal published a very interesting review about the pioneers of infrared imaging in medicine [35]. More journals and examples of important papers could be listed but, with the increasing quality of research databases (e.g. Pubmed, Scopus, Web of Science), the access to relevant information is facilitated.

Other important sources of information are reference books. Two historical references must be mentioned: Recent advances in Medical Thermology [36] and The Thermal Image in Medicine and Biology [37]. The first was edited by Ring and Phillips and is a collection of papers presented at the 3rd International Congress of Thermology in 1982 and the second, edited by Ammer and Ring, is a collection of papers presented at two meetings, the Meeting of the Royal Photographic Society, Imaging Science & Technology Group and the 6th European Congress of Thermology in 1994. Another solid reference is the book Medical Infrared Imaging: Principles and Practices [38], edited by Diakides, Bronzino and Peterson, a comprehensive source of information covering all aspects of the use of thermal imaging, from technology and hardware to data processing and applications. Two more titles are worth mentioning, Infrared Imaging: A casebook in clinical medicine, edited by Ring, Jung and ?uber [39], and Innovative Research in Thermal Imaging for Biology and Medicine, edited by Vardasca and Mendes [40]. The first is a follow-up of the original Casebook in Clinical Medicine published twelve years earlier and evidences the advances in infrared technology and the knowledge about thermal physiology, covering theoretical and technical aspects and a wide variety of applications. The second offers an overview of recent research in biology and medicine covering the use of thermal imaging. For those particularly interested in the metrological aspects of thermal imaging, the book Infrared Thermography: Errors and Uncertainties [41] is an interesting read.

This overview is intended to provide the trainees with a list of educational references covering the topics of the course, and others, stimulating their curiosity and willingness to contribute to increase the body of knowledge in thermology.

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News in Thermology

Evaluation of submissions to the EAT2018 conference is completed

For the next EAT conference in London Teddington, 58 submissions were received in total. In 1 submission, the title and the transferred abstract did not fit together. The abstract submitted, was already presented at the EAT2015 and despite repeated requests the author did not provide the correct text and consequently evaluation of the submitted abstract was not considered.

2 abstracts were received from invited speakers. Each of the 55 remaining abstracts was reviewed by 2 referees, in case of large discrepancy of the outcome, the opinion of a 3rd referee was requested.

The mean evaluation score was 3.4 ± 0.8 points, 2 referees scored 2 different abstracts with 5 points, the highest combined score of 2 reviewers was 4.7.

The following table shows the number of submission in relation to achieved scores.

Score range	Number of submissions	Score: median (range)	Difference of scores: median (range)
<2	3	1.7 (1.5-2)	0.4 (0.4-0.8)
>2<3	11	2.8 (2.0-2.95)	0.5(0.0-0.9)
>3<4	28	3.3 (3.0-3.95)	0.6 (0.0-1.1)
>4<5	13	4.4(4.0-4.7)	0.6(0.0-1.6)

12 papers that have been rejected after the first round of evaluation, had a median score of 2.5 points (range 1.5 to 3.95) and the median of difference in scores between referees was 0.5 (range 0 to 2.4). The large discrepancy of 2.4 points in score was resolved by 3rd referee who recommend rejection of the paper.

All authors whose submissions were rejected, have been invited to re-submit a totally revised version. One author retracted his submission, 3 authors followed this invitation and their improved manuscripts were finally accepted, whilst the remaining authors have not responded yet.

Only in 3 of 45 accepted submissions, amendments were not requested. About half of the invited authors took the chance to improve their work.

Acknowledgment

This review process was only possible by the assistance of EAT members and their expertise and willingness to evaluate the submitted papers. I like to thank the following colleagues for their help:

John Allen, Newcastle, UK

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Graham Machin, London, UK

Rob Simpson, London, UK

Aderito Seixas, Porto, Portugal

Ricardo Vardasca, Porto, Portugal

James Mercer, Tromsö, Norway

Damiano Formenti, Milano, Italy

Anna Jung, Warsaw, Poland

Maria Soroko, Wroclaw, Poland

Mari Vainionpää, Tuusula, Finland

David Pascoe, Auburn, AL, USA

Ram Purohit, Auburn, AL, USA

Tim Conwell, Denver, CO, USA

Srini Govindan, Wheeling, WV, USA

Phil Hoekstra, Birmingham, MI, USA

Kurt Ammer, EAT, Vienna, Austria

Obituary notice

Bill Hobbins (1924-2018)

It is with deep sorrow to inform the thermographic family of the heartbreaking news of the death of our colleague, mentor, and dear friend, William B. Hobbins, MD. "Bill" passed in the early hours of February 12th at home. He was 94. He had been in poor health for many months before his passing. He is survived by his wife Paula and nine children.

Dr. Hobbins was one of the pioneers in the utilization of medical infrared imaging (thermography) in evaluating breast health with a focus on early detection of breast cancer. Dr. Hobbins continued to generously share his extensive expertise in IR breast imaging to scores of health professionals throughout the world up until his death. He also had an avid interest in the application of IR imaging in neuromusculoskeletal pathology, particularly in autonomic dysfunction and chronic pain. Dr. Hobbins was not only an encourager but a mentor to so very many physicians, academicians, and Infrared researchers in a wide variety of specialty areas.

Bill's passing is indeed a significant loss to infrared imaging, to the extended EAT family, and to the healthcare community as a whole. Bill's dedication to the medical field and Infrared research was driven by a deep sense of community and unwavering love and compassion for all. He will be profoundly missed by everyone whose lives he touched. Bill's impact on those who were fortunate enough to have known him is so aptly characterized by one of his closest colleagues, Dr. Francis Ring, who wrote, "He was an inspiration all of my working life!" Thank you, our dear friend and Godspeed!

Drs. T. Conwell, D.Pascoe, R.Purohit and S Vlasuk

2018

13th - 15th April 2018
XXII Meeting of the Polish Society of Medical Thermography Combined withThe European Association of Thermology, Zakopane, Poland

All are warmly invited to the annual meeting in Zakopane.

Conference venue:
"HYRNY" Hotel, Pilsudskiego str. 20, Zakopane

Abstract form will be published in Thermology International
Abstract should be submitted to a.jung@spencer.com.pl.

Abstract deadline is 15thMarch 2018

Registration fee:

Accommodation (2 nights) / meals, welcome dinner 120 E per person (participant, accompaning person) will be paid in cash/credit card on arrival in hotel reception.

EARLY RESERVATION FOR ACCOMMODATION before March 15th to ensure hotel reservation by email: a.jung@spencer.com.pl

Scientific Committee

Dr Kevin Hovell Ph.D (UK)
Prof.Kurt Ammer MD,Ph.D (AUT)
Prof.Sillero-Quintana Manuel Ph.D (SPA)
Aderito Seixas MSc. (POR)
Prof. Ricardo Vardasca Ph.D (POR)
Prof.Boguslaw Wiecek Ph.D,Eng (Poland)
Prof.Francis Ring Dsc (UK)
Prof.Anna Jung MD,Ph.D (Poland)
Prof.Antoni Nowakowski Ph.D,Eng (Poland)
Dr.Janusz Zuber MD,Ph.D (Poland)
Prof.Armand Cholewka Ph.D, Eng (Poland)

PROGRAMME AT A GLANCE.

13th April, Friday - 7 p.m.

Welcome Dinner (HYRNY Hotel)

14th April, Saturday

9.00 - 11.00 Session I
11.00 - 11.20 Coffee break
11.20 -13.00 Session II
13.00 - 14.15 Lunch
14.30 - 16.00 Session III
16.00 - 16.15 Coffee break

16.15 - 18.00 EAT board meeting

24th - 29th June 2018
QIRT 2018 in Berlin, Germany

14th Quantitative Infrared Thermography Conference

Venue Conference

H4 Hotel Berlin Alexanderplatz
Karl-Liebknecht-Straße 32
10178 Berlin

Venue Short Courses

Bundesanstalt für Materialforschung und - prüfung (BAM) in Berlin-Adlershof
Richard-Wilstädter-Straße 11
12489 Berlin

Key Dates:

Deadline for abstract submission: 30.November 2017
Acceptance notification: February 2018
Deadline for paper submission: 31 March 2018
Deadline for registration: 27 May 2018

Contact:

German Society for Non-Destructive Testing (DGZfP e.V)
Steffi Dehlau
Email: tagungen@dgzfp.de

QIRT Conferences http://qirt.gel.ilaval.ca
QIRT 2018: www.qirt2018.de

4th July 2018
Short Course on Medical Thermography

Pre-conference course
to the 14th European Congress of Thermology

Venue:

National Physical Laboratory, London, Teddington, UK

Registration fee : 200.- Euro

Course teachers:

Prof Kurt Ammer MD, PhD

Prof James Mercer PhD

Aderito Seixas Msc

Prof Manuel Silero-Quintana PhD

Rob Simpson PhD

Prof Ricardo Vardasca PhD

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XIV European Association of Thermology Congress

"Thermology in Medicine:
Clinical Thermometry and Thermal Imaging"

4th – 7th July 2018

National Physical Laboratory, Teddington, London

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www.eurothermology.org

The EAT and the National Physical Laboratory are delighted to invite you to participate in the XIV EAT Congress in Teddington, London, United Kingdom from 4th to 7th July 2018.

The European Association of Thermology exists to promote, support and disseminate research in thermometry and thermal imaging in the fields of human and veterinary medicine and biology. We do this through our peer-reviewed journal Thermology International, regional seminars around Europe, and our flagship Congress, which takes place every three years.

Following on from the most recent meetings in Porto (2012) and Madrid (2015), the Congress heads back to northern Europe for 2018 to the National Physical Laboratory (NPL) in the United Kingdom.

The EAT Board looks forward to welcoming you to NPL's world class conference facilities in the summer of 2018.

Dr. Kevin Howell
EAT President
Chair, 2018 EAT Congress Organising Committee

VENUE.

The National Physical Laboratory (NPL) is the United Kingdom's National Measurement Institute and is located in Teddington, south west London, approximately 30 minutes by taxi from Heathrow Airport and a 30 minute train journey from London Waterloo. www.npl.co.uk/location.

NPL's modern lecture theatre can comfortably accommodate more than 100 people. For delegates submitting posters, these can be supplied in A4 portrait format as .pdf files, and will be displayed electronically in NPL's state-of-the-art exhibition area.

LONDON 2018
XIV E.A.T. Congress, 4-7 July NPL

XIV EAT CONGRESS 4th – 7th July 2018, NPL.

ORGANISING COMMITTEE.

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Rod Thomas (GBR)
Ricardo Vardasca (POR)

KEY DATES.

Abstract submission is now open, with the closing date extended to **15th January 2018**, and authors will be notified of acceptance for oral or poster presentation by 20th February 2018.

15th January 2018. Abstract submission deadline.
20th February 2018. Acceptance notification to authors.
26th February 2018. End of Early Registration and deadline for registration of presenting authors.

UPDATES.

Follow all the latest news in the run-up to the congress via our Twitter feed:

@EAT_London_2018

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KEY MEETING THEMES.

Calibration and traceability in biomedical thermometry
Infrared thermography in biomedicine
Contact temperature measurement
Hardware and software solutions for infrared imaging
Biomedical applications: surgery, neurology, vascular and pain syndromes
Thermometry in exercise physiology, rehabilitation, and human performance research
Temperature measurement in animal welfare, veterinary applications and equine physiology

REGISTRATION FEES

	Early Registration (Until 26 FEB 2018)	Late Registration (After 26 FEB 2018)
EAT/IPEM/RPS MEMBER	£200	£250
Non-Member	£250	£300
Student	£170	£220

Registration includes access to all congress sessions, congress lunch and coffee breaks, and the Congress Gala Dinner. Guided visit to the historic Hampton Court Palace on 7th July for a small additional fee. Register online at the congress registration website from 17th August 2017 at https://www.regonline.co.uk/XIVEATcongress2018

ACCOMMODATION

There are a number of hotels within walking distance of the National Physical Laboratory and Teddington railway station, and even more choice within a 15-minute radius by train, taxi or bus. Further information about local hotels can be found at http://www.npl.co.uk/contact-us/local-hotels. Early booking in 2018 is advisable!

ACCOMPANYING PERSONS

With central London just 30 minutes away by rail, Teddington is an excellent base for accompanying persons to enjoy the capital city of the UK without the need for an organised tour. All accompanying persons are invited to join the Congress Gala Dinner and social programme upon payment of the appropriate fee.

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PROVISIONAL CONGRESS SCHEDULE

Wednesday 4th July (evening):

Registration desk opens, followed by opening keynote address – **"Cardiovascular and thermoregulatory responses to heat therapy" – Prof. José González-Alonso, Centre for Human Performance, Exercise and Rehabilitation, Brunel University, UK**

Welcome drinks reception

Thursday 5th July:

Keynote address – **"The Kelvin redefinition and its implications" – Prof. Graham Machin, Head of Temperature Standards, National Physical Laboratory, UK**

Science sessions – day 1

Evening – EAT 2018 Congress Gala Dinner

Friday 6th July:

Keynote address – **"History of uncooled thermal-imaging technology" - Dr. Michael F. Tompsett (formerly English Electric Valve Company and AT&T Bell Telephone Laboratory)**

Science sessions – day 2

EAT General Assembly

Saturday 7th July:

Guided visit to Hampton Court Palace (morning, additional entrance fee payable)

Close of Congress

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European Association of Thermology

Short Course on Medical Thermography

Wednesday 4th July 2018, National Physical Laboratory, Teddington, UK

Following on from successful courses in Porto and Madrid, the next EAT Short Course on Medical Thermography will take place immediately prior to the EAT 2018 Congress at the National Physical Laboratory. The course aims to deliver a thorough introduction over one full teaching day to basic thermal physiology and the principles of infrared thermography for human body surface temperature measurement. It will be taught by an experienced faculty of EAT clinicians, biomedical researchers and imaging scientists, along with metrology experts from NPL. Aspects of reliable thermogram capture will be demonstrated in a laboratory session, and students will have the opportunity to practice thermal image analysis in a supervised "hands-on" session.

Syllabus

- Physical principles of heat transfer
- Principles of thermal physiology/skin blood perfusion
- Standardisation of thermal imaging, recording and analysis
- Quality assurance for thermal imaging systems
- Producing a thermographic report
- Provocation tests
- Image analysis
- Hands-on supervised practice
- Educational resources

Registration

The course fee (inclusive of lunch and coffee breaks) is €200
Register online from 17th August 2017 at www.eurothermology.org/congress2018/course
Questions? Contact Dr. Kevin Howell at k.howell@ucl.ac.uk

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