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MEDICAL THERMOMETRY TRAINING FOR CLINICIANS: CHALLENGES AND SUCCESSES

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Over the last decade tympanic (ear) thermometers, along with other new digital thermometers, have replaced traditional mercury-in-glass thermometers for measuring patient temperature in a medical environment. However, there has been concern among users over their performance and accuracy, leading to many clinicians distrusting them. Some of the problems are likely to be due to: calibration issues or the instrument performance (some of the less expensive instruments have shown a tendency to drift over periods of minutes, possibly due to heating by the hand); misuse (incorrect positioning within the ear, incorrect placement of probe covers, 1); or incomplete understanding of human body temperature regulation and normal temperature differences between different measurement sites.

In conjunction with SEEDA (South East England Development Agency) the NPL developed a training course for clinicians concerned with human body temperature measurement. The content included fundamentals of temperature measurement, body temperature regulation, the concept of core body temperature, body temperature measurement sites, plus information about different types of clinical thermometer including best practice and correct usage. Two pilots of the course were run for almost 30 medical staff within the Oxford Radcliffe Hospitals Trust, focussing primarily on the use of tympanic thermometers. This talk will outline the content of the course and the outcome of the trials.

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TIME FOR A CHANGE WHEN ASSESSING AND EVALUATING BODY TEMPERATURE IN CLINICAL PRACTICE

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Evaluation of body temperature is one of the oldest known diagnostic methods and still is an important sign of health and disease, both in everyday life and in medical care. In clinical practice, assessment and evaluation of body temperature has great impact on decisions in nursing care as well as medical diagnosis, treatment and the laboratory test ordered. Especially, morbidity and mortality in infectious diseases, and difficulty to discover signs and symptoms of ongoing infection early on in multi-diseased elderly is a well known problem in clinical practice. As there is a lack of specific symptoms in the presentation of infection in this group, the presence of fever becomes most important.

The definition of normal body temperature as 37° C and fever as > 38° C still is considered the norm world- wide, but in practice there is a widespread confusion of the evaluation of body temperature. In addition, tradition and culture seems to have a great impact on what is considered fever and necessary actions. When assessing body temperature, we have to consider several "errors", such as the influence of normal thermoregulation, gender, ageing and site of measurement. Actually, there is a lack of evidence for normal body temperature as 37°C, due to inter- and intra individual variability. In addition, as normal body temperature shows individual variations, it is reasonable that the same should hold true for the febrile range. By tradition, the oral and axillary readings are adjusted to the rectal temperature by adding 0.3° C and 0.5°C, respectively. However, there is no evidence for adjusting one site to another, i.e. no factor does exist which allows accurate conversion of temperatures recorded at one site to estimate the temperature at another site.

Taken together, it is time for a change when assessing and evaluating body temperature in clinical practice.

CAN INTEGRATED AND CONTINUOUS VITAL SIGN AND TEMPERATURE MONITORING CONTRIBUTE TO THE CARE OF HAEMODIALYSIS PATIENTS?

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For patients with end stage renal disease (kidney failure) awaiting a transplant or considered unsuitable for transplant, haemodialysis is the most prevalent modality of life-sustaining maintenance therapy.

The majority of patients receive outpatient haemodialysis three times per week, each session lasting four hours.

During treatment, some patients may become unwell with a sudden, unpredictable drop in blood pressure. This condition known as intradialytic hypotension (IDH) and is reported to affect 20-30% of all dialysis treatment sessions.

Haemodialysis causes a rise in core body temperature although the exact mechanisms for this are unclear. Research suggests that a rising body temperature on dialysis leads to an inability to control blood pressure and is a key factor in the occurrence of IDH.

Our research at the Oxford Kidney Unit studies the physiological changes that lead to IDH and our aim is to be able to predict and prevent it.

In addition to multiple other physiological parameters, we are monitoring skin temperature continuously, using novel ambulatory hardware, and tympanic temperature on an intermittent basis.

Early results suggest that our patients have a lower pre-dialysis body temperature than expected. This is potentially important because the temperature of the dialysis fluid is arbitrarily set at 37 degrees and may be actively warming our patients with deleterious effects.

VITAL DENTAL THERMOGRAPHIC IMAGING

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The aim is investigate the vitality of teeth by modern thermographic images.

It is hypothesized that a vital tooth will have a higher temperature and central warming, compared to a non-vital tooth, due to the perfusion of blood in the pulp.

Previous studies using tooth-surface temperature and re- warming rate to assess tooth vitality have been inconclusive. Some demonstrate a higher temperature and quicker re-warm rate in vital than non-vital teeth (1, 2, 3) whilst others have demonstrated no detectable difference (4, 5, 6).

The warmest area of the anterior tooth-surface is reported as being the upper- middle ninth quadrant (7). Teeth have different temperatures according to arch position but the temperature range of each tooth is so wide it is not possible to determine individual temperatures for tooth-type (8). However, a temperature gradient from the incisal edge to the gingival margin does exist (3, 5).

The warming-effect has been attributed to the pulpal blood supply (9) or the periodontal circulation (7). Both these theories may be applicable but have been challenged (5) because, after the initial 20 seconds of re-warming, there is no difference between gingival margin and incisal edge warming-rate.

Initial investigations in-vitro have demonstrated further analysis is needed with current thermography equipment.

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THERMAL SYMMETRY ON UPPER AND LOWER EXTREMITIES ON HEALTHY SUBJECTS USING STANDARDISED IMAGES.

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Background: Infrared thermal imaging is being increasingly utilised in the study of neurological and musculoskeletal disorders. In these conditions data on the symmetry (or the lack of it) of skin temperature provides valuable information to the clinician. In current times the appearance of newer generations of higher resolution cameras a lack of reference data resulting from comparison between total body views with close-up regional views in both anterior and dorsal visualisations existed.

Objective: Establish a value for Sagital and Coronal thermal symmetry of the human body, to be used as indicator in clinical assessments.

Method: In this study skin temperature measurements have been carried out using thermograms, of hands 75 healthy volunteers and for other body 39 healthy subjects were imaged. Measurements were obtained from an infrared camera (FLIR A40) using the CTHERM application. A computational analysis application was developed to standardise and optimise the time of analysis. This tool performs thermal image morphing based on anatomical landmarks preserving the temperature values associated with the regions of interest (ROI) and generates statistics about mean temperature, standard deviation of those ROI's.

Results: Sagital Thermal Symmetry using regional views:

	Dmean T C°	D s.d. C°
Dorsal hands	0.33± 0.34	0.12 ± 0.15
Anterior arms	0.49 ± 0.29	0.28 ± 0.29
Dorsal arms	0.23 ± 0.16	0.33 ± 0.23
Anterior forearms	0.44 ± 0.24	0.47 ± 0.28
Dorsal forearms	0.34 ± 0.25	0.39 ± 0.29
Anterior thighs	0.14 ± 0.13,	0.07 ± 0.07
Dorsal thighs	0.17 ± 0.12	0.07 ± 0.06
Anterior lower legs	0.2 ± 0.16	0.08 ± 0.05
Dorsal lower legs	0.23 ± 0.18	0.11 ± 0.07
Dorsal feet	0.34 ± 0.34	0.16 ± 0.15
Plantar feet	0.38 ± 0.36	0.14 ± 0.16

Conclusion: Total body views and regional views produced comparable results. However in regional views better results were achieved. Using a high-resolution camera the study achieved better results on thermal symmetry in normal subjects than previously reported. Symmetry assumptions can therefore now be used with higher confidence when assessing abnormalities in specific pathologic states.

DAILY VARIATION OF SKIN TEMPERATURE IN HUMANS THROUGH INFRARED THERMOGRAPHY. A PILOT STUDY ABOUT CIRCADIAN RHYTHM.

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Background. Infrared thermography IR is a technique, which allows us to get rapidly and noninvasive thermal images from objects or human beings. (Barnes, 1967). Despite the large amount of studies and articles about circadian rhythm, infrared thermography was rarely used as analyze instrument and skin temperature commonly has a secondary role. However, the development of IR new applications needs a larger knowledge of skin temperature variations and influence factors (Ring, 2006).

Methods. Thermal images of two young men (24 years old±3) were taken during 12 hours in an isolated room (23.9ºC±0.2ºC) following a protocol (Gómez Carmona, 2010) and using a t335

FLIR camera to take the images and Thermotracker software to analyze body areas temperatures.

Results. The results showed a daily variation, reaching the higher temperature at 14 pm and the lower in the first image at 8 am. Thermal asymmetries between bilateral body areas were less than 0.36ºC (normally less than 0.10ºC). Significant temperature variations were observed through the evolution.

Conclusions. Skin temperature follows a similar daily variation comparing with central temperature, nevertheless this variation are significantly different depending on which body area is analyzed. Thermal asymmetries are rare and normally less than 0.3ºC. As well, we observed the necessity of a calibration system in order to avoid significant temperature variations due surely to the error margin of the thermal camera (±2°C).

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DETECTING INFLAMMATORY DISEASE IN PATIENTS WITH ACTIVE THYROID EYE DISEASE

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Thyroid-associated orbitopathy (TAO) is an inflammatory condition affecting the eyes of patients with Graves' disease. It is estimated that the prevalence of TAO in the UK is around 400,000. Treatment can be successful in selected cases and consists of high dose steroids, orbital irradiation and surgery. Choice of treatment is highly dependent on accurate clinical assessment as anti-inflammatory treatments are effective only during the active phase of the disease, while some of the surgical treatments are appropriate only when the disease has become inactive. The clinical assessment of TAO is fraught with difficulties because it is subjective. This pilot study therefore explores the clinical value of medical thermography for the objective assessment of the inflammatory aspects of TAO (such as redness of the lids and conjunctivae).

In this pilot study 15 patients with thyroid eye disease were recruited from the regional Joint Thyroid Eye clinic. Each was requested to follow a pre-test preparation protocol prior to thermography. Patients also underwent a formal clinical assessment of the eyes to form a standard quantitative Clinical Activity Score (CAS). The CAS was measured within a few days of thermography and gave evidence for whether the disease was likely to be active. Thermograms were collected whilst the patient lay comfortably supine and still on a measurement couch, with measurements performed in a temperature controlled thermal imaging facility under cooled room conditions (18ºC). The thermal imaging system comprised a FLIR SC300 camera with FLIR ThermaCAM image processing software employed to summarise thermal characteristics in selected regions around the eyes.

A range of thermal characteristics were observed in non-active (9 patients) and active disease groups (6 patients), with the two groups age- and sex-matched. Linear discriminant multidimensional analysis was employed to assess a range of bilateral eye temperature differences, giving a diagnostic classification accuracy of 93% overall (i.e.14/15 correctly grouped).

Further image analysis is now needed to better understand the relationships between the constituents of the CAS score and the complex thermal characteristics of the eye, and the diagnostic accuracy of classifying active disease assessed in a larger patient group.

ISO STANDARDS FOR FEVER SCREENING AND THEIR IMPLICATIONS

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From the international concern with the SARS outbreak in 2002, infrared thermal imaging has been increasingly employed in screening of travelling passengers, especially in the Far East. The instrumentation and methods used have varied widely, leading to an international call for careful guidelines to optimise the technique.

In 20081 and 20092, an ISO work group finally received inter-, national acceptance of two documents that were published on the use of a screening thermograph.

It is certain that without careful technique, and the use of a calibrated IR camera used in close up to image the face, this technology is very inefficient. There is also a lack of published data on normal temperature values for the human face in health and infective states. Establishment of both the correct technique and clinical data for healthy and febrile subjects of all ages is essential to the success of this methodology.

As a member of the ISO working group the author has been able to conduct a study among hospital patients to compare some different methods for registering temperature in both healthy and febrile children. Thermal imaging with a calibrated FLIR IR camera has been conducted on over 300 children, with a sub group of proven fever patients. Tympanic membrane ear thermometry and conventional clinical thermometry on the same patients have also been employed. The data shows that correctly used according to the ISO standard recommendations, thermal imaging can give a reliable fast and non-invasive indication of fever by measuring the temperature at the inner canthi of the eyes.3

The standard describing the deployment of this method has far reaching implications on the authority (health or airport etc.) deploying this technology. From the specification required for the cameras, how they are utilised in a screening booth, and the testing and training of operators and hardware checks, all require responsible management and regular record keeping. During the last declared Pandemic for H1N1 (swine Influenza) a number of new installations were set up in International airports. Few seemed to have employed the required standards to maximise their efficiency. Publicity in the media that these camera systems were in place, appeared to provide reassurance to the travelling public, while in reality they were unlikely to have met with great success in identifying passengers with raised temperatures. Since the threat of a pandemic has now been lifted, there has been little activity to improve the situation, although one airport authority in the Far East has successfully identified some passengers with a different form of fever, and attributed this to the use of the infrared cameras used for screening.

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THE CONUNDRUM OF MEASURING BODY CORE TEMPERATURE

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The concept, definition and measurement of the deep body temperature (DBT) have been a long standing subject of debate for thermal physiologists. This problem is reflected in the general way in which terms such as thermal core are defined in The Glossary of Terms in Thermal Physiology1. Although no one core site can exactly represent which temperature(s) is/are being regulated, invasive measuring methods such as rectal and oesophageal temperature are often regarded as representing DBT. Common alternative sites are oral (sub-lingual), axillary and inguinal temperatures, which all underestimate DBT. Recently infrared thermometers for measuring auditory canal and forehead temperature have become available. Their reliability to accurately reflect DBT is debated and many use mathematical algorithms in their calculations. These devices involve direct body contact which is undesirable in situations such as mass fever screening, due to fear of spreading infection. For this reason non-contact infrared thermometry of the skin to indirectly measure DBT is attractive. Until recently there was little data on the relationship between the thermal core (e.g. rectal temperature) and thermal images of the head (especially the facial area) in either non-febrile or febrile subjects. Indeed, the question as to which skin site on the head is the most suitable is also debated, although the inner canthus of the eye is regarded by many as being a suitable site. It is important to note that inner canthus temperature is not the same as DBT and will always be somewhat less. Infrared based temperature measurements at the inner canthi are also affected by air temperature and relative humidity. The question as to what threshold skin temperature one should use to indicate that a subject is febrile is also uncertain. Although the issues mentioned above are not new it is important that we are aware of them and realise that indirect measurements of the thermal core will always be "second best" solutions. This conundrum will be discussed with examples from some simple laboratory experiments.

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NON-INTRUSIVE AND CONTINUOUS FEVER RECOGNITION SYSTEM FOR CHILDREN

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Feverish illness in young children usually indicates an underlying infection, which remain the leading cause of death in children under the age of 5 years. Hence, fever ought to be detected as early as possible. Traditional techniques of core body temperature measurement are only used when some other fever symptoms are evident. A continuous monitoring system is of practical importance, especially in scenarios where the ratio of children to adults is considerable, such as schools or nurseries.

The present research developed a non-intrusive indicator that provides means for early fever detection on children under the age of 2 based on the relation between core and skin temperatures at different locations on the body. Suitable locations were identified and an appropriate skin temperature selected based on the alpha and beta errors, keeping low the number of false positives. The use of a 5-sensors-set system is recommended, such that it correctly alerts fever in an 85% of the cases using an alpha error of 0.1. When all 5 sensors are at the same location (upper arm), different degrees of alarm can be identified with probabilities of fever being 20, 30, 45, 60 and 70%. Such systems could potentially save lives.

APPLICATION OF A PORTABLE, LOW COST THERMAL IMAGER FOR THE ASSESSMENT OF FINGER TEMPERATURE AFTER HAND COLD CHALLENGE

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Infrared thermography with mild cold challenge is well- established for the quantification of peripheral vasospasm in disorders such as Raynaud's phenomenon.1,2 Despite the reducing costs of thermographic equipment in recent years, even the lowest-priced fixed-installation thermal cameras based on uncooled detector technology remain beyond the budget of most healthcare establishments. This has contributed to medical thermography remaining a niche technique performed in a limited number of specialist centres.

Cherkas et al.3 demonstrated that a portable infrared radiometer could detect vasospasm with reliability equal to that of a thermal imager. The disadvantage of a radiometer, however, is that only spot-temperatures are recorded: no imaging is possible and measurements from multiple fingertips are time-consuming.

We investigated the performance of the FLIR E30, a new handheld thermal imager costing under £2,500 with a spatial resolution of 160 x 120 pixels. The device was validated against a Land P80P blackbody source with a calibrated platinum resistance thermometer, and spatial resolution was compared to that of a FLIR A320 (320 x 240 pixels) by means of the University of Glamorgan spatial resolution test object.

Raynaud's phenomenon patients who attended the Royal Free Hospital microvascular laboratory for cold challenge thermography using the A320 had their rewarming responses additionally recorded by the E30, and the results were compared. Healthy control subjects also underwent cold challenge with evaluation by the A320 and E30. Results will be presented showing the ability of both devices to discriminate vasospastic from non-vasospastic subjects.

Hand-held thermal imagers such as the E30 open up opportunities for medical thermography at low purchase cost for applications where high spatial resolution and thermal sensitivity are not critical. Quality assurance of the imager and strict adherence to measurement protocol remain vital elements of medical thermography. Further work is required to investigate the utility of handheld thermography across a wider range of medical applications.

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THERMOVISON APPLICATIONS IN WHOLE BODY CRYOTHERAPY

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The studies were performed in 50 volunteers suffering from ankylosing spondylitis, sciatica, spondyloarthrosis and healthy.

The patients were exposed to -120°C in cryogenic chambers for 3 minutes. The thermograms of their backs were taken by a Thermovision Camera (A40M) before and immediately after cryotherapy, in a room with stabilized temperature.

For patients with sciatica the increase of skin temperature occurred in the lower lumbar region of the spine and over adjacent tissues. Similar situations were observed for patients suffering from spondyloarthrosis, but the inflammatory state was connected with a wider range of the spine than with sciatica. For patients with ankylosing spondylitis, the areas of higher temperature were observed along virtually the whole spinal column (a specificity of this disease).

The temperature contrast $\Delta T = T_{max} - T_{min}$ and new relative contrast ratio Q=(?T)/(Tmean) were introduced. ΔT registered along the spine about 3ºC for healthy patients, while for unhealthy patients it was markedly ($p<0.01$) higher (4.5ºC). For patients the Q increased about 50%.

Thermograms of the backs revealed differences in skin temperature distribution between healthy subjects and patients with spine diseases. The nature of the observed temperature variations along the spinal column depends on the degree of advancement and kind of disease.