OUTLINE OF THE AUBURN-GLAMORGAN WORKSHOP

HISTORICAL INTRODUCTION

Francis Ring

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

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

Radiometric temperature detection of the naturally emitting infrared radiation has been a more recent development. In clinical medicine, simple radiometers are now used for aural temperature, and in some countries are replacing glass contact thermometers, mainly because they are considered to a lower risk for infection. The current interest in mass fever screening in airports etc. is based on thermal imaging, but verified by clinical thermometry to relate to core temperature.

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

IR DETECTORS AND CAMERAS

Rod Thomas

The use of Infrared Technology has developed significantly in recent years from the very cumbersome, sometimes unreliable, often liquid nitrogen cooled and extremely expensive infrared cameras prevalent in the later part of the twentieth century. Infrared detector technology has developed to an extent where repeatability, reliability and accuracy are now synonymous with modern systems.

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

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

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

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

QUALITY ASSURANCE IN THERMOGRAPHY

Peter Plassmann

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

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

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

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

PRINCIPLES OF THERMAL PHYSIOLOGY

Kurt Ammer

Thermal physiology describes all body functions related to thermal energy given to or removed from a living body. The most important physiological system in this context is temperature regulation, which keeps the temperature of the inside of the body on a constant level. This is achieved by changing the temperature in the outside of the body varying the superficial blood flow and heat production or activation of additional cooling mechanisms such as evaporation of sweat on the skin surface. The human body uses sympathetic nerve fibres for information spread related to temperature regulation. However, temperature regulation is only one function of the autonomic nerve system. Its main function is the non-voluntary control of smooth muscle fibres.

Strong interactions exist between temperature regulation and the cardiovascular system, also with fluid and energy control Heat generated by contraction of striated muscle fibres is the most important internal heat source of the body. Understanding the mechanisms of heat exchange of the body with the environment is essential for correct interpretation of temperature patterns on the body's surface. Any disturbance of the heat balance of the body is followed by temperature regulation, which keeps the deep body temperature close to the set point. Exhausting the regulation capacity of the system leads to a new set-point i. e. either increase (hyperthermia) or decrease (hypothermia) of the core temperature. The mean skin temperature and the core temperature jointly determine the regulation process. Skin temperature is the result of the heat storage of the body and the thermal environment. The law of physics for heat transfer provides the means of predicting the mean skin temperature under defined conditions.

Various mechanisms unrelated to temperature regulation may affect the diameter of superficial skin vessels, resulting in different levels of skin temperature. Temperatures on the surface can only be correctly interpreted if the condition of the thermal environment is known. It is not true to assume that the surface temperature is synonymous with perfusion or that blood flow is exactly the same as surface temperature. However, very specific responses of vessel control do occur in certain thermal conditions.

Temperature regulation under working conditions is of practical importance to man, especially for research into safety procedures in extreme temperature conditions. The balance between protection against either heat or cold and gross endogenous heat production can be a very difficult challenge. In such a situation interactions of temperature regulation with the cardiovascular system and fluid balance become significant.

Many physiological functions are related with the thermal phenomenon, but not all are the result of temperature regulation. Basic knowledge of thermal physiology is necessary for the correct interpretation of human body temperature measurements.

STANDARD PROTOCOLS FOR THERMOGRAPHY

Francis .Ring

Despite the availability of infrared thermal imaging for medical investigation for 50 years, there is a notable lack of reference data for normal subjects. Human body temperature is known to be self regulating (homeothermic) and to remain within narrow range of temperatures in a healthy subject. Inflammation, reduced blood perfusion and a number of defined clinical conditions can affect skin temperature to a significant degree. Nevertheless, to use thermal imaging to study body surface temperature, strict protocols must be followed; to obtain the thermal sensitivity required for measuring the changes in the limited thermal range. Thermal imaging equipment has increased thermal and spatial resolution, now attainable at lower cost than in the past. Even with the improved technical performance, there are a number of pitfalls to be avoided in order to obtain reproducible and reliable thermal data from medical thermography.

Eight stages for potential errors or artefacts have been identified.

1.Patient information and preparation for examination.

2. IR Camera systems and calibration.
3. Patient positioning & Image Capture.
4. Thermal image analysis.
5. Image storage.
6. Elec-tronic image exchange (radiometric)
7. Image presentation.
8. Information on protocols and learning resources.

The critical factors in a thermal imaging protocol begin with the patient. Prior information to and from the patient is needed. To register any possible effects of drugs, physiotherapy or surgery on body temperature, the patient is always asked to rest in a cubicle, with the examination areas unclothed for a minimum of 10 minutes at a defined ambient temperature.

The equipment must be of proven stability and accuracy, with the IR camera mounted on a parallax free stand. The examination room must be at a controlled temperature, usually from 20°C (used for inflammatory studies) t0 24°C (used for vasomotor studies). Standard views of each required area of the body are essential, and the angle between camera and patient should be around 90° whenever possible.

Standard distances are also advised, since resolution (thermal and spatial) are usually decreased as scanning distance increases. Image analysis must also be standardized. Regionsof interest are frequently chosen on subjective parameters,which have been shown to be irreproducible even by the same investigator on the same image with repeated analysis. A protocol for defined regions of interest based on anatomical limits is the only sure way to minimize inter operator variation.

Finally, reporting the images requires al relevant data on the temperature range and level of the camera setting, the location of regions of interest and their data, and the conditions under which the ex amination was carried out. Failure in any of these parameters can lead to sizable errors, and misinterpretation of the findings.

Examples will be given of false results in thermal imaging from failure of the investigator to understand the essential factors for the patient examination. Inadequate camera settings, or unproven stability after starting the camera have been found to significantly alter the final image. Errors resulting from subjective sizing and placement of regions of interest also show significant variations, all of which can be avoided. The importance of standardized reporting is evident when comparisons over time are required.

In medical-legal issues, each image must be clearly identified, and shown to be taken under comparable conditions. No less a standard is required for normal clinical work with this technique. Knowledge of the normal patterns, and causes of hyperthermia or hypothermia are also important to both the technician and the physician using this technique.

CAUSES OF HUMAN TEMPERATURE INCREASE & DECREASE

Kurt .Ammer

Thermal imaging is a technique capable to map the temperature distribution on the human skin. In healthy subjects skin temperature is highly symmetrically distributed related to a symmetry axis situated in the median plane of the human body. In the extremities, higher temperatures are normally seen at the proximal end of the limb than on the tips of fingers or toes. Any disturbance of these normal temperature pattern may be detected either as hyperthermic or hypothermic area.

Hyperthermic areas within medical thermal images may be caused by inflammation, increased blood flow, growing tumor, heat generation due to muscle contraction or artefacts due to the environment. Examples will include inflammatory joint disease such as rheumatoid and osteoarthritis, inflammation of tendon insertions and tendon sheets and bursitis. In Paget´s disease of bone hyperthermic areas have been related to increased blood flow within the affected bone.

Skin inflammation caused by herpes infection, skin rash due to virus infection, irradiation induced dermatitis will be presented. Varicose veins and deep venous thrombosis are related to hyperthermic changes. A diffuse hyperthermia on the diabetic feet may be caused by neuropathia, an intensive local hyperthermia was related to underlying osteomyelitis.

Malignant tumors of the female breast or of the skin such as melanomas can be visualised in thermal images as hyperthermic areas. These "hot spots" might be caused by an increased angio-genesis.

Recently performed muscular work, muscle spasms and tender points in fibromyalgia patients are characterized by increased skin temperature. Artefacts due the environment such as heating by infrared radiation, conductive heat therapy or skin contact with other hot surfaces can result in hyperthermic areas on the body surface.

Hypothermic skin changes may be caused by decreased blood flow, loss of muscle contraction, sympathetic hyperactivity induced by partial nerve lesion, lymphedema or artefacts due to the environment. Typical findings from patients with obstructive angiopathy . Raynaud`s phenomenon, motor deficit due plexus paresis, poliomyelitis, herpes zoster, radiculopathy, peroneal palsy and decreased range of motion induced by arthritis or arthodesis will be presented . The thermographic changes of common nerve entrapment syndromes such as carpal tunnel syndrome, thoracic outlet syndrome and ulnar nerve entrapment will be discussed. Cases of reflex dystrophy, thermal images from patients suffering from lymphedema and some artefacts causing hyperthermic changes of the skin temperature will close this lecture.

PROVOCATION TESTS

Francis Ring

Infrared thermal imaging of the human body skin surface is normally carried out after a standard period of acclimatisation in a temperature-controlled room. A number of normal temperature patterns have been identified. Clinical abnormalities in temperature can be identified. Once the normal pattern is established. Dynamic reactions to provocation tests can be useful when there is a possibility of loss of thermal symmetry between the two sides of the body. The effects of some work related injuries on skin temperature may also be made more obvious following such tests.

In general, provocation or stress testing the skin can be made by using either *Chemical, thermal or mechanica challenges*.

1.*Chemical* and pharmacological skin tests are used in dermatology.[1] These may be applied allergens, or inflammatory mediators such as prostaglandins, 5HT etc. Nicotinic acid compounds in sufficient dose are known to provide local and transient areas of inflammation on the skin under normal conditions. In certain circumstances, this reaction may be inhibited or enhanced, depending on local blood perfusion to the skin and the status of the sympathetic nervous system.

2.*Therma*l tests have been used primarily to quantify the finger and toe temperatures in Raynaud's Phenomenon.[2] Immersion of the hands in a water bath at 20^{0}C or colder for a fixed period e.g.1 minute, provides a useful clinical test of recovery which is related to the local perfusion and the sympathetic response. Normal subjects may produce reactive hyperaemia in the fingers, or should recover baseline temperatures quite quickly (<10 mins) A vasospastic reaction is marked by delayed recovery in one or more fingers. Exposure to Ultraviolet radiation may also be used to generate local inflammation, and has been used to test solar barrier creams on the skin in-vivo.[3]

3.*Mechanical* tests may be based on muscular work, by performing controlled exercises and observing the muscular heat so generated. This may be absent in some cases of pain syndrome or where permanent damage to the nervous or vascular system has occurred. In vibration white finger VWF, which is work related, cold fingers and hands may occur as a result of local damage to the peripheral micro-vascular and nervous systems. Controlled contact with a suitable vibrating surface is one means of provoking a reaction in these patients. Rapid re-warming of the fingers is normal, but delayed localised recovery of skin temperature can be found in fingers affected by VWF.

Examples of the above techniques demonstrate that thermal imaging has a valuable role in assessing the response to provocation tests on the skin. Under standard conditions the tests can be quantitative, thus providing the means for clinical trials of pharmaceutical compounds, and evoking abnormal responses in certain injuries which affect the vascular and local sympathetic nervous systems.

IMAGE PROCESSING PRINCIPLES

Peter Plassmann

Over recent years practitioners of medical thermography have recognised the need for introducing standards into the various processes of image acquisition, analysis and data exchange. Commercially available thermal imaging software, however, is generally designed with industrial applications in mind and as such often more a hindrance than a help in achieving this goal.

A set of 24 standard "masks"is proposed which can be superimposed onto live thermal camera images in order to aid the precise positioning of subjects in pre-defined standard views. Embedded in the description of each mask are codes and descriptions which simplify searching and indexing of acquired images in data bases.

Images captured in such a way have a number of advantages: they can be readily compared with other images and lend themselves to semi-automated analysis such as a cold-stress-test. Morphing techniques can be used to create an average image of body region of interest and such average images me be used for reference and comparison with images recently captured.

Examples of standardised image capture and semi-automated analysis produced by the CTHERM software package are presented. The author has developed data file conversion tools so that images captured and analysis data produced by CTHERM can imported into the ImageThermabase package (and vice versa). Conversion tools for AGEMA CATS-Images and images recorded with the software package IRIS from NEC-Thermotracers are also evailable. It is planned to incorporate conversion tools for further packages, to enable and simplify consultation and data exchange within the medical thermology community.

EDUCATIONAL RESOURCES

Kurt Ammer

Knowledge of thermal imaging is necessary Rehabilitation medicine (in Austria part of the postgraduate training for Physical Medicine and Rehabilitation), Human Physiology, Occupational Medicine and optional in Rheumatology, Dermatology, Orthopaedics, Neurology, Neurosurgery. In 1993, the European Association of Thermology (EAT) organized in cooperation with the Austrian Society of Thermology a course on medical thermography with lecturers from around Europe, Francis Ring and myself conducted a three days course on thermal imaging in Sao Paolo in 1999, which triggered the foundation of a Brazilian Society of thermology. The University of Glamorgan offers since 2001 a regular training course on medical thermal imaging. Thermology Societies all around the world provide training and certification for technicians and physicians (for example the AAT), organize meetings and conferences and publish journals.

The International College of Thermology was founded in 1987 and links the three continental associations, namely the American Academy of Thermology, European Association of Thermology, and Asian-Pacific Association of Thermology. The president and the International Congress of Thermology used to change for a one year period from Asia to Europe, from Europe to America and from America to Asia. The cycle of international Thermology-Conferences started 1989 in Georgetown, Washington DC, went then to Ghent, Belgium, Matsomoto, Japan, Ft.Lauderdale, Florida, Vienna, Austria and Seoul, South Korea and is now 2007 in Auburn. The EAT started with European Congresses in 1974 in Amsterdam and had the last European Conference last year in Zakopane, Poland. National conferences on thermology were regularly organized in Japan, Korea, USA, Austria, Germany, Hungary, Poland, United Kingdom.

Scientific journals related to temperature are manifold, but only some were dedicated to medical thermology. Acta thermographica and Thermology had ceased publication years ago, Biomedical Thermology publishes now only in Japanese, the German ThermoMed has problems to appear regularly. Thermology international is at the moment the only journal which publishes 4issues/ year with thermological papers in medicine and biology. A number of books are related to thermal imaging in medicine, the latest is a spin off of the chapter on infrared imaging in the handbook of biomedical engineering.