Quality assurance for thermal imaging systems in medicine

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SUMMARY

Infrared thermal imaging was first made available to medicine in the early 1960's. Despite a large number of research publications on the clinical application of the technique, the images have been largely qualitative. This is in part due to the imaging technology itself, and the problem of data exchange between different medical users, with different hardware. In 2001 an Anglo Polish collaborative study was set up to identify and resolve the sources of error and problems in medical thermal imaging. Standardisation of the patient preparation, imaging hardware, image capture and analysis has been studied and developed by the group. The collection of normal reference images from a multi-centred study is required, but is dependant in improved reliability and cross calibration of camera systems. This paper specifies the areas found to be the source of unwanted variables, and the protocols to overcome them.

KEY WORDS: thermal imaging, standardisation, reliability, source of error

QUALITÄTSSICHERUNG FÜR THERMOGRAPHIESYSTEME IN DER MEDIZIN

Die Infrarot-Thermographie wird in der Medizin seit den frühen 1960iger Jahren eingesetzt. Trotz einer Großzahl von Forschungspublikationen zum klinischen Einsatz dieser Technik wurden die Wärmebilder meist nur qualitativ beurteilt. Das war teils durch die Bildtechnlologie selbst bedingt und zum Anderen durch das Problem des Datenaustauschs zwischen unterschiedlichen medizinischen Nutzern mit unterschiedlichen Geräten verursacht. Im Jahr 2001 wurde die Englisch-Polnische Kooperationsstudie initiert, um Fehlerquellen und Probleme in der medizinischen Thermographie zu identifizieren und Lösungsvorschläge zu erarbeiten. Die Vorbereitung der Patienten, die bildgebenden Geräte und die Erfassung und Analyse der Wärmebilder wurden von der Gruppe untersucht und Standards dafür wurden entwickelt. Der Aufbau einer Datenbank von normalen Referenzbildern ist im Rahmen einer multizentrischen Studie ist notwendig. Dies ist jedoch nur bei verbesserter Zuverlässigkeit und gegenseitiger Kalibrierung der Infrarotkameras möglich. Diese Arbeit spezifiert jene Bereiche, die als die Quelle unerwünschter Variabilität gefunden wurden, und beschreibt die Maßnahmen, um sie zu vermeiden

SCHLÜSSELWÖRTER: Thermographie, Standardisierung, Zuverlässigkeit, Fehlerquelle

Thermology international 2007, 17: 103-106

Problems in thermal imaging in medicine

Disease and temperature change has a recognised association since the earliest days of recorded medicine. Fever, one of the earliest observations, was for centuries a subjective assessment on the part of the physician. The introduction of thermometers in the 16-18th century brought the first opportunities to objectively measure fever in man, although the technical limitations, and lack of standards, did not help in the understanding and acceptance of such measurements. Dr Carl Wunderlich in Leipzig in 1868, systemized the measurement of temperature in diseased patients, and introduced the clinical thermometer, showing the value of serial measurements. This situation remained a cornerstone of medicine until the introduction of infrared imaging in the early 1960's (1). Unfortunately, like the early thermometers, satisfactory calibration and standardisation of the imaging systems has taken many years to achieve. As a result many papers have been published on clinical studies, but the acceptance of such studies is limited by uncertainty about the techniques used, the imaging hardware and overall reliability (2,3) The predominant lack of control data over the last 40 years of thermal imaging in medicine has been compounded by the fact that the vast maj ority of publications refer to studies in diseased patients. The limited sources of normal control thermal images are rarely addressed. Similarly, there have been only a limited number of publications on standardisation of technique with thermal imaging (4,5).

The Anglo-Polish database project

Modern computing power, and significantly improved infrared thermal imagers for medicine, led to a new project in 2001 to address the above issues. A multidisciplinary team investigated each of the stages involved in performing a thermal imaging investigation on normal subjects. This team involved, physicians, clinical scientists and computer scientists from established centres of expertise in Poland and the UK. The aim is to investigate the total process of thermal imaging in a clinical environment, and to document all areas in which variables, which may affect the reliability of the process. This initial phase of study was completed at the end of 2003, and is described below. The ultimate aim is to collect a statistical sample of normal men and women (and probably some children) for a reference atlas of the human body thermograms, based on the protocol which has now been presented at some international conferences on thermal imaging in medicine (6). It is anticipated that access to the atlas/database of normal subjects will become possible either for on-line use, or by an electronic or hardware publication.

The standard protocol

The main areas of a clinical thermal imaging procedure that require standardisation are

a preparation of the patient

b standardisation of the thermal imaging system (including calibration)

c image capture protocols

d image analysis protocols

e reporting, archive and storage of images

f education and training of clinical users of the technique

Preparation of the patient.

Existing publications draw attention to the key essentials, which may be conveyed to the patient in prior advice regarding smoking, exercise, drugs and cosmetics on the day of examination. The need for stabilisation after removal of essential clothing in a controlled environment (temperature and humidity) has been internationally agreed.

Standardisation of the Thermal Imaging System

There are a number of thermal imagers in medical use, using different detectors and optics. They are not equal in thermal or spatial resolution, and each depend on the manufacturers calibration. It has been found that most camera systems, both cooled and un-cooled detectors require much longer to achieve radiometric stability than stated by the manufacturer. This means that the common practice of setting up a camera just prior to use, is frequently inadequate. Variation in the measurement from a black/grey body radiant source at a known temperature or temperatures must be established for each imaging system, and the minimum warm-up time recorded. In addition, most thermal imagers are calibrated by the manufacturer before delivery, and may not be checked again until a fault is detected. Furthermore, each manufacturer in each country may use a different reference system, resulting in a wide offset range in terms of absolute temperature, Figure 1. In order to correct for this, the project team are collaborating with the National Physical Laboratory, UK in the development of a portable series of temperature standards which can be used to cross calibrate all imaging systems to be used in a multi-centre image collection. A large variable in camera position, caused by conventional photographic tripod use is simply overcome by the use of a large format camera studio stand, which allows vertical adjustment of the camera parallel to the ground.

Image Capture Protocols

We have found image capture to be a maj or source of variability, with varying camera angles and distances. A complete set of standard views was therefore devised, that require the camera to be mounted on a parallax free stand (Figure 1), ideally a heavy-duty studio pillar stand. The cameras than then be maintained at 90to the target, and parallel to the ground. The most useful modification, however, has been the introduction of software generated capture masks for each standard view of the human body. This is an electronic outline written in to the software that automatically appears when each standard view is selected from the menu. The outline ensures that the target fills the frame as much as possible, and that the limits for each view are defined by anatomical description (i.e. visible topographic features). The investigator adjusts the distance between the subject (target) and camera to fit the thermogram of the area to be recorded as closely to the mask outline as possible. This brings the thermogram to approximately the same size for all normal adult subjects regardless of their body size. Figure 3 and four show the description provided for each field of view, and form part of a defined set of 27 such views to cover the

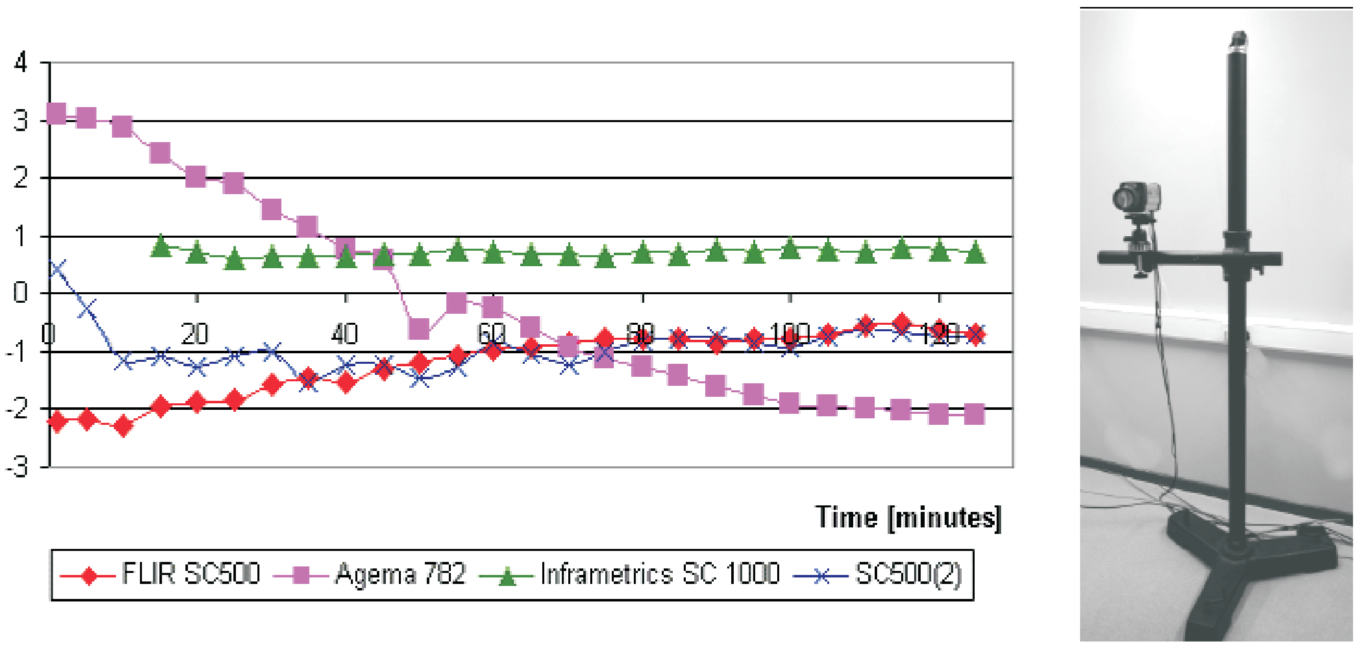


Figure 1.
Shows variable offset in four calibrated IR cameras and camera mount.

body surface which are likely to be of clinical importance in a medical examination. The temperature range and level is kept constant for the standard set of images, although supplementary images can be added if essential to record the full dynamic range of the subj ect.

These standardised procedures allow the collective analysis of groups of subjects within specified age bands placed in decades of life viz.20-80 years of age, male and female.

Image Analysis

Having obtained a standardised image, a set of regions of interest for temperature analysis have been drawn up for each standard view. These are accurately placed, again following anatomical definition, if the image has fitted well to the mask. Minor adjustments can be made if the fit is less good. Figures 2, 3 and 4 show the definitions of regions of interest for three of the standard views, the anterior face, forearm, and anterior total body. Experiments have shown that the usual practice of selecting rectangles or free drawing regions of interest, are poorly reproduced even by the same operator.

However, the policy of following described anatomical landmarks in drawing each region of interest results in very good reproducibility, whether made by the same operator or another (7). Such measures, which ensure that many of the subjective variables in analysis are removed or minimalized, are of critical importance in medicine.

In order to create a mean normal image of each anatomical area, with defined standard deviations, a further process of morphing has been developed. In this way larger numbers of images of the same anatomical area, and for a selected age band, can be merged to derive a mean range of temperature and thermal patterns for each area of the human body.

Reporting, Archive & Storage

Modern software greatly facilitates the reproducibility, from importing the image and the analytical data to a word-processing package. It is important that the images are stored complete with all demographic identification, and the temperature analysis from the standard regions of interest. We are investigating the effects of commonly used compression techniques on the thermal data, and at the present time avoid the use of these methods during the building of the image database. Suitable back up of all files is a standard requirement in medical imaging protocols. Software developments are also in progress to find a range

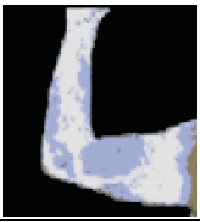
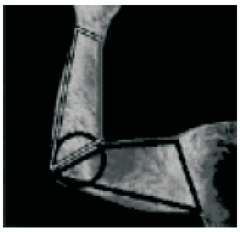
Standard View	LEFT ARM (dorsal view)
Upper	wrist
Lower	below the axillar fold
Other	arm 90° abducted and elbow 90° bent, the outline of the of the deltoidmuscle is within the image
Image	
IMAGE ANALYSIS	
Standard View	LEFT ARM Number of ROIs 3
Description	
ROI 1	Shape: circle Outline of the circle is adjacent to the cubital fold and the lower edges of the elbow.
ROI 2	Shape: trapezoid Upper left corner: cubital fold. Upper right corner: insertion of the deltoid muscle. Lower right corner: axillary fold. Lower left corner: tip of elbow.
ROI 3	Shape: trapezoid Upper left corner: ulnar end of the wrist. Upper right corner: radial end of the wrist. Lower right corner: cubital fold Lower left corner: tip of the elbow.
Image	

Figure 2
Anatomical description of the field of view for image capture of the fore arm

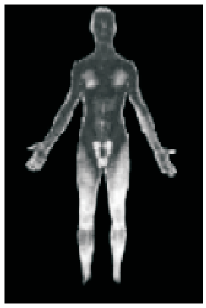
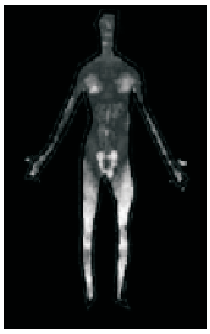
Standard View	TOTAL BODY (anterior view)
Upper limit	the most cranial point of the head
Lower limit	soles of the feet
Other detail	arms and legs slightly abducted, palms point forwards, head is a vertical position, not rotated or tilted to the side
Image	
IMAGE ANALYSIS	
Standard View	TOTAL BODY (anterior) Number of ROIs 1
Description	Shape: polygon, following the outline of the body
Image	

Figure 3
Anatomical description of the field of view for image capture of the whole body according to the new protocol and the region of interest for image analysis of the anterior surface.

of useful parameters for searching, especially important when the database becomes large enough to be used to compare or subtract a normal thermogram from an unknown undiagnosed medical condition or disease.

Education and Training of Clinical Users of Thermal Imaging

Past experience of clinicians using infrared thermal imaging has been variable, ranging from good sound science to poorly understood technique, and negative results. The aim of the protocol leading to a standard reference database will greatly improve the understanding and reliability of the technique for physicians who have no previous experience in thermal imaging. In all areas of medical imaging, physicians are first taught to recognize normal findings, and only then are they able to learn the features presenting in know diseases or abnormalities. The group have also co-ordinated some archive materials from earlier publications on a CDROM, and published a clinical casebook to aid physicians who may need examples of thermographic abnormalities associated with certain diseases (8). The University of Glamorgan, in Wales UK, also holds regular short residential training courses on the theory and practice of thermal imaging in medicine. This course includes the need for rigorous standardisation of the whole procedure. In addition, specialist conferences are held throughout Europe on a regular basis, and a j ournal which maj ors on thermal imaging in medicine – Thermology international are further aids to this necessary subject of education and communication within clinical science and medicine[9].

Conclusion

After 4 years of collaborative research involving physicians, clinical scientists and academic engineers, the Anglo Polish Project to construct the first normal reference of human body temperature has made important progress. Protocols for standardisation of the medical examination using thermal imaging have been established and have been accepted on an international basis. Further refinements; especially in the camera calibration, and software to aid standard image capture and analysis are being continued or have been completed. The collection of groups of normal males and females volunteer healthy subjects for the database is in the early stages, but some progress has been made.

The wider involvement of clinical centres in the UK and Poland will enable this data collection to be accelerated. The use of modern communication and imaging technology means that larger numbers of subjects can be sampled than would be the case for a single centre. It will also enable the study of any minor ethnic differences that could occur, particularly during the winter season.

It is hoped that this programme will make a substantial contribution to the ultimate wider acceptance and use of infrared thermal imaging in medicine. Furthermore, since thermal images are sometimes used in courts of law, the reduction in variability should improve confidence in their inclusion as objective evidence in medico-legal trials.

Acknowledgments

The authors gratefully acknowledge a 3-year grant from the British Council (Poland), without which this project would not have been possible.

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