History of Thermology and Thermography: Pioneers and Progress

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SUMMARY

The measurement of temperature, particularly with reference to medicine had a slow beginning, with the primitive thermometers of the 16th century. Dr Carl Wunderlich, a great pioneer in clinical thermometry showed the real significance of the use of temperature measurements for both diagnoses of fever and also for monitoring the course of temperature in relation to the medical condition of his patients. The radiometric determination of human body temperature is however more modern. Remote sensing of infrared radiation became of practical value in the 1940's and has continued to develop steadily since 1960. Modern high speed and high resolution camera systems have now reached a dramatic level of performance at more modest costs, which medicine has now the opportunity to employ as non-invasive and quantifiable imaging. This has applications in many areas of medicine both for diagnostics and monitoring treatment. In recent years the acute threat of pandemic infection has increased, heightened by today's every expanding world travel. Special interest has been shown in the potential of thermal imaging for airport and travel screening. This is effect where Dr Wunderlich's studies began, and it has yet to be proven that the technique can be responsibly employed for efficient screening of large numbers of the travelling public.

1. INTRODUCTION

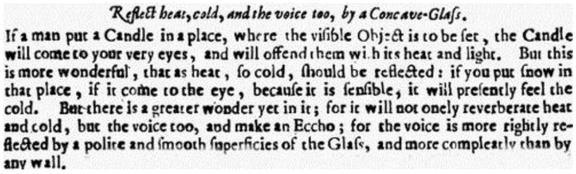
Thermology is the science of heat, which is a very wide topic, and one that applies to many diverse processes of our modern life. In this paper, it is confined to one narrow but highly complex application, that of human body temperature. For many years contact thermometry was the only means of determining human temperature. Thermometry itself slowly developed from Galileo's early thermosope in 1592 to the more usable calibrated scales devised by Fahrenheit (1720) and the metric scale attributed to Celsius in 1742. It was the Danish scientist Linnaus, who in 1750 proposed that Celsius' scale should be inverted; so that low temperature at zero and boiling water would be 100 degrees (1).
The great pioneer of clinical thermometry was Carl Reinhold August Wunderlich who was born in Germany in 1815 (Fig. 1). He studied at Tubingen University and wrote his MD thesis in 1838. By 1850 he had become professor and medical director of the University Hospital at Leipzig.

Fig. 1 - Dr Carl Wunderlich 1850 medical thermometry pioneer.

He was a gifted teacher, strong in physiology and methodology of diagnosis. Among his several significant publications was his treatise on "Temperature in Diseases, a manual of medical thermometry" in 1868. He set out numerous statements of clinical significance especially relating to fever, the course of temperature related to increases and decreases of fever, and the importance of regular and consistent measurement to provide objective evidence of the status of the patient (2). His maximum clinical thermometer, and the daily records of temperature charts are still in evidence today despite the many changes in technology and computerised records.

2. THERMAL RADIATION

The story of infrared radiation is different, and took many years to reach the level of use that is recognised today. Jean Batista Della Porta of Naples made an early record of "reflected heat" in 1593 (Fig 2). In his studies on the behaviour of light he also recognised that heat could be sensed by a human that must have come via reflection, something he proved by locating a candle in front of a silver plate. When the plate was removed the sensation of heat from the candle flame was reduced.



Reflect heat, cold, and the voice too, by a Concave-Glass.

If a man put a Candle in a place, where the visible Object is to be set, the Candle will come to your very eyes, and will offend them with its heat and light. But this is more wonderful, that as heat, so cold, should be reflected: if you put snow in that place, if it come to the eye, because it is sensible, it will presently feel the cold. But there is a greater wonder yet in it; for it will not onely reverberate heat and cold, but the voice too, and make an Eccho; for the voice is more rightly reflected by a polite and smooth superficies of the Glass, and more compleatly than by any wall.

Fig. 2 - Della Porta's publications on optical refraction (1593).

Then in 1800 some 200 years later, William Herschel, amateur astronomer in England, began to investigate the heating powers of the separate colours of the spectrum, in order to improve his optical eyepieces for telescopes. The Royal Society in London published his findings that increased temperature could be detected by thermometry beyond the visible red. In 1840, his son, John Herschel (Fig. 3) continued his father's experiments after his Father had died, and made a simple image by evaporation of a carbon and alcohol mixture using focussed sunlight. He named the image a "thermogram" (3). It is interesting to note that John's closest friend was Charles Babbage whom he had met at Cambridge University, and with whom he travelled around Europe in scientific pursuits.
Another important finding was published in 1935, when JD Hardy, an American Physiologist showed that the human skin surface has the characteristics of a near perfect black body radiator, being highly efficient in irradiative heat exchange (4). In the meantime physicists had been studying the ways to increase the sensitivity of thermometry especially by electrical conductors, and thermocouples. An American Prof Samuel Langley (Fig. 4) made a great contribution by developing a bolometer. This was a means of remote sensing of temperature, and formed the basis for a whole new generation of heat sensor technology.Babbage is generally acclaimed to be one of the pioneers of computing; since he built a mathematical machine called a difference engine, and constructed simple mathematical programs to operate it. So father, son and family friend can be regarded as true pioneers of today's computerised thermal imaging.

Fig. 3 - John Herschel who made and named the thermogram in 1840.

Fig. 4 - Prof Samuel Langley who invented the bolometer in 1880.

In Germany Marianus Czerny (Fig. 5) who was Prof. of Physics at Goethe Institute Frankfurt University, became well known in spectroscopy, but also laid foundations for thermal sensors. He developed an Evaporograph in 1925. One of his students Bowling Barnes went to the USA and built the first thermal imager based on themistors in the 1950's (5).

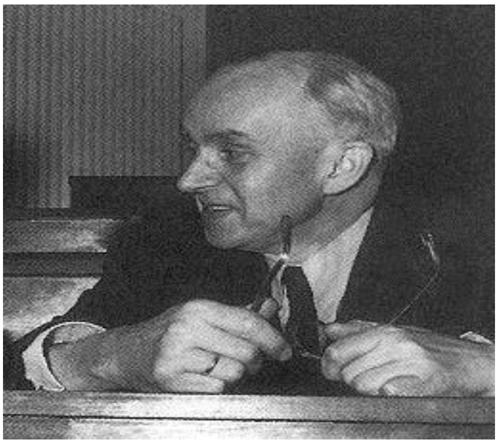


Fig. 5 - Prof. Marianus Czerny (1896-1985).

In the UK, a research physicist Dr Max Cade had built a scanning infrared thermograph using an electronic detector of indium antimonide. This had been built during World War 2 but did not prove fast enough for navigation compared to radar systems. This prototype was brought to our hospital in Bath in 1959, following the post war declassification of infrared imaging. Though the images were primitive, it was evident that inflammation due to arthritis in joints showed increased heat emission. This led to a more usable, large device being built that produced a better quality image of the human body (6), although a single hand thermogram took 5 minutes to record (Fig. 6).

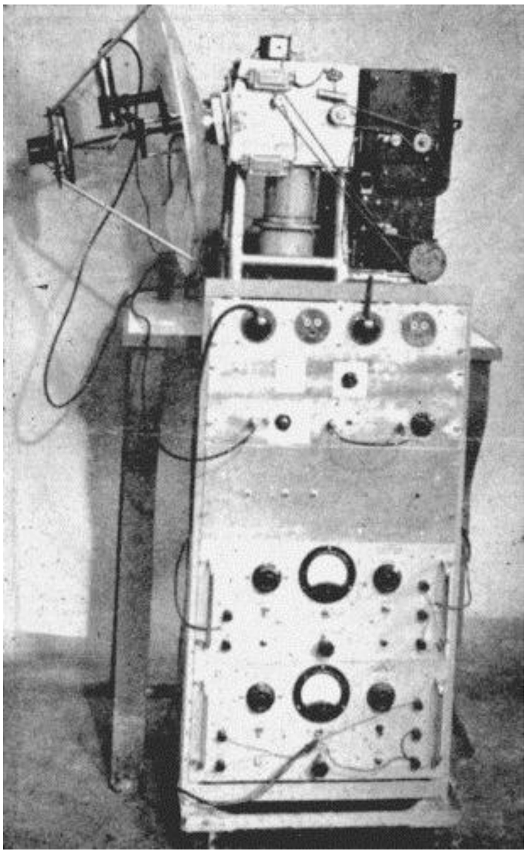


Fig. 6 - Pyroscan, first British medical thermograph in 1960.

Much if this information came together in the early 1960's. In particular, there was a medical thermography conference held in New York in 1963 and in Strasbourg in France in1966. While the potential for infrared imaging in medicine was in its infancy, it is remarkable to read from those early proceedings of the variety and detail given the relatively primitive state of the technology. One author concluded "All that has been revealed by this technique is nothing compared with what is left to be discovered". Sixty years have passed since this was written, and certainly more has been revealed, but we may well repeat the optimistic statement from 1963 today (7).

3. DETECTORS AND CAMERA TECHNOLOGY

Dramatic progress of course has been made in infrared detector systems that have passed through several generations of innovative technology. We now have infrared transmitting lenses that have made an enormous difference to thermal imaging of the human and biological subjects.

Of major importance to medicine is not just the two dimensional expression of temperature in a thermal image, but the ability to record a large number of adjacent temperature measurements from the skin temperature distribution. For some time, this process was not straightforward, and uncertainties about the data obtained from a thermogram remained. Electronic assistance was possible through the use of isotherms, and in 1972, our group in Bath UK, developed a system called the thermographic Index based on measuring the area of isotherms within a specified anatomical region (8). At this time imaging was achieved by scanning optics using a single element detector. This was cooled by liquid nitrogen, added manually to the detector flask at regular intervals. Some years later, Leidenfrost transfer systems were developed. These did reduce the need for regular topping up of nitrogen. It is now known that some of the variables encountered with the thermal imagers could well have been due to inconsistent levels of the coolant on the detector cell. More advanced cooling systems for infrared detectors were introduced, that removed the need for liquid nitrogen handling that certainly increased the convenience for those working in the hospital or clinical environment.

The need for quantitation, and to use the thermal image as a non-invasive means of determining skin temperature was ever present in medical thermography. All this changed, as in so many other areas of medicine with the arrival of the computer.

In the early days (1970's) it was possible to use a basic computer linked to the infrared camera by an analogue to digital circuit. Rapid developments followed, in parallel to those continuing in the field of infrared radiation detection. Quantitative thermal imaging became a reality. However, despite the increasing sales of thermographic cameras with image processing computers, application progress was often slow. Clinical trials were published especially in the field of Rheumatology, where anti-inflammatory therapy could be objectively compared in differing doses of the drug within groups of patients (9, 10). It was always clear that rigorous attention to technique was essential to obtain reproducible results. It is now known that the camera technology of the time often had variables that were not evident to the clinician. Factors such as offset drift (deviation from the true calibration level) and stabilisation of the camera, influences of ambient temperature etc. were all factors that could introduce large variables, but often unrecognised by the investigator.

4. STANDARDISATION OF TECHNIQUE

In the use of thermal imaging in clinical trials, especially those used to evaluate treatments, whether they are physical, surgical or pharmaceutical, have highlighted the need for standard protocols in clinical practice. Some of the first principles of clinical thermographic technique were included in a series of training courses at the University of Glamorgan in the UK. Ring and Ammer published the outline of these requirements in 2000 (11). It has been shown that the addition of an external temperature reference source can greatly improve the consistent technique, and provide the user with valuable early warning of calibration drift or lack of stability in the camera being used. Many of the modern thermal imaging cameras used in medicine are un-cooled bolometric systems. It is all the more important that these devices should be used with regular reference to an external and stable reference source. It has also been shown that a standard protocol should use definable fields of view of the human body regions examined. Regions of interest used for temperature measurements should also be similarly defined and reproduced, since unknown variables lead to inconsistent findings, thus lessening the clinical reliability of the investigation (12).

5. APPLICATIONS AND FEVER SCREENING

Many varied applications of thermal imaging can be found in the literature. The limitation that thermal imaging can only record skin temperature distribution remains. However, there are clinical conditions that influence skin temperature, and with due attention to stabilisation of the patient, and reproducible standards of investigation, a number of useful applications have been found. Many of these apply more readily to the extremities of arms and legs, but a number of diseases do have influences on skin temperature (13).

In recent years, the global threat of pandemic influenza has become evident. Beginning with the SARS outbreak (Severe Acute Respiratory Syndrome) in the Far East with rapid fatalities, infrared cameras were rapidly deployed for screening travellers. High temperatures on the face were used to exclude those with fever from travelling and infecting fellow passengers. There were, however, limitations with this strategy. There was a lack of clinical data to provide a baseline for febrile subjects, and some of the camera systems rapidly deployed were non-radiometric, and therefore not designed for temperature measurement. The International Standards Organisation was required to set up an international committee to examine the essential criteria required for mass screening of fever in human subjects. It began with two excellent documents already prepared by the Singapore Standards for public screening for fever using thermographic imaging. Two new standard recommendations were ultimately published with International acceptance. The first described in detail the necessary performance of a screening thermograph, and how it should be calibrated, and the second was written for those responsible organisations who would be purchasing, installing and operating thermal imaging for screening for fever (14, 15). While not exclusive to airports, there was an emphasis given on the requirements for deployment of screening of air travellers, and the necessary training and monitoring of both the equipment and the operators (16).

In serious influenza outbreaks, children and young families are usually at high risk, and few data had been found on the use of thermal imaging in febrile children. A study was set up in the Paediatric department of The Military Institute of Medicine in Warsaw using the ISO criteria for screening for fever with thermography. In a cohort of 406 children, 354 were afebrile and 52 were identified with fever using thermal imaging to measure the inner canthi of the eyes, and by clinical thermometry of the axilla (underarm) for 5 minutes.

Measurements were also made at the tympanic membrane by ear radiometry and of the forehead from the thermogram of the frontal face. The inner canthus of the eye, as recommended by the ISO correlated well with clinical thermometry, with a mean of 36.48ºC (SD 0.49) in the afebrile children, and 38.9ºC (SD 0.84) in the febrile group. No correlation was found with sex or ages of the children in this study (17). However concerns remain, that where some installations have been made in airports, few have employed the strict recommendations of the ISO. For example it is required that the subject to camera distance is minimal, to ensure that a minimum of 9x9 pixels will be available in the thermogram to obtain the meaningful differences in temperature between febrile and afebrile persons. Furthermore it is impossible to obtain the correct positioning in moving subjects, and particularly those at a distance of several metres from the camera.

6. CONCLUSION

Modern infrared thermal imaging is currently more highly developed than at any time in its remarkable history. In industry, astronomy and many aspects of modern science infrared imaging has expanded and exceeded expectations. In medicine, the applications need to be cautiously and critically developed with a clear understanding of the underlying thermal physiology. Careful interpretation of results is essential. Medicine has embraced many other high performance image technologies such as ultrasound radiography, magnetic resonance etc. Medical thermography will only be more accepted, despite, the advantages of being non-contact, non-invasive and objective, if the published data is responsibly obtained, and open to others as reproducible findings.

REFERENCES

1. Ring EFJ. The historical development of temperature measurement in medicine. Infrared Physics and Technology 2007; 49, 297-301.
2. Wunderlich CA. On the temperature in diseases, a manual of medical thermometry (Eng. Transl.) The New Sydenham Society, London 1871.
3. Ring EFJ. The discovery of infrared radiation in 1800. The Imaging Science Journal 2000; 48, 1-8.
4. Hardy JD. The radiation of heat from the human body. II The human skin as a black body radiator. J. Clinical Investigation 1934; 13, 615-620.
5. Barnes RB. Thermography, Thermography & its clinical applications. Ed. Whipple HE Annals of the New York Academy of Sciences 1964; 121, 34-48.
6. Cade CM. High-speed Thermography & its clinical applications. Ed. Whipple HE Annals of the New York Academy of Sciences 1964; 121, 71-79.
7. Winsor T, Bendbezu J. Thermography & the peripheral circulation. Thermography & its clinical applications. Ed.Whipple HE Annals of the New York Academy of Sciences 1964; 121, 135-156.
8. Collins AJ, Ring EFJ, Cosh JA, Bacon PA. Quantitation of Thermography in arthritis using multi isothermal analysis - The Thermographic Index. Annals of Rheumatic Diseases 1974; 33,113-115.
9. Bacon PA, Ring EFJ, Collins AJ. Thermography in the assessment of anti rheumatic agents Rheumatoid Arthristis ed. Gordon JL and Hazleman BL Amsterdam: Elsevier/North Holland Biomedical press 1977.
10. Bird HA, Ring EFJ, Bacon PA. A thermographic and clinical comparison of three intra-articular steroid preparations in rheumatoid arthritis. Annals of Rheumatic Diseases 1979; 38, 36-39.
11. Ring EFJ, Ammer K. The technique of infrared imaging in medicine. Thermology international 2000; 10(1), 7-14.
12. Ammer K. The Glamorgan protocol for recording and evaluation of thermal images of the human body. Thermology international 2008; 18(3), 125-144.
13. Ring EFJ, Ammer K. Infrared thermal imaging in medicine. Physiological Measurement 2012;33, R33-46.
14. ISO/ TC121/SC3-IEC SC62D Particular requirements for the basic safety and essential performance of screening thermographs for human fever detection 2009.
15. ISO/TR 13154:2009 ISO TR 80600 Medical Electrical Equipment - deployment, implementation and operational guidelines for identifying febrile humans using a screening thermograph 2009.
16. Ring EFJ, McEvoy H, Jung A, Zuber J, Machin G. New standards for devices used for the measurement of human body temperature. Journal of Medical Engineering & Technology 2010; 34(4), 249-253.
17. Ring EFJ, Jung A, Kalicki B, Zuber J, Rustecka A, Vardasca R. Infrared thermal imaging for fever detection in children. Medical Infrared Imaging Ch 23 (Boca Raton FL, CRC Press) 2012, *in press.*

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