The Medical Use of Infrared-Thermography History and Recent Applications

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Abstract. The medical use of infrared thermography started shortly after 1950 in Germany, where long time before Prof. Czerny in Frankfurt am Main presented the first infrared image of a human subject (1928). In the beginning, single IR detectors have been used. Due to the development of other thermographic devices like contact thermography by electronic thermometers and by LC (liquid crystal) plates they were integrated in medical diagnostic systems.

Early infrared imaging cameras derived from military systems suffered for a long time from a poor resolution (thermal as well as spatial) and extremely high prices. Additionally there was a lack of computer hardware and software. Better technology suitable for medical purposes was available since about 1980 and then used worldwide, mostly LN_2 cooled MCT (HgCdTe) scanners. Since 2000 uncooled microbolometer FPA systems got more affordable and were, despite some methodological problems leading to medical misinterpretation, frequently used in medicine.

In 2007 the first medical infrared imaging systems (MammoVision, ReguVision and FlexiVision by InfraMedic) have received a CE certification allowing to be used as thermal measuring medical devices (Category 1) and matching the European Medical Directive legislation. Other devices without medical CE certification are limited to be used as imagers only without measurement functions and without temperature reading.

Qualified medical infrared imaging covers a broad field of applications: female breast, rheumatology and orthopedics, neurology, vascular imaging (arterial and venous), occupational (vibration related vasospastic syndrome), forensic, surgery, and full body screening including thermal stress response examinations (IRI – Infrared Regulation Imaging).

Medical infrared imaging can only be applied by physicians who have been educated and trained intensively and have received a medical certificate (either by the German Society for Thermography and Regulation Medicine, the European Association of Thermology, or the University of Glamorgan, Wales).

Kurzfassung. Der medizinische Einsatz der Infrarot-Thermographie begann kurz nach 1950 in Deutschland, wo bereits 1928 die erste Infrarotaufnahme eines Menschen durch Prof. Czerny in Frankfurt am Main angefertigt wurde. Anfangs wurden Einzelelement-IR-Detektoren benutzt. Nach der Entwicklung anderer thermographischer Geräte wurden auch kontaktthermographische elektronische Thermometer (Punktmessungen) und Flüssigkristallplatten zur medizinischen Diagnose herangezogen.

Frühe bildgebende IR-Kameras, aus militärischen Systemen entwickelt, waren lange Zeit durch schlechte geometrische wie auch thermische Auflösungen und extrem hohe Preise gekennzeichnet. Ebenso gab es damals keine befriedigenden Möglichkeiten zur Computer-Bearbeitung. Erst ab etwa 1980 wurde verbesserte IR-Technologie verfügbar, meist auf stickstoffgekühlten HgCdTe-Scannern basierend, die dann weltweit für medizinische Zwecke eingesetzt wurden. Seit 2000 wurden

ungekühlte Mikrobolometer FPA-IR-Kameras immer günstiger angeboten und auch, trotz teilweise erheblicher methodischer und zu Fehlinterpretationen führender Mängel, vermehrt in der Medizin eingesetzt.

Die ersten ausschließlich medizinischen Infrarot-Untersuchungssysteme (MammoVision, ReguVision und FlexiVision von InfraMedic) mit entsprechender medizinischer CE-Zertifizierung nach der europäischen Medizinprodukte-Gesetzgebung erhielten erst 2007 ihre Zulassung. Ausschließlich derart zertifizierte Geräte dürfen in der Medizin als messende Infrarotsysteme (Kategorie 1 MPG) eingesetzt werden. Andere Infrarotkameras ohne medizinische CE-Zertifizierung dürfen am Menschen lediglich zur Betrachtung eines Wärmemusters ohne Messfunktion und ohne Temperaturangabe herangezogen werden.

Qualifiziertes medizinisches Infrarot Imaging ist in zahlreichen Fachgebieten einsetzbar: weibliche Brust, Rheumatologie und Orthopädie, Neurologie, Gefäßuntersuchungen (arteriell und venös), Arbeitsmedizin (vibrationsbedingtes vasospastisches Syndrom), Gerichtsmedizin, Chirurgie sowie Ganzkörper-Thermographie unter Einbeziehung eines Kältereizes (IRI – Infrarot Regulations Imaging).

In der Medizin darf die Infrarot-Thermographie nur von speziell ausgebildeten und trainierten Ärzten angewandt werden, die über ein entsprechendes Zertifikat verfügen. Hierfür stehen die medizinisch-thermographischen Fachverbände Deutsche Gesellschaft für Thermographie und Regulationsmedizin e.V. und Europäische Gesellschaft für Thermologie sowie die Universität Glamorgan in Wales zur Verfügung.

Introduction

Medical diagnosis is based on structural as well as on functional information. Structural methods are X-ray, ultrasonography, MRI and microscopy (histology). Functional methods are ECG, blood pressure measurement, EEG, pulmonary air flow tests, and thermography.

Every diagnostic method has its own scientific approach and knowledge base, depending on state of the art technology, methodological standards and protocols and experience of the experts. The diagnostic value of every method is characterized by its sensitivity (ability to identify disease) and its specificity (ability to identify healthy subjects).

Due to a lot of limitations (early infrared systems, poor or no computer hard and software, a lot of diverging methods and medical protocols) the first decades of medical infrared thermography suffered of non acceptance by the medical establishment. Most of the physicians favored the emerging structural diagnostic methods like advanced X-ray CTG (computer tomography), USG (ultrasonography) and MRI (magnetic resonance imaging). Structural imaging is much easier to be linked with disease than functional methods.

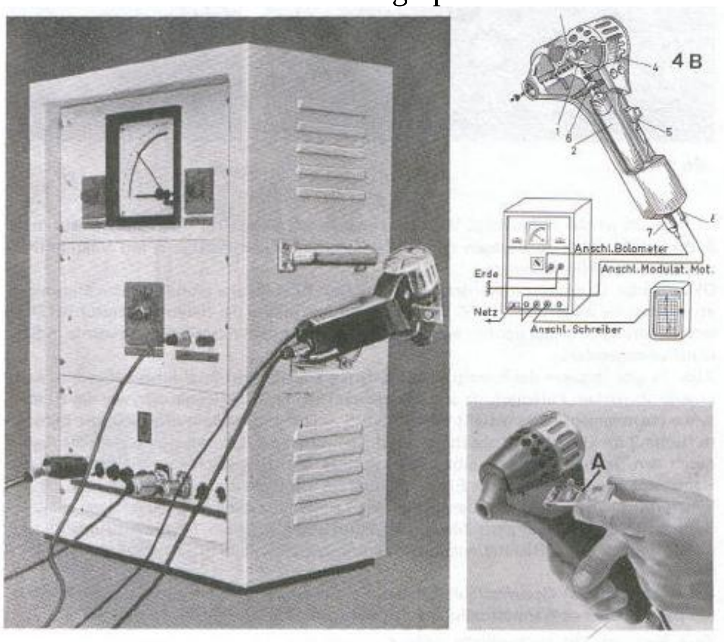
Nevertheless there is a growing chance for infrared thermography in modern medicine. IR thermography has a high diagnostic specificity and, therefore, is able to identify health as well as first deviations of the ideal health state. The recent shift of the traditional medical paradigm (diagnose and treatment) to a more modern approach (identify risks and eliminate them) and, even more, identify health and help keep it, opens new horizons for IR thermography.

1. Comprehensive history of medical thermography and infrared imaging

1.1 From HIPPOKRATES to SCHWAMM and REEH

HIPPOKRATES is described to be the first physician looking at body heat by putting mood on the abdomen and regarding its change in color when getting dry. SANTORIO, an Italian physician and contemporary of GALILEI, first used a "thermometer" based on GALILEI's "thermoscope". Centuries later WUNDERLICH introduced thermal measurement into clinical routine [1]. CZERNY documented the first infrared image of a human subject in Frankfurt 1928 [2].

The medical use of infrared thermography started 1952 in Germany. The physician SCHWAMM together with the physicist REEH developed a single detector infrared bolometer for sequential thermal measurement of defined regions of the human body surface for diagnostic purposes [3]. Their method was patented in several countries including the USA. They founded the first medical association of thermography 1954, today still active as German Society for Thermography and Regulation Medicine (Deutsche Gesellschaft für Thermographie und Regulationsmedizin e.V.), worldwide the most established and experienced medical association covering medical thermography. Figure 1 shows the first medical thermographic device.



Ultrarot-Strahlungsmesser für Diagnostik und Therapiekontrolle nach Dr. Schwamm-Reeh.

Fig. 1: First medical thermographic device, developed by SCHWAMM und REEH 1953

1.2 Electronic and LC (liquid crystal) contact thermography

Also by contact measurement the temperatures of the skin can be recorded. There have been electronic thermometers (thermistor or thermo couple devices, Fig. 2) for punctual registration in use as well as plates including encapsuled LC (liquid cholesterol crystals, Fig. 3) for two-dimensional area covering. ROST [4, 5, 6], FERGASON [7]. These devices are of historic interest and have been used as long as infrared cameras were extremely expensive and in early stages of development. They have a lot of disadvantages such as interfering with the measured object by contact.

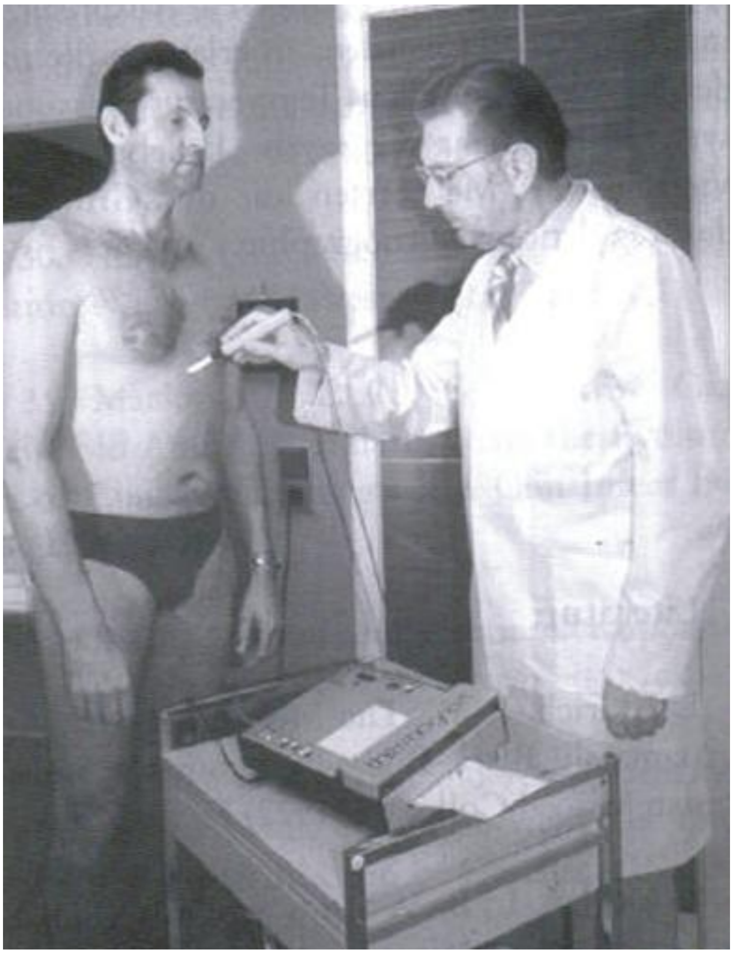


Fig. 2: Electronic thermometer used for medical examinations (Prof. ROST applying regulation thermography)

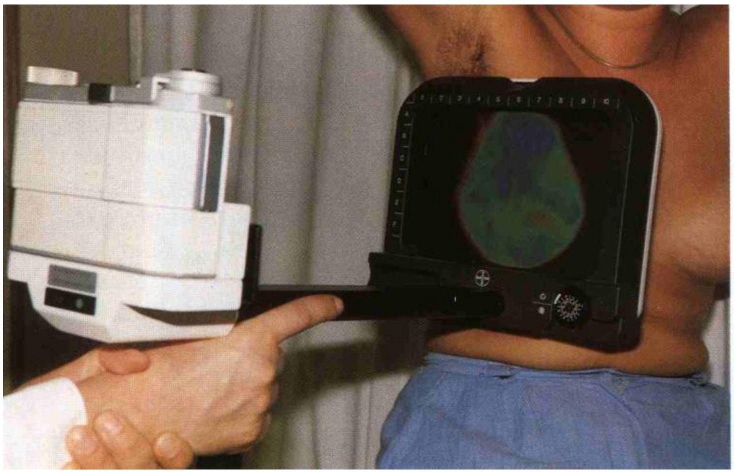


Fig. 3: LC contact thermography system with encapsuled liquid cholesterol crystals

1.3 Early IR cameras

From today's point of view the early infrared cameras were poor regarding thermal and geometrical resolution and a lot of other items like stability, reproducibility, exact measurement and more. Nevertheless they allowed recording the measurement data without contacting and by this interfering with the measured skin, first used by LAWSON [8]. In the mid 1980s Carl Zeiss Oberkochen developed a leading device for medicine for many years: the LN_2 cooled MCT scanner Icotherm (Fig. 4), unfortunately extremely expensive und unaffordable for physicians and clinics. They mostly used the much cheaper AGA Thermovision devices (Fig. 5), for a long time the medical standard. BERZ [9, 10, 11] used both cameras since 1983.

Fig. 4: The legendary Zeiss Icotherm 1985

Fig. 5: One of the medically broadly used AGA Thermovision cameras (AGA 680 medical, ca. 1975)

The last two decades of the 20th century were characterized by an “explosion” of models and manufacturers of IR camera, also used for medical purposes. Their technology, though usually based on scanning MCT sensor systems, advanced. Additionally the first IR cameras with a totally new technology, uncooled FPA (focus plane array) microbolometer cameras, appeared fur medical use, in the beginning suffering of noise, fixed pattern, thermal drift and much more instabilities (Fig. 6).

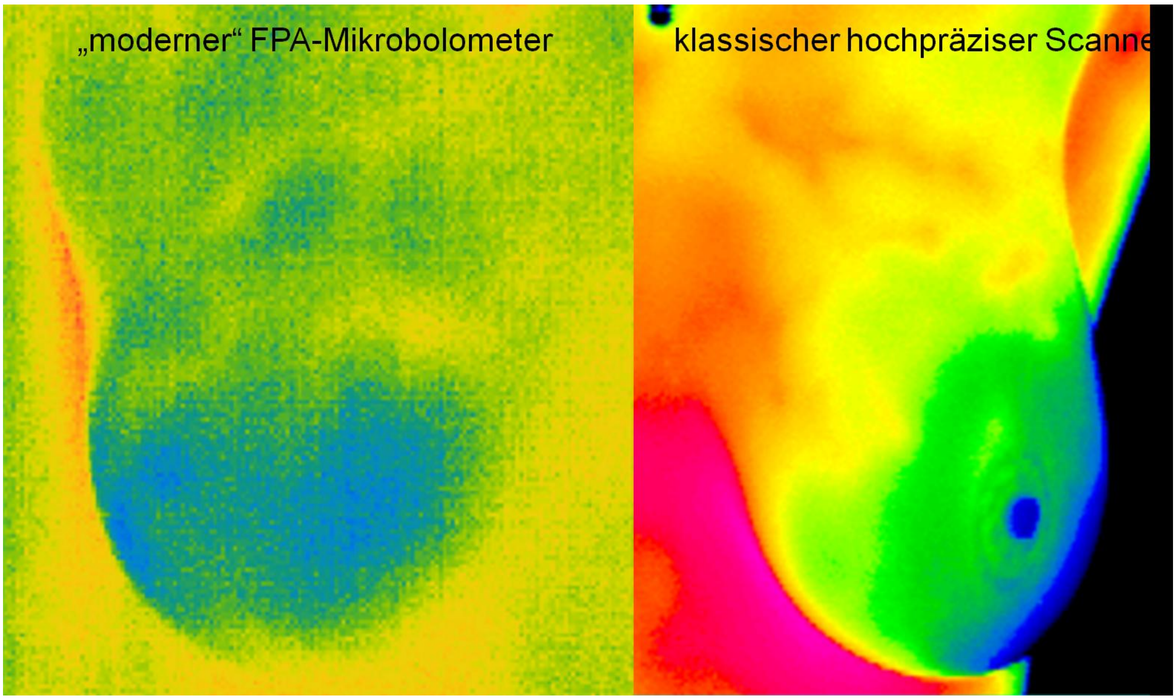


Fig. 6: Images of an early uncooled FPA microbolometer camera, compared to cooled MCT scanner (both built in the late 1990s

1.4 Recently used infrared cameras for medical examinations

Together with the advanced microelectronic development infrared cameras recently achieve major advantages. While still the cooled MCT scanner must be called the gold standard, it is a slowly recording (1 Hz) and therefore not a real time imaging system. Modern scanners like the Jenoptik VarioScan HR (Fig. 7) have brilliant, clear, noise and pixel error free images with a high resolution and best stability, reproducibility, sensitivity (better than 30 mK) and avoidance of any thermal drift.

Fig. 7: Still today’s gold standard in medical thermography: Jenoptik VarioScan HR

Compared to Megapixel photo cameras the geometrical resolution even of the latest high resolution IR cameras is low and reaches up to 1 million sensors (Jenopik VarioCam HR with resolution enhancement). Suitable for medical use are IR cameras with high resolution microbolometer arrays (320x240 or 384x288, Fig. 8).

Fig. 8: Enhanced resolution 384x288 stationary FPA microbolometer IR camera Jenoptik VarioCam HR used for MammoVision and ReguVision

2. Thermo-Physiology and Infrared Radiation of Humans

2.1 Heat loss and heat pattern at the body surface

Body heat is generated by metabolism and by muscular activity and keeps the core temperature at a defined, slightly oscillating level (about 37 °C). The organism's heat loss depends on ambient factors and results of conduction, convection, IR radiation, and of evaporation (sweating) of the surface, the skin (despite of breathing and other mechanisms, Fig. 9). Inside the organism heat is transported by convection (blood flow) and by conduction.

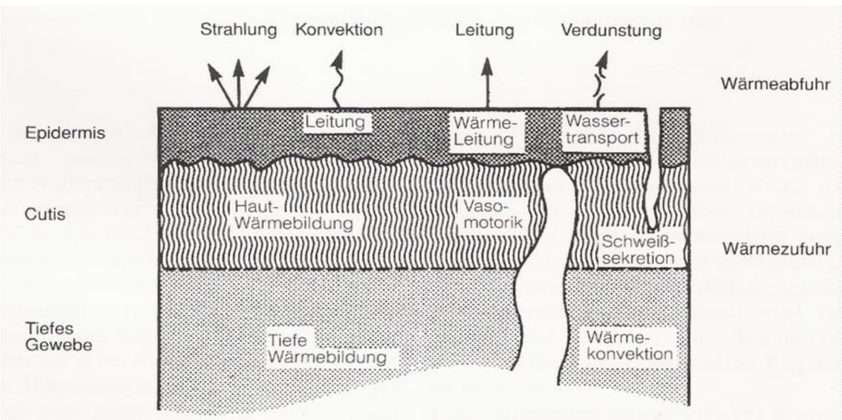


Fig. 9: Mechanisms of heat loss at the human body surface

The thermal pattern of the surface (skin) under defined laboratory conditions is far from arbitrary. It is the result of different synergistic and antagonistic factors and processes, well described by human physiology and pathophysiology.

According to PLANCK's law the dry human skin, nearly an ideal blackbody (Emissivity 0,98), is a long wave IR radiator with a maximum emission at about 10 µm.

In general there is a human body "stairway of heat" with (at least after a cold stimulus) the highest temperatures in the head and cervical regions, followed by the trunk and more decreasing over the limbs to the acral region (fingers, toes). Where skin is close to skin (e.g. under the breasts, Fig. 6) there is excessive heat that cannot be used for diagnose.

Lateral symmetry is one of the most important characteristics of the human surface heat pattern.

2.2 Diagnostic use of cold stimulus response examinations (thermo regulation)

Like in many other medical examinations (ECG, EEG) stimulation can be applied aiming to test the organism's ability to adequate responding to the stimulus. Usually the patient is exposed undressed to cool ambient (20 °C ± 1 °C) for 10 minutes. This leads to a blood centralization to keep the core temperature constant, resulting in a temperature decrease in all surface areas (except head and cervix) of ca. 1,0 °C (Fig. 10).

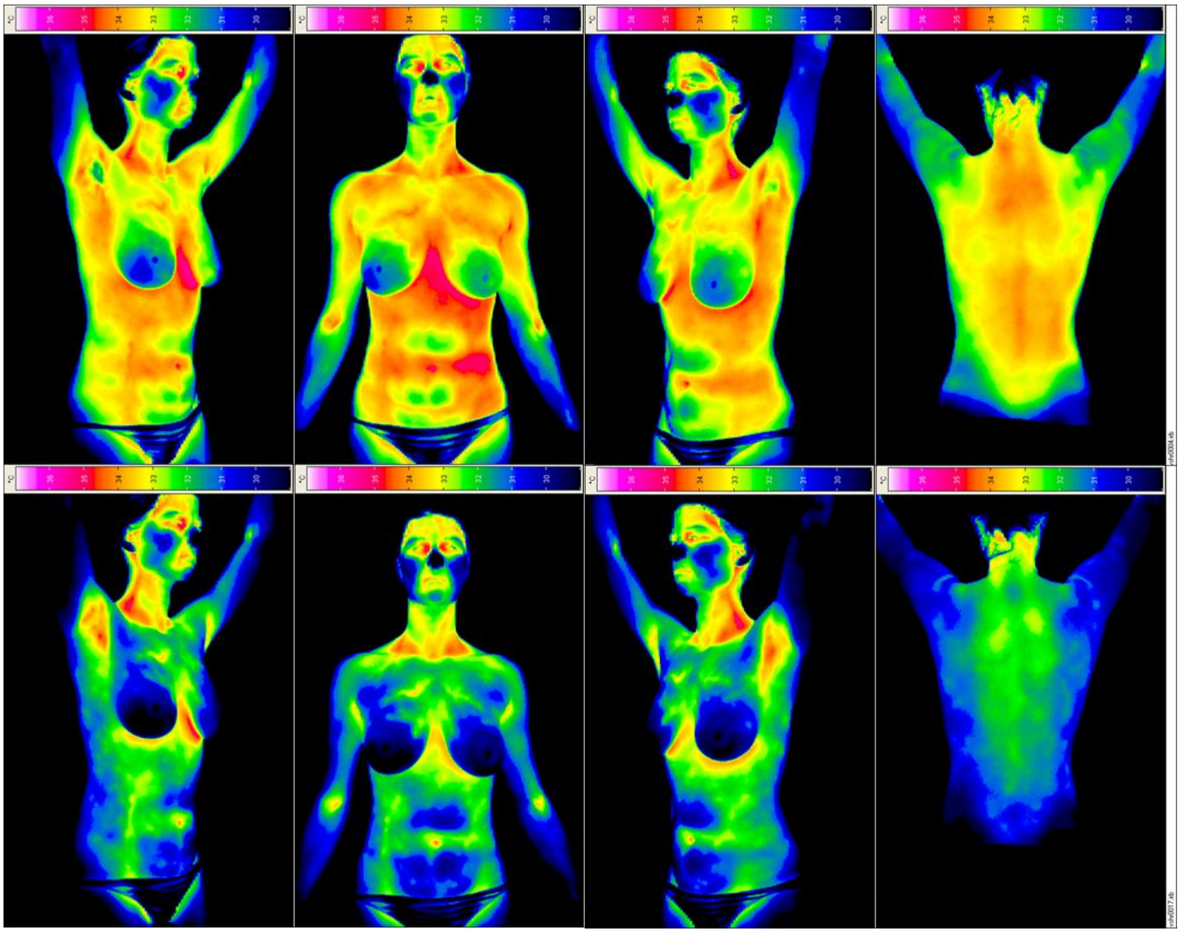


Fig. 10: Heat loss at the human body surface (thermo regulation) following a standardized cool air stimulus (above: before regulation; down: after regulation

Diagnostic infrared imaging (medical IR thermography) is a functional examination and cannot be directly compared to structural methods like X-ray, Ultrasonography or MRI.

3. Medical Requirements regarding Diagnostic Infrared Systems

3.1 Infrared Cameras

Medically suitable IR cameras have to meet certain criteria. Their geometrical resolution has to be at least 320x240 detector elements, and their thermal resolution (sensitivity) has to be 80 mK or better, ideally better than 50 mK. Thermal drift has to be kept in a very narrow range, the measurement data have to be exactly reproducible and reliable (less than ± 2 K @ 30 °C, better less than ± 1 K).

There are only few affordable IR cameras recently complying with these criteria. Each IR camera used for measurement in Medicine has to be medically CE certified and has to be registered according to the medical device legislation (in Germany Medizinproduktegesetz).

3.2 Measurement and data management

The measurement data have to be sent to the data management system error free and lossless in a data format that is readable by any medical expert program. Proprietary data formats as used by some manufacturers of IR cameras leads their devices to be unacceptable for medical use.

The data management is extremely specialized for medical issues and never can be done by universally applicable standard software solutions delivered with the most industrial IR cameras. Analogue to the IR cameras also every IR software used for medical purposes has to be medically CE certified and has to be registered according to the medical device legislation (in Germany Medizinproduktegesetz).

3.3 Data evaluation and diagnose process

The most challenging and weakest link in the chain of medical infrared thermography is the use of a proven, evaluated and clinically reliable software solution. Overall exactness in the transfer of true measurement data from IR camera via Computer into the medical IR expert program has to be testified by a CE certifying body.

Based on the reliable measurement data medical IR programs allow to assess the process of evaluating the data and give hints for pathological processes, for diagnostic relevance and for therapeutically considerations.

3.4 Standardisation and protocols

In the past decades medical infrared thermography was characterized by a lack of overall accepted and mandatory standards. These standards have to cover the patient preparation and patient management in the clinic before and during the examination (details in ROST [6].

In the same way the processes of data management and storage, of applying geometrical or other evaluation tools, of used statistical approaches has to follow accepted protocols. Different from the situation in the USA, where there are many competing medical associations and academies, in Europe there are only two accredited and co-operating medical societies covering infrared thermography: the above mentioned Deutsche Gesellschaft für Thermographie und Regulationsmedizin e.V. (DGTR, German Society of

Thermography and Regulation Medicine), existing since 1954, and the European Association of Thermology (EAT).

3.5 CE certification of medical IR thermal measurement systems (European Medical Directive legislation)

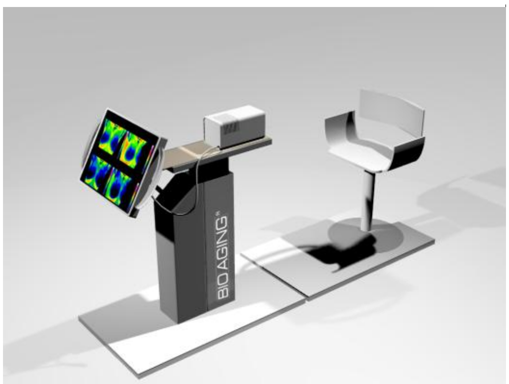
As mentioned before the European medical device directive (in Germany Medizin-produktegesetz) ensures that only medically CE certified infrared examination systems are allowed to be used for medical purposes. IR cameras and systems not complying with this regulations can only be used as imagers, they are not allowed to display any temperature. Measuring devices are regulated as category 1 of medical products with the need for certification. A simple CE sign on a camera or other device is far from being sufficient.

Medical users of not proper registered infrared thermography devices (physicians, medical technicians, directors of clinics etc.) are in high risk of getting penalties and of loose money invested in non compliant IR equipment.

4. Established Applications of Medical Infrared Imaging

There are many medical fields where infrared thermography can be applied. Here only a short overview can be presented (details in BERZ [12, 13, 14, 15], in ROST and BERZ [16], and in BERZ and SAUER [17, 18, 19]:

- Infrared breast imaging (MammoVision, Fig. 11)
- Full body Infrared Regulation Imaging – IRI, ReguVision (Fig. 10)
- Partial infrared imaging of certain body areas (FlexiVision)
- Rheumatology, orthopaedics, joint imaging (Fig. 12)
- Neurology
- Angiology, Infrared Imaging of vessels (arterial and venous, Fig. 13)



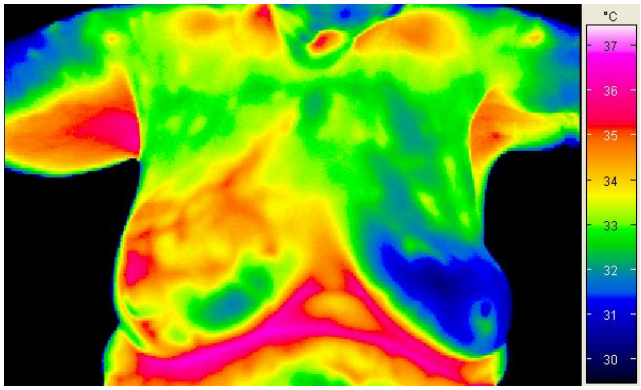


Fig. 11: MammoVision examination unit (left) and resulting image of breast cancer (right)

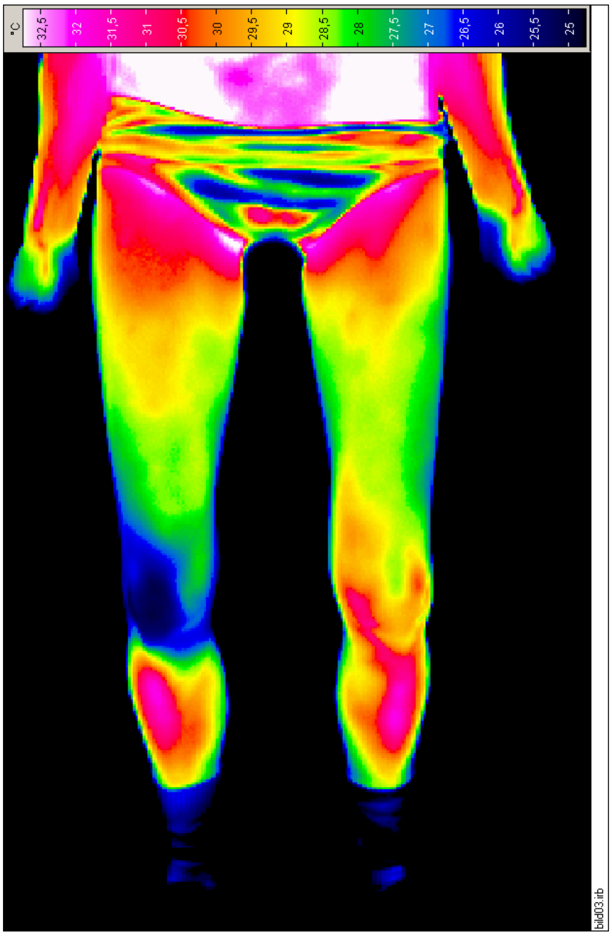


Fig. 12: Gonarthritis left knee

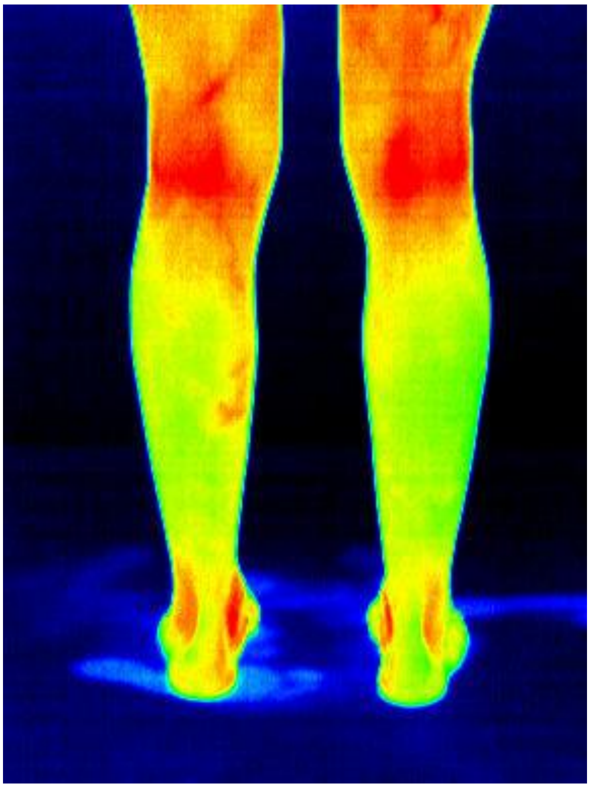


Fig. 13: Vascular infrared imaging: Varicosis left medial

5. Medical Education and Training regarding Infrared Thermography

The two European medical thermographic societies (DGTR and EAT together with the University of Glamorgan, Wales, UK) offer regularly conferences, education, training and expert meetings regarding all relevant aspects of medical infrared thermography.

Further Information is available at www.thermomed.org, www.inframedic.de and at www.comp.glam.ac.uk/pages/staff/pplassma/default.htm

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