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Contents

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

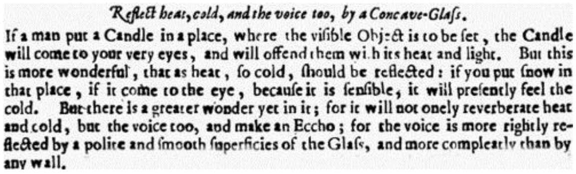
Thermology is the science of heat, which is a very wide topic, and one that applies to many diverse processes of our modern life. In this paper, it is confined to one narrow but highly complex application, that of human body temperature. For many years contact thermometry was the only means of determining 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).

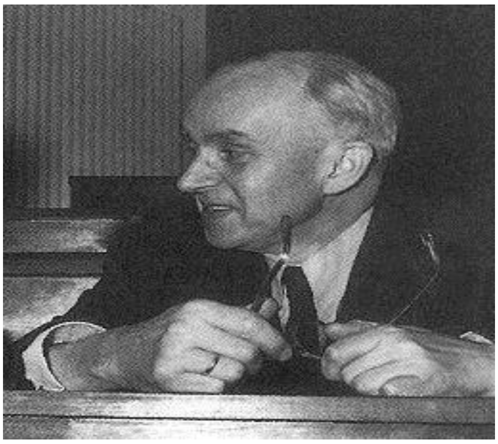


Fig. 5 - Prof. Marianus Czerny (1896-1985).

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).

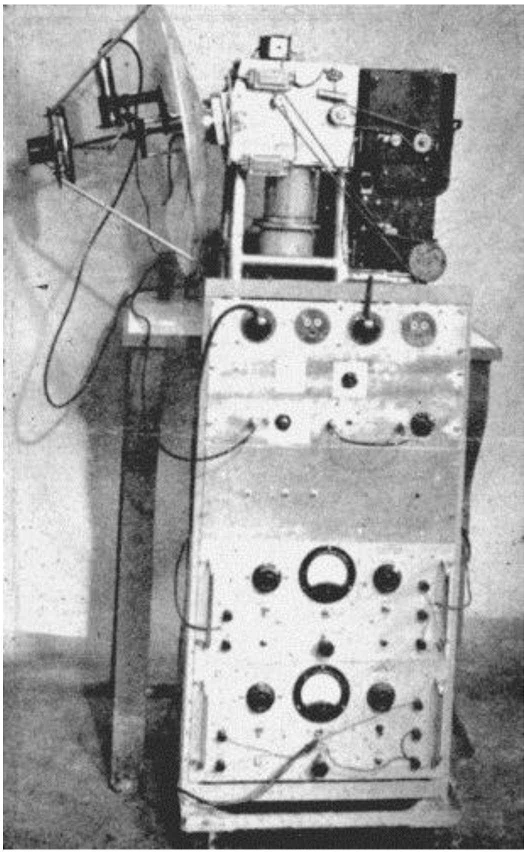


Fig. 6 - Pyroscan, first British medical thermograph in 1960.

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.

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Thermography in Plastic Surgery

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1. INTRODUCTION

Plastic surgery and tissue transfer

One of the main goals in plastic surgery is the correction and restoration of form and function. The realm of plastic surgery is large ranging from well-known cosmetic surgery to less well known sub-specialties such as reconstructive surgery, burn, craniofacial surgery, hand and micro-surgery. Reconstructive surgery deals with the closure of defects and restoration of form and function after trauma, pressure sore treatment, infection, cancer treatment and the treatment of congenital deformities. The use of tissue transfer or so-called flaps in the same patient is an important instrument in reconstructive surgery. Such a flap may consist of skin and subcutaneous tissue, muscle or bone or a combination of these tissues. Tissue transfer can be performed with so-called pedicled flaps and free flaps. In pedicled flaps the blood supply to the tissue is left attached to the area the flap has been harvested from, the donor site, and tissue is simply transposed to a new location, the recipient site. Blood supply of the flap is maintained via a pedicle which consists of an artery and vein or veins. In free flaps, the blood supply is detached from the donor site and the tissue is transferred to the recipient site to cover a defect and to restore form and, if possible, function. A free flap procedure involves disconnecting the blood supply via the pedicle of the flap and then reestablishing the blood supply again at the site of the defect.

Here the blood supply is reestablished by suturing the blood vessels of the pedicle, to blood vessels at the recipient site. Since the diameter of the blood vessels can be as small as 1 to 2 millimeters in diameter, skillful microsurgical techniques are required. Both pedicled and free flaps rely for their survival on adequate tissue perfusion. Inadequate tissue perfusion will lead to partial or total flap failure. Successful flap surgery requires a thorough knowledge of vascular anatomy and how the flap is perfused as well as microsurgical skills.

Tissue flaps

In earlier days, the use of myocutaneous flaps was the gold standard in reconstructive surgery. Such a flap consists of skin, subcutaneous tissue (fat) and the underlying muscle with its fascia. The muscle was included as a carrier of the blood supply to the overlying skin and subcutaneous tissue. The blood supply to the skin originates from a deeper lying main vessel under the muscle. Branches from this main vessel pass through the muscle, perforate the overlying fascia and continue their way through the subcutaneous tissue up to the skin. Since they perforate the fascia these branches are called perforators. During the earlier days surgeons included the muscle to guarantee the inclusion of many perforators so that adequate perfusion to the overlying skin of the flap was provided. A breakthrough in flap surgery came when Koshima & Soeda (12) discovered that the overlying skin and subcutaneous tissue could actually survive on a single perforator without including the underlying muscle. A perforator consists of a perforating artery and its concomitant vein. A flap that relies for its perfusion on a perforator is called a perforator flap. The main advantage of perforator flaps is that no muscle is included and therefore there is no loss of muscle function at the donor site. These perforator flaps are now the gold standard in reconstructive surgery. Preoperatively the most suitable perforator has to be selected to guarantee adequate perfusion to the flap. The use of perforator flaps requires microsurgical skill as the perforator is easily damaged intra-operatively. In free perforator flaps, the reestablishing of the blood supply to the flap after transfer is crucial for survival of the flap. In the direct postoperative phase, occlusion of the pedicle that supplies the flap due to a blood clot or due to torsion or kinking of the pedicle may lead to flap loss.

First use of thermography in perforator flap surgery

Theuvenet et al. (21) were one of the first to use thermography in the pre-operative planning of flap surgery, they called the technique thermographic assessment of perforating arteries in their myocutaneous flaps. They realized that warm blood

transported by perforators caused a hot spot on the skin surface. These hot spots became clearly visible during the rewarming phase following a cold challenge where a plastic bag filled with ice water was shortly brought in contact with the skin surface. Publications from Salmi et al. (17) and Zettermann et al. (25) from Finland have confirmed the usefulness of thermography in reconstructive surgery with myocutaneous flaps. Itoh and Arai (10, 11) described for the first time the use of thermography in the selection of a suitable perforator in free perforator flap surgery. Pre-operatively they employed the same cold challenge as Theuvenet et al. (21). The usefulness of thermography in pedicled perforator flap surgery was described by Chijiwa et al (4) from Japan.
At our department we have since 2000 successfully used dynamic infrared thermography (DIRT) as a technique to assist the plastic surgeon in the pre-operative, intra-operative and post-operative phase of perforator flap surgery (15). DIRT is used to help to more clearly identify vascular patterns in the skin (22). In DIRT the area of interest is exposed to a thermal challenge (cold or warm) and the thermal recovery towards equilibrium is registered. We have been using DIRT in perforator flap surgery for reconstruction after trauma surgery, cancer surgery and treatment of pressure sores. In order to illustrate the use of thermography in the pre, intra- and post-operative phases of plastic surgery we shall use breast reconstruction with the deep inferior epigastric perforator flap (DIEP flap) which is one of the most popular free perforator flaps as a main example. The usefulness of thermography in reconstructive surgery after trauma will be illustrated with some cases presentations.

2. AUTOLOGOUS BREAST RECONSTRUCTION

The deep inferior epigastric perforator flap (DIEP) in breast reconstruction.
Breast reconstruction using tissue from the patient's lower abdomen has become an increasingly popular method after surgical treatment of breast cancer with removal of the breast, a so-called mastectomy (2). The lower abdomen can provide a large amount of skin and subcutaneous tissue that allows for the reconstruction of a natural looking breast with a soft consistency and adequate volume. The deep inferior epigastric artery and vein are the main blood source to the lower abdomen. Perforators arising from the deep inferior epigastric system traverse through the overlying rectus abdominis muscle, perforate the overlying muscle fascia and connect with the subdermal plexus. The perforators provide the blood supply to the skin and subcutaneous tissue. Each deep inferior epigastric system has often 4-7 of these perforators. Normally, the area between the umbilicus and symphysis and between both anterior iliac spines is harvested as a flap. In a DIEP (deep inferior epigastric perforator) flap the blood supply to the flap is provided by a perforator of the deep inferior epigastric vessels. After transfer to the thoracic wall, where the blood supply to the flap is reestablished by connecting the perforator to the internal mammary vessels, a breast is reconstructed (Fig.1). With a DIEP flap, the abdominal wall muscles are left intact and patients can after recovery do sit-ups as normal.

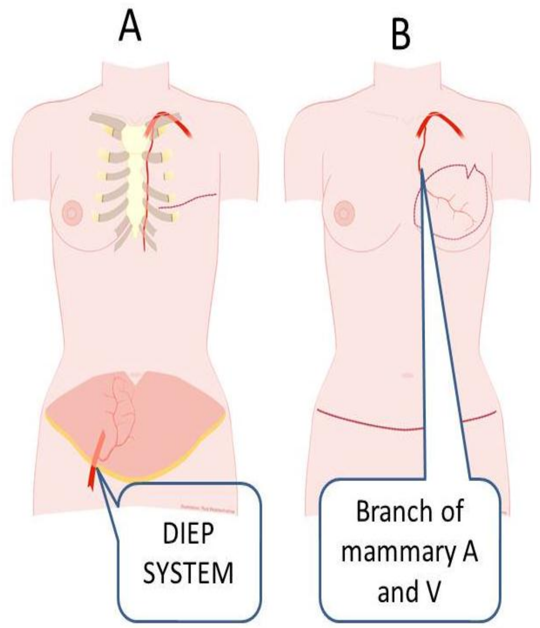

Fig. 1 - Principle of autologous breast re-construction. (A) Abdominal skin flap with blood supply from deep inferior epigastric artery and vein DIEP system (B) Transplanted abdominal skin flap anastomosed to branch of mammary artery and vein.

The wound at the abdomen is closed as in a tummy tuck which is by many patients considered a bonus of this technique.The psychological, cosmetic and sexual benefits of post-mastectomy breast reconstruction have been well documented. As with any operation complications may occur. One of the most serious complications in breast reconstruction is flap loss due to inadequate perfusion. Flap loss is a devastating experience for a patient. In addition, it causes an economic burden on the hospital health budget as re-operations are necessary. To prevent flap loss it is important to guarantee adequate blood supply to the flap. Breast reconstruction with DIEP flap can be divided into a pre-operative phase, an intra-operative phase and a post-operative phase. Below we present our experiences with the use of DIRT in each phase.

2.1 The pre-operative phase

In the preoperative phase the surgeon has to plan the breast reconstruction. An estimate has to be made of the size of skin area and subcutaneous fat volume that is required to reconstruct the new breast. The dimensions of the flap will be marked on the skin surface. To guarantee adequate perfusion of the DIEP flap the surgeon has to select a suitable perforator to perfuse the flap. Although one could select such a perforator intra-operatively, the large variability in the numbers and locations of perforators makes this time consuming. Perforator selection is preferably done pre-operatively as this reduces operation time and minimizes the risk of damaging the perforator due to inadvertent traction. The use of the multi-detector row computer tomography (MDCT) scan is today considered the gold standard in pre-operative imaging of perforators. The location, caliber and branching pattern of the perforator can be visualized nicely with the MDCT scan (1, 3, 13). The disadvantage of MDCT is the exposure of the patient to ionizing radiation and intravenous contrast medium. With over 10 years of experience we have been able to demonstrate that DIRT provides an excellent non-contact, non-ionizing, real-time imaging technique for the pre-operative selection of suitable perforators (7, 8).

The mapping of the locations of perforators from the deep inferior epigastric system is simply based on the fact that perforators that transport blood to the skin surface become visible as hot spots on the skin surface on the infrared images (thermograms).The localization of the hot spots can be more clearly defined by observing the rewarming pattern following a cold challenge. We normally examine the patient in a special examination room (room temperature ca. 22-24°C) with the abdomen exposed. After an acclimatization period of 10 minutes air is blown over the skin surface for 2 minutes using a desk top fan. This form of mild skin cooling is well tolerated by patients and causes skin temperature changes well within the physiological range. The rate and pattern of rewarming is continuously monitored with the infrared camera. Analysis of the rate and pattern of rewarming of the hot spots makes the identification of the most powerful perfused perforator easy. A hot spot that shows a profound rewarming of the area surrounding the hot spot is of interest as such a hot spot is considered to be associated with a well-developed vascular network. An example of a cooling and recovery sequence on the abdomen is shown in fig 2.

Interestingly there is a large variability between the number and location of hot spots between the left and right side of the abdomen in an individual patient, in other word there is no clear left/ right symmetry in their distribution. Also, there is a large inter-individual variability in the number and position of hot spots between patients.

The hot spots revealed by the DIRT technique are the result of transport of warm blood from the body core through the perforators. This can easily be confirmed by the use of Doppler ultrasound flowmometry. We have shown that first appearing hot spots are always associated with an arterial Doppler sound. There is a positive relation between the brightness of the hot spot and the auditive Doppler volume. Very recently we have carried out further studies in which we have compared the results from DIRT, Doppler ultrasound flowmemetry and MDCT for preoperative perforator selection on the abdominal skin. These studies confirm that DIRT is, indeed, a reliable technique for identifying suitable perforators in the pre-operative planning phase for autologous free flap surgery. All first appearing hot spots could be related to clearly visible perforators on the MDCT scans (5, 7, 8, 23).

2.2 The intra-operative phase

During the intraoperative phase we have our infrared camera mounted on a special rig so that the camera is suspended above the patient on the operating table and above the heads of the operating team (Fig. 3). The thermal images can be viewed in real time on a large monitor. The camera is controlled by an operator using a lap-top computer located outside the sterile field. We use thermography to establish if the perforator is still working after it is prepared free but still connected to the lower abdomen (9).

Damage of the perforator can easily be verified using thermography. By applying a metal plate at room temperature to the skin surface overlying the perforator, the rate and pattern of rewarming after this cold challenge is analyzed. If the perforator has been damaged, there will be no or a slow rewarming. In such a case the surgeon may decide to use another perforator in order to avoid the use of a possible damaged perforator.

The main use of thermography during the intra-operative phase is to monitor the outcome of the microsurgical procedure where the blood supply to the flap is re-established after it has been transferred to the thoracic wall (6) (Fig 4). Suturing together blood vessels with diameters as little as 1 to 2 mm requires great skill in order to avoid damage to the vessels. Damaging the blood vessels may lead to a blood clot in the vessel lumen that will cause perfusion problems of the flap and finally flap loss.

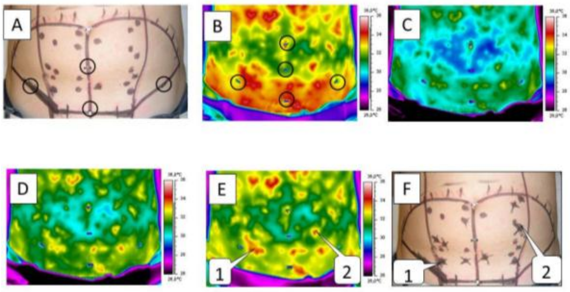

Fig. 2 - A: photograph of lower abdomen. The 4 black circles mark the location of small pieces of metal tape used as reference points in the IR images. B. IR thermal image prior to abdominal cooling. C: IR thermal image at end of 2 min cooling period. Following the abdominal cooling the skin temperature rapidly rewarms (D and E). The location of two strong hot spots are indicated in E. In panel F each black spot marked with an X indicated where a strong arterial sound can also be heard at the hot spot with a Doppler ultrasound instrument.

Fig. 3 - IR camera system used during surgery

After the blood vessels have been connected the clamps, that have temporarily occlude the vessels, are removed and the flap will become perfused with warm blood again. During the entire process we monitor the skin temperature of the flap with the infrared camera. Typically, a successful procedure is characterized by a rapid reappearance of hot spots on the flap and a general rewarming of the entire flap (Fig.4. top panel).

The thermal challenge in this form of DIRT is created by a reperfusion of the flap with warm blood. The information obtained from the infrared image proves the surgeon with real-time indirect information on the skin blood perfusion.

Thermography during surgery can also be used to register other causes that may lead perfusion problems. For example there may be partial or total restriction of arterial in flow. By observing the thermal images the surgeon is able to see immediately such a problem which is characterized by a slow or no rewarming of the flap. Sometime inadequate in flow (poor or absent rewarming) may be caused by a torsion or kinking of the vessels or by external compression of vessels. Such a problem can easily be corrected as soon as it is noticed.

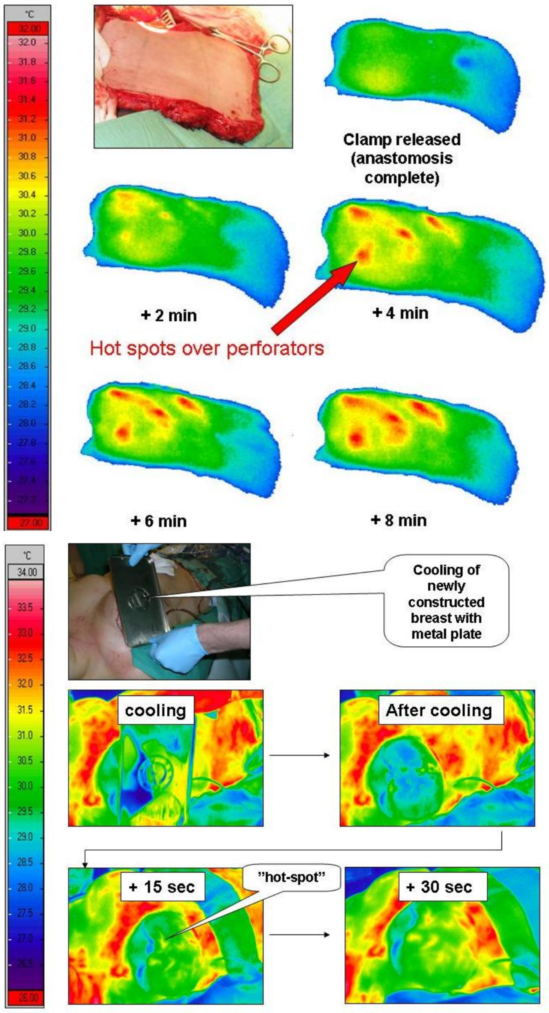

Fig. 4 - Top Panel: A series of IR thermal images illustrating rewarming of a free DIEP flap following the successful completion of the microsurgical anastomotic procedure. Note the rapid appearance of hot spots.

Bottom Panel: Final test at end of surgery. Cooling of the newly modeled breast with a metal plate at room temperature. Rapid return of warm spots indicates adequate perfusion.

However, if such a problem is not diagnosed, partial or total flap failure will occur. Inadequate venous outflow (venous congestion) is also easily diagnosed and is characterized by a diffuse rewarming without a clear appearance of hot spots on the thermal images. By anastomosing a second vein of the flap to a recipient vein such as the cephalic vein a super drainage of the flap will be created.

Opening of this second venous route showed that in case of venous congestion, the diffuse pattern disappears and a pattern of hot spots appears. After the flap perfusion has been successfully re-established the flap is molded into new breast. We continuously monitor the flap with thermography during this procedure. This is important since the remodeling procedure involves physical manipulation of the flap which may compromise its newly established blood supply due to torsion or external compression of the blood vessels. The advantage of intraoperative use of DIRT is that perfusion problems can be identified rapidly and that corrective measures can be taken immediately during the same operation (18).

At various stages during the surgery we routinely check blood flow status by applying small cold challenges to the flap (DIRT). This is normally done by applying a metal plate at room temperature for 5-10 seconds against the skin. A similar result can also be obtained by washing the skin with using physiological saline at room temperature. Immediately after the washing the skin is quickly dried with a surgical compress to remove excess liquid. Either way, the rate and pattern of rewarming after these mild thermal challenges give the surgeon a clear indication of the perfusion status of the flap (Fig. 4. Bottom panel). It has become our standard to perform such a cold challenge at the end of each operation. In an experimental situation it has also been shown that thermography can provide valuable information on the perfusion of other types of flaps (20, 24).

The post-operative phase

Although post-operative complications are rare they may occur and DIRT is a very convenient way to monitor flap perfusion in the post-operative phase. Again simple cooling and recovery protocols, such as fan cooling can easily be used. In addition to carrying out such procedures to detect possible complications, post-operative monitoring has revealed some interesting facts on perfusion dynamics of DIEP flaps during the first week after the operation (7, 8). The thermal images show an improvement in perfusion during this period. Characteristically the number of the hot spots on the thermal images increases with time. In the first day we see hot spots confined to the skin area associated with the location of the selected perforator. During the following days hot spots appear in the neighbouring skin areas. Interestingly, there is initially a state of hyperaemia, which is most pronounced in the area of the hot spot related to the selected perforator. During the following days this hyperaemia disappears. Our results have shown that the perfusion of the DIEP flap during the first postoperative week is a dynamic process. This phenomenon can be explained by the angiosome concept (19). Initially the vascular territory belonging to the deep inferior epigastric system is optimally perfused through the selected perforator. During the following days neighbouring vascular territories become perfused after the interconnections, the so-called choke vessels, between these territories have opened. The perforators in the neighbouring vascular territories become now perfused and their associated hot spots become visible on the thermal images. With the increased perfusion of the neighbouring vascular territories, a redistribution of blood starts which may explain the disappearance of the hyperaemia. After about 6 days the entire flap is normally adequately perfused. Thermography can also help to optimize flap design as it has shown that it may identify areas that are inadequately perfused. These areas can then be removed before they cause complications (14, 20).

3. THE USE OF DIRT IN RECONSTRUCTIVE SURGERY FOLLOWING TRAUMA

Introduction

As mentioned before reconstructive plastic surgery also deals with the closure of defects and restoration of form and function after trauma. One of the challenges in reconstructive surgery after trauma is that there is often extensive tissue damage surrounding the defect. Such tissue damage may include damage to the blood vessels. It can be difficult to detect the extent of vessel damage and sometimes this can only be done intra-operatively. Thus a reconstructive procedure with either a pedicle flap or free flap for closure of a traumatic defect can be quite a challenge as the pedicled perforator flap and free perforator flap rely for their blood supply on the quality of the blood vessels surrounding the defect. The use of perforator flaps, either pedicled or free, is associated with a higher risk of flap failure compared to situations where the anatomy of the tissue surrounding the defect is intact.

The reverse sural artery (RSA) island flap

A typical example of where DIRT can be useful in trauma surgery is the treatment of soft tissue defects of the lower part of the tibia and dorsum of the foot. The reverse sural artery (RSA) island flap is commonly used to close such defects. The RSA flap is based on the vascular network that accompanies the sural nerve and is therefore classified as a neurovascular flap. The RSA flap is harvested from the posterior side of the leg with its base approximately 5 cm above the lateral malleolus and its axis along the sural nerve. This distally based flap receives its blood supply from a perforator that arises from the peroneal artery at the lateral distal third of the leg and that communicates with the vascular network accompanying the sural nerve. What is interesting here is that the direction of the blood flow in the flap is the reverse of normal. The flap relies entirely for it blood supply on the perforator of the peroneal artery after the flap has been transposed to the defect. It takes about 3 weeks for the vessels at the defect to make contact with the vessels of the flap. For cosmetic reasons it may be necessary to resect the skin bridge that connects the flap with the perforator. However, this can only take place after vessels at the defect have grown into the flap and contribute to the flaps' blood supply.

Hand and elbow traumas

In as similar way we have also used DIRT to treat traumatic defects of the hand and elbow where open wounds had to be covered with a free flap in the case of the hand injury and a pedicled flap in the case of the elbow injury. As the preferred recipient vessels were damaged by the trauma another recipient vessel had to be selected. DIRT provided important pre-surgical information on the quality of these other recipient vessels as well as providing the surgeon with important intra- and post-operative information on tissue perfusion.

4. CONCLUSION

In this short article we have shown that infrared thermography and specifically DIRT has a clear place in the battery of imaging technologies available in the 3 main phases of perforator flap surgery, namely the pre-operative, intra-operative and post-operative phases. Even though the technique only measures changes in skin surface temperature these simple thermal signals combined with a thorough knowledge of physiology and vascular anatomy provide plastic surgeons with a relative simple, non-invasive tool for real time indirect monitoring of skin blood perfusion. In our experience this technology can not only help in pre-surgery planning but also can help to reduce surgical time and post-operative complications by quickly detecting problems in skin blood perfusion, thereby allowing the surgeon to take appropriate corrective measures. Medical thermography has for many years been a recognized medical imaging technique (16) suitable for many areas of medicine and as these authors point out and as we have described in this article, it has a valuable place in plastic surgery.

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Thermography in Viticulture

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SUMMARY

Infrared Precision agriculture matches inputs to crop demands, enhancing crop yields and product quality, of-fering economic benefits to the producer, and reducing resource wastage and pollution. Dwindling water resources make precision irrigation an area of particular interest. Precision irrigation is especially appealing in viticulture, where precise regulation of vine water status is necessary to optimize yield and grape (and hence wine) quality simultaneously. Precision irrigation requires monitoring of both spatial and temporal variation in vine water status.

Closure of stomata, the pores on the leaf surface through which gas exchange takes place, is a rapid response to water deficit. Detection of stomatal closure could alert the viticulturist to the need to irrigate. Monitoring stomatal aperture, however, until recently was a very slow process. When stomata are open, transpiration cools the leaves, but when the stomata close, there is no longer any stomatal cooling. As a result, leaf temperature is a good indicator of transpiration rate or stomatal conductance, or conversely of water stress, when environmental conditions are constant. Much progress has been made in determining the impact of a range of variables (meteorological, leaf surface radiative properties etc.) on leaf temperature. This means that even under varying environmental conditions, stomatal conductance can now be estimated from leaf temperature.

Thermal imaging means that the temperature of large numbers of leaves, plants, rows of crops, or even whole fields can be assessed rapidly. Therefore in theory it should be possible to use thermal imaging to detect individual vines that require irrigation, and to determine changing irrigation requirements over time. In practice, there is still some way to go before thermal imaging is used routinely for irrigation scheduling. Whole crops do not behave identically to individual leaves, variation in temperature caused by variability in crop structure can be difficult to separate from variation caused by differences in transpiration, and the best means of removing the effect of variation in meteorological conditions is still unclear. There are additional challenges relating to grapevine. Firstly, it is not a continuous crop, meaning that in overhead images leaf temperatures need to be separated from the temperatures of the soil or ground herbage in corridors between vine rows. Secondly, for many cultivars understanding of grapevine physiology has been derived from measurement on the vertical leaves facing into the corridors, whereas aerial or satellite imaging captures horizontal leaves at the top of vine canopies. Nonetheless, grapevine is one of the best studied crops with respect to thermal imaging under field conditions, and the potential of thermal imaging for detection of spatial variation in vine water status has been amply proven. With sufficient focusing of effort and collaboration between disciplines, the remaining technical problems should not be insurmountable.

There has recently also been some interest in utilizing thermal imaging to better understand different physiological responses in different cultivars, and there is no reason why thermal imaging could not be used for large-scale screening of different genotypes under particular environmental conditions, as is being undertaken as part of genetic improvement programs in other crops. Thermal imaging has also been shown to be useful for pre-visualization detection of pathogen infection and for monitoring the temperature of developing grapes (an important determinant of final grape, and wine, quality). Diverse uses of thermal imaging in other disciplines, such as ecology, may also be found to be relevant to enhancing modern viticulture. Additionally, it is likely that thermography will increasingly be combined with other imaging techniques (near infra-red, chlorophyll fluorescence, multi/hyperspectral, laser-induced) for a more complete understanding of vine, or vineyard, be-haviour.

1. INTRODUCTION

Precision agriculture

Precision agriculture matches inputs to crop demands, enhancing crop yields and product quality, offering economic benefits to the producer, and reducing wastage and pollution. Matching inputs to demands means prevention of the range of biotic and abiotic factors that can lead to sub-optimal growing conditions. Since crops do not grow in uniform environments, some sections of crop will need more of certain inputs than others. Requirements will also vary with the stage of crop development, season etc. To prevent a reduction or adverse changes in a crop's growth or development, it is important that alterations in crop requirements can be detected rapidly.
Dwindling water resources make precision *irrigation* an area of particular interest. Climate change will exacerbate water shortages: in the Mediterranean Basin, for example, the summer drought period will lengthen, and heat waves are expected to be more frequent and severe (4, 32), while spring and summer precipitation will decrease by 20-40% (15). Summer droughts are already more frequent in this region than they were 30 years ago (31). Compounded with climate change is increasing demand for water from the domestic and industrial sectors, reducing the quantity of freshwater available for use in agriculture (36). Water use is becoming increasing regulated (e.g. EU Water Framework Directive), with an onus on growers to demonstrate efficient use of water resources.
Precision irrigation is especially appealing in viticulture, where precise regulation of vine water status is necessary to optimise yield and grape (and hence wine) quality simultaneously. Too much irrigation leads to excessive vegetative growth and although yields under these conditions can be very high, this is to the detriment of grape quality (12). On the other hand, where irrigation is not applied, yields can fluctuate dramatically between years. In some vine-growing regions, such as the Alentejo in southern-Portugal, summer precipitation is very limited, while evaporative demand is high, making efficient use of available irrigation water a priority. Moreover, there is increasing interest in using deficit irrigation techniques in order to impose a degree of water stress that enhances grape quality. The risk with such techniques, however, is that too severe a stress could accidentally be imposed, causing a drastic reduction in yield. Sensing plant water status (as opposed to soil or meteorological conditions) is considered the most accurate means of determining irrigation requirements. Thus in viticulture, precision irrigation requires monitoring of both spatial and temporal variation in vine water status.

Stomatal closure

Closure of stomata, the pores on the leaf surface through which gas exchange takes place, is a rapid response to water deficit. Detection of stomatal closure could alert the viticulturist to the need to irrigate. Monitoring stomatal aperture, however, until recently was a very slow process. In research, it is usually monitored with porometers or leaf-chamber methods (Fig. 1A). While these are very sensitive means of measuring stomatal conductance, they are not suitable for routine application in crop production, because their use is too time-consuming: stomatal conductance follows a diurnal course and is also sensitive to changes in the weather, so there is a relatively narrow window in which plants can be assessed, if their stomatal conductance is to be compared.
When stomata are open, transpiration cools the leaves, but when the stomata close, there is no longer any stomatal cooling (Fig. 1B). As a result, leaf temperature is a good indicator of transpiration rate or stomatal conductance, or conversely of water stress, when environmental conditions are constant. We can use this approach to relatively rapidly assess spatial variation in stomatal conductance.

2. APPLICATIONS OF THERMAL IMAGING IN VITICULTURE

Application to irrigation scheduling

Thermal imaging means that the temperature of large numbers of leaves (Fig. 1C), plants, rows of crops, or even whole fields can be assessed rapidly. This has been applied in the vineyard to monitor the impact of water deficit. Grant et al. (18) showed that on several dates in summer in the Alentejo, at different times of day, leaf canopy temperatures were higher in non-irrigated grapevines than in those vines irrigated to match all the water they lost in transpiration.
Moreover, thermal imaging showed canopy temperature differences not only between those extremes, but also between vines that were exposed to different levels of deficit irrigation (not all the water they lost in transpiration was replaced) (Fig. 2). Vines receiving less irrigation had higher leaf canopy temperatures, indicating lower stomatal conductance. Therefore it should be possible to use thermal imaging to detect individual vines that require irrigation. Thermal imaging of ornamental crops for example has successfully indicated areas of the crop inadvertently subjected to water stress (10). This possibility of assessing plant water status over large areas is hugely appealing in viticulture: one vineyard can consist of numerous fields, with different varieties, variation in soil depth, a range of row orientations etc., and to be able to assess water status over such a diverse area from an aerial thermal image would be extremely advantageous for the irrigation manager.
Unfortunately, the approach is not in fact so straightforward to apply in viticulture. Firstly, grapevine is not a continuous crop, meaning that in overhead images leaf temperatures need to be separated from the temperatures of the soil or

ground herbage in corridors between vine rows. Secondly, in a commonly used growing system, vertically shoot positioned (VSP), the majority of leaves face into the corridors between vine rows rather than upwards. Thus, for many cultivars understanding grapevine physiology has been derived from measurements on the vertical leaves facing into the corridors, whereas aerial or satellite imaging captures horizontal leaves at the top of vine canopies. For this reason, some recent research has focused on exploring whether thermal images taken from above the vine canopy, from a grape-picker (Fig. 3) provide information on the stomatal conductance of the majority of leaves. Preliminary results have been encouraging (33).

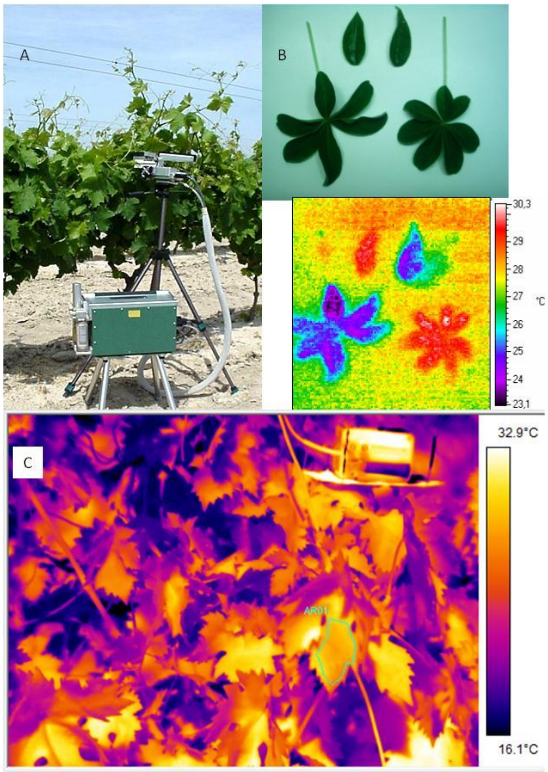

Fig. 1 - An infra-red gas analyser with a vine leaf inserted in the leaf chamber so as to measure stomatal conductance and other features of leaf gas exchange (A), digital (top) and ther-mal (bottom) images of lupin leaves, where the leaf on the right of the images is from a plant that had been subjected to drought, and the leaf on the left is from a plant that had been watered daily (B), and a thermal image of a section of grape-vine, showing a number of leaves (C).

Another problem is that some of the very causes of variation in water status within a vineyard also complicate the application of thermal imaging. Different row orientations mean that some vines are more exposed to solar radiation than others, and different cultivars may have different canopy structures, leading to variation in shading. Even within a cultivar, we have found that variation in soil depth leads to variation in vigour, which in turn results in variation in shading, and hence the relationship between leaf canopy temperature and vine water status is not always consistent. This can be particularly problematic where it is difficult to separate soil and leaf components of a thermal image - for example from an aerial thermal image with relatively low resolution. Soil temperature can vary hugely depending on shading (Fig. 4A-B). Despite this reservation, aerial thermal imaging, even with relatively poor resolution (each pixel equated to about 1 m^2 on the ground) has been shown to very clearly identify areas of a vineyard with greater or lesser soil water availability (11). Moreover, the size and weight of thermal imagers has fallen so much in recent years that it is now possible to install them in micro-aircraft, including unmanned aerial vehicles (3, 5), which fly at lower altitudes, allowing higher resolution imaging.

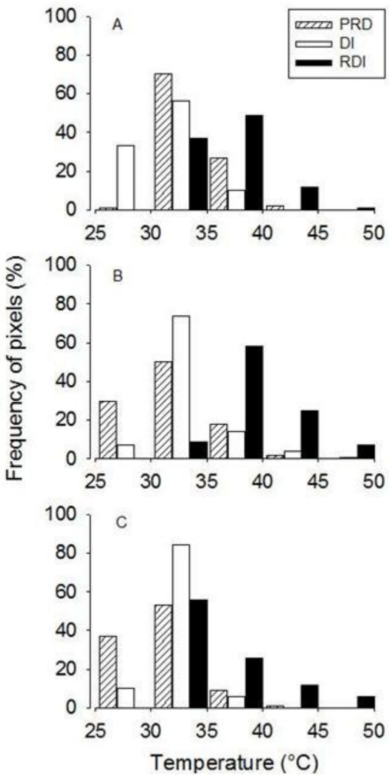

Fig. 2 - The percentage of pixels in thermal images of Aragonêz vines subjected to different levels of deficit irrigation (PRD, DI, and RDI), in three separate sections of a vineyard (A-C). At the time of imaging, less irrigation was applied under the RDI regime than the under the other two irrigation regimes. Hence pixels of images of vines given RDI tended to have higher temperatures. These data were collected in the Alentejo with Ł. Tronina.

In theory, thermal imaging could be applied not only to detecting areas of the crop that need irrigation at a particular point in time, but also to determining changing irrigation requirements over time. In practice, there is still some way to go before thermal imaging can be used routinely for irrigation scheduling. Initially, a major constraint was separation of the impact of changing meteorological conditions from the impact of changing stomatal conductance.

Fig. 3 - H. Ochagavía capturing thermal images of the top of Tempranillo grapevines in Rioja.

Much research has therefore been devoted to separating the impact of environment e.g. air temperature from the impact of stomatal conductance on leaf temperature. One approach is to include reference surfaces within each image. The temperature of the leaves of interest is then calibrated against that of the reference surfaces.

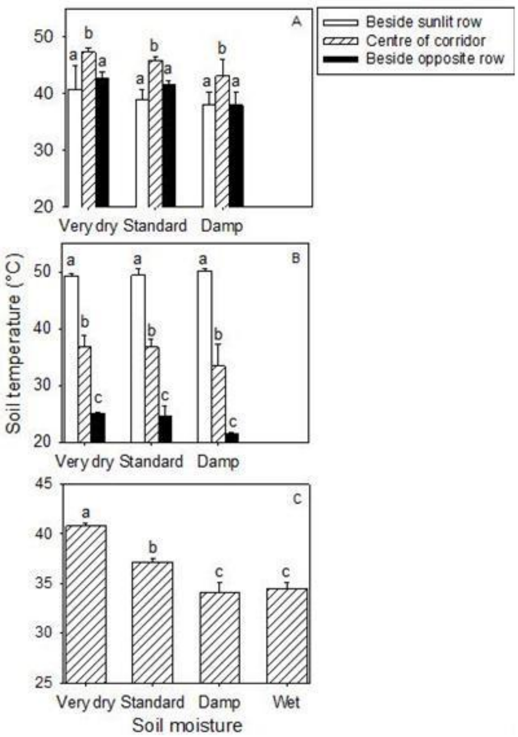

Fig. 4. Temperatures of soils in different classes of soil moisture (A-C) and in different parts of the corridor between vine rows (A-B). A refers to one crop and B-C to a different crop; the two crops differed in row orientation; data in A and B were gathered in August, whereas data in C were obtained later in the season, in September. Within a graph, different letters indicate significant differences at $P < 0.001$. These data were collected in Rioja with H. Ochagavía, M.P. Diago, and J. Baluja (3).

Particularly popular is to use two references, one wet and one dry, representing the extremes of no stomatal resistance and no stomatal conductance, respectively. Various indices are in use, including an adaptation of Idso's (24) Crop Water Stress Index (CWSI), where

$$CWSI = (T_{leaf} - T_{wet})/(T_{dry} - T_{wet})$$

where T_{leaf} is the temperature of the leaf/leaves of interest, T_{wet} is the temperature of wet reference surface, and T_{dry} is the temperature of the dry reference. Another increasingly used index (21, 22, 33) is the index I_G (an index of stomatal conductance) (27), where

$$I_G = (T_{dry} - T_{leaf})/(T_{leaf} - T_{wet}).$$

What to actually use as the reference surfaces, however, is not so straightforward. Firstly, the radiative properties of the reference surfaces need to be similar to those of leaves. Wet and dry filter papers are easy to install within a canopy (28), but the temperature of the wet filter paper has sometimes been found to be higher than that of the leaves of interest (19), even though the leaves would be expected to show intermediate temperatures. Even where the references surfaces have identical properties to the leaves of interest (for example if real leaves are used), differences in the angle of the reference surfaces towards the sun compared to that of the leaves of interest will mean that the reference and the leaves of interest are effectively not in fact in the same environment: a surface will be hotter if exposed to more radiation. Particularly as stomata close, the impact of slight changes in leaf angle on leaf temperature can become large (19). In some work this problem can be solved by forcing the leaves of interest and the reference leaves to the same angle. Grant et al. (21, 22) when screening different strawberry cultivars for variation in response to water deficit, for example, used narrow gauge fishing line to keep leaves flat. Where the average temperature of a large section of vine canopy, rather than the temperature of individual leaves, is used, variation in leaf angle is likely to be less problematic (18). However, forcing a large section of vine to behave as a wet or dry reference is not so straightforward, as preparing such references would be too time-consuming. Grant et al. (18) therefore took the approach of using the temperatures of fully irrigated and non-irrigated vines as references, when interested in vines subjected to deficit irrigation. Although the fully irrigated and non-irrigated vines may not have been perfect extremes (the fully irrigated vines could have had partial stomatal closure for example at midday, and the non-irrigated vines may not have had complete stomatal closure), they were nonetheless suitable references against which the vines of interest could be compared. The difficulty in that case, however, was that it was not possible to include fully irrigated and non-irrigated vines at sufficient spatial replication within the crop so that they could be included in thermal images of each vine of interest. Therefore, the fully irrigated and non-irrigated vines were imaged at intervals, and their temperatures *extrapolated* so as to obtain reference temperatures for *the same time* as each thermal image of the vines of interest was obtained. Although fully irrigated and non-irrigated vines have been used as references in other work (7, 9), to my knowledge this approach of extrapolating the temperatures has never been used since. This, in my opinion, is disappointing, since we know that vine temperature can change substantially within a short period of time e.g. over the morning. Extrapolating the temperatures therefore seems to me to be the only way to ensure that the reference temperatures really relate to the same conditions as the temperatures of the vines that are of interest in the study/monitoring.

Despite the above complications, the expected relationship between I_G and stomatal conductance, measured with a porometer or in a leaf chamber, has been validated under laboratory (26), greenhouse (17) and field conditions (18, 19, 30), and in some cases thermal imaging has been shown to be *more* sensitive than porometry (19, 30). The use of thermal indices rather than leaf temperature alone can accentuate differences (21), aiding their detection, and absolute values of the indices can be quite consistent even over large differences in air temperature. Standardisation of reference surfaces would seem desirable, allowing comparison of different studies, and increasing confidence in a protocol amongst irrigation managers. Research is underway to explore the potential of sensors with wet and dry artificial leaves - the wet 'leaf' in this case being kept wet by means of a wick into a small reservoir of water. Even if such an approach was standardised, however, the size of the artificial leaves would probably need to be adjusted for different species, but the standard model could probably be used for all grapevine work.

In aerial thermal imaging, small reference surfaces such as mentioned above will not be detected within the image, and anyway would not be appropriate. What *is* appropriate, however, is difficult to determine. Some authors have used air temperature + 5°C (1) as the upper (dry) reference, but this is an arbitrary value. The temperature of water in a basin, or of wet material, has been used as the wet reference (1). Water, however, has different radiative properties to leaves, and we have found (data not shown) that the temperature of different materials, even though of the same colour, can vary hugely. Moreover the structure of these flat surfaces is completely different to that of vine leaf canopies. It is interesting to note that in aerial imaging studies, microclimatic variation within the region imaged to date has been completely ignored. Thus there is a need to consider installation of several reference surfaces within a vineyard, to ensure that the reference surfaces are in fact in the same environment as the vines of interest in different sections of the vineyard.

Phenotyping

There has recently also been some interest in utilising thermal imaging to better understand different physiological responses in different cultivars. Modern genetic improvement techniques often require phenotypic information on very large numbers of different genotypes. Imaging techniques, including thermal imaging, allow assessment of the physiological performance of large numbers of plants, such as would not be possible with other, more traditional measurements.

An alternative to the use of thermal indices, is to combine leaf temperature with meteorological information in order to estimate stomatal conductance. This approach was described by Leinonen et al. (30), who found good agreement between stomatal conductance estimated from leaf temperature and that measured with a porometer. Comments above regarding microclimatic variation within a vineyard apply to this method, however, as it is unlikely that there can be more than one full meteorological station on the vineyard. It is possible, though, that some sensors measuring the most variable meteorological variables could be dotted around the vineyard. Air temperature sensors, for example, are cheap and robust. To my knowledge, this approach of combining very fine (spatial) resolution leaf temperature data with low resolution data for some meteorological variables, but medium resolution data for others, has not been tested in any crop or ecosystem. A variation on this idea, which has been assessed in the field and greenhouse (21, 30), is to estimate one of the references (usually T_{wet}) from meteorological data, but include reference surfaces to determine the other.

Measurements such as pre-dawn leaf water potential are not influenced by transitory meteorological changes such as brief cloud cover, or the angle of the leaves relative to the sun at the time of measurement. Such measures still therefore are of importance, but in future could be used *in conjunction* with thermography, rather than as the main means of monitoring water status. Thus thermography would provide frequent assessment of large areas of crop, allowing selection of specific time-points and locations that may require other, more labour-intensive or destructive, once-off or infrequent measurements. Alternatively, occasional thermal images could be used to determine vines of interest for continuous measurement, such as installation of sap flow sensors (13). Sap flow sensors are far too expensive to be used on large numbers of vines, but if a small number of vines in strategic locations are selected (making use of the thermal image to define zones with different water status), they can be used for continuous monitoring of vine transpiration.

Despite these issues, grapevine is one of the best studied crops with respect to thermal imaging under field conditions (8), and the potential of thermal imaging for detection of spatial variation in vine water status has been amply proven. With sufficient focusing of effort and collaboration between

disciplines, the remaining technical problems should not be insurmountable.
The only application of thermal imaging in determining of variation in performance of different grapevine varieties, to my knowledge, is that of Costa et al. (9). Vine canopy temperature were found to differ between varieties. Additionally, it is interesting that of all the other measurements conducted (leaf area, specific leaf area, leaf stomatal density, chlorophyll content, pre-dawn leaf water potential, net assimilation rate, stomatal conductance, intrinsic water use efficiency, and pre-dawn maximal photochemical efficiency), only stomatal conductance showed significant differences between varieties in *both* years of assessment. This seems to indicate that measuring stomatal conductance (and hence use of thermography) is one of the most sensitive means to detect physiological/growth variation between grapevine varieties.
There is no reason why thermal imaging could not be used for large-scale screening of different grapevine genotypes under particular environmental conditions, as is being undertaken as part of genetic improvement programmes in other crops (29). Phenotypes may need to determined in a wide range of environments, but given the huge current research interest in drought (20), screening responses to drought seems a useful starting point.

Disease detection

Thermal imaging has also been shown to be useful for pre-visualisation detection of pathogen infection. Stoll et al. (37) found that thermal imaging could be used to detect infection of grapevine leaves with the fungus *Plasmopara viticola* at least three days before symptoms were visible to the human eye. Such early detection of fungal attack clearly could be hugely beneficial in vineyard management, allowing spraying prior to further development of the pest. Interestingly, in that study the temperature response to fungal attack differed between well irrigated and drought-exposed vines, but by assessing variation in temperature within a leaf, rather than absolute temperature, it was possible to routinely detect presence of the fungus, independently of water regime. The study was conducted in a greenhouse, and to my knowledge the potential for using thermal imaging in disease detection of field-grown vines has not yet been assessed, but this is an area worthy of future research.

Other applications

Thermal imaging has also been used for monitoring the temperature of developing grapes (an important determinant of final grape, and hence wine, quality) (37). Apart from an assessment of the reductions in stomatal conductance, monitoring leaf or canopy temperature should be useful as a record of the duration for which leaves are at temperatures above optimal for photosynthesis, which can be incorporated into model predictions of productivity.
Thermal imaging of soil rather than leaves may be useful in some instances, although detection of water deficit may only be slower in soil than in leaves: for example in a Rioja vineyard soil temperature was only significantly affected by water deficit in September (see Fig. 4C compared to Fig. 4B), whereas leaf canopy temperature was affected as early as July (data not shown). As water resources dwindle and there is increasing pressure for agriculture to use low-quality water (14), assessment of vine response to saline conditions is likely to be of interest. A wide range of stresses lead to partial stomatal closure, so thermal imaging holds potential in monitoring or exploring responses of vines to any such stress.
Diverse uses of thermal imaging in other disciplines, such as ecology, may also be found to be relevant to enhancing modern viticulture. For example, thermal imaging has been used to monitor shifting vegetation temperatures on mountain slopes, as an aid to predicting vegetation distribution under future climatic scenarios (34, 35). A similar study might be relevant to grapevine grown on slopes. From a different perspective, there is no reason why vineyards could not be used as model systems for studying the impact of climate on agriculture, or *vice versa*. Thermal imaging has been applied to modelling regional fluxes of water (2) and, given the close coupling of stomatal conductance and photosynthesis, holds potential for modelling fluxes in carbon dioxide concentration (40). Frequent thermal images of the same vineyard would aid long-term monitoring of the impacts of climate change on crops.

3. FUTURE

In future it is likely that thermography will increasingly be combined with other imaging techniques (near infra-red, chlorophyll fluorescence, multi/hyperspectral, laser-induced) for a more complete understanding of vine, or vineyard, behaviour.
Care, however, needs to be taken in determining *which* type of imaging is most appropriate. For example, in some species maximal photochemical efficiency, measured as the difference between variable and maximal chlorophyll fluorescence of dark-adapted leaves (F_V/F_M), falls drastically when plants are exposed to drought and high light combined. Substantial variation in this decline has been found between populations (16) and cultivars (23), and therefore chlorophyll fluorescence of dark-adapted leaves is being used in screening for alterations in behaviour in the lab in response to manipulated gene expression (e.g. http://biology.nuim.ie/staff/documents/Olga-Grant.shtml), and for screening for stress tolerance. Chlorophyll fluorescence imaging allows visualisation of non-homogenous responses and/or rapid assessment of

large numbers of leaves. F_V/F_M, however, has not been seen to fall much below optimal in grapevine in various field studies in Spain and Portugal. F_V/F_M values were around 0.8 in all five grapevine varieties studied by Costa et al. (9) in August 2006, suggesting the absence of photoinhibition. This agrees with earlier work in the Alentejo (10) and more recent work in Rioja (Fig. 5): there is little photoinhibition in grapevine under drought despite high radiation during summer. Moreover it is clear from Figure 5 that stomatal conductance is a far greater determinant of photosynthetic assimilation (which affects growth, yield, and grape composition) than is photochemical efficiency. This suggests that remote sensing methods relating to F_V/F_M would not be very useful for early detection of stress nor for screening for physiological variation. Chlorophyll fluorescence of light-adapted leaves may be more informative, as this can show an impact of stress even where F_V/F_M is not much affected (19); imaging of chlorophyll fluorescence during sunlight is however very complicated (6).

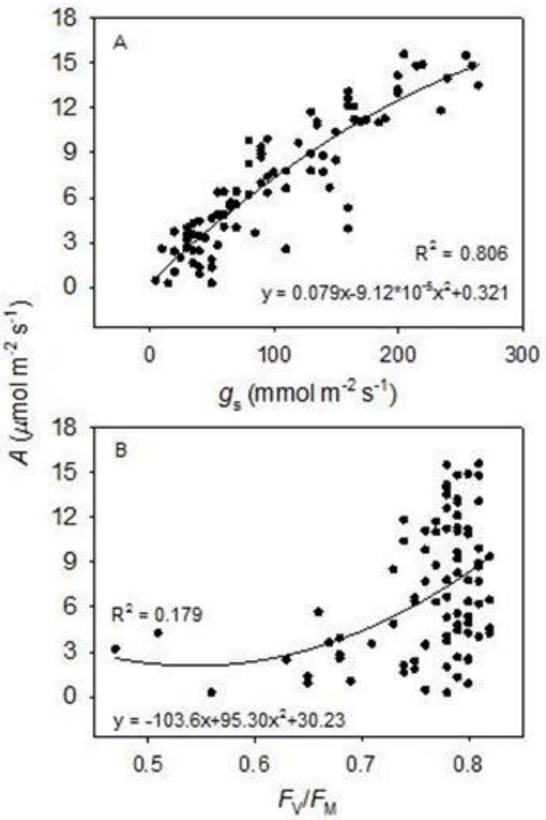

Fig. 5 - The relationship between photosynthetic assimilation rate (A) and stomatal conductance (gs) (A) or maximal photo-chemical efficiency (FV/FM) (B) in leaves of Tempranillo grapevine over the summer of 2010. Equations describe quad-ratic curve fits to the data; both regressions were significant at P < 0.001. These data were collected with H. Ochagavía, M.P. Diago, and J. Baluja.

Hyperspectral imaging is increasingly gaining scientific attention. The Photochemical Reflectance Index based on reflectance at 530 and 570 nm has been considered useful for assessing photochemical function and also water stress (25, 39), and may be worth exploring in grapevine. The clear theoretical basis for using thermal imaging, and the fact that its utility in detecting variation between vines has been proven, however, mean that for the moment where physiological information is required, thermal imaging is unquestionably the most applicable imaging technique for viticulture.

4. CONCLUSIONS

The *potential* of thermography in viticulture has been amply demonstrated in a number of publications over the last ten years. It is now important that viticulturists, engineers, software experts etc. work together to ensure that thermography is applied practically, to improve both the productivity and sustainability of viticulture. While the most explored application of thermography in viticulture is in monitoring vine water status, there are a number of other areas that would benefit from incorporation of thermography into existing or future research programmes.

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Accuracy When Assessing and Evaluating Body Temperature in Clinical Practice: Time for a Change?

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SUMMARY

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 the laboratory test ordered, medical diagnosis and treatment. 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. 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. This raises the question about accuracy in measurement of body temperature. What precision can we expect in clinical practice? How is the unadjusted variation of body temperature in different sites related to health and disease? Taken together, it is time for a change when assessing and evaluating body temperature in clinical practice.

Keywords: Accuracy, assessment, normal body temperature, fever

1. INTRODUCTION

In clinical practice, assessment and evaluation of body temperature, i.e the presence of fever, has great impact on decisions in nursing care as well as medical diagnosis, treatment and the laboratory test ordered. From both a technical as well as a clinical view, accuracy of the reading is significant to ensure a correct assessment (32, 63). Accuracy indicates proximity of measurement results to the true value and precision of the measurement. However, when assessing body temperature, we have to consider several "errors", such as the influence of normal thermoregulation, gender, ageing and site of measurement.

This raises the question about accuracy in measurement of body temperature. What accuracy can we expect in clinical practice? In addition, is it accurate to convert a temperature measured at one site to in order to estimate the temperature at another site?

Therefore, the objective of this paper was to discuss accuracy of body temperature measurement and implications in clinical practice.

2. METHODS

2.1 Literature search

A literature search was performed in MEDLINE, CINAHL and manually from identified articles reference lists. The results of the literature search and implications for clinical practice is presented in an earlier paper (63). Briefly, the search included English or Swedish textbooks, original papers, reviews and scholarly papers, addressing the concept body temperature related to different constellations of key- words, such as measurement / normal / core/ human / review / adult / gender / tympanic / rectal/ oral / axillary / thermometers. Also hypothermia and elderly, thermoregulation, circadian rhythm, fever, febrile response and shivering was used to identify articles. No restriction was made concerning when the paper was published. For the purpose of the present paper we have added published papers focusing on accuracy from a technique point of view.

3. RESULTS

3.1 Accuracy and standardisation

According to the ISO (32) standard the clinical accuracy of a clinical thermometer is verified "*by comparing its output temperature with that of a reference thermometer, which has a specified uncertainty for measuring true temperature"*.

However, for an equilibrium clinical thermometer it is possible under laboratory conditions to adequately determine the clinical accuracy, i.e. equilibrium state between the two devices. For a clinical thermometer, operating in the adjusted mode, the output temperature includes characteristics of the patient and the environment. Hence, according to international standards, the clinical accuracy of a thermometer in the adjusted mode has to be clinically validated with statistical methods to compare its output temperature with a reference clinical thermometer. This clinical device, in turn, should have a specified clinical accuracy, representing a particular reference body temperature (32). In addition, the calibration has to be performed according to ISO standards in an accredited laboratory (30, 60). For electronic contact thermometers the standard states an operating range of 35.5° C to 42° C and a laboratory accuracy of ± 0.1° C (15).

Also, there are ISO standards for establishing clinical accuracy for infrared (IR) ear thermometers (31). According to this standard clinical accuracy is defined as the *"ability of an IR ear thermometer to give a reading close to the temperature of the site that it purports to represent as measured by the reference thermometer"*. Maximum permissible error shall not exceed ± 0.2° C operating from 35.5° C to 42° C (15). At present no manufacturing standards have been developed for the forehead thermometers (15).

For the clinicians accuracy is about a thermometer that accurately and consistently measures, or estimates the "actual" body temperature (15). McCarthy & Heusch (40) summarize that a site that quantitatively and rapidly reflect changes in arterial temperature and is independent of local blood flow or environmental changes appropriate estimate central temperature. Also, the repeatability of the thermometer is important in the clinical setting (50). The most important factor influencing the reading is probably a correct placement, as an incorrect placement can cause serious variations (15). The site should also be convenient for the clinician, pain free and harmless for the patient and reliable and traceably standardized. Also, bilateral sides should be compared, studies should be based on large populations and there should be scientific cut-off points for clinically relevant conditions, such as fever (40).

3.2 Definition of normal body temperature and fever

The definition of normal body temperature as 37° C and fever as ≥ 38.0°C was established in the middle of the 19th century (70). The axillary site, which estimates the periphery body temperature, was used as the reference temperature. Also, the fact that the measurements were performed on patients, indicate that a large number might have been febrile (38, 43). In 1869 the understanding about the influence of thermoregulation, hormones, metabolism and physical activity on body temperature was unknown. In addition, knowledge about immunology and microbiology and insight about the importance of calibration of thermometers were lacking. DuBois (16) pointed out that *"a range of temperatures may be found in perfectly normal persons"* and raised the question *"Would it not be wise to remove the little red arrows from our thermometers?"* Galen & Gambino (23) further stated that a concept of normality is itself inadequate for the proper interpretation of test results if it is not interpreted in relation to a reference value.

Today there is a general acceptance of body temperature as a range rather than a fixed temperature. Even so, the norm from the middle of the 19th century is still the basis for assessment and decisions about body temperature, causing a widespread confusion of the evaluation of body temperature in clinical practice (39). Also, there is a lack of studies performing temperature measurements in a standardised way (62).

3.3 Core body temperature

According to the International Union of Physiological Sciences (IUPS), Thermal Commission, a site providing a core temperature would be expected to be stable in relation to the temperature in internal organs, irrespective of circulatory changes or heat dissipation affecting the periphery, or external factors, such as environmental temperature and humidity. The ideal core temperature is the mean temperature of the thermal core. In changing core conditions the oesophageal or aortic temperature readings are recommended (42). Ring et al. (52) pointed out that there is not a single unique core temperature as there are temperature gradients between internal organs in the body. This was already suggested by

DuBois (16) who defined the core of the body as the thoracic and abdominal contents, some of the muscles and the brain, while the peripheral areas were defined as the skin and a small amount of subcutaneous tissue. He also pointed out the misconception of *the* body temperature and underlined that there is not one, but several core body temperatures depending on temperature gradients within the body.
Today, the temperature in the pulmonary artery (PA) is considered the gold standard of core temperature (35, 37), although, some suggests the nasopharynx and the bladder as gold standards for core temperature (15). However, still it is not clear what a clinically accessible core body temperature is (50). In clinical practice, as well as in research and stated by the IUPS, the rectal or the oral site is used as a surrogate for the core temperature (39, 50). This might be an explanation to the tradition, although without no scientific base, that the oral and axillary readings are adjusted to the rectal temperature adding 0.3°C and 0.5°C, respectively (2).
In order to make the reading more familiar to clinicians, this tradition has been applied also to ear based temperature measurements, which can be measured without adjustments to other sites, or readjusted in order to equalise the oral, rectal or PA temperature (2). These adjustments to other sites vary considerable between manufactures (5, 19, 57, 59, 66), and there is a lack of studies supporting these offsets (40). Also, thermometers estimating the tempory artery temperature are adjusted with pre- decided offsets to equalize a temperature at a reference site.

3.4 Comparison between sites in assessment of body temperature

A large amount of papers have focused on accuracy by comparing non-invasive measurements to a reference site, often PA or the rectal site. However, the question is if this is the best approach to describe clinical accuracy (63). 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 (34, 64).
Simply adding an offset, assuming that the differences between different sites and methods are linear do not consider thermoregulation and the complexity of the human body (40). Lack of agreement between measurements does not necessarily mean that one site is true and the other one false, due to different thermal influences and profiles (50). However, this is often the conclusion in studies on body temperature measurement. As an example, a world-wide cited systematic review, including 45 studies (14) found that the ear temperature could be 0.2°C to 1.4°C below and 0.1°C to 1.9°C over the rectal temperature in children. They therefore concluded that the ear site is not an acceptable approximation of rectal temperature, due to the wide limits of agreement. The pooled limits of agreement for all reviewed studies are presented in Table 1.

Table 1. Comparison between ear based and rectal temperature. The difference is presented as the pooled limits of agreement in °C. Adapted from Craig et al. (2002).

Mode	Pooled limits of agreement
	°C
Rectal mode	-1.0 to 1.3
Actual mode	-0.2 to 1.6
Core mode	-0.8 to 1.3
Oral mode	-0.9 to 1.5
Tympanic mode	-0.4 to 1.6
Mode not stated	-0.6 to 1.2

A positive number means that the measured temperature overestimates, and a negative number that the temperature reading underestimates the rectal site.
Another study (6) summarize comparison of ear, oral, axillary and tempory artery with PA, as the reference temperature, in intensive care patients. They found that the ear thermometers could underestimate and overestimate the PA temperature with -1.7°C to -0.4 ° C and 0.3°C to 1.5°C, respectively. For oral thermometers the corresponding figures were -1.6°C to -0.4°C and 0.6°C to 4.5°C, for the axillary devices -1.9° C to -0.4°C and 0.2°C to 1.2°C and for tempory artery -2.5° C to -0.8°C and 0.8°C to 3.3°C, respectively. (table 2).
The mode of the ear thermometers included in the study by Craig et al (14) varied (table 1). In the review by Bridges & Thomas (6) unfortunately the mode was not reported at all.
A positive number means that the measured temperature overestimates, and a negative number that the temperature reading underestimates the pulmonary site.
A third study, comparing simultaneously measured rectal, oral, ear and axillary temperatures, without adjustments, in healthy adult subjects, reported deviations for rectal - ear of – 0.7°C to + 2.8°C, for rectal - axillary – 1.4°C to + 2.3°C and for rectal - oral temperatures - 1.5°C to + 2.3°C . These three studies all compare different sites to a reference temperature.

Table 2. Comparison between pulmonary artery and ear, oral, axillary and tempory artery temperature in adult patients in the intensive care unit. The difference is presented as limits of agreement in °C. Adapted from Bridges & Thomas (2009).

Ear based	Oral	Axillary	Tempory artery
-1.2 to 1.2	-1.6 to 4.5	-1.6 to 1.2	-1.3 to 3.3
-1.3 to 0.6	-1.4 to 1.0	-1.9 to 0.5	-2.1 to 2.3
-0.7 to 1.5	-0.5 to 1.3	-1.2 to 0.6	-2.3 to 2.0
-1.2 to 1.3	-0.9 to 0.8	-1.1 to 0.6	-2.5 to -0.1
-1.6 to 0.5	-0.9 to 0.6	-1.2 to 0.3	-1.1 to 0.8
-1.7 to 0.3	-0.5 to 0.6	-1.0 to 0.4	-0.9 to 0.9
-0.9 to 1.1	-0 3 to 0.7	-0.5 to 0.9	
-0.7 to 0.9	-0.5 to -0.4	-0.4 to 0.2	
-1.2 to 1.0		-0.8 to- 0.6	
-0.8 to 1.1			
-1.2 to 0.8			
-0.4 to 0.6			
-0.4 to 1.2			

However, Craig et al. (14) recommend and condemns different sites. Bridges & Thomas (6) do not conclude about "best site", but illuminate factors that affect accuracy and precision of different sites. In the third example Sund-Levander et al. (64) confirm that there are large variations between sites due to intra-individual variation. The authors conclude that, in order to improve evaluation of body temperature, the assessment should be based on the individual variation, the same site of measurement and no adjustment between sites. Hence, these three studies exemplify three different approaches and interpretation of results that might have a great impact on assessment and evaluation of body temperature in clinical practice. Recently Pursell et al. (50) published a study with a somewhat different approach. They focused on normal variation, stability and repeatability of an ear based thermometer, without comparing with a reference temperature at another site. This is more in line with the approach of Sund-Levander et al. (64) i.e. intra- and inter individual differences makes it a hazard to compare or adjust different sites when assessing body temperature.

3.5 Thermoregulation

Temperature regulation is defined as the maintenance of the temperature or temperatures of a body within a restricted range under conditions involving variable internal and/or external heat loads (42). In order to maintain the body temperature within an individual temperature range, the set point, thermosensitive neurons in the preoptic anterior area of the hypothalamus (POAH) assimilate information from the surrounding blood and peripheral receptors (4, 11). In the midbrain reticular formation and in the spinal cord neurons respond to thermal stimulation of the skin (68). Another pathway from the periphery to the brain is through the vagus nerve (46).

In a thermally neutral environment, warming of the POAH above the set point activate heat loss responses, and cooling below set point, stimulate heat production responses. Several factors, such as diurnal variation, cellular metabolism (61, 68), exercise (47) and ambient temperature (69) influence thermoregulation. The diurnal rhythm is consistent within the individual both in health and disease. For each 4 mm of depth, from the body surface there is a rise in temperature of approximately 1°C (26).

3.6 Gender

In general, women have a higher average body temperature compared to men (10, 29), explained by female hormones (8). Resent research indicate that postmenopausal women have a lower body temperature compared with premenopausal women (64). Females also have a lower baseline metabolic rate (20) and it is suggested that they have a higher sweat onset and lower sweating capacity compared to men when exposed to heat (7). Furthermore, the thicker layer of subcutaneous fat helps to insulate the core from heat gain during hot conditions in women (20).

3.7 Ageing

A recently published review showed large variations in different non-invasive sites in older people (36). Others have also reported an increased frequency of hypothermia (41) and an altered shivering response(12, 22). Cognitive decline, dependency in activities in daily living and a body mass index ≤ 20 have been observed to be associated to an increased risk of a lower body temperature, while daily medication with paracetamol was related with increased temperature(62). Age-related factors, such as reduced proportion of heat-producing cells, decrease in total body water, delayed and reduced vasoconstriction and vasodilation response, a decreased metabolic rate and secondary to impairment and disease may also affect thermoregulation in old aged (17, 22, 33, 44, 49).

3.8 Body temperature measurement - The rectal site

The rectal temperature is in general higher than at other places in steady state (71), because of the low blood flow and high isolation of the area, which cause a low heat loss (48). It significantly lags behind changes at other sites, especially during rapid temperature changes (54, 55). The temperature increase by 0.8°C with each 2.54 cm the device is inserted (54, 67) a standardised depth of 4 cm in adults is recommended (3).

3.9 Body temperature measurement - The oral site

The sublingual temperatures differ between the posterior pocket and the front area (18), as well as between the posterior pockets (45). Other influencing factors are vasomotor activity in the sublingual area, salivation, previous intake of hot or cold food and fluids, gum chewing, smoking and rapid breathing (3, 13, 51).

3.10 Body temperature measurement- The axillary site

Several factors affect the accuracy of axillary measurement, such as ambient temperature, local blood flow, evaporation, inappropriate placing or closure of the axillary cavity, and inadequate period of the reading (3). Even with careful positioning, axillary measurements are slow to register changes in temperature, which cause a wide deviation from other sites (54). During fever, the skin temperature varies dynamically due to vasomotor activity. Therefore, monitoring the skin temperature is an insensitive technique for estimating the body temperature (38, 43).

3.11 Body temperature measurement - The ear site

The tympanic membrane and hypothalamus share their blood supply from the internal and external carotid arteries (1, 24) and the area is relatively devoid of metabolic activity. As the probe is placed about 1.5 cm away from the tympanic membrane (67), the reading is a mix of heat from the tympanic membrane and the aural canal (21). No affect was found during facial cooling or fanning (56, 58). The influence of cerumen and otitis media is uncertain (9, 45, 53).

3.12 Body temperature measurement - forehead thermometers

Forehead thermometers estimate the temporal artery temperature by repeatedly sample the temperature of the overlying skin (15). This site fluctuates considerably due to perspiration, make-up, lotions, oils, hair and environmental factors need to be carefully controlled. In addition vasopressive medication may affect the accuracy (6).

4. CONCLUSION

This literature cited revealed that there is considerable scientific knowledge about thermoregulation, factors influencing normal body temperature, and technology for measuring body temperature. In spite of all this knowledge many studies have focused on the degree of closeness between different sites of measurement in order to define the best choice for estimating the core temperature non-invasively (63). To define acceptable accuracy (25), between sites or to use the term equivalence only contributes to misunderstandings and confusion (2). Hence, still there is a shortage in the application and assessment of the body temperature in clinical practice.

As body temperature varies with age, gender and site of measurement, our interpretation is that body temperature should be evaluated in relation to individual variability, i.e. a baseline value, and that the best approach is to use the same site, without adjustments to other sites. Also, as normal body temperature shows individual variations, it is reasonable that the same should hold true for the febrile range (38). In addition, all methods require careful handling and experienced users (28, 66).

We approve with others have observed the lack of studies based on large populations divided into subgroups such as age, sex and cut-off points for clinically relevant conditions, such as fever (27). Additionally others have also noted the need to study stability and repeatability and to define normal range in various environmental conditions (50).

We also agree with the conclusion from McCarthy & Heusch (40) about designing equipment measuring body temperature in line with today's data set, instead of out-of-date data.

In addition, in order to promote evidence-based practice we suggest that the future research pay attention to the following questions:

- instead of a fixed cut-off value can an increase of x° C from individual baseline body temperature be assessed as fever?
- how is the unadjusted variation of body temperature in different sites related to health and disease?

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Core Body Temperature Evaluation: Suitability of Measurement Procedures

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SUMMARY

Infrared Core body temperature (T_c) is regulated to achieve the homeostatic balance between production and dissipation of heat. This parameter is one of the most important factors to monitor and study the regulation of human temperature. It helps at studying the cognitive response to high temperatures' exposure and it is one of the best physiological indicators used to avoid heat injuries in different activities independently from individual characteristics such as: age, height, body weight or body fat. It has also been used in several studies, both in the laboratory and in the real work context, including athletes, students, and military forces. The main goal of this study was to select the most suitable method and equipment for measuring core temperature in occupational environment. This study was based on literature review from large databases and scientific journals. The literature reviewed confirmed that the gold standard methods for T_c measuring (rectal and esophageal) have some advantages but also limitations, especially due to discomfort caused by sensors implantation. Alternatively, it is possible to use thermal ingestible sensors without the limitations of the other methods. This technique was applied, tested and validated by several researchers and approved by the ethic committees. However, there are still doubts about the scope of its applicability. According to all the information collected, it was concluded that the most suitable procedure to measure core temperature in occupational activities is the TIS. For this reason, the authors believe that the intra-abdominal temperature measurement with TIS is, from the available methods, the most suitable for the measurement of T_c in the workplace. The method was, therefore, selected for further research.

1. INTRODUCTION

All human body activities produce heat that has to be dissipated into the environment in order to prevent an excessive increase of core temperature (T_c) and to maintain body temperature equilibrium. This capability to sense, regulate and maintain T_c within a range pre-determined of about 37ºC (2, 18, 31), is a fundamental characteristic for human survival. For this reason, it is said that man is an homeothermic being. What is achieved is a dynamic equilibrium and not a steady state (31). A deviation of ± 3.5 °C from the resting temperature of 37 °C (T_c) can result in physiological impairments and fatality. It is in this moment necessary to distinguish between core (inner) and shell (outer) temperature. Core temperature refers to the abdominal, thoracic and cranial cavities, while shell temperature (T_s) refers to the skin, subcutaneous tissues and muscles (22).

The core temperature is achieved by autonomous mechanisms that, actively, balance the production and loss of heat. These mechanisms are mainly controlled from the hypothalamus and depend on the input signal from the different parts of the body via the afferent neurons Insler & Sessler (15).

It is known that the hypothalamus plays a key role on temperature control using signals received from sensors spread throughout the body to act in several physiological mechanisms. It is composed of several parts and two of them are in charge of thermoregulation:

- Anterior hypothalamus - acts in a situation of overheating and is responsible for the activation of the heat loss mechanisms, such as sweating and vasodilation;
- Posterior hypothalamus - acts as a protection mechanism against the cold, triggering actions such as vasoconstriction to reduce losses to the environment, and shivering to increase heat production.

The efferent defenses may be divided into autonomous responses (e.g., sweating and shivering) and behavioural responses (e.g., seek for warm environments, clothing). Autonomous responses are about 80% dependent on core temperature and largely managed by the anterior hypothalamus. On the other hand, the behavioural changes are about 50% determined by skin temperature and largely controlled by the posterior hypothalamus Insler & Sessler (15).

There is consensus among the authors that the control of core temperature is one of the best ways to reduce the risk of heat damage (13, 22) and to evaluate human performance (37). This last author also says that the state of alertness, performance and T_c are related, concluding that the neurobehavioral

reactions change according to the internal biological rhythm and the wakefulness time.
When core temperature nears the circadian peak there is an improvement in performance factors (such as working memory, attention and subjective visual attention), but reaction time is 10% slower. When core temperature is low, near its circadian minimum, a worse performance occurs. These results show that an increase in T_c associated with the internal biological clock, are correlated with a better performance and alertness. It has long been shown that there is a positive relationship between daily rhythms of T_c, neurobehavioral performance and alertness in humans (37).
In extreme occupational environment (hot or cold), all these issues are critical because they can make the difference between sickness and health, or have influence on the occurrence of accidents. So, the main objective of this study was to select the method and the device most suitable for the measurement of core temperature (T_c) in occupational environment. For this was performed a comprehensive survey and compared the different methods and measurement techniques.

2. METHODS

This study was based on a literature search in major databases such as Pub Med, Web Science and Scientific Journals, which allowed us to identify, select and analyse relevant papers. The research has been developed by combining a set of keywords that were predefined: *Core Temperature; Ingestible Temperature Sensor; Temperature Capsule, Thermoregulation, Heat*. Some books based on recognized scientific literature and standards related to the subject were also analysed.
According to the objective of this paper, only studies with ethics committee approval or, at least, informed consent, have been considered to decide the most appropriate methods of behavioural procedures. The selection criteria of these methods include: calibration; real time data acquisition; real time monitoring; reliable and precise sensors; comfort in use; less invasive method compared with those used for the same purpose, easy to manage and adaptable to rest and exercise situations.

3. CORE TEMPERATURE

According to Parsons (31), core temperature has no definition. However, it is generally considered an internal temperature or the temperature of the vital organs including the brain. An alternative definition for T_c is provided by ISO (16). By this standard, the *internal body temperature* or *core temperature* refers to the temperature of all tissues located at a depth sufficiently distant from the outer surface of the body in order to do not be affected by temperature gradients occurring in the superficial tissues. The same standard refers that differences in internal temperature may be possible, depending on local metabolism, on the concentration of vascular networks and on local variations in blood flow. For this reason, T_c has not a single value, constant, uniform and measurable as such, but depends on the location of the measuring point. His value can be measured in different parts of the body as, for instance:

- esophagus: esophageal temperature (t_{es});
- rectum: rectal temperature (t_{re});
- gastrointestinal tract: intra-abdominal temperature (t_{ab});
- mouth: oral temperature (t_{or});
- tympanum: tympanic temperature (t_{ty});
- auditory canal: auditory canal temperature (t_{ac});
- urine temperature (t_{ur}).

Clinically, it is taken into consideration the temperature of the blood in the pulmonary artery (PA), as measure of brain temperature (2, 11) and tracheal temperature. These methods have many applications in physiology and medicine. In general, the brain temperature is not measured directly due to possible damage by the introduction of temperature probes. Likewise, at this level, it is assumed that the brain temperature is equal to core temperature. However, during hypothermia or hyperthermia, the brain and core temperatures are very different (2).
The pulmonary artery catheters allow the measurement of central blood temperature, which is also considered the gold standard for measuring core temperature. Thus, pulmonary artery catheter measurement is usually used as a reference for all other devices. The obvious disadvantage of monitoring pulmonary artery temperature is the high cost and invasiveness of the catheter and the difficulty of its insertion. So, although considering the temperature in the pulmonary artery the gold standard for T_c, this measurement method is invasive, and not suitable for non-surgical applications.
According to Matsukawa et al. (24), in clinical measurement, to detect thermal perturbations, continuous core temperature monitoring is often used when general anaesthesia is administered for more than 30 min. In this situation, tracheal temperature has been proposed as an easier alternative in patients requiring endotracheal intubation.
The different techniques of internal temperature monitoring, differ in difficulty of implementation and in degree of tolerance or acceptance by different individuals. The standard ISO 9886 (16) refer that depending on the technique used, the temperature measured can reflect:

- "*the mean temperature of the body mass, or*
- *the temperature of the blood irrigating the brain and, therefore, influencing the thermoregulatory centre in the hypothalamus.*

This temperature is usually considered for evaluating the thermal stress endured by an individual".

The measurement of skin or axillary temperature is another way to obtain a value. This kind of measure is influenced by skin blood flow and environmental conditions. Parsons (31) and Ribeiro (34) state that the temperature measured at the surface of the skin is about 4 to 5 ºC less in relation to the core temperature. This temperature can be measured in different places such as the: forehead, arm, forearm, chest, back, the thigh and leg, through sensors glued to the skin. The same authors consider the axillary temperature as a close estimation to T_c, despite measuring a value that is less than the oral or rectal temperature. However, in spite of being easy to use, its value lacks scientific objectivity.

According to an analysis by Kelly (17), the temperature can be controlled in different parts of the body. The choice of the measurement place is the result of the convenience and reliability required.

In Kelly's (17) literature review, it is stated that T_c is a complex and nonlinear variable that is affected by many internal and external factors. It is known that in homoeothermic animals, the core temperature undergoes slight changes, not only from species to species but also, although to a lesser extent on a smaller scale, among individuals. In people, the normal value for oral temperature is 37ºC, but the normal human T_c undergoes a regular circadian fluctuation of 0.5ºC to 1.0ºC. T_c depends more on the time of the day than on the activity, except in activities which imply a heavy workload. It is usually lower while sleeping, slightly higher in the relaxed awake state and it rises with activity (15).

Also according to Kelly (17), the mean expected difference between the minimum and maximum core temperature over any 24-hour period is about 1.0 °C in most individuals. However, research suggests that, more than any T_c value by itself, the variation of its value over 24 hours can be an important factor in assessing the health of each individual. Thus, bigger differences are consistent with better health. Two of the factors that can have an effect on T_c's range are: the physical fitness and the age. The existing studies suggest that a better physical fitness and younger age are characterized by larger temperature amplitudes, while poor fitness and advanced age are characterized by lower amplitudes (17).

The variability is more pronounced in the morning and early afternoon (until about 2p.m.) and again in the evening (after 7p.m.). Axillary temperatures change ±1.0-1.5°C for a period of one hour, while the rectal temperature remains relatively stable ±0.1-0.3 °C (17). The range between 36.2 ºC and 37.5 ºC is considered the normal core temperature and it is proved that T_c increases with mental exertion, constipation, and urinary retention. It was also shown that there are changes in core temperature in both, healthy and unhealthy subjects, according to the time of day (17).

4. CORE TEMPERATURE MEASURING TECHNIQUES

There are numerous methods for measuring internal core temperature, some are more convenient to measurement than others which are more acceptable by individual.

4.1 Esophagus: esophageal temperature (t_{es})

According to ISO 9886 (16), this temperature is measured with a transducer that is introduced in the lower part of the esophagus, at the level of the heart, to reflect the internal blood temperature. For example, the aorta's blood that goes to the brain and the rest of the body (31). In this position, the transducer registers variations in arterial blood temperature with a very short response time. With this method, the measured temperature can be affected by breathing and also by the saliva swallowed. So, the measurement temperature is not given by mean value of recorded temperatures, but by peak values. This situation is more evident in cold environments, where the saliva could be chilled due to temperature. However, this method is considered by the ISO 9886, the one which more accurately reflects changes in temperature of blood leaving the heart and, in all likelihood, measures the temperature of the blood that irrigates the thermoregulatory centres in the hypothalamus (16). Although, according to this standard, esophageal measurement is uncomfortable and the individual should be warned of this. It is recommended that the probe be introduced via the nasal fossae rather than through the mouth. It is also recommended that the tip of the probe be coated with an analgesic gel in order to reduce discomfort when going down. This method is used in laboratory experiments but, due to the caused discomfort it is not very accepted by subjects and non-physicians researchers. It is also disadvantageous because swallowed drink, food and saliva influence the readings (31).

4.2 Rectal Temperature (t_{re})

Rectal temperature (t_{re}) is independent of ambient conditions. In this case the probe is inserted into the rectum to a depth of, at least, 100 mm. This sensor will be surrounded by a large mass of abdominal tissues with low thermal conductivity. Slight temperature differences may be registered depending on the depth of insertion of the transducer. Therefore, the depth should remain constant throughout the measurement period. The measurement of rectal temperature should be avoided in person's suffering from local lesions. Typically insertion is done by flexible and unbreakable probes.

According to Parsons (31), this measure gives a value of the mean core temperature. However, it may not be representative of brain temperature. It will also be affected by "cold" blood or "hot" blood

from the legs during vasoconstriction or vasodilation respectively.
Although rectal temperature has a value close to T_c, the readings can be affected by the presence of stools and bacteria. Under these conditions can be generated heat, raising the t_{re} above T_c.

4.3 Urine temperature (t_{ur})

The bladder and its content may be considered as being part of the core of the body. Therefore, the measurement of urine temperature during its discharge can provide information concerning T_c. The measurement is done by means of a temperature transducer inserted in a collecting device. By definition, the measurement possibilities are dependent on the quantity of urine available in the bladder.
According to ISO 9886, the collecting device and the transducer should be thermally insulated, having both a very short time response. *The temperature should be recorded during and directly under the urine stream and not in the collected urine.* In the present state of knowledge, it is recommended to perform measurements with an air temperature between 15 °C and 25 °C.
The bladder temperature can be measured with a Foley catheter with an attached temperature thermistor or thermocouple. Although bladder temperature is a close approximation of core temperature, the accuracy of this method decreases with urine output.

4.4 Intra-abdominal temperature (t_{ab})

This temperature is measured by a TIS that is swallowed by the subject. During its transit through the intestinal tract, the recorded temperature will vary according to its location: near large arterial vessels or organs with high local metabolism, or, conversely, close to the abdominal walls (16).
When the transducer is located in the stomach or duodenum, temperature variations are similar to those of esophageal. As the thermal ingestible sensors (TIS) goes through the intestine, the temperature characteristics become closer to the rectal temperature. Consequently, the interpretation depends on the time elapsed since the TIS swallowing and on the gastrointestinal transit speed for a given subject. According to present knowledge, this measure seems to be independent of ambient climatic conditions, except when a strong radiant heat impinges on the abdomen.
The abdominal temperature is representative of the central trunk and the TIS are used for recording T_c for long periods, e.g. in astronauts in space missions (31).

4.5 Oral temperature (t_{or})

The mouth is one of the common places to measure the core temperature in clinical context. Oral temperature requires about 5 minutes to achieve a stable value. This value are about 0.4ºC below intra-pulmonary artery (IPA) (22). In this method, the transducer is placed underneath the tongue, being in contact with the lingual artery. It will then provide a satisfactory measurement of blood temperature which influences the thermoregulatory centre.
However, the measured temperature depends on the external conditions and can also be influenced by breathing rates. When the mouth is open, the heat exchanges by convection and evaporation on the surface of the oral mucosa, contribute to a reduction in temperature in this cavity. Even when the mouth is closed, the temperature can be significantly reduced due to a decrease in face temperature (16, 22).
The transducer should be placed under the tongue, at the side and close to the base of the tongue. The mouth must remain closed throughout measurement time. The transducer should be small in size, flat and of low thermal capacity. The probe must be flexible enough so that it can remain near to the lingual artery without discomfort.
The measured value just can be considered as a satisfactory approximation of the T_c under the following conditions:

- Ambient temperature above 18 °C;
- The mouth remains closed, before transducer insertion, at least in the:
  - 8 minutes before the measurements, if the air temperature is between 18 °C and 30 °C;
  - 5 minutes, if the air temperature is higher than 30 °C;
  - 15 minutes after drinking, eating or smoking for the last time.

Some authors use the method, and according to Casa et al. (6), the oral thermometer is often used to obtain core temperature in individuals at rest. However, its clinical validity is relative. Results can be contradictory as a consequence of mouth temperature be affected by actions like eating, drinking, breathing, swallowing saliva, and also by ambient temperature that can change facial temperature (6). The same point of view was supported by Kelly (17) on a literature review, where the oral temperature was considered inaccurate. This temperature, although having some parallel in terms of amplitude and "acrophase" with the T_c, tends to be lower than rectal temperature (17).

4.6 Tympanic temperature (t_{ty})

According to ISO_9886, this method aims at measuring temperature on the tympanic membrane whose vascularisation is provided in part by the internal carotid artery that also supplies the hypothalamus. As the thermal inertia of the eardrum is very low due to its low mass and high vascularity, its temperature reflects the variations in arterial blood temperature which affects the thermoregulatory centres (16). As in other methods

to get the T_c, the tympanic temperature is also influenced by the local exchanges of heat.
Still according to ISO_9886, tympanic temperature can only be used when tympanum and walls of the auditory canal are in perfect conditions. All deposits of wax should be removed. The tympanic temperature can be measured using a thermistor or a thermocouple. Contact between the transducer and the tympanum is easily identified by the sensation felt by the subject. The shape of the transducer and the stiffness of the probe are critical factors in avoiding injury to the tympanic membrane. The transducer should have a low thermal capacity so as to cause a minimal disturbance to the thermal equilibrium of the tympanum.
Tympanic temperature is only an acceptable indicator of T_c if:

- the initial position of the transducer is maintained throughout the measurement period;
- the auditory canal and the outer ear are thermally isolated from the exterior environment;
- the environmental conditions around the subject's head, are:
  - air temperature between 18 °C and 58 °C;
  - air velocity less than 1 m/s;
  - mean radiant temperature close to air temperature.

If the working conditions involve direct thermal radiation or a strong convection in the head (air speed greater than 1 m/s), a correct measurement can only be achieved placing a helmet covering a large surface of the head.
Tympanic temperature may also be measured using a non-contact infrared radiation (IR) thermometer. In order to apply this equipment, in addition to the above-mentioned conditions, it should be ensured that the device only measures the tympanic membrane temperature and not the walls of the auditory canal. The factors that interfere with the use of the method are:

- an angle too wide of the optic sensor;
- no control over sensor focus;
- an auditory canal narrow and/or bent;
- hair in the auditory canal;
- presence of cerumen;
- difficulty in insulating the auditory canal.

For these reasons, the values recorded with IR devices used discontinuously are often invalid. If used, the environmental conditions around the head of the subject should not be outside a range between 18°C and 30ºC, air velocity less than 0.2 m/s and the mean radiant temperature close to air temperature.
According to Ribeiro (34) tympanic temperature measurement is very easy to apply and provides results in seconds. Nevertheless, it is not clear if it reflects or not the brain temperature, seen that there are contradictory opinions (31).

4.7 Auditory canal temperature (t_{ac})

According to ISO 9886 (16), *the transducer is, in this case, located against the walls of the auditory canal immediately adjacent to the tympanum. These are vascularized by the external carotid artery and their temperature is affected by both, the arterial blood temperature at the heart and by the cutaneous blood flow around the ear and adjacent parts of the head. A temperature gradient is thus observed between the tympanum and the external orifice of the auditory canal. Insulating the ear adequately from the external climate may reduce this gradient*. This method is very similar to the tympanic temperature (16).
According to ISO_9886, preference must be given to the measurement of the temperature in the auditory canal compared with tympanic measurements. The procedure for placing the transducer is the same as for t_{ty} but, once in contact with the tympanum, the transducer is pulled about 10 mm. Alternatively, the transducer can be inserted through an ear mould, in such a way that, when the mould is fitted into the auditory canal, the transducer is placed at less than 10 mm from the tympanum.
The conditions of use are identical to those presented for the tympanic temperature, except that the maximum difference between the air temperature and t_{ac} is 10 °C. However, even with the strict observance of all the procedures, this method only provides an approximation to core temperature. When all procedures cannot be met, T_c should be measured at another place (t_{re} or t_{es}).

5. RESULTS AND DISCUSSION OF THE SUITABILITY OF MEASUREMENT PROCEDURES

From what has been described above in relation to measurement techniques, their advantages and limitations, three of them were chosen to discuss, analyse and select the most suitable for use in occupational environment. These techniques were: the measurement of esophageal, rectal and intra-abdominal temperature. On these, the values are not affected by temperature gradients that occur in the superficial tissues. Thus the impact of environmental conditions is minimized. In this selection were valued the reliability, usability in outpatient as well the accuracy level.
In this research were analysed three recent reviews, four papers with the comparison between the three methods and twenty–one papers based on studies that made measurements with at least, one of these three techniques, as shown in table 1.

Table 1 - Studies of Core Temperature Sort and Ethical Committee.

Authors	TS*	EC**	IC***
	Intra-abdominal		x
	Rectal	x	x
	Intra-abdominal	x	x
	Intra-abdominal	x	x
	Intra-abdominal	x	x
	Intra-abdominal	x	x
	Intra-abdominal	x	x
(Nybo et al. 2002)	Esophagus	x	x
	Esophagus	x	x
	Intra-abdominal	x	x
	Intra-abdominal	x	x
	Rectal	x	x
	Rectal	x	x
	Intra-abdominal	x	x
	Intra-abdominal	x	x
	Rectal	x	x
	Intra-abdominal	x	x
	Esophagus	x	x
	Esophagus	x	x
	Intra-abdominal	x	x
	Intra-abdominal	x	

* TS – Temperature Sort
**EC- Ethical Committee
***IC-Informed consent

5.1 Comparing rectal, esophageal and intra-abdominal temperature

Kolka et al. (23) compared esophageal and intra-abdominal temperature in women in moderate exercise. TIS were taken two hours before the test. It was found that the mean resting t_{es} was 37.11±0.21 ºC and the mean resting t_{ab} was 37.17±0.27ºC. The combination of exercise (225±30 W.m^{-2}), ambient temperature (T_a = 30°C) and clothing, caused an increase in t_{es} to 38.67±0.28°C and an increase of t_{ab} to 38.71±0.33°C for one hour of treadmill walking. This study data suggest that, under controlled experimental conditions, the TIS provides accurate measurements.
In the same year, O´Brien et al. (30) compared the results between the measurements of T_c obtained using a TIS system, with those obtained from esophageal and rectal temperature. This study showed that TIS system provides a valid measurement of T_c during both, rest and exercise, in cold as well as warm conditions. Nevertheless, the authors refer the need for a further study, to better quantify the variation in T_c measured by the TIS as it goes through the gastrointestinal tract. The TIS system is particularly appropriate for monitoring T_c in field environments where other techniques are not feasible O´Brien et al. (30).
Another study, conducted by Lee et al. (21), aimed at determining if the intra-abdominal temperature could be an acceptable alternative to esophageal and rectal temperature in order to evaluate the thermoregulation over supine exercise. It was concluded that T_c measurement using a TIS may be more appropriate in exercise testing, circadian monitoring, protective clothing monitoring and testing, and other field environments, such as microgravity, where instrumentation for measurement of t_{re} or t_{es} may not be feasible. The facility of TIS use, and the few health concerns, compared with thermistors in the esophagus and in rectum make it the ideal candidate for studies involving exercise or occurring in an uncontrolled environment. However, the delay in detecting increases in T_c, suggests that this technique may not be appropriate to prevent heat injury when the core temperature changes quickly. Measurement of t_{ab} may be an acceptable alternative to t_{es} and t_{re} with an understanding of its limitations (21).
On the other hand, Casa et al. (6) concluded that compared with rectal temperature (the criterion standard) intra-abdominal temperature measurements are the alternative with the necessary accuracy to measure core temperature. Likewise, according to the Byrne's review (5), the TIS represent an alternative to esophageal and rectal temperatures as an index of core temperature during exercise. Different relationships between these three indices have been observed in validation studies using small sample sizes, varied protocols and several statistical methods of comparison. Consequently the TIS applications shows excellent applicability for ambulatory field based applications. Rectal and intra-abdominal temperatures are considered comparable in terms of measure, amplitude, and acrophase.
Monitoring core temperature is one of the best methods to reduce the risk of heat injury in different activities once it avoids illnesses related with warm temperatures (25). Despite the different methods to measure T_c, the TIS were the one that gained an widespread acceptance in recent years. The advantages of continuous measurement of T_c, over different physical and cognitive activities has also been described by several authors (32).

Validity of thermal ingestible sensors

According to the Kelly's review (17), and considering the differences from thermometer placement in terms of convenience and reliability, the conclusion was that intra-abdominal temperature, obtained via a TIS, is considered to be relatively convenient and nearby rectal temperature. Although rectal temperature be an internal measure, very reliable and generally considered, the "gold standard" is the least suitable for ambulatory use (17).
Byrne & Lim (5) compared the correlation between core temperature measurements recorded simultaneously from intra-abdominal, esophageal and rectal temperature. They used criteria such as: calibration, time of ingestion, size of sample, protocol, environment and statistical analysis. From

the twelve analysed studies, two were only abstracts and ten validated studies. Nine of them used ingestible sensors in sports or occupational tasks involving physical activity. From those nine studies, the data collection was done continuously in four and intermittently in the other five. It was also concluded that the t_{ab} measured with the TIS as valid values for T_c and shows an excellent utility for ambulatory field based applications (5). For the purpose of discussing thermoregulation mechanisms during exercise, Lim et al. (22) concluded that intra-abdominal temperature measurement, using TIS, provide an acceptable level of accuracy to T_c measuring, without causing discomfort to the user. This way of measuring the T_c also allows continuous measurement in the field. This has allowed to gain a wide acceptance in the last decade (22).
Also Goodman et al. (13) proposed the validity and the reliability of the use of t_{ab} via TIS to measure T_c. However, the effect of elapsed time between TIS ingestion and t_{ab} measurement has not been thoroughly studied. The timing for ingestion of TIS is critical for accurate and reliable T_c monitoring. This study shows that t_{ab} measured 5 h after ingestion may still differ significantly (>0.25°C) from t_{ab} measured 29h after TIS ingestion. Gastrointestinal mobility is highly variable and strongly influenced by many factors difficult to control. It is also known that measurement quality improves when there is an interval of more than 5 hours between the TIS intake and measurement. It was suggested that coaches, athletic trainers, and researchers must balance their need for accuracy and safety with the limitations of ingestion of a TIS (13).

6. CONCLUSION

The conclusion drawn was based on a synthesis of analysed papers and according to the main objective, that was to select the best option to measure the T_c into occupational environments, the most suitable procedure is to measure the t_{ab} with a TIS.
The core temperature measured with a TIS provides a valid indication of T_c (6). Works performed by different researchers suggest that there is a good correlation between rectal and intra-abdominal temperature. After a careful analysis of all papers collected, it was also concluded that, the method with less technical limitations, and less invasive, is the TIS.
The results show that this system provides a valid measurement under conditions of decrease, increase and steady state of T_c. This also makes it possible to detect thermal complications at occupational context, without movement restrictions, such as in sports science, safety, hygiene and occupational health, military and even in the laboratory. It allows a continuous data acquisition, and a real time monitoring of T_c. According to the research the temperatures considered with less accuracy are tympanic, oral and axillar. For this reason, they reproduce T_c with difficulty. Comparatively to rectal temperature, considered the *gold standard* method of T_c measurements, thermal ingestible sensors (TIS) present one of the best possible approximations (22, 25).
Lee et al. (20) suggests that further, data must be collected in order to know (TIS) location in the body so as to be interpreted in relation to the thermal response at the site under the specific experimental conditions. This is also Goodman's et al. (13) opinion, which refers that the timing for ingestion of a TIS is critical for accurate and reliable T_c monitoring.
According Brake & Bates (4), intra-abdominal temperature is an effective method of profiling the core temperature of workers in difficult occupational settings (4).
Finally, according to Byrne et al (5) and Mckenzie & Osgood (25) can be concluded that the TIS are of the best methods to measure core temperature.
According to all information collected, the authors of this paper conclude that for the measurement of T_c in occupational context, the best option is the use of t_{ab}, measured with TIS. The method was, therefore, selected to be used in the next research works.

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Potential Errors in Mean Skin Temperature Calculation Due to Thermister Placement as Determined by Infrared Thermography

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SUMMARY

Introduction: Blood flow to the skin is the conduit for heat transfers between internal core temperatures of the body and external conditions of the environment. The use of infrared imagining provides a thermal map of the skin that can quantify skin thermal measurements that can be correlated to qualitative measures of skin blood flow (11). The regulation and control of heat transfer (heat gain, heat loss) is imperative for maintenance of body temperatures within the thermal survival zone. The advent of infrared (IR) imaging has allowed researchers to accurately (0.05˚C sensitivity) determine skin temperature via generation of a skin thermal map made up of approximately 11,000 data points. This allows researchers to determine sites of the body with the greatest variation in temperature and to examine the accuracy and validity of estimating whole-body average skin temperature using thermocouples attached to the skin at various locations. However, to date, researchers using IR imaging have only used mean skin temperature for a region, equivalent to optimal skin probe placement, to validate these formulas (2). In reality, due to the poikilothermic nature of the skin, when placing thermocouples at a given location on the human body (e.g. "chest") one could actually be measuring the hottest or coldest spot at a certain site. This "hot" or "cold" spot would then be used as an average temperature for the region in a skin temperature calculation, introducing error into the estimation. This study used IR imaging to determine which of 13 sites used in mean skin temperature calculations has the greatest variation in a thermoneutral environment, and to quantify the error in calculating average skin temperature due exclusively to the range of possible skin temperature measurements at recommended thermocouple locations.

Methods: Thirty college-aged subjects (15 male, 15 female) were recruited for this study. Prior to participation all subjects completed a medical screening questionnaire assessing current medication use, pre-existing orthope-dic or any metabolic condition that would be contraindications for participation. Subjects were instructed to ab-stain from food and caffeine consumption as well as smoking and exercise three hours prior to participation and to arrive in exercise attire. Men wore gym shorts that did not cover the thigh region. Women wore gym shorts that did not cover the thigh region and a sports bra with the straps tucked into the top. Subjects stood for 15 minutes in a controlled, neutral environment with temperature held constant at 30˚C and 40% relative humidity. Anterior and posterior infrared images were taken at 13 standard locations as described in figure 1. Polygons were drawn around the areas of interest where probe placement was recommended by prediction formulas. A range (high, average, low) of skin temperatures was determined for each site. The range of temperatures at each site represents the scope of all possible measurements that could be acquired by placing a skin probe at that site. The ranges at each location were compared to determine which sites had the most variability. Then, the minimum, maximum, and mean temperatures at each site were used in calculations of average skin temperature using the Burton (1), KSU (10), Ramanathan (12), and Gagge/Nishi (6) formulas (table 2) to determine the range of error in the calculations due exclusively to probe placement. All calculations were compared to true mean skin temperature, as determined by using the mean value from all 13 sites measured via IR imaging in an unweighted formula that has been shown to be over 95% accurate when used in this manner (2).

Results: The average temperature range at each site was 3.19 ± 0.93˚C, with the smallest ranges found at the forehead (1.81 ± 0.46˚C) and occipital (1.98 ± 0.47˚C) and the greatest ranges occurring in the posterior lower leg (5.17 ± 1.21˚C) and anterior lower leg (4.77 ± 0.92˚C). The true mean skin temperature from the 13-site unweighted formula was found to be 31.70 ± 1.06˚C. When the hottest and coldest temperatures were used in the formulas, the average range of possible temperatures calculated for the Burton, KSU, Ramanathan, and Gagge/Nishi formulas were 3.71 ± 0.55˚C, 3.85 ± 0.64˚C, 3.33 ± 0.48˚C, and 3.44 ± 0.51˚C respectively. Even when using the optimal, 13-site formula, the range from using all high or all low temperatures was 3.19 ± 0.35˚C.

Conclusions: Under thermoneutral conditions (30˚C, 40% relative humidity) the greatest local temperature variation occurs in the lower leg, and the least variation is found in the head and neck. These results also indicate that skin temperature calculations have a wide range of error due to local temperature variation, especially when considering that a temperature difference of 0.5˚C is physiologically significant (13). These results call into question the legitimacy of using skin temperature calculations from thermocouples. Since there is no way to tell whether the value measured via thermocouple is close to the mean temperature of the site outside of using IR imaging, formulas using data from thermocouples may be questionable for accurate or valid mean skin temperature estimation.

1. INTRODUCTION

Regulatory alterations of skin blood flow can modulate heat transfers between the body core, skin, and environment. Decreasing blood flow to the periphery (vasoconstriction) makes the skin as an insulated barrier, while increased blood flow (vasodilation) allows greater heat dissipation/loss by conduction, convection, radiation, and evaporation from the skin. Sweat, a filtrate of blood, provides the medium by which evaporative cooling can promote significant heat loss. This regulation is essential in maintaining thermoregulatory control over a wide range of environmental conditions while responding to the increased production of metabolic heat that linearly increases with work intensities. During exposures to hot environmental conditions and intense exercise, the increase in skin blood flow promotes a great heat dissipating capacity. Under these conditions, the skin operates like a very efficient radiator (0.98 emissivity as compared to a blackbody source of 1.0) in an attempt to avoid excessive heat storage. Thus, the regulation and alterations of blood perfusion to the skin are critical to our survival with a tightly regulated zone of internal core temperatures. Given this importance, accurate assessments of skin temperatures (T_{sk}) are important to our understanding of thermoregulation.

The challenge in acquiring "accurate" mean skin temperature (T_{ms}) measures have been related to the identification of site locations, instrumentation for obtaining the skin surface temperature, environmental conditions that influence skin blood flow, and the "assigned" contribution (formula weighting) of regional areas to the overall thermal status of the individual In describing mean skin temperatures, 20 sites have been identified and numerous formulas, varying in the number of reference sites for each formula, have emerged. Variance in the measurement assessment can be attributed to regional sites that have been inadequately defined and not consistent between formulas. For example, the upper arm measurement has been defined as the deltoid region or proximal area of the humorous while others refer to the area as the biceps/triceps (lower humorous) region. Some formulas include a thermal measure of the feet which will be influence by the wearing of socks and shoes.

In physiological investigations, the use of thermocouple probes is the most commonly employed method for determining T_{sk}, while only a few studies use infrared imaging. Thermal probes placed on the skin surface are able to detect temperatures at a single site, but are influenced by the micro-environment that is created between the skin and the probe, the pressure exerted on the skin, and the location-placement of the probe. In contrast, non-contact infrared thermography provides a skin surface temperature map with a 0.05°C sensitivity from which a T_{ms} can be computed based on approximately 11,000 thermal pixels (2). In their research, infrared thermography was used to evaluate male T_{ms} during ambient temperatures between 40°C and 4°C in stepwise decreases of 4°C every ten minutes. Their study did not investigate females nor investigate the influence of changes in temperature independently. It is unclear whether this design approach provided adequate time for the skin to equilibrate to changes in ambient temperature, such that the dynamic changes to skin temperature can be related to any particular ambient condition. For thermographic clinical evaluation, a minimum of 15 minutes equilibration is often required to allow for the skin temperature to reach a thermal steady state in a testing environment.

Environmental conditions can have a great impact on the distribution of skin temperatures across and within regional surface areas. In warmer environmental conditions, the temperatures across the skin surface tend to be more homogenous as compared to colder conditions. Based on these observations, Olsen (10) proposed that fewer sites (2-4) are necessary when assessing the mean skin temperature when exposed to warmer climactic conditions, compared to neutral conditions (4-8 sites recommended), and colder climatic conditions (8-12 sites recommended). The ability of regional tissue surfaces to respond to climatic temperature conditions varies due to differential heat transfers from the skin.

Finally, the regulation or regional skin blood flow and the ability to transfer heat is influenced by the distribution of sweat glands for evaporative cooling, reflex neural regulation of skin surface blood flow (vasoconstriction & vasodilation), and the existence of arteriovenous anastomaoses (AVA), which are primarily found in the acral tissues (digits, lips, ears, cheeks, and palmer surfaces of the hand/feet). The AVAs are thick walled, low resistance vessels that can provide direct blood flow from the arterioles to the venules. By changing the path of the blood flow that moves through the skin blood plexus, the skin can promote restricted or maximal heat loss from the surface. To compensate for these anatomical and physiological factors (e.g. existence of AVAs or not), T_{ms} formulas have been created with contribution factors (weighting) based on thermal sensitivity (9), surface area, and local heat loss coefficient for convection and radiation (8).

As a research tool, questions remain for obtaining accurate mean skin assessment: How many points of reference are needed to accurately determine T_{ms}? Should all sites be given equal representation? To obtain an accurate assessment of T_{ms}, previous research has focused on four basic formula approaches:

1) unweighted average of sites recorded;
2) weighted formulas based on regional surface averages as defined within population norms;
3) variable weighting based on individually determine surface area, often as determined by the DuBois (4) linear formula;
4) weighted formulas that incorporate factors that describe both surface area and the thermoregulatory response to thermal stimuli (3,9).

This fourth approach recognizes that while the surface areas of the various regions help to explain the exposed surface available for heat exchange, differences in regional blood flow temperature and sweat gland distribution that contribute to differences in the regional area's ability to dissipate heat through evaporation may not be adequately expressed.

This study used IR imaging to determine which of 13 sites used in mean skin temperature calculations has the greatest variation in a thermoneutral environment, and to quantify the error in calculating average skin temperature due exclusively to the range of possible skin temperature measurements at recommended thermocouple locations. Sex dependent variations in T_{sk} variation were also examined to determine their effect, if any, on the accuracy of the calculation of T_{ms}.

2. METHODS

Subjects

Fifteen male and fifteen female college aged students were recruited for this investigative effort. Prior to participation, subjects completed a pre-screening medical questionnaire and provided written consent for participation using an institutionally approved informed consent document. Subjects who indicated problems related to heat exposure, use of contraindicated medications under thermal conditions as indicated by the Physician's Desk reference or medical conditions were excluded from the subject pool. Research has demonstrated an increase in core temperature in females of 0.4°C in the luteal phase compared to the follicular phase Women in this investigation were asked to refrain from participation during the time of menstruation. If their cycle began during their participation, they were asked to notify the investigators to reschedule their test trials. Men wore gym shorts that did not cover the thigh region. Women wore gym shorts that did not cover the thigh region and a sports bra with the straps tucked into the top.

Procedures

Subjects entered the Thermal Lab climactic chamber wearing clothing as described above. Climactic chamber was maintained at 30°C and 40% relative humidity. Anterior and posterior IR images were taken using an infrared thermographic system (Bales Scientific Thermal Imaging Processor; Walnut Creek, Ca) at 13 standard locations as illustrated in Fig. 1.

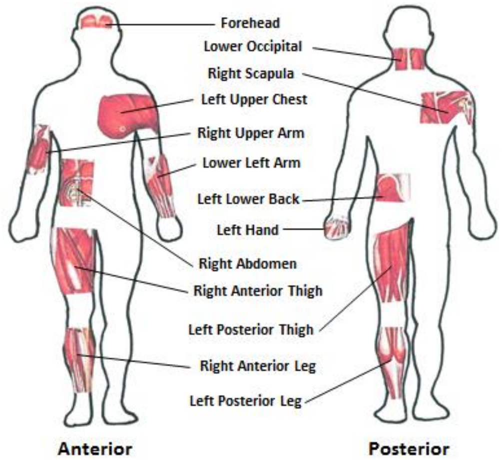

Fig. 1 - Sites of skin temperature measurement for calculation of mean skin temperature.

Subjects stood in the climactic chamber conditions for 15 minutes prior to image capture to allow for equilibration to environmental conditions.

T_{sk} estimated by IR

Polygons were drawn around the areas of interest where probe placement was recommended by prediction formulas (Figure 1). The mean temperature from thermography was taken as an arithmetic mean of points from this region. High and low temperatures for each region were also recorded.

Infrared-determined T_{ms}

The true value of mean skin temperature was calculated using values measured, in a similar manner to Choi et al. (2), via infrared thermography. True mean T_{sk} was calculated for all 13 sites examined by averaging each pixel for that site included in the IR image. The sum of the IR-determined means of T_{sk} for each site was averaged to give a highly accurate calculation for true T_{ms} (13-site optimal formula).

Calculated T_{ms}

Local T_{sk} (Table 1) was determined from the corresponding thermal image.

Table 1. Abbreviations used in formulas for calculations of T_{ms}

A = Forehead	H=Right Abdomen
B = Lower Occipital	I = Left Hand
C = Left Upper Chest	J = Left Posterior Thigh
D = Right Scapula	K = Right Anterior Thigh
E = Right Upper Arm	L = Left Calf
F = Left Lower Upper Arm	M = Right Shin
G= Left Lower Back	N = Right foot

Formulas compared in the present study are listed in table 2 with sites of measurement and weighting factors. Formulas were utilized to calculate T_{ms} using the mean T_{sk} for each site, High T_{sk} using the highest value of each site, and Low T_{sk} using the lowest value from each site.

Calculated T_{ms} Agreement Frequency %

Agreement frequency of calculated T_{ms} was determined for each equation by comparing the value to the calculated 13-site optimal T_{ms}. The agreement frequency for each formula was defined as the percentage of calculated T_{ms} values within ± 0.20°C of T_{ms} calculated by the 13-site optimal formula. Agreement frequency was calculated according to the following equation (Mitch & Wyndham, 1969):

Agreement frequency (%) = (# agreeing within ± 0.2˚C of IR determined Tms / total number) x 100 [1]

Statistics

A two way three (temperature) by five (equation) was run on absolute T_{ms} calculations. Level of significance was set at $p < 0.05$.

Results

Local T_{sk}

Analysis of IR images revealed large variations in T_{sk} at each site used in T_{ms} calculations. Average T_{sk} range at each was 3.19°C ± 0.93 with the smallest range at the forehead (1.81 °C ± 0.46) and largest found at the posterior lower leg (5.17°C ± 1.21). Site specific variations in T_{sk} are presented in Table 3.

Calculated T_{ms}

T_{ms} was calculated according to formulas described in Table 2 using the High, Mean, and Low T_{sk} measured and calculated via IR thermography for each local site. Statistical significance ($p < .001$) was found within each formula when all High, all Mean, and all Low temperatures were used. No significance was found between calculated T_{ms} for any equation when the use of all High, all Mean, and all Low values were compared between each. When all Mean values were used, T_{ms} was calculated as 31.99°C ± 0.95 for the Burton, 31.97°C ± 0.91 for KSU, 31.81°C ± 0.96 for the Ramanathan, 31.79°C ± 0.92 for the Gagge/Nishi, and 31.79°C ± 0.99 for the 13-site optimal formula (true T_{ms}). Range was calculated by subtracting the all-Low formula.

Table 2. Equations used for T_{ms} calculation

Formula	Equation
Burton	(0.5*C) + (0.148*F) + (0.36*M)
KSU	(0.5*C) + (0.14* F) + (0.36*L)
Ramanathan	0.3(C+E) + 0.2(K+J)
Gagge/Nishi	(0.07*A) + 0.175(D+C) + 0.07(E+F) + (0.05*I) + (0.19*K) + (0.32*L)
13-S Unweighted	(A+B+C+D+E+F+G+H+I+J+K+L+M) *0.0769

Equations used to calculate T_{ms}. Equation.

Calculated T_{ms} from the all-High formula calculated T_{ms}. The 13-site equation had the lowest calculated range (3.17°C) of all the equations followed by the Ramanthan (3.27°C), Gagge/Nishi (3.39°C), Burton (3.52°C), and KSU (3.68°C). Males tended to have a higher calculated value for all calculations (High, Mean, Low) than female subjects while female calculated ranges tended to be greater. Calculated T_{ms} and ranges are presented in Table 4.

Aggreement Frequency %

Agreement frequency (% of T_{ms} within ± 0.2°C of calculated T_{ms} from 13-site optimal formula) was calculated as described above. Combined, (male & female) no equation yielded larger than a 93.3% aggreement frequency (range: 33.3% - 93.3%). There appeared to be a strong relationship between the number of sites and the agreement frequency (r = 0.89). Interestingly, males tended to have larger agreement frequency percentages compared to females: 53.3% vs 20% for the Burton, 33.3% vs. 33.3% for the KSU, 80.0% vs. 66.7% for the Ramanathan, and 100% vs. 86.7% for the Gagge/Nishi. Aggreement frequencies are presented in Table 5. Use of High and Low temperatures from regional sites to calculate T_{ms} yielded 0% agreement frequencies to 13-site T_{ms} calculations.

Conclusion

The purpose of this investigation was to utilize IR imaging technology to determine the range of T_{sk} variations at sites often used to calculate T_{ms} and to quantify the error of possible T_{ms} calculations due to local T_{sk} variations. Secondly, it was the purpose of this investigation to include female subjects in the population pool for determination of possible male vs. female complications in calculating T_{ms}.
The results of this study indicate that a large variation is present within regional T_{sk} in resting individuals in a thermoneutral (30°C and 40% RH) environment.

Table 3. Greatest and least individual variations in temperature (°C) with overall mean difference for each site.

Site	Greatest Difference	Least Difference	Mean Range
Forehead	2.81	0.89	1.81(0.46)
Occipital	3.21	1.18	1.98(0.47)
Scapula	5.61	1.80	3.05(1.02)
Upper Chest	5.87	2.01	3.08(0.93)
Upper Arm	3.68	1.37	2.58(0.61)
Lower Arm	6.49	1.78	3.22(1.09)
Hand	6.24	1.64	3.07(1.07)
Abdomen	4.76	1.88	2.88(0.76)
Lower Back	5.05	1.67	3.05(0.69)
Anterior thigh	4.75	1.96	3.39 (0.67)
Posterior Thigh	5.04	1.89	3.42(0.74)
Anterior Leg	8.19	3.63	4.77(0.92)
Posterior Leg	7.99	3.53	5.17(1.21)

Temperatures presented as °C. Greatest and least individual differences represent absolute highest and lowest value above and below T_{ms} for that site. Range (± SD) calculated as average high temperature minus average low temperature for each site.

These variations may complicate calculations of T_{ms} regardless of the formula utilized.
The range of temperatures found within a single region was lowest in the forehead (1.81°C) measurements and highest and in the posterior leg (calf; 5.17°C) regions. These variations are most likely do to anatomical (i.e. fat distribution) and physiological (i.e. sweat gland density, skin vasculature) differences between regions of the body (5, 7). Considerations of these anatomical and physiological values should be made in future research in the use of infrared imaging and $T_{sk.}$ It is interesting to note that the range of T_{sk} variation within single site did not show a gender bias (data not presented).

Variations within regional T_{sk} also call into question the use skin thermistors or skin probes. Two considerations for the use of these in determination of T_{sk} (and thus T_{ms}) are pertinent:
1) the single T_{sk} value obtained and;
2) the micro-environment created by the application of the probe. Results of this study indicate that a single measurement, without knowledge of whether it represents the high or low extreme of the regional T_{sk} can influence T_{ms} calculations for equations including up to 13 sites. Furthermore, it can significantly reduce agreement frequencies of equations that rely on skin probes to estimate regional skin temperature, regardless of the number of sites. The application of such probes may also artificially alter the measurement due to the micro-environment created between the probe and the skin.

Table 4. T_{ms} values estimated via infrared thermography in 30°C & 40% humidity using High, Mean, and Low Values.

	Temperature °C			
Formula	High*	Mean*	Low*	Range
Burton	33.51 (0.81)	31.99 (0.95)	29.99 (1.13)	3.52
Male	33.57 (0.74)	31.98 (0.95)	30.00 (1.03)	3.57
Female	33.37 (0.97)	31.84 (1.11)	29.70 (1.29)	3.67
KSU	33.43 (0.82)	31.97 (0.91)	29.75 (1.09)	3.68
Male	33.48 (0.84)	31.92 (0.99)	29.79 (1.00)	3.72
Female	33.30 (0.94)	31.88 (1.04)	29.46 (1.24)	3.84
Ramanathan	33.25 (0.87)	31.81 (0.96)	29.98 (1.14)	3.27
Male	33.27 (0.89)	31.78 (1.03)	29.97 (1.14)	3.30
Female	33.12 (1.01)	31.68 (1.11)	29.75 (1.28)	3.37
Gagge/Nishi	33.22 (0.83)	31.79 (0.92)	29.83 (1.12)	3.39
Male	33.22 (0.85)	31.78 (0.99)	29.91 (1.11)	3.31
Female	33.09 (0.97)	31.63 (1.06)	29.52 (1.24)	3.57
13-site	33.15 (0.88)	31.79 (0.99)	29.98 (1.12)	3.17
Male	33.17 (0.86)	31.80 (1.00)	30.05 (1.08)	3.12
Female	33.01 (1.03)	31.62 (1.03)	29.75 (1.26)	3.26

Values are presented as means (±SD). * Statistical difference ($p < 0.001$) between values (Male & Female combined). No statistical difference was detected for any values between formulas. No statistics for Male vs. Female comparisons for any values are presented.

Also, consideration for the pressure used to apply and anchor the probe to the skin need to be taken into consideration due to variations found in T_{sk} measurements in different proximities to skin surface (5, 7).
These variations in regional skin temperatures also indicate a strong need for more complete guidelines to probe/thermistor placement within a region of interest (2).

Table 5. Agreement Frequency % for calculated T_{ms} equations as compared to 13-site calculations.

Formula	Agreement Frequency %		
	Combined	Male	Female
Burton	36.7	53.3	20.0
KSU	33.3	33.3	33.3
Ramanathan	73.3	80.0	66.7
Gagge/Nishi	93.3	100	86.7

Agreement Frequencies with 13-Site calculated T_{ms}.

In this investigation, no significant difference was detected between absolute calculated T_{ms} regardless of the amount of sites the equation utilized. However, when one takes into consideration the agreement frequency the opposite is true. The equations taking fewer sites into consideration (e.g Burton and KSU) had vastly lower agreement frequencies (with the 13-site optimal set as the standard) than those with more sites (e.g. Gagge/Nishi). A strong, positive relationship ($r = 0.89$) was found between the amount of sites taken into consideration in an equation and the agreement frequencies. This is in contrast to Choi et al. (2) who found no relationship between agreement frequency and number of sites taken into consideration. However, that study used progressively decreasing temperatures (4°C every 10 min) to assess T_{sk} temperature. This protocol may not have allowed for proper equilibration to the environment and subsequent readings may have been influenced by previous conditions (5).

The use of females in this investigation provided unique insight into the differences between males and females with considerations to T_{ms}. First, no difference in absolute T_{ms} was detected regardless of the equation used. However, female subjects had consistently lower High, Mean, and Low temperatures in combination of having a higher range of calculated T_{ms}. This was found despite males and females showing no recognizable differences for within region T_{sk} variations. Accordingly, female subjects also had vastly smaller agreement frequency percentages than males for the Burton (20% vs. 53.3%), Ramanathan (67.8% vs. 80%), and Gagge/Nishi (86.7% vs. 100%). These results suggest:

1) some equations (i.e. KSU) are highly unreliable for T_{ms} calculations in both males and females (agreement frequency % = 33.3% for both);

2) the Burton equation is especially unreliable for females (agreement frequency % = 20%);

3) that anatomical and physiological differences between male and females may need to be taken into consideration with the development of gender dependent weighting factors for equations;

4) and that more research should be conducted into the differences between males and females with consideration T_{sk}.

In conclusion, our research shows that the use of IR imaging technology detected large variations within regional T_{sk}, and that these variations may complicate calculations of T_{ms}. Furthermore, the efficacy, as determined by agreement frequency %, of certain equations may not be suitable for use in males or females. It is suggested that further research take into consideration the inclusion of females and the systematic analysis of differences between male and female T_{ms} calculations. Furthermore, we believe it pertinent to further determine the efficacy of the use of skin thermistors and skin probes for the reliable and repeatable determination T_{sk}, and thus T_{ms}.

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Using a Climatic Chamber to Measure the Human Psychophysiological Response Under Different Combinations of Temperature and Humidity

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SUMMARY

Climatic chambers have been built and use for many proposes, including environmental psychophysiology research. The aim of this study is to determine the appropriateness of using the climatic chamber FITOCLIMA 25000 to measure human psychophysiological response under different settings of temperature and humidity. To evaluate its performance were done several tests. Results and chamber specifications were analysed according standards and scientific criteria. In spite of some disadvantages detected in short time settings, it was concluded that FITOCLIMA 25000 is able to reach the highest standards of regulation.

1. INTRODUCTION

1.1 Climatic Chambers in Occupational Health and Safety Research

There are a lot of activities exposed to different severe thermal environments in outdoor work, such as farming, fishing, open pit mining, constructing, police patrolling, street cleaning, and sweeping, wild land fire-fighting and so on. Indoor activities also have hard exposure conditions such in cooking, laundering, mining, foundry work etc. The hazards usually occur when the workers are exposed to extreme heat/cold for too long. In a situation of heat, exposure, hyperthermia can be worsened by the exercise/work that is being executed. Despite decades of research and technological development combined with sophisticated methods of risk assessment and preventive measures implementation, the accidents still happens.
Climatic chambers have been built and used with many purposes, such as: to assess thermal comfort for energy savers buildings (2), to test the treatments of respiratory diseases since 1955 (9, 10, 12) and for occupational health and safety, at least since 1968 (1, 5, 13, 14). Climatic chambers results have also been used to validate mathematical models of human thermoregulation applied in several knowledge areas (4).

1.2 Environmental Psychophysiology Experiments

Environmental physiology experiments related to psychophysiological response to thermal environment are usually done in controlled laboratory environments.
As it happens in other experimental devices it is necessary to control the parameters under study (in this case temperature and humidity) and ensure that the influence of other parameters that may interfere on the results is reduced or eliminated.
These thermal environmental studies comprise three levels of concern:

- Environmental Factors;
- Human Psychophysiological Response Factors;
- External Factors.

Environmental Factors can be divided into physical (including thermal environment parameters) chemical and biological parameters. Thermal environment can be characterized by temperature, humidity, radiation and air velocity. From these variables only temperature and humidity are regulated. The others have to keep their values over the time to assure environment stability. The noise is another concern. In spite of there is no relationship between noise level and human thermoregulation response noise clearly affects performance, so it must be reduced and kept as low as possible inside the chamber. During experiments one or more individuals are inside the chamber. Because of human occupancy, it is important to monitor the oxygen and carbon dioxide concentration. More people consume more oxygen and produce more carbon dioxide. The climatic chamber in test is the *Fitoclima 25000* that can be considered a closed room where the air exchange is performed with the inherent restrictions to the regulatory capacity and the accuracy of the camera itself. The problem here is that, in longer experimental exposures, high levels of carbon dioxide as well as low levels of oxygen can decrease physical and mental performance. High levels of occupancy and low rates of air flow may also increase environmental bio-burden. But air quality is not only influenced by human occupancy. The combination of temperature and humidity influences the individual consumption of oxygen, production of carbon dioxide and the increase and dissemination of microbiological organisms. High levels of temperature and humidity may also

influence the releasing of volatile organic compounds (VOC's) from chamber's building materials (plastics, glues and paints).
Human psychophysiological responses are the most important factors. The state of knowledge gives us important information about the kind of factors that may influence psychophysiology performance; the human physiology provides clues about exposure limits where there is no influence; the human psychology gives advices about human behaviour and sensations of comfort/discomfort. For example, human thermoregulation responses, physical and cognitive performances are all influenced by the circadian rhythm. The performance after 1h of exposure to a specific environment is not the same as after 3h or 4h. The very own diversity of the human being makes difficult to define exactly what is or is not relevant to a specific analysis. When designing an environmental psychophysiological experiment, the collected data will always depend on several factors that must be taken into account but, by obvious reasons, cannot be completely eliminated.
This dimension helps in chamber's validations by quantifying the levels of environmental factors mentioned above, defining:

- The accuracy degree of the temperature and humidity regulation to assure a steady state environment;
- The admissible levels of radiant heat and air flow to assure steady state;
- Lighting quality within the chamber;
- Admissible levels of occupancy due to air quality changes;
- Cognitive ergonomic design to inhibit anxiety, fear and increase levels of confidence inside the equipment.

External factors include variables such as lifestyle, diet, individual characteristics, global health condition, medications, sleep deprivation and many others. All these variables influence human tolerance to heat and cold, and also, the mental and physical performance. Nevertheless, they are not directly related to the features of the equipment or facilities, so they are out of the aim of this study.

1.3 Other Climatic Chamber Features

In some studies that analyse the thermal sensation is stated that the control of the accuracy is: ±0.12ºC around a set point temperature (Schellen et al. 2010); ±0.5ºC and ±5% of relative humidity and special discrepancy less than 0.2ºC (Chen et al. 2011); ±0.2ºC of temperature and ±1% to ±5% of relative humidity (0.25g/Kg), also ensure that *mean radiant temperature* and *air temperature* are the same over *steady* and thermal *transient* states (8).
For instance, based on the studies of Kjerulf-Jensen et al. (1975), Kolarik (8) describes a climatic chamber with 5m wide, 6m long, and 2.5m high. It was developed to accurately control the thermal environment. Temperature inside the climate chamber could be regulated between 5ºC and 50ºC, with the accuracy mentioned above. The control system of this climatic chamber was modified to provide steady changes of the temperature set point, necessary to establish the planned temperature ramps. The climate chamber walls consisted of vinyl sheets, which were separated from the solid outer chamber walls by an air space of approximately 16 mm. A fraction of the air supplied to the chamber flowed behind the vinyl sheets, ensuring that air and mean radiant temperatures were equal during both steady and thermal transients. Air and operative temperatures, air velocity, and air humidity are measured continuously at the center of the chamber at 0.6m above the floor (8).

2. MATERIALS AND METHODS

2.1 Methodology

The ability of climatic chamber to control temperature and humidity lead us to the concept of stability. The human thermal response is linked to the environment exposure, and is continually adapting to it. When the objective of an experiment is to see exactly how the cognitive and physical factors change according to a specific environment, it is fundamental to assure the stability of the system. Otherwise, instead of relating human response to a specific environment, it would be related to transient conditions (such as ramps, drifts or cycle variations), which are the opposite situations.
To define the system stability is not enough to ensure steady state conditions of temperature and humidity. It is also very important to assure that all environmental parameters that influence human cognitive, physical and physiological responses are under control.
The first thing to do is to define the purpose. Climatic chamber is a valid equipment if it is suitable to the experimental goals. Firstly, it is important to define what to measure, and in what circumstances.
Secondly it is fundamental to define evaluation criteria. Here the current state of knowledge gives information about what is or not admissible in relation to what may or may not influence the collected results.
Finally it is important to prove the suitability of the equipment. The evidence is based on data collected from the equipment and laboratory facilities, and these results must be compared with the established criteria.

2.2 Environmental Factors Evaluation Procedure

2.2.1 Temperature and Humidity

To test the ability of the *Fitoclima 25000* chamber in order to regulate temperature and humidity several tests were performed. Accuracy was tested in a

representative central combination of 25ºC and 60% RH for a 24h period. The trials were repeated 3 times to verify if the equipment' behavior was reproducible and stable for short, medium and long periods. All the tests were done through a period of 24h of data collection and 24h of resting time.
It was also tested how long the chamber takes to achieve steady state. Steady state is reached when the measured values are ranging up to ±0.5ºC and ±2.5% HR around the set points, according to the manufacturer's technical specifications. To collect these data, all trials started from the same environmental conditions (22ºC and 40% HR). The initial combination was chosen because it represents the most common temperature and humidity found indoors, inside the laboratorial room. Depending on humidity level, tests could be 6h to 8h long. At this point were evaluated: the time necessary to achieving a steady state, the upper and lower bounds of maximum and minimum values, and the higher amplitude at set point level. According to the manufacturer, the accuracy may depend on adjustment values, so these tests were done using different combinations of temperature and humidity in order to map the controlling behavior of *Fitoclima 25000*.

2.2.2 Concentration of CO_2 and O_2

The occupancy level, in the chamber, may change from 1 person to 3 people. In order to study the production of CO_2 and O_2 consumption, its concentrations were measured along a 2h period at 9 combinations of temperature and humidity and 3 levels of occupancy showed in table 1.
Tests were performed after both, temperature and humidity, set points were achieved and kept above ±0.5ºC and ±2.5% HR respectively. In all trials people were simulating sedentary pursuits. They were seated for the two hours, spending the least possible energy.
During the trials the door was only opened twice, at the beginning and at the end of the trial (two hours later) to allow the entry and exit of the people.

Table 1. Temperature, humidity and occupancy level

*Occupancy Level**	*Temperature (ºC)*	*Relative Humidity (%)*
1 2 3	20/25/30	30/60/90

* Number of people inside the chamber.

3. RESULTS

3.1 Fitoclima 25000 description

The entire camera design was thought to be used by human subjects so the design of the chamber transmits comfort and confidence when being in use. It was built by "ARALAB" which strictly follow all the international rules of safety engineering and cognitive ergonomics.
Fitoclima 25000 has one door, three windows, the walls are all white, have very good artificial lighting levels, the floor is grey, the indoor lock is green, (in order to be easily seen), and the door can always be open from inside. That is an important feature, because it allows the research subjects to end the trial whenever they want and, still more important, it assures that no one can be locked inside. Windows are very important because they allow subjects to see what is exactly happening outside the chamber all through the period of the trials (in the entire laboratory facilities), reducing anxiety and increasing confidence (fig. 1).

Fig. 1 - Climatic chamber seen from the inside.

The climatic chamber also has safety mechanisms that shut it down automatically when overheated. Given the following conditions or inadmissible anomalies, safety devices turn off the apparatus in order to avoid its destruction:
• High temperature inside the chamber;
• Low temperature within the chamber;
• Excess temperature in the condenser;
• Lack of water in an ultrasonic generator;
• High pressure in the cooling system;
• Low pressure in the cooling system;
• High temperature compressor discharge;
• Low temperature at compressor suction;
• Internal failure of the compressor;
• Excessive consumption of the compressor;
• Excessive consumption of the fan;
• Failure of the internal fan;
• Abnormal conditions in the supply voltage.

Installed sensors continuously monitor the levels of CO_2 and O_2 inside of the chamber and an alarm sounds when limit values are exceeded.
As recommended (7), the laboratory facilities have changing room, with shower, as well as areas for subjects to change clothes, to be prepared in privacy and, if necessary, to rest and recover after going through an experiment. The entrance of the climatic chamber has a large free area to assist people who may feel sick during the trial. The space is large enough to lie down a person and provide medical aid considering all the emergency equipment that may be necessary. The area also has natural direct ventilation trough two windows to facilitate the cooling down of the air.

3.2 Technical Specifications

The climatic chamber *Fitoclima 25000* was built to regulate temperature and humidity within a specific range (-20ºC to 50ºC and 30% to 98% RH), being able to control relative humidity (<±2.5%) between 10ºC and 40ºC (see fig. 2).
Carbon dioxide and oxygen cannot be adjusted but are controlled all along. Carbon dioxide monitor presents a measuring range from 0 to 5000 ppm, an accuracy of less than ±50ppm plus 3% of measuring value, at 25ºC, with an increase of 2ppm/ºC around it. The sensor supports temperatures and conditions ranging from -20 to 60°C and from 0 to 100% RH. Oxygen sensor is also a sturdy apparatus. It works in environmental conditions ranging from -25ºC to 70ºC and from 0 to 95% RH. The accuracy assured is 3% in the range of measurement.

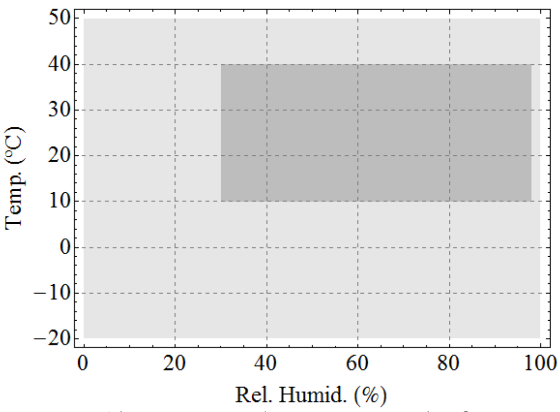

Fig. 2 - Climatic regulation interval of temperature and humidity.

3.3 Temperature and Humidity Adjustment

According climatic chamber specifications, *Fitoclima 25000* is only able to ensure relative humidity regulation between 10ºC to 40ºC and that is why it were tested combinations within this temperature limits.
It was proved the reproducibility of the tests. Although the environmental conditions within the laboratory facilities being different for all experiments, the behaviour of the chamber was exactly the same in the three experiments performed for each one of regulation combinations (fig. 3).

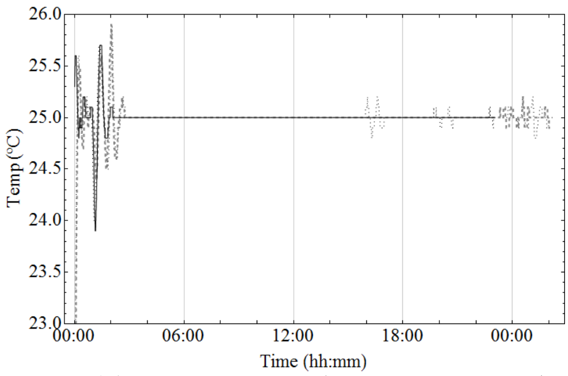

Fig. 3 - Temperature regulation at 25ºC with 30%RH. (Legend: Day 1 – Gray Dashed Line; Day 2 – Black Dotted Line; Day 3 – Black Thin Line).
This test also shows a slight instability after a work period that exceeds 16h of consecutive work. But the amplitude of this change does not exceed 0.2ºC. Temperature set point is reached faster than humidity set point. With this first trial we got 1:2 period. The lowest amplitude value (zero variation), was achieved after 2h for the temperature test. For the humidity, the time increased to 6h. A completely stable environment inside the chamber was always assured in less than 10h. After the 10h period the temperature and humidity amplitude ranged within 0.1 to 0.2ºC and 1 to 2% respectively.
The stabilization times were measured considering the criteria defined in section 2.2.1. It was chosen points that represent the boundaries of the climatic regulation range.
According to *Fitoclima 25000* specifications, its admitted stability is reached when amplitude ranging 2ºC and 5% RH around set point values. Data confirm that temperature get always set first than humidity, that is because relative humidity depends on temperature values and a precise regulation can only be done after temperature is set. Results also showed that is easier to regulate humidity at moderate temperatures. At 40ºC, the *Fitoclima 25000* does not reach the target of 98% relative humidity in the first 8h of trial. From the intermediate values we can see that in these boundary limits chamber's behaviour is more unpredictable, more instable, maybe because as in nature, these environments are difficult or impossible to get. Very high temperatures are not compatible with extreme levels of humidity, and the same happens with low temperatures.
The values in table 2 are examples of boundary conditions. Under these conditions have been found the largest amplitudes and stabilization times

For all the other combinations the results are, at least, equal to ones listed on Table 2. For long trials, such as 24hrs, the *Fitoclima 25000* proved to be able to ensure high stability throughout the test.

Table 2. Maximum/Minimum and Amplitude Values after steady state and steady state achievement time.

a) Temperatures				
T(ºC)_HR(%)	Max	Min	Amp	Time
10_30	10,4	9,7	0,7	03:14:10
10_98	10,4	9,8	0,6	01:43:10
25_30	25,1	24,9	0,2	00:45:50
25_98	25,1	24,7	0,4	00:52:10
40_30	40,3	39,7	0,6	02:22:10
40_98	40,2	39,7	0,5	01:31:30
b) Humidity				
T(ºC)_HR(%)	Max	Min	Amp	Time
10_30	30,8	27,8	3,0	02:13:10
10_98	98,0	96,3	1,7	07:30:50
25_30	30,8	29,1	1,7	01:45:10
25_98	97,7	96,0	1,7	03:27:50
40_30	30,9	38,5	2,4	00:49:50
40_98	Not achieved in 8h trial.			

3.4 Concentration of CO_2 and O_2 Monitoring

Fitoclima 25000 presents an excellent behaviour in the air renewal. Carbon dioxide concentration along the time was studied by linear regression models, and Person's correlations indices were calculated to assure the best levels of correlation. Linear regression models represent, with high accuracy, the collected data (fig. 4). The concentration increase per hour was calculated and the values for 1 person and 3 people are showed in Table 3.

The Figure 5 shows the drift of the data along a 2hrs trial period for the Oxygen. More tests were done and the maximum variation found was of 0.1-0,2% in the whole period. This proves that insufflated air is enough to assure a good level of oxygen. Oxygen level is always maintained around 21% of volume.

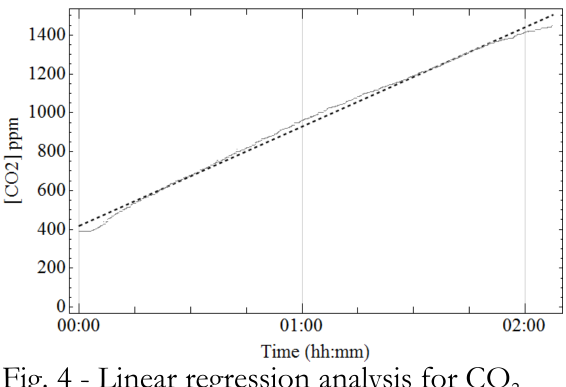

Fig. 4 - Linear regression analysis for CO_2 concentration over a 2h trial at 30ºC/90%HR with 2 people inside. (Legend: *Linear regression curve*: black dashed line; *Original data*: grey dots)

Pearson's coefficient values vary around 0.9. So, all the models were considered to be representative of the experimental data. Calculated results prove an increase in CO_2 levels with the occupancy and with the set point of temperature and humidity. The production of CO_2 increases more rapidly to higher values of temperature and humidity than for lower temperatures.

3.5 Other environmental conditions

In order to prove complete suitability of climatic chamber *Fitoclima 25000* there are other aspects that must be tested as mentioned above (lightning, noise levels, COV's release, bio-burden concentration, etc.). The diversity and extension of the theme, thus, demands that these aspects be subject of a further analysis.

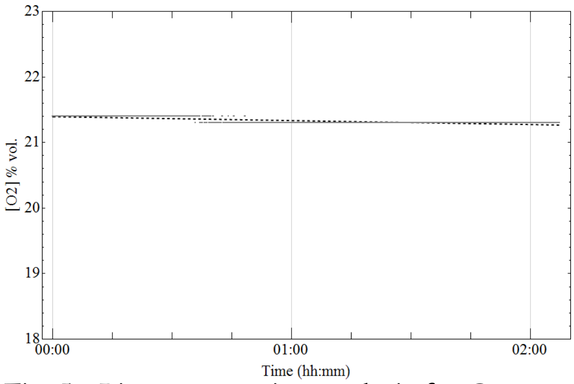

Fig. 5 - Linear regression analysis for O_2 concentration over a 2h trial at 30ºC/90%HR with 2 people inside. (Legend: *Linear regression curve*: black dashed line; *Original data*: grey dots)

Table 3. Variation of CO_2 concentration according temperature, humidity and number of people.

Temp.(ºC)/Humid.(%)/_Nº. People	[CO2] $ppm.h^{-1}$
20_30_1P	329
20_30_3P	493
30_30_1P	174
30_30_3P	579
20_90_1P	209
20_90_3P	838
30_90_1P	425
30_90_3P	94

4. CONCLUSIONS

According international standards drifts should not vary over 2ºC/h and cycle temperature should be less than 1ºC peak-to-peak (6). The 2ºC in space can warrantee no variation in thermal sensation (2) between acceptable limits. Literature values are more demanding than international standards.

Technical specifications of *Fitoclima 25000* perfectly assure the interval considered admissible to experiments.

Some scientific studies said that for drifts, with 0.5clo, are suggested 0.5-0.6ºC/h to assure non-sensible variation within a period of at least 3-4h (2, 8).

In their study, Schellen et al. (11) refer an accuracy of ±0.12ºC around the set point. Kolarik et al. (8), in turn, present an accuracy of ±0.2ºC, ±1 to 5% RH (0.25g/Kg) and also ensure that mean radiant temperature and air temperature are equal during steady and thermal transient states.

For less accurate settings *Fitoclima 25000* is able to do several trials in one day, depending on the exact values of temperature and humidity set point needed. For high accurate adjustments, *Fitoclima 25000* is able to do a trial per day or one in two days. This happens because it needs to include a rest period from one set point to another. However, when properly rested and settled, *Fitoclima 25000* is also able to reach the highest demanding criteria of stability.

Finally, according the presented facts, we can state that the chamber *Fitoclima 25000* and laboratory facilities, considering the presented analysed data, are adequate to the purpose of evaluating psychophysiological responses of the human body at different combinations of temperature and humidity.

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Application of Cold Provocation for Breast Cancer Screening Using IR Thermography

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SUMMARY

A new approach of breast cancer screening using thermovision camera is presented in this paper. The idea is to cool down the healthy and unhealthy breasts or if it's impossible the part of the breasts, and then register a sequence of thermograms in order to get a curve of temperature versus time. We assume that the thermal reaction of the external part of the skin due to the thermoregulation for healthy and unhealthy cases.
Background: A new approach of breast cancer screening using an infrared camera is presented in this paper. Previous studies have shown good results. In this study we are using cold provocation and movement correction in order to enhance the result. We assume that the reaction for cold provocation differs in healthy and cancerous tissue.
Materials and methods: The cancer patients for the study are from a preliminary investigation made in Tampere University hospital. Three out of nine patients examined were suitable for this study. We used a microbolometric uncooled camera IRvox384 thermal camera developed at Technical University of Lodz for medical applications. We cooled the breasts for 15 seconds and then a sequence of 300 images was recorded with the frame rate of 2 frames per second. The total recording time was 150 s.
Results: We found out that the value of time constant is higher in cancerous areas. It means that the reaction of unhealthy tissue for thermal excitation is slower. The temperature is coming back to normal in a longer period of time.
Conclusions: In order to confirm that results are correct and the time constant of breasts with the cancer has a higher value it is necessary to collect more data from patients with diagnosed cancers. We also need to create standard procedures for the imaging sessions so that the results could be repeated as precisely as possible.

1. INTRODUCTION

Breast cancer is the most common cancer among women nowadays (1). It's very important to diagnose the cancer in the early stage, because the chance of being cured is 85% if the tumor is detected and treated before it is over 10 mm in diameter and 10 % if it gets to grow to over 10 mm (2). Very often it is impossible using traditional methods such as mammography, MRI or USG (3). Some of them are invasive and may not be repeated frequently, fig 1.
Traditionally, the screening of breast cancer has been made primarily with mammography and secondarily with magnetic resonance imaging (MRI) and medical ultrasound (USG). The advantages of using mammography are that its specificity is high (up to 99.5 %) and disadvantages that it requires radiation, it is uncomfortable to the patient due to the compression of the breasts, and the fact that the density of the breast tissue affects the sensitivity. MRI has good sensitivity (up to 100 %) and specificity (up to 95 %), but it is expensive, it takes a lot of time, and it needs to be done with a contrast medium. USG generates a lot of false positives, but it has good specificity in dense breast tissue (4).

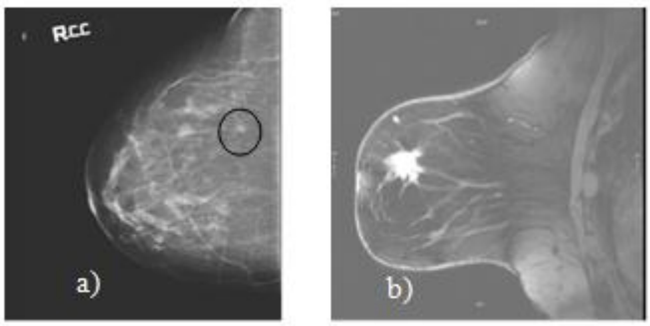

Fig.1 - Imaging of breast cancers using mammography (a) and MRI (b).

Due to these facts, there have been many trials of using infrared thermography (IR) to detect and evaluate the breast cancer. Previous studies have given promising results. Combining IR with

mammography has resulted in good sensitivity (up to 96.5 %) in patients under the age of 50 (5).
The cellular basis of IR imaging is that the metabolic activities of healthy and cancerous tissue differ from each other. The glucose metabolism of a tumor often results in lactate, which causes the cells to need less oxygen but much more glucose than a healthy cell. Due to this, the limiting factor of tumor growth is perfusion, and because of this the tumor stimulates vasculogenesis. The differences in distribution of perfusion are visible in thermography (1).
Most of the previous studies are based on asymmetric distribution of thermal or texture features (signatures) obtained from infrared images (6-9). Typically, the healthy patients have a symmetrical temperature distribution on both breasts, fig. 2 (10, 11).

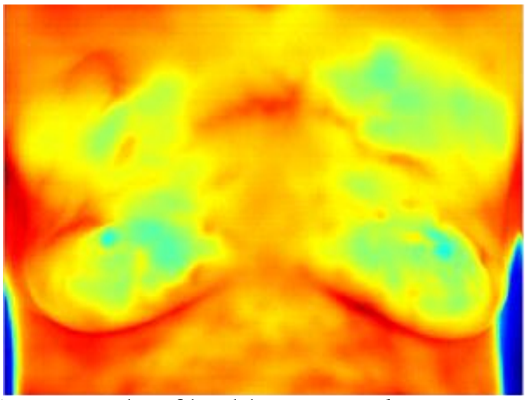

Fig. 2 - Example of healthy woman breasts.

During thermographic measurements it is very important to keep the same environmental conditions. Patients should wait 10-20 minutes before the measurement in the stable and comfortable room temperature and humidity (12-15).
In many cases, the static temperature distribution on the breast skin surface is measured, and typically the cancerous tissue gives higher temperature spots as shown in fig 3 (16). Direct temperature measurement is not very reliable, because temperature of the skin depends on many different factors. This was the main argument to try to correlate the change of the temperature after cooling down the skin with the cancer.

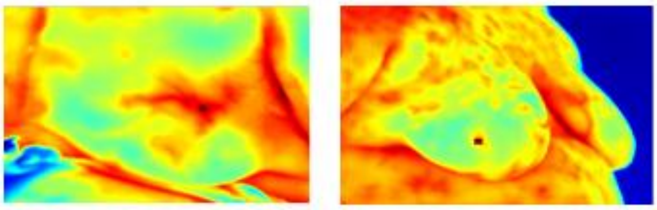

Fig. 3 - Breast cancer thermal images, the cancer position is locate.

2. MATERIALS AND METHODS

It is assumed that cancerous tissue has different thermal time constant. It is due to the different blood perfusion and metabolic rate in contrast to the healthy tissue. We cooled down the skin of the breast of the patients for about 15 seconds using a gel that has been in a fridge for an hour. The initial temperature is not very important as we measure the temperature difference in respect to the initial temperature value just after removing the gel. We used a cooling pad 5 mm thick, which was cooled in refrigerator to the temperature of +4 Celsius. The cooling pad was set right on the skin covering both breasts, and was removed before IR imaging. The measurements were performed for entire breasts, but motion correction was applied to selected ROI's.
The exemplary images for the set of a few hundred recorded for every patient, are presented in fig. 4. Both breasts are cooled to compare the recovery time after cooling. The sequence of 300 images was recorded with the frame rate of 2 frames per second. The total recording time was 150s. The small square region of interest with 16 pixels was chosen, fig. 3 (17, 18).

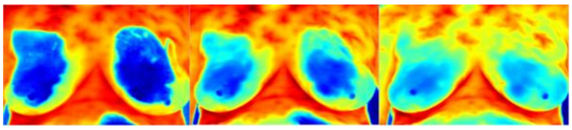

Fig. 4 - Breast cancer thermal images, frames no. 1, 32 and 300, sampling rate 0.5s, total recording time 150s.

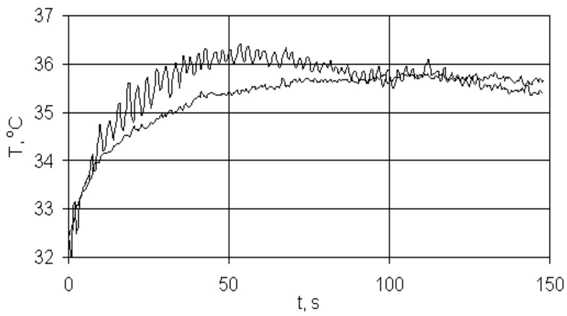

Fig. 5 - Temperature vs. time for a chosen with and without the movement correction.
The breast cancer had been defined with mammography and/or ultrasound, and biopsy before IR-imaging. The breast cancer was localized from mammography images.
The approximation using the exponential function was the next step of the data processing. The example of approximation is presented in fig. 6.

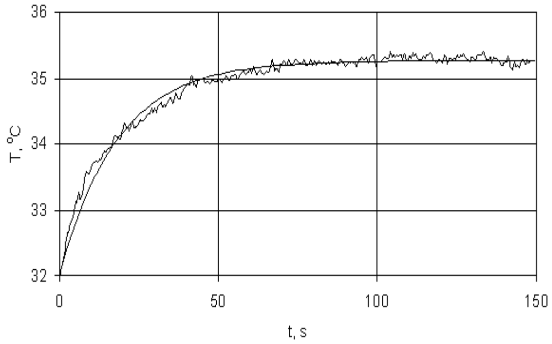

Fig. 6 - Approximation of measured temperature recovery curve with exponential function

We assume the single thermal time constant model of the skin. It denotes that the temperature evolution is time can be expressed by the equation (1).

$$T = T_s\left(1 - e^{\frac{t}{\tau}}\right) \qquad (1)$$

Where T_s is the temperature after full recovery and τ is the thermal time constant describing the heating inertia.

3. RESULTS

The preliminary investigations have been performed as the result of scientific cooperation of Finnish and Polish Technical Universities in Tampere and Lodz. Measurements have been made in Tampere University Hospital using microbolometric uncooled camera IRVox384 thermal camera developed at Technical University of Lodz for medical applications. During the investigation 9 cases of breast cancer were examined. Only 3 of them are reported in this work. The main characteristics of the patients' tumors are summarized in table a below.

Table 1. Characteristics of the tumors

Patient	Tumor type	Tumor size (pathology)	Gradus
B5	Ductal	8 mm	1
B6	Ductal	14 mm	2
B7	Lobular	20 + 10 mm	2

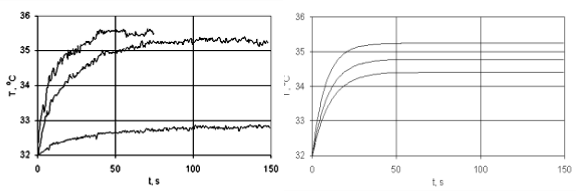

Fig. 7 - Temperature evolution for breast cancer tissue after cold provocation, raw data (left), approximated data (right).

Table 2. Single thermal time constant model parameters for 3 cases of breast cancer

Case	Ts, °C	τ, s
B5	35,5	9,2
B6	35,3	18,1
B7	32,8	27,5

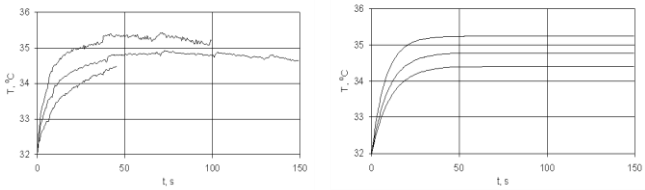

Fig. 8 - Temperature evolution for healthy tissue after cold provocation, raw data (left), approximated data (right)

We can see that the value of time constant is higher in cancerous cases. It means that the reaction of unhealthy tissue for thermal excitation is slower. The temperature is coming back to the normal in a longer period of time. It happens mainly due to the difference of perfusion in healthy and unhealthy tissue.

Table 3 - Single thermal time constant model parameters for 3 cases of healthy tissue

Case	Ts, °C	τ, s
B5	35,2	7,9
B6	34,8	9,4
B7	34,4	10,5

4. CONCLUSIONS

This paper shows preliminary studies of using dynamic thermovision in diagnosis of breast cancers. In order to confirm that results are correct and the time constant of breasts with the cancer has higher value it is necessary to collect more data from patients with diagnosed cancers. The measurement should be done very precisely taking into account environmental condition and other standard procedures in order to repeat the measurement correctly. Next step in our investigation is to extract parameters from the thermal model of human tissue which will suits to the experimental results. Then we will be able to do classification for healthy and unhealthy cases in automatic and quantified way.

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The Effect of Whole-body Vibration in the Skin Temperature of Lower Extremities in Healthy Subjects

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SUMMARY

<u>Introduction</u>: Vibration exercise has been increasing in popularity although the impact of this exercise modality is still under investigation. Vibration exercise is practiced mostly while standing on vibration platforms, as whole body vibration. Several researchers have studied the effects of exposure to whole body vibration in strength, flexibility, equilibrium and blood flow, but the use of medical thermography in these investigations is still very limited. The aim of this research is to study the impact of acute exposure to whole body vibration in the skin temperature and thermal symmetry of the lower extremities in healthy subjects.

<u>Methods</u>: The skin temperature of 24 healthy and untrained subjects, randomly assigned to two groups (vibration and no vibration), was accessed using medical thermography before and after exposure to the intervention protocol. All subjects followed a protocol suggested in previous literature for image capturing. Thermograms were obtained from several lower limb regions of interest in different views before and after exposure to vibration. The mechanical stimulation was provided by the Power Plate® with parameters set at a frequency of 35 Hz, high amplitude (5-6 mm) for 5 minutes.

<u>Results</u>: The analyzed regions of interest mean temperature decreased significantly in the control group in the posterior thighs, anterior knees, lower legs and ankles ($p \leq 0.05$). Acute exposure to whole-body vibration was responsible for a significant decrease in temperature of the anterior thighs, lateral aspect of knees and medial aspect of the left knee ($p \leq 0.05$) and an increase in temperature of the lower legs and ankles ($p > 0.05$). The highest temperature symmetry difference was observed in the lateral aspect of the ankle (0.29±0.23 ºC) followed by the medial aspect of the ankle (0.27±0.22 ºC) and the medial aspect of the knee (0.26±0.14 ºC) and whole-body vibration increased temperature symmetry difference in all regions of interest.

<u>Discussion</u>: The results show that the exposure to 5 minutes of vibration (35 Hz) in a single session has an effect in the skin temperatures of the lower extremities. In the control group, at the regions of interest with significant statistical difference, a mean decrease in temperature of 0.48 ºC was found and in the experimental group the mean temperature decrease was of 0.41 ºC. In the experimental group, at the regions of interest with mean temperature increases, the mean difference observed was of 0.24 ºC. Caution should be taken before vibration exercise prescription since the effects in microcirculation are not fully understood. The results of this investigation are expected to contribute to better understand specific pathologies affecting the lower limbs.

1. INTRODUCTION

1.1 Human Body Vibration

Vibration is used within this work as a mechanical movement characterized by oscillations around a fixed point following a wave movement. Each wave produced by vibration is characterized by four components: frequency (number of cycles per second, measured in Hertz [Hz]), acceleration (change in velocity over time, measured in meters per square second [m/s2]), velocity (the rate of change of position, measured in meters per second [m/s] and displacement (vector that specifies the change in position of a point to a previous position, quantified in meters [m]) (18). Amplitude is defined as the maximum displacement of a vibration point from a mean position and peak-to-peak amplitude is the height from the lowest to highest point of the wave (7). It should be noticed that it is not clear what the optimal amplitude should be (16).

1.2 Vibration Exercise

Vibration exercise has been increasing in popularity both in leisure, sport and clinical settings but the impact of this exercise modality in subjects health is still being studied by the scientific community. This exercise modality has been acknowledged as a viable option in sport and health sectors and suggested as a complementary modality to traditional exercise for different populations (7). Neurogenic potentiation involving spinal reflexes and muscle activation based on the tonic vibration reflex has been appointed as a possible explanation for this occurrence, increasing muscle spindle activity and consequent stretch reflex (5). Bosco et al. (2, 3) pointed that the increase in muscle performance is due to neural factors, which are similar to those seen after weeks of conventional resistance and power training.

The load on the neuromuscular system is imposed by vibration frequency and amplitude. According to Luo et al. (15), in order to activate the muscle effectively, vibration frequencies should be between 30Hz and 50Hz. Bosco et al. (2) has reported an increase in vertical jump performance with a frequency of 26 Hz but no rationale was given for the selection of the vibration frequency.

Vibration exercise is mostly practiced as whole-body vibration while standing on oscillating platforms. Currently there are two commercial types of vibrating platforms being manufactured for the health and sports industry. The first type produces side-alternating vertical sinusoidal vibration, the platform rotates around an anteroposterior horizontal axis and vibration amplitude varies according to the distance between the feet and the axis (e.g. Galileo®). The second type produces only vertical synchronous vibration while both legs oscillate symmetrically up and down as the platform moves in the vertical direction (e.g. Power Plate®). Scientific community still debates which platform is superior (6, 7).

1.3 Vibration Exercise and Blood Flow

Recently, Games and Sefton (10) stated that whole-body vibration (WBV) has been used by researchers as a treatment for multiple conditions. However, studies produced mixed results regarding its effectiveness as a treatment modality. Differences in equipment, vibration parameters and the variety of pathologic conditions studied may explain the diversity of results. The physiological effects of WBV are still not fully understood. Effective and safe clinical applications for this exercise modality demand this understanding. Several studies (13, 17) point to an increase in blood flow in the lower limbs following exposure to WBV. When standing on a vibrating platform muscular activity increase in order to attenuate the imposed vibration and there is an evident need for perfusion to comply with higher demands. This muscular activity appears as rhythmic muscle contractions that increase peripheral circulation by widening of small vessels in the quadriceps and gastrocnemius (12, 23). Lythgo et al. (17) demonstrated that isometric squatting alone can significantly increase leg blood flow and that in WBV conditions it increased with higher frequencies. These authors stated that WBV produced significant increases in leg blood flow that are higher than those achieved with isometric squatting alone.

The influence of this exercise modality on peripheral circulation has been investigated accessing intramuscular temperature (9), laser Doppler (14) and diagnostic ultrasound (13) with unclear results according to Games and Sefton (10) that emphasize the difficulty of blood flow measurement.

1.4 Vibration exercise and skin temperature

Few authors have addressed the effects of WBV in skin temperature (Tsk) of the lower limbs. These effects have been accessed using thermistors (15), infrared thermometers (7), temperature probes (12) and dynamic thermography (10). Medical thermography is a non-invasive, non-ionizing and radiation emission free medical imaging modality. It records skin surface temperature that is influenced by blood flow, without interfering with it. The validity and reliability of this method has been previously documented and it may be of use for better understanding the effects of WBV on peripheral blood flow (4, 11, 21).

1.5 Thermal Symmetry

Thermal symmetry has been defined as the degree of similarity between two regions of interest (ROI) mirrowed across the human body longitudinal axis, which are identical in size and position (26). Skin blood flow is controlled by autonomic nervous system which is assumed to be anatomically and histologically symmetrical (19, 20). The degree of thermal symmetry between ROI reported has been increasing and differences tend to be subtle (19, 26). Advances in camera technology and implementation of more rigorous experimental protocols explain these improvements. Localized and asymmetric temperature changes in Tsk may be valuable as a diagnostic indicator of diseases relating to autonomic dysfunction (19).

The aim of this study is to assess the impact of acute exposure to WBV in the Tsk Tsk of the lower limbs in healthy subjects and to address thermal symmetry in the ROI evaluated, assessing briefly the impact of acute exposure to vibration on thermal symmetry.

2. METHODS

2.1 Participants

Twenty four untrained male participants were recruited from the local community (24.9±3.4 years; 24.2±2.5 kg/m^2). Participants self-reported neither cardiovascular, neurological, metabolic or musculoskeletal diseases nor taking any medication which affected the previously mentioned systems. After all the procedures were explained, participants signed the informed consent form in order to participate in the study. Subjects were randomly assigned to one of the study groups, the experimental group or the control group (table 1).

2.2 Materials and Methods:

Early studies were done using thermography to establish normal thermal patterns of the horses and specific attention was directed towards thoracic and pelvic limbs. During these studies, standards were established for the use of infrared thermography in veterinary medicine. Auburn University studies were also done to document thermographically assisted diagnosis of various inflammatory processes.

Table 1 - Group characterization, Age (years) and Body Mass Index (kg/m^2).

Study Groups	n	Age	BMI
Experimental Group	12	26.33±1.12	24.10±2.31
Control Group	12	23.42±4.23	24.29±2.80

2.3 Study Design

Each participant reported to the laboratory a single time in which two Tsk measurements were performed, one before the experimental condition and one after the experimental condition. After the initial Tsk measurements subjects in the experimental group were exposed to a vibration protocol and subjects in the control group were exposed to the same procedures but with no vibration. Immediately after the second Tsk measurement was performed.

2.4 Equipment

For the investigation, a thermal camera FLIR A325 was used, presenting a resolution of 320x240, a measurement accuracy (bias, offset) of ±2ºC and a precision (repeatability) of ±0.1ºC. Thermograms capture and analysis were made using the software FLIR ThermaCAM Researcher Pro 2.10®.
The mechanical stimulation of vertical synchronous vibration was provided by the Power Plate® with parameters set at a frequency of 35Hz, high amplitude (5-6 mm) for 5 minutes.

2.5 Procedures

2.5.1 Thermographic Capture Protocol

The thermogram capture protocol followed the conditions and processes to obtain thermal images suggested in previously published literature (1, 21, 25, 26). Volunteers were asked to don't smoke, don't eat heavy meals, don't drink alcohol two hours before Tsk assessment, to avoid exercise, the use of cosmetics and oil ointments on the assessment day. The examination room was clear of unnecessary objects, to avoid thermal reflection, and had adequate dimensions. The thermal camera was switched on at least one hour before examination, the emissivity was set to 0.98 and the temperature scale set from 25 to 35ºC. All subjects were instructed to undress, remain still in the examination room for thermal equilibrium for a period of 15 minutes, with temperature stabilized at 22º, humidity less than 50% and absence of air flow. Thermograms were obtained from the views: Thighs (anterior view); Thighs (dorsal view); Leg, right (lateral view); Leg left (lateral view); Leg, right (medial view); Leg left (medial view); Lower legs (anterior view); Lower legs (dorsal view); Both knees (anterior view) and Both ankles (anterior view) before and after exposure to vibration (figs. 1, 2 and 3).

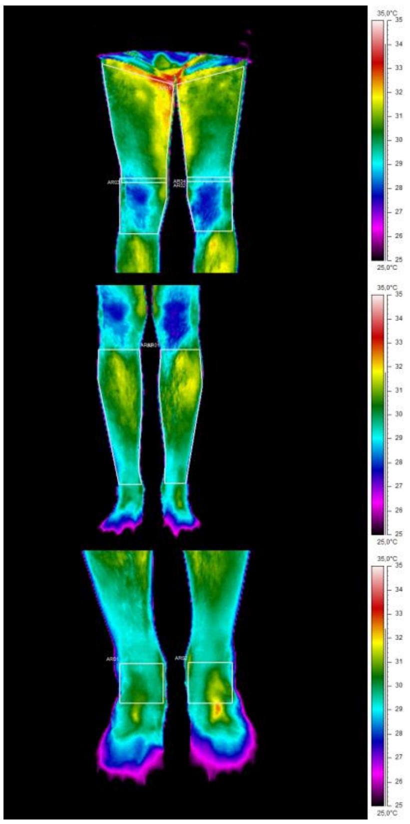

Fig. 1 - Anterior thighs, knees, legs and ankles ROI.

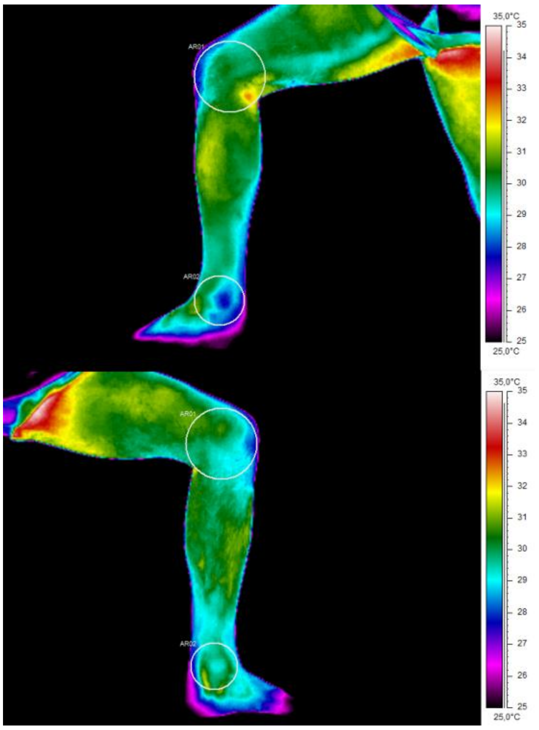

Fig. 2 - Legs and ankles lateral (above) and medial (below) ROI.

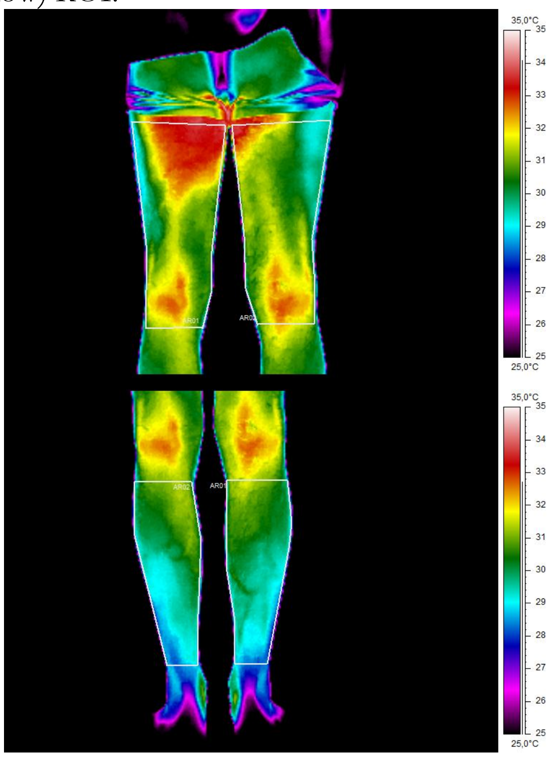

Fig. 3 - Dorsal thighs and legs ROI.

2.5.2 Whole-Body Vibration Protocol

Participants stood on the vibrating platform with their feet at shoulder width and knees at approximately 45º of flexion and lightly griping the safety handles (but not resting their body weight on them) and feedback was given in order to maintain this position. Participants were barefoot during the protocol in order to diminish the attenuation of vibration by shoes and not to interfere with Tsk measurements. To reduce the risk of sliding of the feet, non-slip foam was attached to the standing surface of the vibrating platform.

2.5.3 Statistical Analysis

Data was collected, entered into a custom database, ROI were drawn with the image analysis software and its values evaluated statistically using Statistical Package for Social Sciences version 20 (IBM SPSS Statistics 20). Descriptive statistics were used for baseline characteristics and demographics. Shapiro Wilk's normality test was performed and non parametric tests were selected (Wilcoxon Signed Ranks Test and Mann-Whitney U Test) to compare Tsk (before and after the WBV protocol and across study groups) and thermal symmetry (ΔT) values (before and after the WBV protocol and across study groups). The significance level was set at $p \leq 0.05$.

3. RESULTS

Baseline Tsk across groups was compared in order to establish the degree of groups' homogeneity. Despite the randomization process of the distribution of subjects, significant differences were observed in 6 ROI (Lower Leg Anterior Left and Right, Lower Leg Dorsal Left and Right and Both Knees Anterior Left and Right).

The results of temperature measurements of the control and experimental groups are shown in table 2 and table 3. An example picture showing the medial and lateral aspect of the leg in both groups is provided (fig. 4).

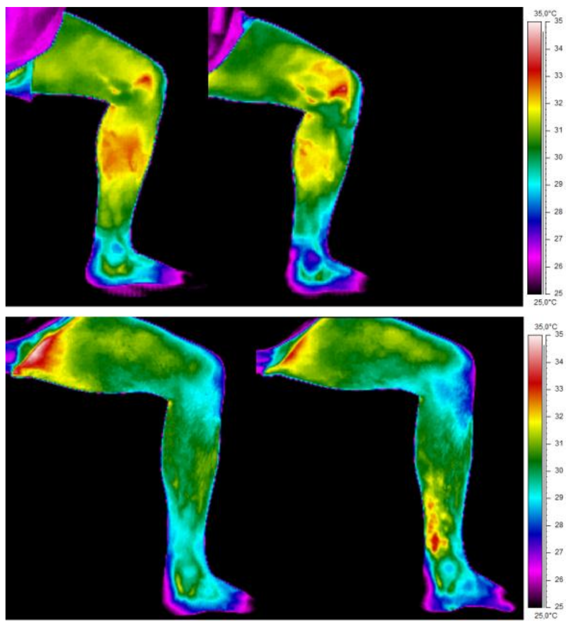

Fig. 4 - Medial aspect of the left leg in the control (above) and experimental (below) groups, before (left) and after (right) whole body vibration.

An overall decrease of 0.48 ºC in Tsk was observed after WBV in the control group and significant differences were found in 14 ROI out of the 20 studied. Only 1 ROI (Leg Medial Knee_R) did not follow this tendency and increased Tsk after WBV but with no significant differences.

Table 2. Tsk before and after WBV in the control group (* - p ≤ 0.05).

Regions of Interest	Initial Tsk ºC	Final Tsk ºC	p
Thigh Anterior_R	31.28±0.64	31.26±0.79	0.94
Thigh Anterior_L	31.28±0.63	31.21±0.82	0.57
Knee Anterior_R	30.65±0.67	30.34±0.60	0.03*
Knee Anterior_L	30.78±0.71	30.49±0.74	0.05*
Lower Leg Anterior_R	31.96±0.61	31.36±0.82	0.00*
Lower Leg Anterior_L	31.98±0.63	31.40±0.86	0.01*
Ankle Anterior_R	31.27±1.42	30.73±1.28	0.01*
Ankle Anterior_L	31.22±1.37	30.67±1.22	0.01*
Thigh Dorsal_R	31.69±0.73	31.35±0.77	0.01*
Thigh Dorsal_L	31.69±0.71	31.38±0.82	0.01*
Lower Leg Dorsal_R	31.41±0.49	30.99±0.54	0,00*
Lower Leg Dorsal_L	31.48±0.52	31.01±0.65	0.01*
Leg Lateral Knee_R	31.27±0.57	31.15±0.71	0.32
Leg Medial Knee_R	30.23±0.73	31.04±0.81	0.06
Leg Lateral Knee_L	31.25±0.63	31.08±0.79	0.14
Leg Medial Knee_L	31.17±0.78	31.02±0.98	0.26
Leg Lateral Ankle_R	30.75±1.04	30.19±1.11	0.01*
Leg Medial Ankle_R	30.83±1.31	30.17±1.19	0.00*
Leg Lateral Ankle_L	30.73±0.93	30.18±1.07	0.01*
Leg Medial Ankle_L	30.73±1.07	30.18±1.17	0.01*

Table 3. Tsk before and after WBV in the experimental group (* - p ≤ 0.05).

Regions of Interest	Initial Tsk ºC	Final Tsk ºC	P
Thigh Anterior_R	31.26±0.83	30.80±1.12	0.01*
Thigh Anterior_L	31.10±0.85	30.60±1.07	0.00*
Knee Anterior_R	30.13±0.88	29.78±1.01	0.01*
Knee Anterior_L	29.93±0.81	29.45±1.00	0.01*
Lower Leg Anterior_R	30.84±0.41	30.86±0.86	0.86
Lower Leg Anterior_L	30.62±0.47	30.85±0.88	0.24
Ankle Anterior_R	30.63±0.84	31.37±1.57	0.35
Ankle Anterior_L	30.49±0.63	31.14±1.68	0.51
Thigh Dorsal_R	31.37±0.72	30.88±0.76	0.00*
Thigh Dorsal_L	31.34±0.91	30.82±0.81	0.01*
Lower Leg Dorsal_R	30.58±0.81	30.66±0.77	0.81
Lower Leg Dorsal_L	30.36±0.96	30.60±0.69	0.58
Leg Lateral Knee_R	30.82±0.77	30.48±0.87	0.00*
Leg Medial Knee_R	30.64±1.13	30.58±1.22	0.23
Leg Lateral Knee_L	30.76±0.75	30.33±0.87	0.00*
Leg Medial Knee_L	30.44±0.95	30.27±0.98	0.01*
Leg Lateral Ankle_R	29.84±1.18	29.97±0.90	0.64
Leg Medial Ankle_R	30.33±0.82	30.40±0.96	0.81
Leg Lateral Ankle_L	30.02±1.05	30.05±0.97	0.88
Leg Medial Ankle_L	30.12±0.86	30.10±0.79	0.94

In the experimental group, temperature changes were not as linear as in the control group. Temperature decreased in 11 ROI with significant differences in 9 of them (mean decrease of 0.42 ºC). A temperature increase of 0.24 ºC was observed in 9 ROI with no significant differences.
The mean values of ΔT with the standard deviations before the experimental procedure are presented in table 4. The largest thermal symmetry value observed was in the lateral aspect of the ankle (0.29±0.23 ºC) followed by the medial aspect of the ankle (0.27±0.22 ºC) and the medial aspect of the knee (0.26±0.14 ºC).

Table 4. Thermal Symmetry observed before the experimental procedure.

Regions of Interest	n	ΔT (ºC)
Thigh Anterior	24	0.18±0.13
Thigh Dorsal	24	0.17±0.15
Lower Leg Anterior	24	0.19±0.12
Lower Leg Dorsal	24	0.20±0.19
Both Knees Anterior	24	0.20±0.20
Both Ankles Anterior	24	0.25±0.26
Leg Lateral Knee	24	0.14±0.09
Leg Lateral Ankle	24	0.29±0.23
Leg Medial knee	24	0.26±0.14
Leg Medial Ankle	24	0.27±0.22

The variation of thermal symmetry after the experimental procedure is shown in fig. 5. Vibration increased the side to side temperature differences observed in all ROI. These changes were statistically significant in the dorsal aspect of the thighs, in the anterior aspect of the knees and in the medial and lateral aspects of the knee. In the control group, side-to-side temperature differences did not change accordingly to the experimental group as a decrease in these differences was observed in 7 ROI. In contrast, the only significant difference was found in the anterior aspect of the knee where side-to-side differences increased.

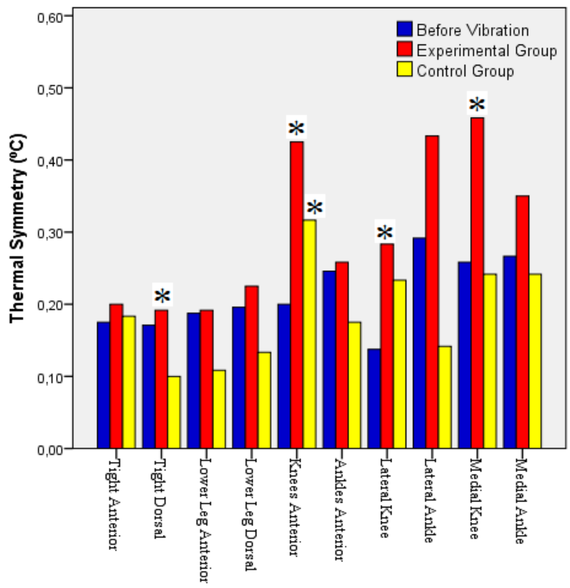

Fig. 5 - Variation of thermal symmetry after the experimental procedure (* - p ≤ 0.05).

Comparing the values of thermal symmetry across groups, statistical significant thermal symmetry differences were found in the dorsal aspect of the thighs, in the medial aspect of the knee, in the anterior aspect of the lower legs and in the lateral aspect of the ankle.

4. DISCUSSION

Previous research regarding the effects of WBV in Tsk of the lower limbs provided diverse results.

Some authors reported a significant increase in Tsk after WBV (10, 12), however other authors (7, 8) reported a lack of significant effects of WBV in Tsk. Vibration protocols used in past studies were different regarding vibration frequencies, amplitudes, exposure time and assessment area but some similarities were found. The protocols that induced a significant increase in Tsk used vertical synchronous vibration, while the protocols that did not increased Tsk used side alternating sinusoidal vibration. To our knowledge, this was the second study to examine Tsk in the lower limbs following vibration using medical thermography and the first to analyze several ROI. Games and Sefton (10) used thermography to examine superficial temperature following vibration, analyzing only the temperature of the medial head of the gastrocnemius muscle of male and female participants, with absence of a control group.

Our results suggest that vibration decreased Tsk in the anterior aspect of the thighs, in the lateral aspect of both knees and the medial aspect of the left knee ($p \leq 0.01$). Even though in the medial aspect of the right knee the Tsk decreased slightly in the experimental group, it should be pointed that in the control group, this ROI was the only one where an increment in Tsk was observed ($p=0.06$). Vibration also increased Tsk in the lower legs and ankles (except the medial aspect of the left ankle) but the increment was not significant. These results are difficult to compare with those of previous studies because the areas analyzed were different. Cochrane et al. (7, 8) used the four site weighted method of Ramanathan that is based on Tsk from the chest, arms, thighs and lower legs to calculate the mean Tsk of the body but don't provide any information about the temperature of each area. The authors reported that side to side alternating vertical sinusoidal WBV didn't produce mean Tsk changes with a frequency of 26 Hz and 6 mm of amplitude. In this study synchronous vertical vibration was used, as in the studies of Hazell et al. (12) and Games and Sefton (10). Hazell measured Tsk with a temperature probe placed 2.5 cm superior to the lateral malleolus of the left ankle and Games and Sefton measured Tsk with dynamic infrared thermography in the medial head of the gastrocnemius muscle by placing the spot temperature indicator lateral to the medial edge of the muscle. Both authors reported significant increases in Tsk, using higher frequencies (45 Hz, 2 mm of amplitude, 15 repetitions of 1 minute with 1 minute rest between repetitions and 50 Hz, 2 mm of amplitude, 5 repetitions of 1 minute with 10 seconds rest between repetitions respectively). Our results differ from those reported before and differences might be explained by the chosen vibration protocol which is different from those mentioned before in frequency, amplitude (35 Hz, 5-6 mm and 5 minutes of exposure).

Lohman et al. (14) hypothesized that exercise of the lower extremities, with and without WBV (synchronous vertical vibration with frequency of 30 Hz and amplitude 5-6 mm) would increase skin blood flow but concluded that skin blood flow actually decreased slightly in both interventions. Tsk is related to skin blood flow and this may explain our findings in the control group where Tsk decreased in 19 ROI. According to Lohman et al. (14), during active and short lasting exercise, blood flow is shunted from organs, including the integumentary system and redirected to the musculature. However, in the experimental group, an increase in Tsk in 9 ROI was observed that cannot be explained likewise.

Hazell et al. (12) concluded that intermittent semi-squat exercise with WBV when repeated for 15 repetitions of 1 minute significantly increases Tsk in the leg. Games and Sefton (10) postulated that the increase in Tsk measured by medical thermography after WBV was either a result of increased muscle blood flow, supported by the increase of superficial temperature, or increased muscle metabolism, supported by an increase in total muscle blood perfusion. They also pointed that superficial skin temperature, muscle blood flow and tissue oxygenation cannot be considered independent and each may influence the other (e.g. as muscle blood flow increases, superficial skin temperature increases). Games and Sefton's (10) results should be taken carefully as only changes in the medial head of the gastrocnemius, which is close to the vibration stimulus, were analyzed.

Roelants et al. (24) studied WBV effect in the activity of muscles in the lower limb during squat exercises, concluding that muscles located closer to the vibration platform showed a higher vibration effect. In the current experiment it was found an increase in Tsk of the lower legs and ankles in the experimental group but the differences were not statistically significant. These results may be explained due to the proximity to the vibration platform. In the control group, a mean increase of 0.81 ºC was observed in the medial aspect of knee. This ROI is related to the vastus medialis muscle and maybe individuals that maintained the isometric squat position without WBV relied mostly in this structure during the test, increasing blood flow and, consequently, Tsk.

Thermal symmetry was also analyzed in this study and the maximum side to side variation of mean Tsk was observed in the lateral (0.29±0.23ºC) and medial (0.27±0.22ºC) aspects of the ankle. Vardasca et al. (26) reported lower limb maximum side to side variation of mean Tsk in the dorsal aspect of the thighs (0.30±0.11ºC) and lower legs (0.30 ±0.10) in total view and the dorsal aspect of the feet (0.32±0.18ºC) when using regional views. Another study (27) reported lower limb maximum side to side variation of mean Tsk in the heel (0.64±0.68ºC) and toes (0.42±0.39ºC). Niu et al. (19) reported higher differences in the heel (0.5±0.6ºC), dorsal foot, sole and foot toes (0.4±0.6ºC). In the lower limb, thermal symmetry seems to be lower in the extremities.

To our knowledge this was the first study to analyze the effect of WBV on thermal symmetry of the lower limbs. WBV increased the thermal symmetry value in all ROI, with statistical evidence of significant differences in the dorsal aspect of the thighs, in the anterior aspect of the knees and in the medial and lateral aspects of the knee. These findings suggest that the effects of WBV are not the same in both lower limbs, which may be clinically relevant, though this result and the possible mechanisms require further investigation.

5. CONCLUSIONS

This experiment assessed the impact of acute exposure to WBV in the Tsk of the lower limbs in healthy subjects. It also assessed thermal symmetry in the ROI evaluated and the impact of acute exposure to vibration on it.

After analyzing and discussing the findings, it can be concluded that isometrically maintaining a position of 45º of knee flexion for 5 minutes is enough to significantly decrease Tsk in the anterior aspect of the knee, anterior aspect of the lower leg, anterior aspect of the ankle, dorsal aspect of the thighs, dorsal aspect of the lower legs and medial and lateral aspects of the ankles.

Acute exposure to WBV with parameters set at a frequency of 35Hz, high amplitude (5-6mm) for 5 minutes was responsible for a significant decrease in Tsk in the anterior aspect of thighs, lateral aspect of knees and medial aspect of the right knee and increase in Tsk (not statistically significant) in the lower legs and ankles.

WBV affected thermal symmetry increasing side to side differences in the dorsal aspect of thighs and knees.

WBV is being increasingly used in sport and rehabilitation and several studies assess the influence of WBV in physical performance. Studies analyzing relevant physiological measures for health and sport medicine professionals, like Tsk, exist but tend to analyze restrict areas of the body. This work addressed the effects of WBV in Tsk of several ROI but further research is needed to strengthen the obtained results. The effect of WBV in Tsk immediately after and during a period of time requires future investigations.

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Using Clinical Thermography as Diagnostic Complementary Procedure for Hand Arm Vibration Syndrome

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SUMMARY

<u>Introduction</u>: **Hand-Arm Vibration Syndrome is an occupational condition that affects people exposed to vibrating tools in the workplace and needs an accurate quantitative and objective diagnostic test to aid clinicians in the judgment of the degree of injury and correspondent treatment. An objective assessing method is needed to provide a permanent evidence record of the degree of injury.**
<u>Methods</u>: **Medical thermography was used with a developed objective mechanic provocation test involving vertical vibration exposure of hands, for 2 minutes at 31.5Hz of vibration frequency and 36 mm/s2 of vibration magnitude, which was followed by a vascular provocation challenge of the hand for a period of 1 minute at 20°C. Images were taken during the whole procedure. In order to assess the peripheral temperature changes of the hand a computational model was developed and the images standardised and analised.**
<u>Results</u>: **It was possible to discriminate between degrees of injury groups ($p<0.05$) but not individuals. It was possible to identify through medical thermography the affected fingers and its temperature changes quantified assessing objectively the stage of the injury.**
<u>Conclusion</u>: **The proposed method is objective and repeatable, can provide information of the evolutionary stage of the condition. Medical thermal imaging can be used as diagnostic tool to provide evidence of occupational condition affecting upper limbs in support to medical history in medico-legal liabilities.**

1. INTRODUCTION

1.1 Vibration

The term vibration within this experiment is recognised as mechanical movement that oscillates in the form of a wave about a fixed point. Each wave produced by vibration is characterised by four components: frequency [Hz], acceleration [m/s^2], velocity [m/s] and displacement [m] (12).

1.2 Hand transmitted vibration

Vibration is transmitted and absorbed by the hand when an individual holds a vibrating tool. Someone using a vibrating tool perceives the vibration though tactile receptors in the skin creating a risk based in the type of vibration and time of exposure to the vascular, neural and musculoskeletal systems. Actions are needed to minimize it and when the problem becomes apparent, medical professional might be required to classify the nature and severity degree of the problem (12).

1.3 Hand-Arm Vibration Syndrome

Workers exposed to hand transmitted vibrations may experience various vascular, neurological musculoskeletal related disorders of the hand, although not all frequencies, magnitudes or durations of vibration cause the same effects. In order to enable reporting and comparison of exposures, there is a need for the exposure to be measured and evaluated using defined standardised protocols. Furthermore it is necessary to identify what should be measured and how measurements should be expressed, taking in account the components of vibration and assessing their impact according to criteria such as the probability of a specific severity for a specific form of the disease. With current assessment protocols it is also difficult to gauge the importance or weight of different frequencies, the axes of vibration, vibration magnitude and daily exposure durations for HAVS (9).

It is understood that Hand-Arm Vibration Syndrome is provoked by a progressive and excessive exposure to vibration over a prolonged period of time. The term HAVS is used to describe a range of injuries that can be incurred after excessive exposure to vibration when using vibrating tools with Vibration White Finger (VWF) syndrome having the highest prevalence, clustered around certain industries (7).

This disorder is characterised by a complete episodic closure of digital blood vessels. Although either central and/or local pathogenic mechanisms may be involved, this pathogenesis is not fully understood yet because the pathophysiological mechanisms underlying muscular disorders in workers operating vibration tool are often unclear. Disorders of organs, nerve fibre dysfunction resembling entrapment neuropathy and diffuse or multi-focal neuropathy are thought to be related to working with vibrating machines causing neuropathy to peripheral nerves, mainly sensory ones but also those of the motor and nervous system. Any of the nerves of the upper limbs may also be affected as this disorder is not confined to the digits. It can also extend to the palm and the arms (10).

The consumption of alcohol, tobacco or drugs as well as the individual lifestyle also influences the risk of contracting HAVS. Age is another important factor that is thought to be linearly correlated with vibration exposure history. People that work a long time exposed to hand transmitted vibration tend to be more susceptible to acquiring the syndrome. According to a 2004 study from Sweden that examined working women exposed to hand-transmitted vibration, there is no difference between genders with respect to power absorption during vibration exposure (5).

The main symptoms of HAVS are apparent in the fingers. Patients report that these can become numb and turn white, and spasm may occur due a lack of blood supply. The main symptoms of HAVS are: vascular effects, which are expressed as coldness and blanching of one or more fingers and neurological effects manifest themselves as tingling sensations, "pins needles" and numbness. The neurological symptoms can arise independently and pre-date vascular symptoms (9).

In most individuals the condition is not severe and attacks only cause minor discomfort. In more extreme cases, however, repeated or constant ischemic episodes can result in skin ulcers and even gangrene requiring surgery or amputation. Picking up small objects such as pins or nails will become more difficult as the sensory capacity of the fingers decreases, along with a loss of strength and grip of the hands. Pain, tingling and numbness in the arms, wrists and hands can make sleeping difficult (10).

HAVS is very difficult to prove in court, the process is slow, the evidences should be strong, and courts are facing the task of striking a balance between suspicious false claims and awarding legitimate compensation. A claimant's detailed, clear and accurate but subjective description of symptoms is not enough. Support, for example by objective photographic evidence of vascular symptoms corroborated by expert medical opinion has shown to be helpful (16).

HAVS can present secondary Raynaud's phenomenon, where exposure to a mild cold stress (water at 20ºC for 1 minute) provokes intense and often painful narrowing of peripheral blood vessels and thus a reduction of the blood supply (hence the white finger) followed by unusually long recovery times where dilatation of blood vessels and re-perfusion only eventually cause the affected limb to warm up again (7). These changes can be monitored and quantified with digital thermography given the right methodology is followed.

An Italian physician has performed the first study on occupational lesions from vibrating tools with medical thermography, he found that the most dangerous vibrations to the human extremities were in the range from 30Hz to 80Hz. The methodology followed by this study was to take a thermal image of the hands before a cold vascular provocation, then using an exposure to water at 5ºC for 5 minutes, followed by thermographic recordings in 5 minute intervals. This test was not considered 'fair' in law due to the difficulty in turning the fingers white without previous exposure to vibration. The infrared thermal imaging technique was compared with the photoplethysmyography modality. He concluded that thermography is a suitable choice for a diagnostic method in liability and insurance cases, and also in occupational and forensic medicine (1).

A year later the same researcher demonstrated that the dorsal hand after vibration exposure presented to be warmer at the radial region and cooler at the ulnar region. He suggested the usage of thermography for the assessment of vascular, nervous and osteoarthritis diseases, strongly proposing the use of medical thermography as a diagnostic tool for pathologies involving vibration and prognostic data for vascular or neuronal traumatic lesions or in sudden atrophy (2).

The current exposure limit value to vibration is defined in the 2002 version of ISO 5349 and is addressed by a European Directive recommended for all member states to incorporate into their national legislation. The directive established as exposure limit a value of 2.5 ms^{-2} and an exposure maximum limit value of 5.0 ms^{-2}. In order to simplify the exposure calculation from a single period of exposure, has implemented the chart presented in fig. 1 where by knowing the time of exposure and the weighted acceleration the draw of a line "calculates" the partial vibration exposure without the need for calculations (17).

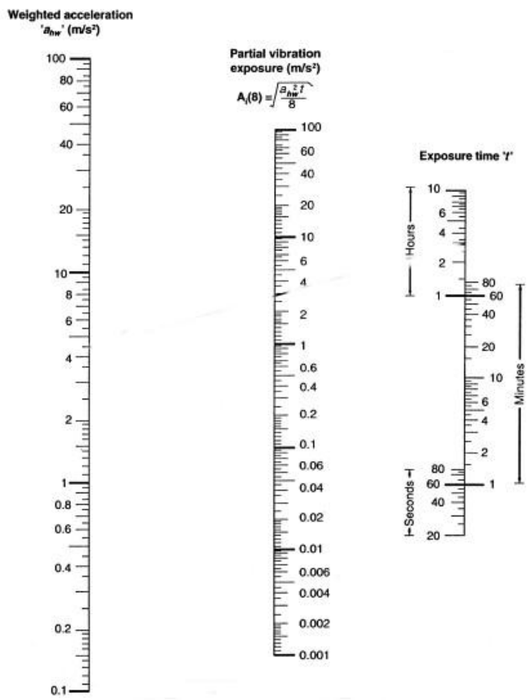

Fig. 1 - HAVS partial exposure calculation chart (17).

Vibration injury to the hands was first reported in 1911 in Italy by Loriga in workers using compressed air tools (13). In 1975 the Taylor-Palmear scale for assessing vibration effect injuries was published. Two alternatives to the Taylor-Palmear scale were introduced in Stockholm in 1987, the vascular scale was subsequently exposed as deficient in that the frequency of blanching attacks is supposed to be used to determine severity. This turned out not to be the case and severity can instead be determined from the results of properly conducted objective vascular tests, such as using a mild cold stress test (water at 20ºC for 1 minute) together with thermal imaging (13). Both scales, like the Taylor-Palmear scale, are entirely subjective.

In 2002 Griffin developed a method of scoring (fig. 2), that can be used to map where blanching symptoms occur. It can be applied to any other type of symptoms that occur in relation with HAVS. The shaded areas correspond to the zones where blanching typically occurs. The author of this map has as-signed a score value to each anatomical region of the fingers to record the severity of the condition (12).

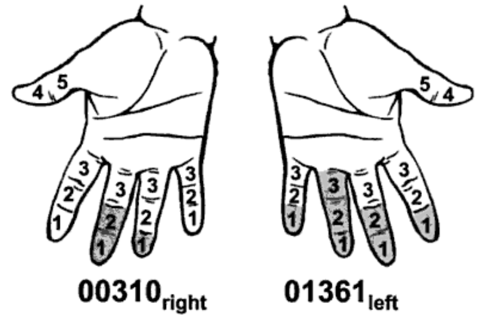

Fig. 2 - Griffin's method of scoring areas of the fingers affected by blanching, (12).

Several clinical and laboratory tests have evolved and became available over the years to assist physicians in evaluating the three components of HAVS. A recent paper, however, concluded that diagnosis and medical tests for HAVS are notoriously crude and can be inaccurate due to clinicians using unsophisticated methods to assess patients (17).

In contrast to this elaborate procedure the already mentioned Italian study that used thermography as a diagnostic technique for assessing vibration injury (1) in conjunction with a study by Bovenzi et al. (4) may offer a faster and more accurate means of diagnosis. Bovenzi concluded that acute exposures to vibration (with equally weighted magnitude) reduces the finger blood flow for all frequencies between 31.5 and 250Hz. While duration of digital vasoconstriction after vibration increases with frequency the constriction severity diminishes: results the study showed that for an exposure time of 2 minutes the frequency with highest reduction of finger blood flow and simultaneously with the shortest recovery time was 31.5Hz.

The aim of this experimental work is to investigate the amount of temperature increase in the hands of healthy controls and subjects presenting early signs, symptoms and clinically confirmed patients of HAVS after holding a vertical vibration device for 2 minutes at a frequency of 31.5Hz.

2. METHODS

2.1 Examination procedure setting

This investigation involved:

- A FLIR A40 (calibrated) thermal camera;
- A PC workstation with CTHERM, MS Excel and SPSS software packages to process and analyse the thermal images;
- A table with a MDF board on top (to improve thermal contrast between limb and background);
- A chair for seating the subject during capture.

• A vibration device (a cinema seat vibration device) as provocation tool, which produces vertical vibration (fig. 3). This type of vibration was suggested by Prof. Griffin in Southampton. This vibration device was isolated with brown paper and plastic (good thermal conductor) to minimize the effect of thermal conductance between the subject and the device.
• A PHILIPS frequency generator set to 31.5 MHz for generating the vibration frequency (fig. 3).
• A PHILIPS frequency counter, to monitor the frequency induced (figure 3).
• A standard GRUNDIG 400W audio amplifier, to amplify the signal from the frequency generator for the vibration device (fig. 3).
• An oscilloscope, to monitor the waveform produced.

The vibration frequency of 31.5Hz frequency was chosen in agreement with literature (4). The induced maximum acceleration from the vibrating device was 36 m/s2, measured by a calibrated laser vibrometer at Swansea Metropolitan University. With the same device the acceleration absorbed by human hands was determined to be 30 m/s2 on average. Using the chart shown in figure 1 and tracing a line from the measured acceleration to the correspondent exposure time of 2 minutes, the partial exposure vibration was found to be 2.5 m/s2, which is half of the maximum allowed by EU regulations (5 m/s2) and was thus considered a safe value for this experiment.

Fig. 3 - The vibration test equipment: on top the vertical vibration motor, underneath the frequency counter, frequency generator and at the bottom the audio amplifier.

A total of 23 subjects participated in this investigation and their characteristics are mentioned in the table 1. They have been divided in 4 groups: the controls (assessed with the EURO-QOL questionnaire with score 0), the signs (which claim the early signs of a condition provocated by using vibration tools), the symptoms (which use vibration handheld tools claim to have at least one symptom of HAVS, however not clinically confirmed) and the HAVS groups (which is composed of medical confirmed patients of the condition).

Table 1. Characteristics of the subjects that participated in this investigation

Group	Gender			
	Males	Females	age	BMI
Controls	5	2	27±8	25±2
Signs	3	4	39±17	25±3.6
Symptoms	1	6	37±8.2	23.2±5.1
HAVS	2	0	49±4.2	27.4±1.5

Posters were used to advertise this study and to ask for volunteers were distributed around the Faculty. Emails were sent to students and staff and an advertisement was posted on the University of Glamorgan intranet website. After volunteers expressed their interest in collaborating in this study, they received information on the experiment and test and were asked to sign an informed consent form.
The HAVS screening questionnaire used in this study is the one suggested and utilised by UK HSE and the NHS (11). Once the volunteers had completed questionnaire and form, their medical his-tory and information on the syndrome relevant for this work could be analysed. Participants were graded and divided into four groups of injury severity based on HAVS signs, symptoms or medical diagnoses according to the guidelines (11).
The thermal camera used in all tests was a FLIR A40 with a resolution of 320x240 pixels, a measurement accuracy (bias, offset) of ±2ºC and a precision (repeatability) of ±0.1ºC. It was connected to a PC using the CTHERM package developed at Glamorgan Medical Imaging Research Unit (14). The lenses used in this imaging system were a standard lens (IR-lens 24º) for regional (close-up) views. All tests were performed in the Thermal Physiology Lab at the University of Glamorgan. All participants while collaborating in the test were constantly monitored for the duration of the test by the author

2.2 Image Capture Protocol

The image capture protocol plays an important role in all infrared imaging investigations, it specifies the subject preparation for the imaging appointment and during the data collection, the room conditions and the capture procedure itself. The recording protocol used in this investigation follows the guidelines of the “Glamorgan Protocol”, which

recommends the standard procedures for recording and evaluation of thermal images of the human body (3). It is divided into three sections: the subject, the room and the image recording process.
The subject to be investigated has to follow the following instructions:
- Instructions to be sent to the subject together with the appointment outlining:
    ◦Avoid smoking for two hours (minimum) before the investigation;
    ◦ Avoid heavy meals on the day of the examination;
    ◦Avoid cosmetics and ointments on the skin, these substances act as skin thermal insulators;
    ◦Avoid physiotherapy or sports on day of the examination;
    ◦Report infections and any drugs taken, either prescribed by a general practitioner or acquired from a standard pharmacy.

- On arrival:
    ◦The investigator explains the procedure;
    ◦The subject completes the needed forms: "Informed Consent", "Euro-QoL" (the score HAS to be zero for controls), and "HAVS screening questionnaire";
    ◦The investigator requests the subject to re-move as much clothing as the volunteer is comfortable with (in changing cubicle) leaving the upper limbs exposed. In actual facts all subjects were wearing either a t-shirt or short sleeved shirt ensuring that the forearms were unclothed;
    ◦The subject must avoid uneven cooling due to jewellery, crossed legs, or hands/arms placed close or on the body;
    ◦The investigator has to check the room temperature repeatedly and humidity (temperature has to be 22ºC and humidity below 50% to pre-vent subjects from sweating).

- On scanning:
    ◦The standard position used is that of both hands in dorsal view as defined in the Glamorgan Standard Capture Protocol (3).
    ◦A off-the-shelf MDF board has to be used for enhancing the background to hand contrast. The MDF board has a high thermal resistance and therefore does not conduct significant amounts of heat to or from the hands during a single investigation. MDF has, however, a high thermal capacitance so that over time it will assume the temperature of the hands and stay at that temperature for several minutes. In extended or consecutively repeated investigations the board must therefore be replaced with an identical one in order to maintain good contrast and to avoid thermal interference from the previous examination.
    ◦Marks from tight clothing or seating have to be avoided.
    ◦No volunteer names/details are stored on any computer system (only a volunteer code is used).This can be cross referenced to the forms which are stored in a locked filing cabinet).

Apart from the member of staff performing the examination, a second member of staff or a person brought in by the participant has to be permanently present in the office area (not the laboratory space itself) as a witness/chaperone.
The examination room has to have a stabilised air conditioning system, that maintains the room tem-perature at 22ºC ± 1ºC and the humidity below 50%. The outside laboratory window has to be completely closed with shutters not only to avoid solar radiation but also to maintain privacy during the examination. An acclimatisation cubicle has to be provided close to the examination room and maintained under the same environmental conditions. The subject can disrobe there and rest for 15 minutes before the exami-nation to facilitate thermal equilibrium. All unneces-sary equipment should be removed from the laboratory area to ensure adequate space for the ex-amination equipment and to avoid thermal reflections. All equipment and the walls have to be away from the subject as far as possible in order to minimise heat reflections. The laboratory area itself should be equipped with the absolute minimum of furniture only to provide adequate room for ma-noeuvre of the equipment and sufficient space between the camera and the volunteer. In order to avoid disturbance during the examination process, a door sign "Examination in progress" should be used.
For the image recording process the investigator has to make sure that all equipment is set up correct-ly (a check list is helpful here). The infrared camera must have been switched on at least 90 minutes be-fore the start of the first capture to avoid start-up drift (15). Before starting the capture process on the subject an image from a calibration source must be taken. The same applies to the end of the process. Both calibration images combined allow the investigator to check for recording errors.
For capturing the desired views from the subject, correct placement in terms of distance, angle to the camera, subject position and field of view of the camera has to be achieved. This adjustment process can be significantly simplified by using capture masks (fig. 4) in the computer capture software which are overlaid onto the live image. Additionally a camera stand (fig. 5), facilitates fast positioning and stable fixation onto the target view.

After capturing the baseline image the volunteer is asked to stand up, hold the vibrating device with the fingertips of the hand maintaining an angle of 90º between arms and forearms. The device was then turned on, inducing the before mentioned vibration frequency of 31.5Hz at an acceleration amplitude of 36 m/s^2 for 2 minutes. After that period the device was turned off and the subject was requested to return to the baseline recording position.

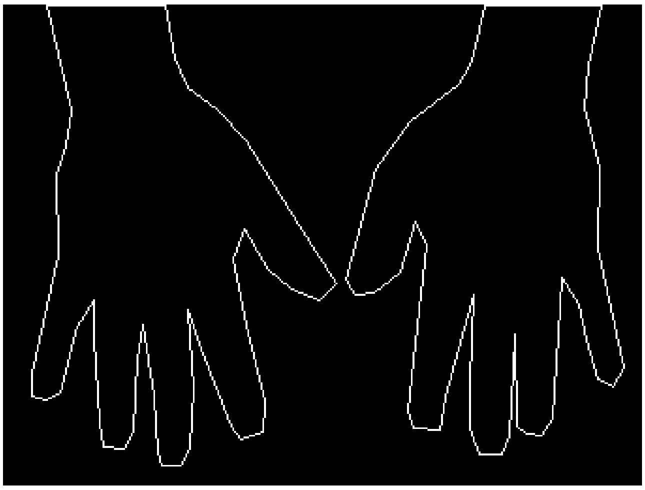

Fig. 4 - Example of a live overlay mask.

Fig. 5 - FLIR A40 IR camera on laboratory stand.

This procedure was immediately followed by a vascular test, where the volunteer is asked to wear a pair of thin latex gloves over the hands and immerse them in a bucket filled with water at 20ºC (monitored by a mercury thermometer). The volunteer remains seated in front of a desk with the hands in a vertical position inside the bucket avoiding contact with the bucket wall or the other hand for a period of one minute. Immediately after this the investigator helps to take off the gloves and makes sure that no direct contact is made with the water. In order to complete the test, the volunteer now places the hands in the recording position (which is the same as the one for taking the baseline image) and for a recovery period of 10 minutes a thermal image is taken at 1 minute intervals. The whole procedure for the case of applying the vascular test only without any pre-provocation is described by the diagram in fig. 6.

For the test, because it involves human subjects, ethical approval was requested and obtained from the Ethics Committee of the Faculty of Advanced Technology at the University of Glamorgan before starting experiment. All individuals collaborating in this research project were treated identically, their confidentiality was respected and no harm was caused to them. All volunteers collaborating in this work could withdraw at any time from the project without being disadvantaged. The author of this work has acted with integrity and has used the available resources as beneficially as possible.

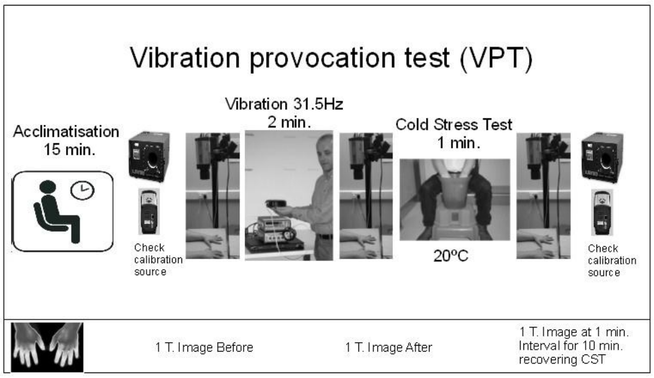

Fig. 6 - The Vibration Provocation Test (VPT) diagram.

3. RESULTS

Observing the right hand Area Of Interest (AOI) (which is based in the model of the hand defined in 18), it can be seen that all the four groups had a decrease of mean temperature, especially the control and confirmed groups. Five minutes after the vascular provocation recovery the greatest negative mean temperature difference was in the control and confirmed groups, the least was indicated by the symptoms group. At the end of the VPT test the greatest negative mean temperature difference was observed in the confirmed group followed by the control group, the symptoms group had recovered

the mean temperature showing the smallest mean temperature difference from baseline (fig. 7).
The left hand AOI as can be observed by fig. 8 only differed from the right hand AOI in the out-come after the VPT test, in this case the signs group presented a minimal higher difference than control group.

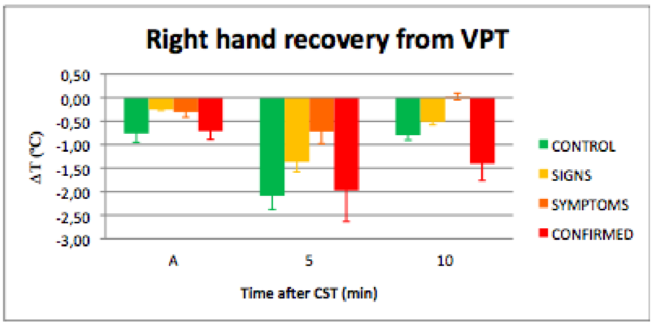

Fig. 7 - Right hand mean temperature difference from baseline when recovering from Vibration provocation test (VPT).

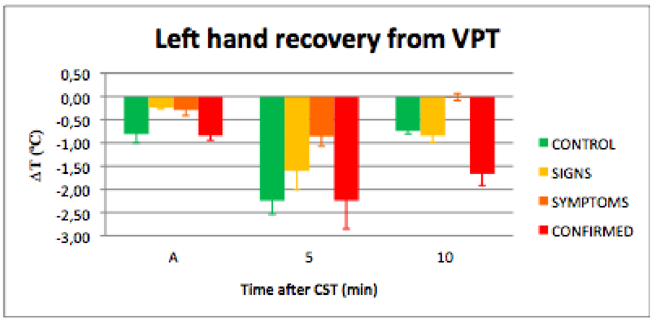

Fig. 8 - Left hand mean temperature difference when recovering from VPT.

In the fig. 9 is shown the variation of mean thermal symmetry (19) difference from baseline over the VPT test. After the vibration expo-sure the value has increased in all groups more significantly in the confirmed group followed by the control group. Five minutes after recovery from vascular challenge the greatest difference was in the confirmed and signs groups. At the end of the VPT test the group presenting the greatest difference was in the signs group closely followed by the confirmed group. The minimal difference was observed in the symptoms group.

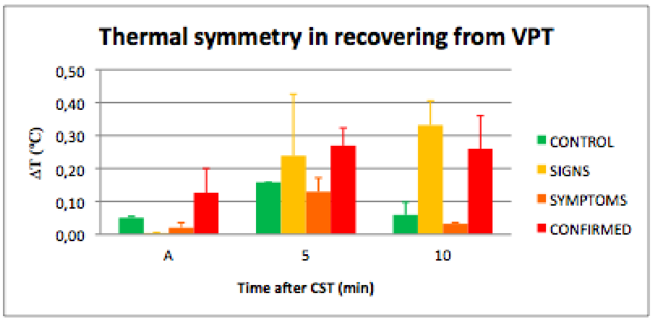

Fig. 9 - Hand thermal symmetry difference from baseline when recovering from VPT.

Observing the mean thermal differences in the index finger DIPs AOI symmetry after the VPT test, it was observed that there was no specific involvement in any particular finger apart from the index in any of the four groups as shown in fig. 10. It can be observed that the confirmed group presented a different pattern than other groups.

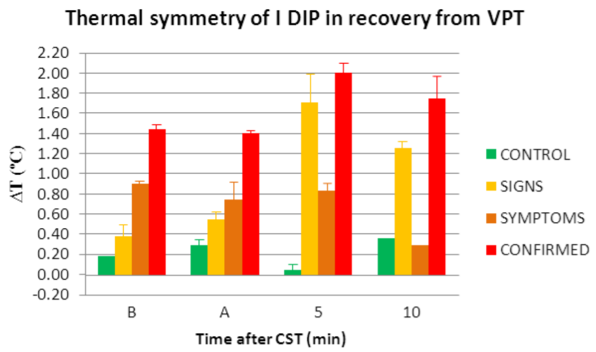

Fig. 10 - Index DIPs thermal symmetry difference when recovering from VPT.

These data have shown that classifying people according to signs rather than symptoms is unreliable.
The fig. 11 presents an example of captured images after being standardised (18), which shows a set of images of a subject from the control group compared with a subject clinically confirmed as having HAVS during a VPT.
Statistical Analysis of the data collected from the VPT test, was obtained a Cronbach Coefficient Alpha for the hand AOI of 0.988, which means good data consistency. The Interclass Correlation Coefficient was of 0.976 with a confidence interval varying from 0.948 to 0.989 demonstrating high reproducibility. The normal distribution of the data was assessed by a K-S test, the p values obtained were 0.515 for the right hand AOI and 0.68 for the left hand AOI. As the K-S test p value > 0.05, it means that the collected data is not different from the normal distribution and the statistical methods associated with this distribution can be used.
A non-parametric Pearson chi-square test was applied between the groups. The result gave a value of 168.000 for the right and left hand AOIs with a significance level inferior to 0.05 (p=0.000 in both AOI). This demonstrates that if their the null hypothesis was true it would be expected to find a x2 value of 168.000 or superior less than 5 times in each 165.000. This rejects the null hypothesis and indicates that the variables are independent. It can therefore be concluded that using thermal images and the VPT test it is possible to identify different HAS stage groups. From the statistical analysis of hypothesis Z-test, there is statistical evidence of

independence between all groups ($p<0.05$) based in both hands AOI.

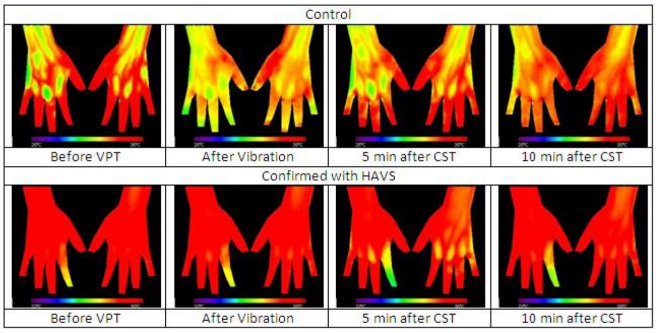

Fig. 11 - An example comparative set of standardised images between a control subject and a clinically confirmed subject with HAVS.

4. DISCUSSION

After vertical vibration exposure for 2 minutes at 31.5Hz all the four groups presented a decrease in mean temperature of the hand in conformity with the literature (2). The application of a vascular provocation test after the vibration exposure produced statistical evidence in mean temperature variation of the hand to discriminate controls from subjects with confirmed symptoms. This procedure significantly differs from most of the published studies in cold provocation testing for HAVS where only a thermal challenge is used (8). These points out the combination of vibration and thermal provocation as objective procedure do provide discrimination between asymptomatic and symptomatic subjects.

The Stockholm scale has not been employed in the classification of subjects in this study. The variation from baseline of thermal symmetry mean value for the four groups during the VPT constituted statistical evidence in the discrimination between healthy controls and confirmed affected symptoms.

There was involvement of the index finger in the subject with confirmed symptoms of HAVS.

The experiment was limited by the sample size available, which limits the weight of conclusions drawn from it.

5. CONCLUSIONS

A standard infrared image capture protocol accompanying a procedure involving mechanical and vascular provocation to the hand was designed, implemented and assessed and is proposed. With the setup described in this publication it is possible to discriminate groups at different stages of the condition, however, for individuals' discrimination a large sample was required, being purposed for future work the implementation in a larger population.

It is also proposed an investigation using the developed methodology, more particularly the thermal symmetry indicator and the proposed campbell's hand injury score system and griffin's havs scoring system to develop an objective and quantitative scale of injury. The purposed methodology of examination could be simplified in exposing mechanically and thermally at same time the subjects to be examined.

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Screening Fever, A New Approach

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SUMMARY

The use of the inner canthus in Humans as a reference for core temperature can be compromised by a number of factors that can lead to faulty measurement.
Despite at inner canthus the ophthalmic artery flow beneath, cerebrovascular disease at internal carotid artery will diminish flow at downstream arteries, and consequently, the amount of heat dissipated at inner canthus and the temperature at surface, drops. Accumulation of mucus discharge at inner canthus will enhance the dropping. Thermographically speaking, the area has an emissivity very well determined, 98 %, which implies, besides this accuracy, the determination of reflected apparent temperature.
On the other hand, external auditory meatus are wave-guides and need to be kept at constant temperature; otherwise the velocity of sound propagation will vary along its length, creating echoes inside of themselves. In this way, external auditory meatus are isothermal cavities and due to its geometrical configuration, an illusion of black body is always present at the interface with the exterior. Unlike the tympanic thermometers which are affected by crooked meatus or wax, because they have to "see" the eardrum, thermographic cameras do not have the accuracy compromised, provided that, the problem is not visible from the outside. In all other situations, the external auditory meatus, when observed from the outside, always have an emissivity of 100 %, relieving the measurement from determination of the reflected apparent temperature.
With this technic, screening fever can be done on people walking in line, without being at a controlled environment and with all sources of error removed.

1. INTRODUCTION

We don't measure temperature with thermographic cameras, we calculate temperature. Thermographic cameras are imagers, each pixel represents an amount of energy sent towards the camera from a surface
This energy has two components, an emitted one and reflected one. Usually, most of surfaces belong to opaque objects; the transmitted component is usual consider, or is, 0. In the application described below the transmissivity is 0
In these cases the equation:

$$W = \sigma(\varepsilon T_{surface}^4 + (1-\varepsilon)T_{reflected}^4) \quad (1) \qquad (1)$$

is used for express the relations between relevant physical quantities.

In each case we have W = the magnitude of Pointing vector towards the camera, σ = Stefan-Boltzmann constant ε = emissivity, $T_{reflected}$ = reflected apparent temperature has to be determined.

2. INNER CANTHUS

In infected patients, during the epidemic of SARS, a huge increase of temperature on eyes zone had been found. This fact in combination with morphology of the ophthalmic artery leads to considerer the inner canthus a possible spot to estimate core temperature in Human Beings.
Ophthalmic artery is fed by internal carotid artery and split itself beneath inner canthus in nasal artery and frontal artery.
Despite these characteristics, inner canthus has a series of snags that compromise, thermographically speaking, the accuracy of the calculations for core temperature.
Human skin is believed to have an emissivity of 98 %, regardless color skin. This, impose an estimation of reflected apparent temperature.
Not doing this, a reference source with a very well knew emissivity and with a very well defined

temperature has to be put in the field of vision to allow the computing of reflected apparent temperature. Placement of source has to be on the same plane of the inner canthus. Otherwise reflected apparent temperature "seen" by the inner canthus and reference source will be different.
Filling 75 % of the camera field of vision with the face of the patient to ensure MFOV smaller the inner canthus size, compromise in several ways the estimation of reflected apparent temperature. First, the rule mentioned before cannot be kept. Second, the narcissism effect of the camera, and possible the operator, over the scene from the camera is huge.
Since the outer layer of the skin has no irrigation, heat flow can only be achieved in a passive way, thermal conduction. This layer will act as low-pass filter and the temperature calculated will be always below or above core temperature, depending if room temperature is below or above core temperature. Mucus discharge at inner canthus also increases this effect.
Cerebrovascular disease also compromise the calculation by promoting false negatives, this syndrome diminish the flow capacity of the internal carotid artery, and consequently the blood flow at ophthalmic artery and heat flow at inner canthus.
Doing efforts before remote fever screening is also strongly not recommend because produce false positives. To allow more blood flow, and help dissipate the heat excess, capillary vessel section increase. This increases facial temperature.

3. EXTERNAL AUDITORY MEATUS

External auditory meatus are wave guide and need to be isothermal cavities to achieve its function. The skin inside and the ear drum have to be at same temperature or variations of sound speed will be present along the meatus, producing echoes and other problems related to poor propagation of the sound waves. Besides thus, when a cavity has a shape that doesn't allows seeing inside, this means the presence of an illusion of a black body.
Equation (1) changes to

$$W = \sigma T_{surface}^{4} \quad (2)$$

Equal as any isothermal cavity, the meatus is completely surround by a volume, the head, with a ratio of 3.5 between length and diameter (1 *cm* × 3.5 *cm*). Has a conical shape with the top cutted (ear drum).

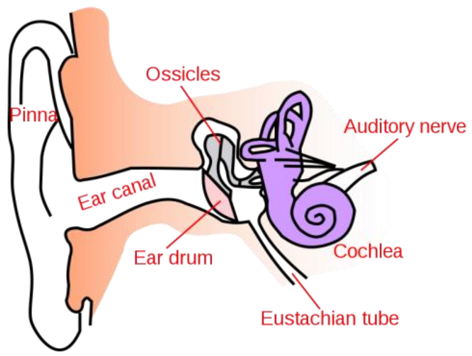

Fig. 1 - External auditory meatus, Gray's subject #229 1036

Like a black-body of room temperature all radiation entering the meatus is trapped inside. The radiation exiting is radiated inside. The meatus when observed from the outside with a thermographic camera appear as an isothermal surface. No details can be seen inside. Only a flat surface at the same temperature can be observed, an "optical" illusion.
This virtual surface, by definition, has an emissivity of 1. No calculus or estimation of reflected apparent temperature and emissivity are need.
Twisted meatus or wax accumulation are no longer a problem, if are not seen from the outside MFOV is the major concern on this kind of calculation. Cameras need to have a MFOV smaller than the diameter of the meatus. Besides this, cameras need to have emissivity selectable to 1 and preferable a box tool with the reading of the maximum.

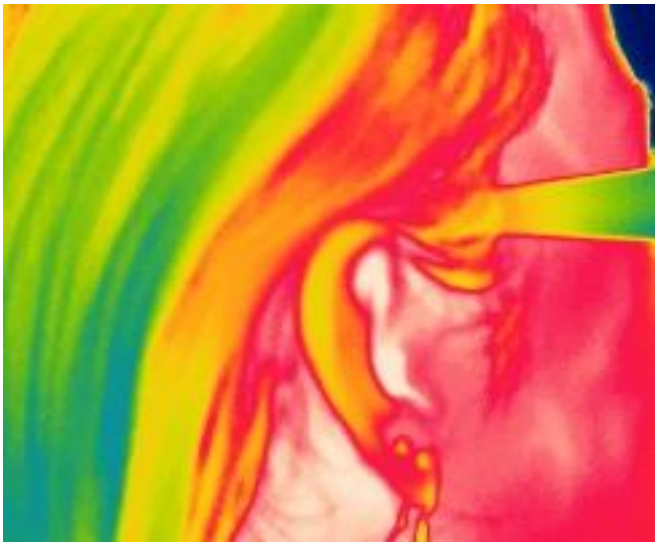

Fig. 2 - Thermogram of the ear.

With adult patients, the cameras available in market have the MFOV smaller enough to allow an accurate reading in the limit. However, at paediatric practice, a camera with a detector of 320 × 240 pixels could be necessary. Cameras with detectors of 120 × 120 pixels, 25 ° FOV and 12 *cm* of minimal focus distance, regarding the MFOV (2.31 *mm*), are examples of ideal cameras for all practices.

Fig. 3 - Child being monitoring during sleep.

4. RESULTS

Auburn University studies resulted in revision of the Horse Protection Act in 1983. This revision was also followed by implementation of new guidelines imposed by the USDA-APHIS. Along with physical examination and evaluation of horses for show purposes, thermography was also used by USDA-APHIS services as a diagnostic aid for detecting cutaneous inflammatory reaction to the horse's' limbs. Over time, use of thermography was discontinued and horse inspection for horse shows was again done by physical examination that also included digital palpation.
Since the 1970's to the present day, prosecution of owners and trainers accused of soring horses has been attempted. APHIS had taken a position in the early 1990's that palpation by itself is sufficiently reliable to accurately determine whether a horse has been sored or not. In some cases, horses that were banned from showing were a cause of litigation in federal courts. Recent rulings by Federal Law Judge Peter M. Davenport questioned whether palpation alone was sufficient "scientific" means to allow expressing an expert opinion. He cited a Supreme Court case which set forth four factors to determine that reliability. He used thermography references of published papers in veterinary medicine. Because of his recent ruling, APHIS lost the court case. USDA-APHIS now wishes to reinstitute the use of thermography as an additional means to document if the horse was sored or not.

5. DISCUSSION

The efficacy of non-contact, electronic infrared thermography has been demonstrated in numerous clinical settings and research studies as a diagnostic tool for veterinary medicine. Sometimes it is very difficult to use radiology, ultrasonography, or magnetic resonance imaging for large animals like horses and cattle (bulls). These procedures require direct contact with the animal, and in some cases the animal must be under general anesthesia to perform these tests. Thermography which can be performed in an unsedated animal has been very helpful as a preliminary diagnostic tool in many clinical cases. Painful conditions associated with peripheral neurovascular and neuromuscular injuries can be easily diagnosed by thermography.

6. CONCLUSION

In modern days', flights are a major concern because of their role in disease transmission. Nowadays, the longest flight is less than 24 hours long and this is the time needed for a H5N1, or other virus, to travel across the world.
The current method at airports implies at least the removal of glass to observe the temperature in the inner canthus. Since a 98 % emissivity should be expected, errors are to be consider. False positives are annoying for those spotted, but the major concern is with false negatives. In airports where the access from the plane to the terminal is done exposed to the elements under frosty weather, the face of patient can chill and the alarm at the thermography camera doesn't goes on and the detection is faulty.
Thermography cameras with detectors of 640 by 480, or greater, strategically placed in the access to and from the terminal could provide detection from a safe distance. Persons only have to be asked to remove the hair from the front of the ear canal and in the camera a box with the size of the detector and alarm has to be set.

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(None Provided)

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Integrating Medical Thermography on a RIS Using DICOM Standard

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SUMMARY

Introduction: Radiology Information System (RIS) is an integrated system, a stand-alone or a component of the Hospital Information System (HIS), which provides patient information of all the medical imaging pictures and reports. This system manages all the workflows on a medical imaging department, facilitating the capture, storing, archiving and delivery of the images. The storage of medical images, in the Digital Image and Communications in Medicine (DICOM) format, is performed by a Picture Archive and Communication System (PACS).
Methods: There is a need of an information system to convert the image raw data, generated by the camera, to the DICOM standard. However, the infrared camera manufacturer does not provide that application. An implementation of software capture that implements the following functionality is needed, read a DICOM work list, which integrates the patient demographic information; updates the RIS when the capture is complete; and archives the captured image to the PACS with all the associated information. All the necessary reporting should be performed in RIS and all the tools to visualize and transform the image should be integrated in the PACS software. Finally, the report created in RIS, and the image in PACS, should be integrated into the Electronic Health Record (EHR).
Discussion: The inclusion of medical thermography in RIS, and subsequently in PACS, is essential for its widespread use in a hospital setting. The usage of the DICOM standard in medical thermography will facilitate the introduction of this modality on all the HIS. The integration of all the systems is fundamental to facilitate the adoption of medical thermography within clinical practice.

1. INTRODUCTION

Nowadays, hospitals host medical imaging modalities with full integration with the information systems available. Such integration is crucial for information availability and for the introduction of new imaging modalities, in order to improve the accessibility. The information systems, available at a hospital, that require this type of integration, are the Hospital Information System, the Electronic Health Record, the Radiology Information System the Picture Archive and the Communications System.
The Hospital Information System (HIS) is the software that supports the patient medical record system and includes numerous additional components (5), such as, billing, patient management (admission, transfer and discharge), and, sometimes, pharmacy management.
The Electronic Health Record (EHR) is the software responsible for the storage of all the relevant patient history and includes a computerized physician order entry.
The Radiology Information System (RIS) is standalone software or a component of HIS software that provides entry, access and storage of patient registration and exam order data, radiology reports and links the patient to associated medical images, & is usually stored on another system (5).
The system also supports the management of the medical imaging department in a hospital or clinic. It allows the generation of a work list for all requested, current, and completed imaging studies, within a given time range. This allows easy access to scheduling data and enables one to tell at a glance the status of a patient in the radiology suite. It also provides access to the exam history and enables access to reports and images on all studies done on that patient. There is a lack of knowledge among healthcare professionals on the analysis of thermal images, so the reporting is essential to stimulate the

usage of medical thermography. The system has all the information of the modalities available at the department.

Picture Archive and Communication System (PACS) is the infrastructure that hosts the technologies that contribute to generate modality worklists, distribution, and archiving of digital images. PACS components typically include the infrastructure needed to communicate with the digital imaging modality or device, an archive device, diagnostic workstations, archive/routing software, and are integrated with the RIS. The system provides the managing and display of images to clinicians in a timely manner, increases the connectivity and the integration between facilities and departments.

1.1 Digital Imaging and Communication in Medicine

Digital Imaging and Communication in Medicine (DICOM) has become the international standard medical imaging. Its influence was critical in the emergence of multi- vendor technical solutions for PACS, and in providing appropriate solutions for the integration with the other information systems involved, especially the Hospital Information Systems and the Radiology Information Systems (1). The adoption of DICOM by thermal infrared imaging is possible (6). All the required capabilities are contained in the standard and hence such an adoption is indeed possible.

Using the DICOM standard for storage, using binary files, a file structure is as follows. The files are divided in two parts, header and data. The header specifies the meaning of the data in the rest of the file and is organised in a tag-like fashion. These tags are called Information Object Definition (IOD). Each of the IODs has a well defined meaning, for example those in-group 8 contain information about the examination and the modality (e.g. TC and X-Ray), group 10 patient information (such as patient name, sex etc.) while group 28 defines the actual image data. In the current version of the DICOM standard there is a modality type TG for the IOD (0008,0060) defined for thermography (2, 7).

Ruminski (6) proposed a method to convert raw data from thermal images using DICOM and XML configuration files. He proposes, the binary file and XML configuration based, offer a basis to establish a full integration of this modality into the standard and to involve manufacturers of thermal cameras into the process.

1.2 Typical medical imaging capturing workflow

A typical medical imaging department workflow requires that the patient demographics are sent from HIS to the RIS. An order is then entered at the EHR and sent to the RIS. After scheduling the radiology procedures at the RIS, the patient demographics, order, scheduled procedure, scheduled procedure steps, and protocol information are made available to the PACS, and then it communicates with the modality equipment by the means of a DICOM modality work list (MWL) message. The images are acquired and then stored in the PACS (3).

A MWL message is a work list protocol that allows PACS to communicate with the modality equipment and automates the entry of patient demographic information for each exam. The communication between the PACS and the modalities is done or by querying the system or is send automatically. (5).

2. METHODS

To facilitate the capture of medical infrared images, software for thermographic cameras must be developed to query and receive the MWL from the RIS. This can be developed as standalone software or a module for an existing system like CTHERM (4) or any software supplied with the camera, developed by the manufacturer. There is also a need for the development of the functionality to convert the raw data from the thermographic camera to the DICOM format and also all the subsequent communication with the PACS infrastructure.

Having all this software in place, there is also a need to develop, with all the major vendors, a plugin for the PACS viewer to help with the specificities that exist on the interpretation of thermal images, such as different scales, and the definition of regions of interest (ROI), as it is done by the CTHERM software.

To complete the workflow there must be a module developed for RIS that could facilitate the reporting of infrared images. This must module can include image-processing algorithms, creating a simple decision support system, that will help the medical thermography imaging professionals to give the final diagnosis on the report.The workflow could be represented as in Fig. 1.

3. DISCUSSION

The guidance provides an easy way to introduce to introduce medical thermography in a medical imaging department, as it does not rapture the existing workflows. This approach provides the medical imaging modality the same level of integration with the existing systems as the modalities already in use. The reporting of thermography images is crucial to the adoption of this modality in a hospital setting, as most of the medical staff does not have sufficient specialised knowledge to interpret the images.

There is much work to be done with the camera vendors to support the DICOM standard, to least support the MWL and image format conversion, but this is a gap that can easily be filled with custom developed software. As for the PACS vendors, it is a much more difficult task, because they must be convinced to develop plugins or modules to the existing viewers. This is difficult because there are many different vendors, and their software development cycle is so long, that they take the time to implement the required functionality.

Using this approach the usage of medical thermal imaging could be more widespread within a hospital setting, and provide greater value when use in comparison to other modalities.

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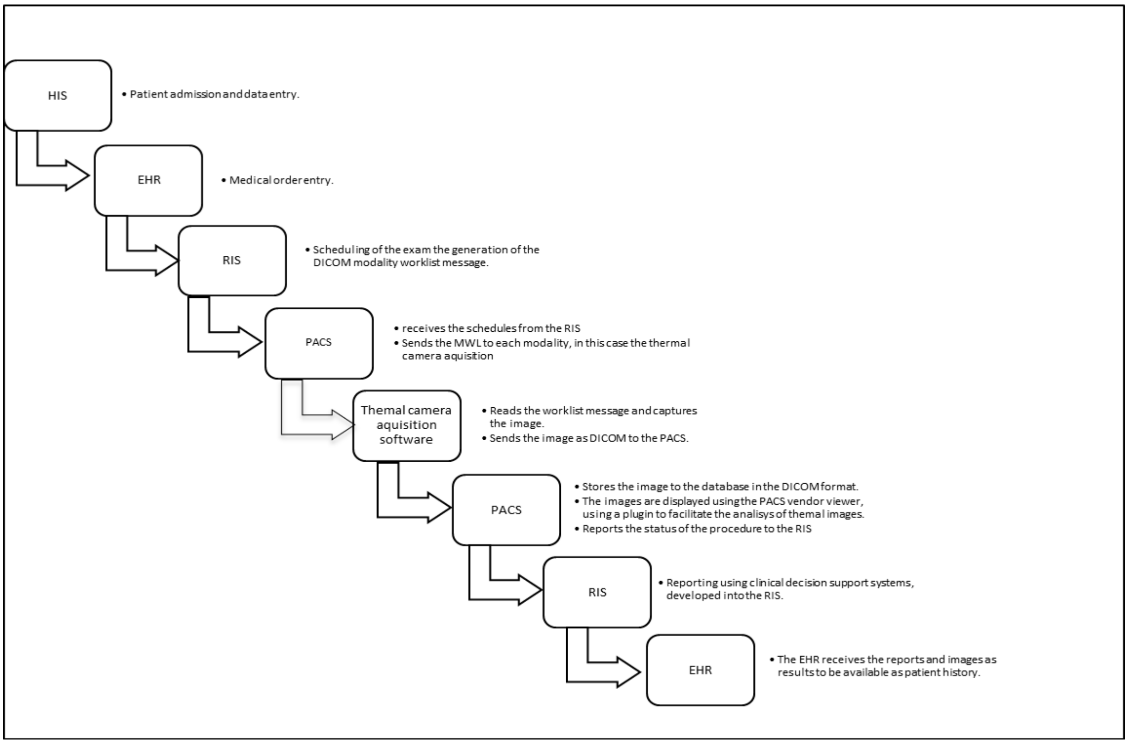

Fig. 1 - Workflow of the integration of thermal imaging

Histographic Method as a Tool of Thermal Image Processing

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SUMMARY

Among essential values characteristic of the histograms, the following are selected: the highest (maximum), the lowest (minimum) and the average temperature in the defined area; the median, standard deviation and skewness; the number of pixels in the examined area and the maximum value on the ordinate of the histogram. The distribution curve D of the histogram is the integral of the histogram and the derivative dD/dt of the distribution curve gives the shape of the histogram.The series of distributions of histograms is more visual and efficient for comparisons than a series of histograms. For illustration, figures are taken from the effects of β irradiation.

1. INTRODUCTION

It is an experience that ionising radiations produce thermal effects in human organisms. Nevertheless, very few data are available on the quantitative relationship of the dose of ionising radiation and the changes of temperature. The studies were planned, therefore, to reveal the thermal detectability of tissue reactions following radiotherapy treatments. By this way during the radiation treatments the thermal measurements made possible to detect the sequential alterations in the thermal map of the involved body surfaces.The thermal studies were performed in collaboration with the National Institute for Oncology by measurements of patients irradiated with beta rays. In the paper the results of infrared thermogrammetry investigations are given by histographic method.

2. ANALYSIS OF TEMPERATURE DISTRIBUTION BY HISTOGRAPHIC PROCESSING

Histographic analysis is the usual mode of processing experimentally and otherwise obtained sets of data, but it may be considered as an efficient way for describing temperature fields, too. Thereby there is still little experience available for such applications and for the proper evaluation all of histogram characteristics (4, 6, 9).

In histograms which represent temperature fields of digital IR-images, pixel numbers (in percentage) with the given temperature are plotted against temperatures occurring within the fields (e.g. Fig. 1). Temperatures occurring in the selected area may be displayed both more simple: graphically (Figs.7, 8 and 9) and more sophisticated: digitally (Figs. 3 and 6), and the obtained data lend themselves for further computations. In our practice satisfactory results were obtained when the temperature varied by tenths of degrees within the range.

Among essential values characteristic of the histograms, the following are pointed out: the highest (max), the lowest (min) and the average (avg) temperature in the defined area; mediane (med), standard deviation (Sdev) and skewness (Skew) (Fig. 3); number of pixels in the examined area (Ncal) and the maximum value on the ordinate of the histogram (Fmax).

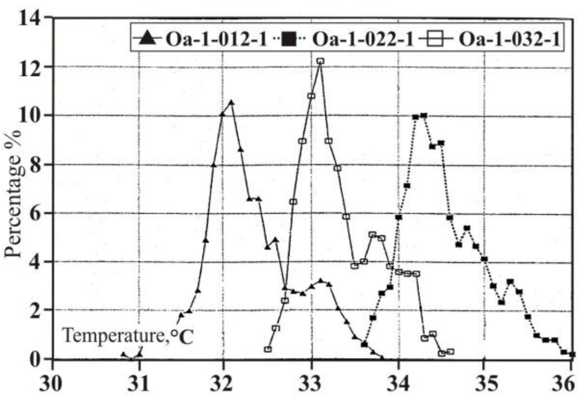


Fig. 1 - Series of histograms of the temperature values of the β-irradiated areas on the first (▲), second (■) and third (⊟) day during radiation treatment (first week).

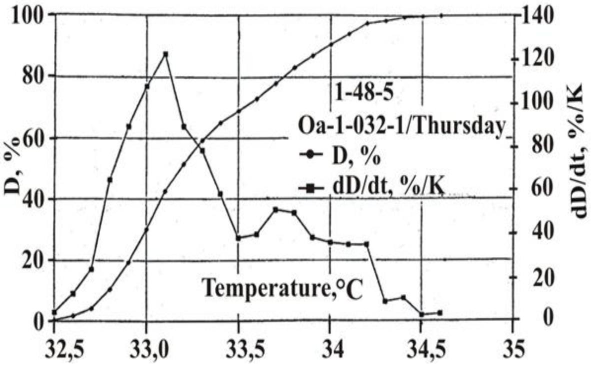


Fig. 2 - The distribution of a temperature histogram *D* and its derivative *dD/dt*, i. e. the shape of the histogram (after the second session).

3. BIOLOGICAL INDICATORS OF THE RADIATION EFFECT

In case of an injury or a radiation treatment the amount of blood circulating through the region during irradiation is too small to contain enough lymphocytes to use them as carriers of chromosome aberrations. At the same time the local tissue reactions might be used to measure the effect of irradiation. Out of the cells of irradiated skin and subdermal tissues the endothelial cells covering the inner surfaces of vessels and representing the walls of capillaries are the most radiosensitive ones. The radiation causes first the dilatation of vessels, then due to the damages of capillaries and vessels the atrophy and necrosis of the tissues (Figs. 7, 8 and 9). The conditions of the vessels and the consequent tissue alterations can be followed by radioisotopic scintigraphy or through image formation by thermogrammetry (1, 2, 8).

4. METHODS OF EXAMINATION

The investigations on the beta-irradiated chest was performed by AGA THV 780 type infrared imaging equipment. The results of measurements were stored from the different investigations, during three weeks (Fig. 5) by an infrared video recording which was evaluated by computerised technique (Fig. 3, in a colour plate)

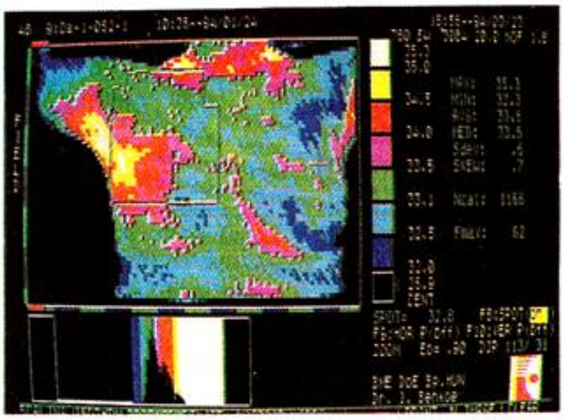


Fig. 3 - Infra-red thermogram of female chest on the 7th day (after 5 sessions, No. 052) evaluated by computerized histographic method.

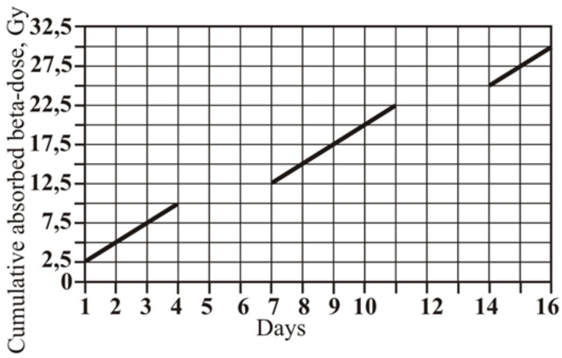


Fig. 5 - Cumulative absorbed beta-dose values during the treatment

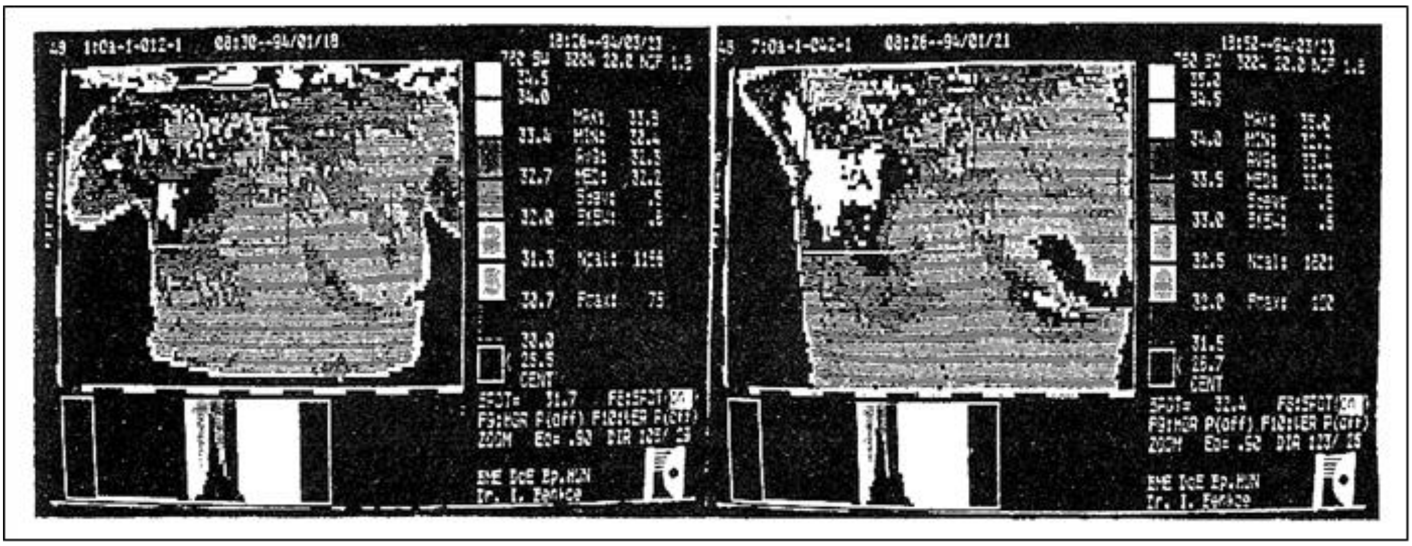
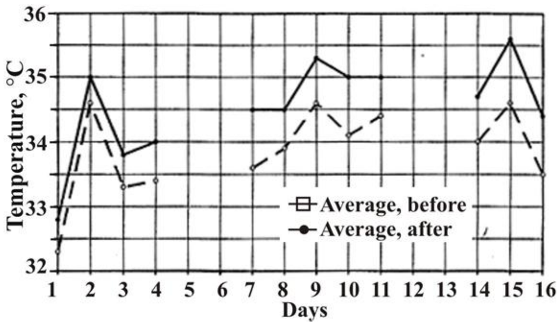


Fig. 6 - Infra-red thermograms of female chest before (left figure) and on the 4th day during radiation treatment (right figure), evaluated by computerized histographic method.

3.1 More simple data presentation

Skin temperature has been used as an indicator of the physiological and pathological condition of the human body for centuries. The infrared (IR) thermogrammetry (TGM) / thermography gives new vistas for the transient skin surface temperature measurements, too. IR-TGM can also be advantageously applied in radiation biology for comparative and quantitative diagnostic investigations. In Hungary, the technique was first applied in 1984, when the authors published a case study on a local radiation injury (4) and suggested that both contact and infrared thermography were useful tools in detection of the areas of radiation injury. While in 1984 a serious injury of a hand (20-30 Gy, locally) was described, later (3, 8) an injury caused by a much lower dose (1-2 Gy, locally) is reported when IR-TGM could still assist the diagnosis. The measurement results obtained enabled the authors to compare the radiation burden and the temperature distribution detected at the involved skin surface.

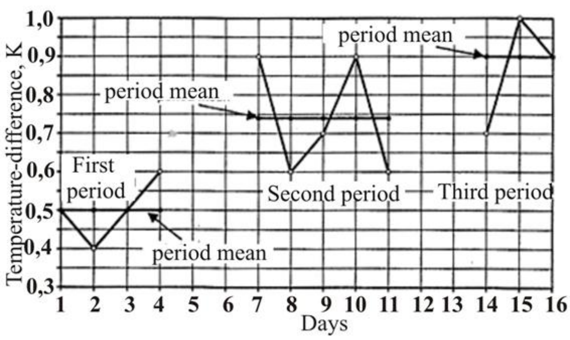
Fig. 7 -



Immediate changes of the average temperatures on the irradiated surfaces before and after each radiotherapy sessions

The method of data analysis was elaborated and applied for the investigation of six patients. The irradiated areas as shown on Fig. 4 have absorbed 2.5 Gy at each session but from various energies. The radiation treatment was performed through three consecutive weeks, 5 irradiation sessions per week applied daily (Fig. 5), the beta-dose was 12 times 2.5 Gy. The treatments on week-end days were omitted.

Fig. 8 -



Changes of average temperature differences as measured before and after radiotherapy sessions during the treatment (based on Fig. 7).

The immediate effect could be seen already 20-30 minutes after irradiation (Figs. 7, 8 and9). These post-operative irradiations always complete the complex therapy of breast cancer patients.

We can observe the immediate changes of the surface temperature because of the radiation treatment and Fig. 7 shows the average temperatures changes on the irradiated surfaces before and after each radiotherapy sessions.

On the base of Fig. 7 we can calculate the changes of average temperature differences as measured before and after radiotherapy sessions during the treatment (Fig. 8).

The fluctuation's process of the field of temperature can be present by Fig. 9 showing the changes of average temperature values of irradiated area before and 24 hours after each irradiation in function of the cumulative absorbed beta-dose.

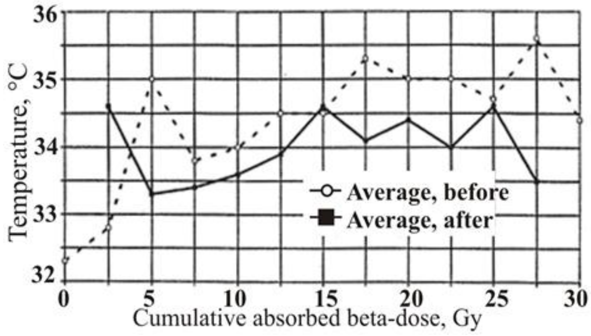


Fig. 9 - Changes of average temperature values of irradiated area before and 24 hours after each irradiation in function of the cumulative absorbed beta-dose.

3.2 Presentation of effects of radiation treatment

The following information can be obtained and this is important for medical application:
(a) the detection of injuries mainly in comparison with the relevant contralateral part of the body;
(b) visualization of the extent of the injury and;
(c) the possibility of follow-up of the pathological condition.

In determining the temperature fields of various characteristics, the choice is between the following general methods, while their relative advantages and disadvantages must be decided in the light of the test being performed:
(a) the selection of the temperature interval to be tested and, within that, the decision over the choice of the number and widths of the isostrips;
(b) determining the temperature at specified points of the surface under test (e.g. the centre point of the cross hairs);
(c) comparison between temperature distributions along the horizontal and vertical lines;
(d) determining the temperature distribution and mean temperature in smaller specified areas of the surface tested;
(e) statistical methods for the description of temperature distribution (e.g. histographic processing, and distribution curve of the histogram) and image filtering.

Thermographic evidence of previous radiation exposure can also be obtained in the latent phase of the pathological process (2). Unfortunately, the dose estimation cannot be performed immediately from the thermal map (thermogram). Recently, however, it is considered to be of value to demonstrate the dose range in which the thermographic signal, i.e. the change in the local temperature, indicates the radiation injury or burn. Accordingly, a series of measurements were initiated on patients submitted to ionizing radiation after surgical mastectomy. The evaluation of thermograms was made by computerized analysis transforming the altered temperature distribution to histograms (5, 6). By this more sensitive approach to analysis it was found that temperature alterations following even a dose 2.5 Gy from accelerated electron irradiation after the first treatment session could be detected and followed during the whole treatment. In a case report, the present authors also published a successful demonstration of temperature increase following an accidental 1-2 Gy irradiation of a hand (9).

Following the post-operative radiation treatment over a period of 3 weeks, three phases of effect were observed. The following characteristics of the thermal reactions were identified : in the case of the thermal approach to the quantitative measurement of radiodermatitis of ionizing irradiation, the thermal skin reactions at the beginning affected by the thermal equilibrium of two main factors, namely biological phenomena of irradiation effects and thermal regulation, i.e. injury and tissue regeneration.

The dynamics of the thermal reactions in the first week can be seen in figure 3. During the first week the patient was irradiated on consecutive days, four times, with 2.5 Gy each session. It is obvious that, after the first treatment session, i.e. 2.5 Gy, the temperature has been considerably increased (Fig. 10). The value of median temperature changed approxymately 32.5 to 34.5 °C .The shape of the distribution curve was not significantly changed.

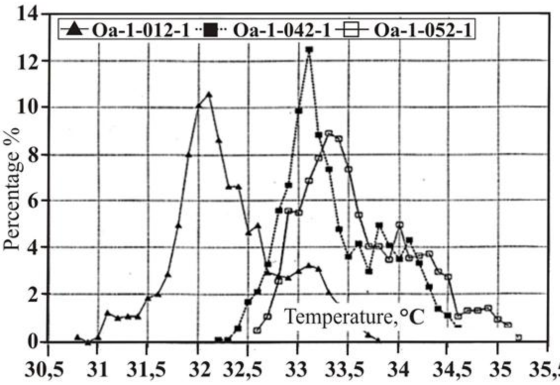


Fig. 10 - Series of histograms of the temperature values on the beta-irradiated areas at the 1st (No. 012), 4th (No. 042) and 7th (No. 052) day during radiation treatment (first week).

Accepting that the increased temperature is a normal tissue reaction to radiation-induced skin reaction, it can be seen that at the end of the first session the skin temperature increased (Fig. 10) in contrast with the second and third sessions (weekends) when it was decreased (Figs 11 and 12). This may indicate that the regulatory functions of the skin have been relaxed. On further irradiation, the radiation reaction were not additive; just a decrease of the average temperature was observed especially when there was a break of two days in the treatment protocol. Accordingly, the increases in radiation doses do not increase the tissue reactions but, in contrast, induce a modulation.

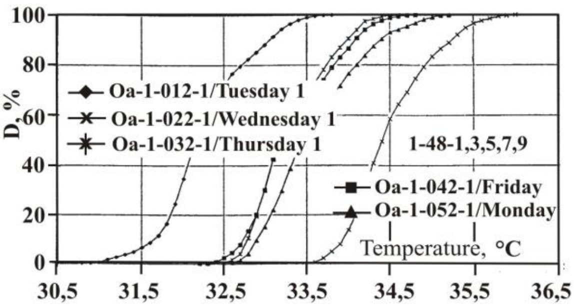


Fig. 11 - Series of distributions of the temperature histograms of β-irradiated areas in the first week.

Finally there is an equilibrium of skin reaction and thermal regulation's fluctuation. Lacking reliable dosimetry, the radiotherapist must consider the nature and severity of signs and symptoms, the protracted expression of the injury, and the timing and differential expression of injury in various tissues, when deciding treatment options and prognosis.

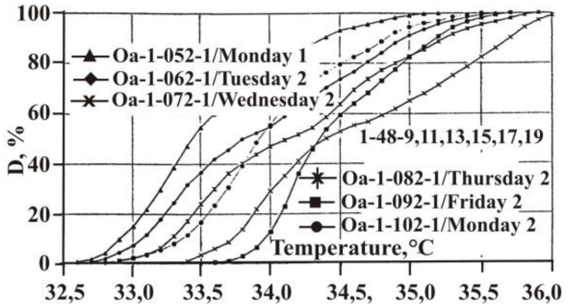


Fig. 12 - Series of distributions of the temperature histograms of β-irradiated areas in the second week.

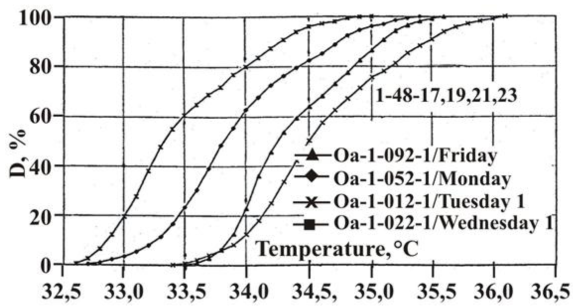


Fig. 13 - Series of distributions of the temperature histograms of β-irradiated areas in the third week.

In summary, the measurements from the thermal image proved to be useful tools in both the

prognosis of local radiation injuries in a wide dose range. A definitive non-invasive method to determine the extent and magnitude of a local or partial body radiation injury was found.
In addition, numerous techniques can be utilized to evaluate circulation in an affected area, to determine the volume, depth and area of tissue affected. Other medical imaging techniques include angiography, radionuclide imaging and non-invasive technique such as impedance plethysmography, magnetic resonance imaging and ultrasound. Techniques capable of evaluating superficial blood flow and tissue perfusion have clinical value for the physician, who must counsel the patient and make critical decisions regarding medical or surgical treatment.

7. CONCLUSIONS

The details of observed results are indicated in the legends of the figures. Diagrams are given describing the temperature variation effects resulting from the beta-irradiation in function of the time of treatment, as well as versus cumulative absorbed beta-dose.The results presented give evidence for the efficient use of infrared technique in diagnosis and follow-up of local beta-irradiation. Upon the former and present experience we suggest that infrared thermogrammetry can be used in detection of the extent of beta-irradiation even at doses which do not cause clinically significant signs and symptoms.

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Thermographic Examination for Hypothermia

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SUMMARY

Hypothermia is one of the critical phenomena for homothermic animals. It was certified that the hypothermic condition in refuges was unpleasant condition for refugees in the first study. In the second study the usefulness of thermography for diagnosing hypothermia of the patients during surgical therapy was evaluated. Pneumoperitoneum using in the laparoscopic surgery was one of the cause of intra-operative hypothermia. The cold carbon dioxide is used for pneumoperitoneum. Posture in surgery also related to hypothermia. The patients with lithotomy position for some lower abdominal surgery had hypothermia in surgery. The reason of this phenomenon is that there are small areas we can warm up the patients. Prone position in the vertebral surgery causes hypothermia. There are also small areas we can warm up the patients. But, the patients avoided hypothermia by warming the air under the patients' abdomen. Thermography was very useful for making sure the effectiveness of these countermeasures.

1. INTRODUCTION

Hypothermia is not only unpleasant phenomenon for the people but also dangerous condition for human life. We had many experiences hypothermia harm the important functions of human body. On the other hand many thermological researchers know that thermography can detect the abnormal thermal condition of the human body easily (1-4). In this paper it is in-troduced the cases thermography was used effectively and it is discussed the utility of the thermographic examination.

2. HYPOTERMIA IN REFUGES

2.1 Purpose

For the purpose of clarifying the uncomfortable ther-mal condition in the refuges the temperatures of the mattress laid on the floor and the temperature change of the bottles with warmed water as simulated body were measured by thermo camera.

2.2 Temperature of matress

In the first experiment the temperatures of the ta-tami mat and floor and that of the mattresses on the tatami mat and the floor were measured by portable thermo camera. The temperature and the humidity of the experiment room were 17.8 centigrade and 40%.

The temperature of the tatami mat was 17.0 centigrade and that of the floor was 16.5 centigrade. The temperature of the mattress laid on the tatami mat was 17.4 centigrade and that on the floor was 16.9 centigrade.

2.3 Temperature change of warmed bottle

In the second experiment the temperature change of the warmed bottles was measured. A mattress was laid on the tatami mat and another mattress was laid on the floor. Two bottles with the water were warmed to 21 centigrade. The bottles were put on the each mattress. They were covered by quilts. The temperature change of the tow bottles were measured by the portable thermo camera from the start to 50 minutes after the start.

The temperature of the bottle on the tatami mat decreased gradually and that of the bottle on the floor decreased more rapidly. The temperature of the bottle on the tatami mat changed to 19.3 centigrade at 50 minutes after the start and that of the bottle on the floor changed to 16.9 Centigrade at the same time (Fig.1).

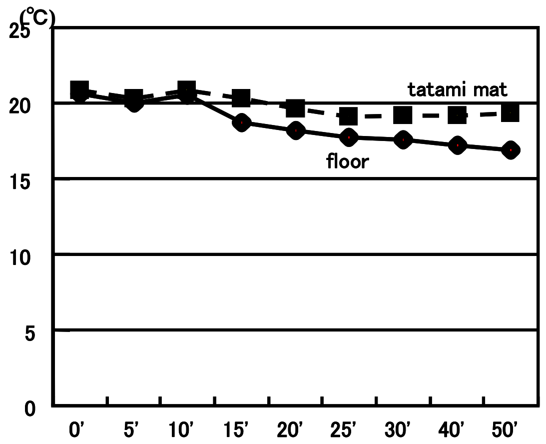

Fig. 1 - Temperature change of warmed bottles. The temperature of the warmed bottle on the floor decreased earlier than that on the tatami mat.

2.4 Discussion

It was well known that there were many people who lived in the cold gymnasiums after the huge earthquake in Japan. They slept in the thin mattresses laid on the floor directly. It was reported that some old people had health troubles in such environment. Then, it was tried to exam the uncomfortable condition in the refuges experimentally. The results show that the thermal condition is uncomfortable for the people sleeping in such refuges. It is also a bad factor that the ceiling of the gymnasium is very high.
After the earthquake two teams for medical assistance brought the portable thermo camera to the distressed area. But, the usefulness of thermo camera was not known by the medical staffs and the people in the refuges, the thermo camera could not be used effectively. Then, the thermological researchers should make the usefulness of thermography known to the world. It can not only detect the diseases but also evaluate the thermal condition for healthy livings.

3. IN SURGICAL CENTER

3.1 Purpose

It is well known for surgeons that the intestinal movement recovers earlier after the laparoscopic surgery than that after the open surgery. They thought that the thermal condition kept well in the laparoscopic surgery. On the other hand many anesthesiologist know the body temperature in the laparoscopic surgery decrease more largely than that in the open surgery. In this part of the study it is evaluated the thermal condition of the patients undergoing surgical treatment and it is also considered about the mechanism of the thermal change. Then, it is showed the countermeasures for the patients undergoing surgical treatment with unusual positions.

3.2 Pneumoperitoneum in laparoscopic surgery

The subjects were the 14 colon cancer patients. They had ascending colon cancers or sigmoid colon cancers. The age of the patients was 73.6 ± 7.2 and there were 10 males and 4 females. Eight of them underwent open colectomy and remained 6 patients underwent laparoscopic surgery. The body temperature of the patients undergoing laparoscopic colectomy was measured and the results were compared with that of the open colectomy.
The body temperature of the patients underwent laparoscopic surgery was lower than that of the patients underwent open surgery (Fig. 2). The thermal difference between two groups at 1 hour before the end of pneumoperitoneum was statistically significant.

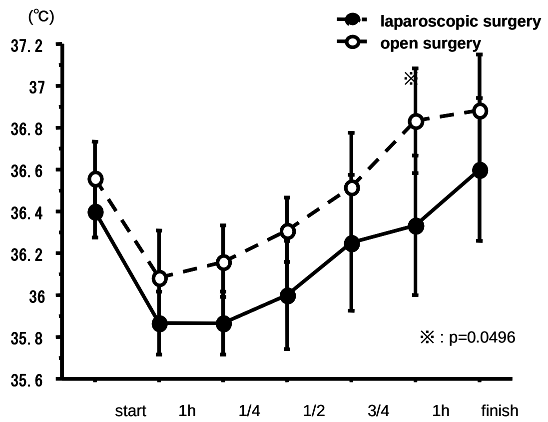

Fig. 2 - Change of body temperature in colectomy. The body temperature of the patients underwent laparoscopic surgery was lower than that of the patients underwent open surgery.

3.3 Mechanism of hypothermia in laparoscopic surgery

The subjects were 8 patients undergoing laparoscopic surgeries. The age of the patients was 65.0 ± 5.5 and there were 3 males and 5 females. Three of them underwent laparoscopic cholecystectomy and 5 of them underwent laparoscopic colectomy. The body temperature, the temperature of the abdominal wall, the temperature of the tube for pneumoperitoneum and room temperature were measured.
The body temperature and the temperature of abdominal wall decreased after the starting point of pneumoperitoneum. The temperature of the tube for pneumoperitoneum also decreased just after the start of pneumoperitoneum. But those temperatures increased in the second half of the operation. The

typical course of the temperature change in laparoscopic colectomy is showed (Fig. 3). The room temperature was not changed in all periods of the operation. But, the tube temperature decreased rapidly after pneumoperitoneum, and the temperature of the abdominal wall and body temperature decreased following it. In the next period, the tube temperature rose gradually. The temperature of the abdominal wall rose with delaying ten minutes after it, and then the body temperature rose.

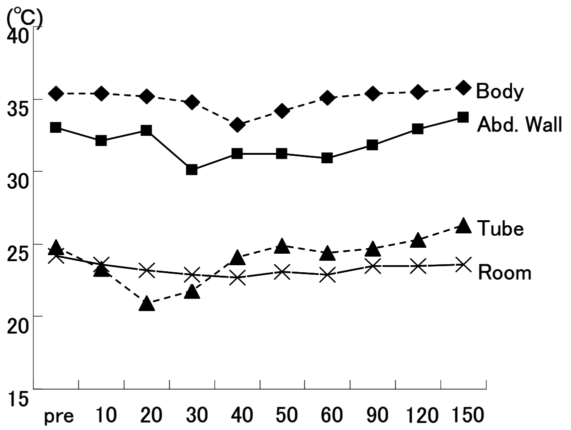

Fig. 3 - Temperature change of the typical case. The lowest point of the abdominal wall temperature was ten minutes later than the tube temperature. In the next ten minutes, the body temperature became lowest.

3.4 Methods for keeping warmth in surgery

The subjects were 28 cases underwent laparoscopic surgery. The age of the patients was 67.3±9.5 and there were 13 males and 15 females. Fourteen of them underwent cholecystectomy, 5 of them underwent distal gastrectomy and 9 of them underwent colectomy. Five patients of 14 cholecystectomy cases underwent the surgeries by broad base position; other patients underwent it by normal lie position with leg closed. The distal gastrectomy was performed by normal lie position. The colectomy was performed by lithotomy position. The conditions of pneumoperitoneum were same for all patients. The changes of body temperature were compared with the operative method and the position in laparoscopic cholecystectomy.

The body temperature of the patients with gastrectomy decreased 0.2 degrees and that of the patients with colectomy decreased 0.6 degrees at 75 minutes after the start of pneumoperitoneum. These differences were statistically significant (Fig.4).

The body temperature of the patients underwent cholecystectomy by normal lie position was almost stable. But, the temperature of the patients who underwent the operation by broad base position decreased from 0.1 to 0.3 degrees (Fig.5).

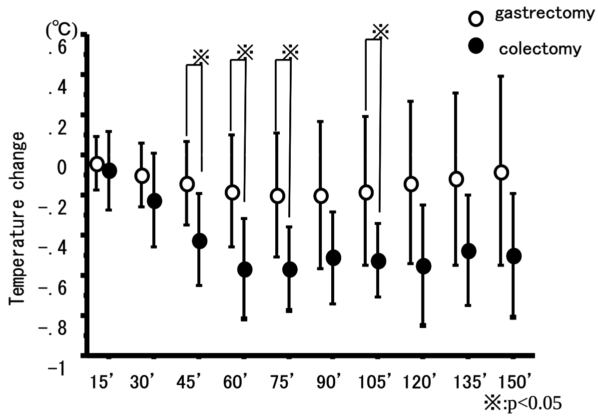

Fig. 4 - Change of body temperature in laparoscopic surgery. The body temperature of the patients underwent laparoscopic colectomy was lower than that of the patients underwent laparoscopic gastrectomy.

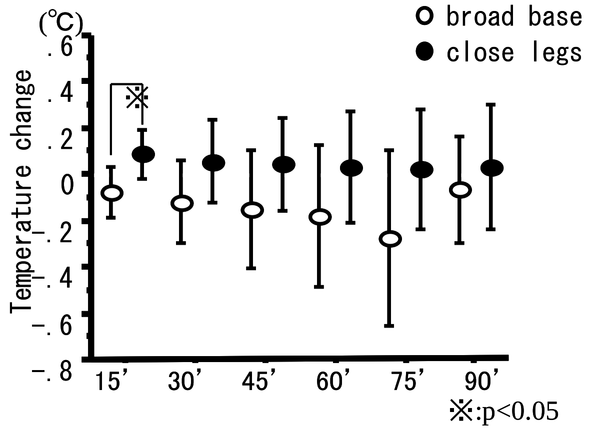

Fig. 5 - Temperature change in laparoscopic cholecystectomy. The body temperature of the patients underwent cholecystectomy by broad base position was lower than that of the patients underwent the operation by normal lie position.

3.5 Warming method in vertebral surgery

The subjects were 14 cases underwent vertebral surgery by prone position, in which the patients' bodies were fixed with floating. Six of them underwent the surgery using traditional warming method and 8 of them underwent the surgery using new warming method. In the new method the patients' chests and abdomens were heated by the warmed air blanket under the bodies.

The body temperature of the patients warmed by the new method was higher than that of the patients warmed by traditional method at 120 minutes after the start of the operations (Fig.6) The difference was statistically significant (p<0.05).

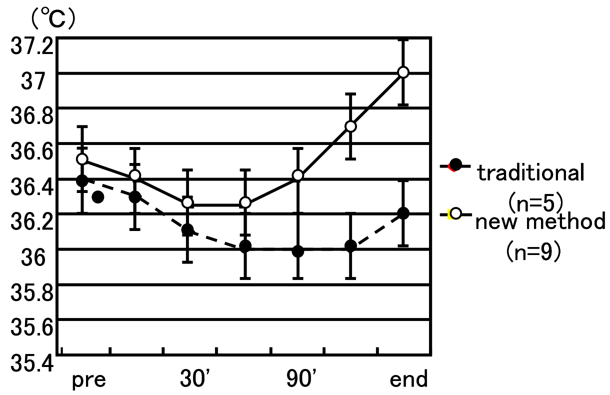

Fig. 6 - Temperature change in vertebral surgery. The temperature of the patients warmed by new method was higher than that of the patients warmed by traditional methods.

3.6 Discussion

Human beings are a homothermic animal and the accidental hypothermia sometimes bring death to them. Even if it is not so sever hypothermia, some organs of the human body are damaged and their functions have some problems. Kurz et al reported that the risk of surgical site infection could be decreased by avoiding the hypothermia in colorectal surgery. Laparoscopic surgery had seemed to keep out of hypothermia, because abdominal cavity was not opened. But the result of this study showed that the body temperature of the patient underwent laparoscopic surgery is lower than that of the patient underwent open surgery.
In the result of the second study it was showed that the temperature of the tube for pneumoperitoneum decreased rapidly because of the cold carbon dioxide gas. And it started to rise at 20 minutes after the start of pneumoperitoneum. The reason of this phenomenon was that the tube was warmed by some medical energy devices just behind the tube. The temperature of abdominal wall and the body temperature rose after rising the tube temperature. These results indicate that the reason of the hypothermia in laparoscopic surgery is the cold carbon dioxide gas for the pneumoperitoneum.
For detecting another reason of hypothermia in laparoscopic surgery the changes of body temperature were measured in some kinds of laparoscopic surgery. The result of this study shows that another reason of the hypothermia is lack of the skin surface being warmed in the operative period. Because the body temperature of the patient underwent laparoscopic colectomy by lithotomy position is lower than that of the patient underwent laparoscopic gastrectomy. It is very difficult to warm the patient bodies in the operation performed by lithotomy position. The results of comparing the temperature of the patients underwent the laparoscopic cholecystectomy by two positions also demonstrate that the patients' position in laparoscopic surgery is important for avoiding intra-operative hypothermia.
There are some other operative methods with the problem in the position. One of them is vertebral surgery. It is performed by the prone position. The patient's body is fixed with the floating position. Then, it was also difficult to warm the patient. It is impossible to warm the patient back, which is surgical site. The new method for warming body was invented as a countermeasure after the thermographic experiment. In the new method the chest and abdomen of the patients were warmed by the warm air blanket under the body. And the result of this study showed that the new contraption for warming the body is useful for keeping body temperature. And these researches demonstrated that the thermographic examination is useful for considering the countermeasures for hypothermia.

4. CONCLUSIONS

Hypothermia should be avoided for the comfortable life and the safety surgery. Thermography is useful for detecting hypothermia and it should be used more frequently for evaluating the methods of keeping away from hypothermia.

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Scrotal Infrared Digital Thermography for Detection of Subclinical Varicocele

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SUMMARY

Varicocele is the condition of abnormal venous dilatation of the pampiniform plexus and scrotal veins with blood reflux. In the literature the association of varicocele with male infertility risk has been described: venous reflux and the following scrotal thermal impairment have a deteriorating effect on spermatogenesis, even when assessed in asymptomatic subjects. Therefore a correct and early diagnosis of varicocele is mandatory. The aim of this study is to emphasize the diagnostic value of scrotal thermography in the investigation of varicocele combined with Color Doppler Ultrasound (CDU), considered the “gold standard” diagnostic tool thanks to its feasibility for measuring venous vessel size and blood flow parameters. 51 young asymptomatic volunteers (age range 18-36 years) underwent clinical examination, scrotal thermography and CDU, after providing informed written consent. Sarteschi classification was used for CDU evaluation. Among subjects, 21 (21/51, 40%) had left unilateral varicocele, detected using CDU; 21% (11/51) presented varicocele grade II, 11% (6/51) grade III and 8% (4/51) grade IV. Scrotal thermography documented an increased temperature and faster recovery of the left hemiscrotum in the same ones; a basal testicular temperature greater than 32°C and basal pampiniform plexus temperature greater than 34°C were considered warning values. Moreover thermal impairment of the left pampiniform plexus was assessed in other four subjects, whose CDU exam showed a higher vessel size (≥ 3 mm) with normal blood flow parameters. Clinical examination, affected by a low sensibility and specificity, showed the presence of left varicocele in only 12 volunteers (12/51, 24%). Our experience confirms that scrotal thermography is a feasible and low cost diagnostic tool for varicocele. Even if CDU remains the method as a reference, thanks to its high sensitivity, we suggest the use of scrotal thermography in screening programme in the assessment of subclinical varicocele.

1. INTRODUCTION

Varicocele is characterized by abnormal dilation and tortuosity of the pampiniform plexus secondary to a defect in the venous renospermatic system. The disorder is due to the blood flow inversion within the internal spermatic vein, which drains into the renal vein on the left side and directly into the inferior vena cava on the right side (1). Its incidence in young healthy male individuals is known to be 8-23%, with the left side being affected in 70-100% of cases and the right side in only 0-9% of cases; it is bilateral in 0-23% of cases (3).
Symptomatic varicocele is rare: it could cause testicular pain and discomfort.
Primary varicocele (idiopathic) could be related to valve incompetence, to retroperitoneal location of the internal spermatic vein (absence of contiguous muscles improving centripetal blood flow), to renal-vein abnormalities (e.g. “nutcracker syndrome”, retroaortic left renal vein) and to vessel wall features. Secondary varicocele can be due to several pathological conditions (e.g. pelvic, abdominal and renal expansile processes, lymphomas, cecum cancer, hydronephrosis, hydroureter, pseudoaneurysm, splenorenal shunt due to portal hypertension).
Varicocele is potentially a progressive condition that may affect male fertility. Its prevalence in infertile men is about 30-40% (9). The most important factor is the venous reflux into the pampiniform plexus and the following scrotal thermal impairment and testicular tissue hypoxia which seem to have a deteriorating effect on spermatogenesis, even when assessed in asymptomatic subjects. Therefore a correct and early diagnosis of varicocele is mandatory.

Currently methods for diagnostic assessment of varicocele are a physical examination and Ultrasonography (US) and unenhanced Color Doppler Ultrasound (CDU), considered “gold standard” tools in the diagnosis and staging of varicocele (4, 10).
Thermography is a diagnostic method to record maximum and minimum temperatures across the skin surface of a select area using a highly sensitive infrared camera: therefore scrotal hyperthermia is evaluated through the measurement of the scrotal cutaneous temperature by means of thermal infrared imaging (2, 5, 6, 7, 8).
The aim of this study is to emphasize the diagnostic value of scrotal thermography in the investigation of varicocele combined with Ultrasonography/Color Doppler Ultrasound (US/CDU), especially in the assessment of subclinical one.

2. METHODS

Between April 2011 to date, 51 asymptomatic volunteers (age range 18-36 years), participating in a screening of young men reproductive diseases, underwent clinical examination, scrotal thermography and US/CDU, after providing informed written consent. No one had recently referred testicular inflammatory or cutaneous layers diseases; four (4/51; 8%) were surgically treated for phimosis. Participants were excluded if they presented history of cardiovascular, or neurovascular disorders, hypertension, history of drug or alcohol abuse and any therapeutic treatment. Men suffering from hydrocele were excluded too.
All subjects underwent clinical examination, US/CDU imaging, and infrared thermal thermography. US/CDU was performed with an Esaote, MyLab Xvision. They were first scanned during quite respiration and during Valsalva maneuver while supine, then while standing. For scrotal structural analysis, B-mode US with a high resolution and linear-array transducer with a frequency of 7.5 MHz was used. Bilateral transverse and longitudinal slices of the scrotum are performed to allow side-to-side comparison of their sizes and echo texture. CDU is established to illustrate scrotal macro and microcirculation, and to detect the varicocele grading based on retrograde blood flow during Valsalva maneuver and increased diameter of testicular veins. Sarteschi classification was used for CDU evaluation.
For each subject, the functional response to a mild cold challenge of scrotum was assessed by thermal infrared imaging (6, 7). All participants were asked to refrain from physical activities and intake of vasoactive substances for 2 hrs prior to the measurements. Before undergoing to measurements, the subjects took off pants and underwear leaving naked only the scrotum and the penis. Then they moved to the recording room which was set at standardized temperature (23 °*C*), humidity (50 - 60%), and without direct ventilation, in which they observed a 20-min acclimatization period prior to undergo the thermal imaging. The subjects comfortably sat during both acclimatization and measurement periods and were asked to keep their legs slightly divaricated in order to facilitate the thermal infrared imaging. The penis was gently attached by using medical tape to the lower abdomen in order to obtain clear thermal images of the scrotum Thermal infrared imaging was performed by means of a digital thermal camera (FLIR SC660, FlirSystems, Sweden), with a Focal Plane Array of 640 x 480 QWIP detectors, capable of collecting the thermal radiation in the 7-14 μm band, with a 0.02 s time resolution, and 0.04 K temperature sensitivity. Cutaneous emissivity was estimated as $\varepsilon \approx 0.98$. The thermal camera response was blackbody-calibrated to null noise-effects related to the sensor drift/shift dynamics and optical artifacts. Thermal images of the scrotum of each subject were recorded for 25 minutes, acquiring images every 30 seconds. Five thermal images were recorded before the cold stress to obtain the baseline of scrotum temperature. Each image series was corrected for motion artifacts by means of a contour alignment algorithm. The cold stress was achieved by applying a dry patch - maintained at 10° C - to the scrotum for two minutes. The penis was protected from the cold stress by avoiding any possible contact with the cooling patch which was shaped to be in contact with the scrotum only. Re-warming curves were obtained separately for each of the two hemiscrota, by averaging the temperature of the pixels within the cutaneous projection of the testis.
The basal prestress temperature and the recovery time constant τ at the level of the pampiniform plexus and of the testicles were evaluated on each hemiscrotum. A basal testicular temperature greater than 32°C and basal pampiniform plexus temperature greater than 34°C were considered warning values (2). Temperature differences among testicles (ΔT_t) or pampiniform plexus ΔT_p temperature greater than 1.0°C were also considered warning values, as were $\Delta\tau_p$ and $\Delta\tau_t$ values longer than 1.5 minutes (Merla 2002).

3. RESULTS

At a physical examination, the presence of left varicocele was evidenced in 12 volunteers (12/51, 24%). At CDU, among subjects, 21 (21/51, 40%) had left unilateral varicocele; 21% (11/51) presented varicocele grade II, 11% (6/51) grade III and 8% (4/51) grade IV. In all 21 patients diameter of pampiniform veins were larger than 2-3 mm, with positive reflux longer than 3 s during Valsalva maneuver. No one had right or bilateral varicocele.

Fig. 1 - Example of scrotal hyperthermia secondary to III grade left varicocele.

Values for ΔT_p and the $\Delta\tau_p$ were higher than the warning thresholds in 25 of the 51 men.
CDU imaging and clinical examination classification confirmed the presence of grade 2-4 varicocele in these subjects.

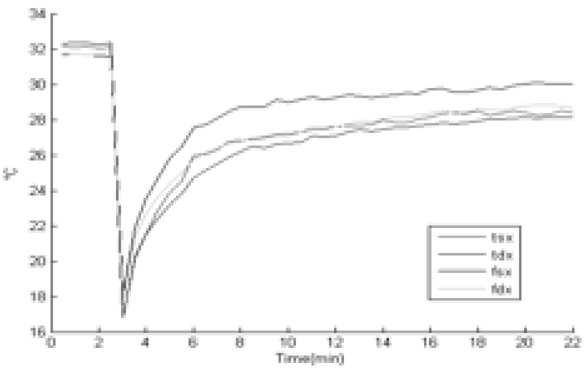

Fig. 2 - Example of scrotal rewarming curves after functional thermal stimulation.

Thermal imaging yielded four false-positive, which were considered as early stage (grade 1 varicocele) at CDU investigation and no false-negative results.
The sensitivity and specificity of thermal imaging were 100% and 92%, respectively. Analysis of variance showed strong statistical significance of basal values and rewarming values associated with scrotal asymmetry. The sensitivity and specificity of the combined thermal imaging and CDU were 100%.

4. CONCLUSIONS

Our data demonstrate that an abnormal change in the temperature of the testicles and pampiniform plexus may indicate varicocele. Furthermore, impaired thermoregulation is associated with varicocele-induced alteration of blood flow (5). Time to recovery of pre-stress temperature in the testicles and pampiniform plexus appears to assist in classification of the disease. Cold stress enhances the altered thermal properties of the affected hemiscrotum and may provide useful information in future studies of scrotum thermoregulation, varicocele, and fertility.
Findings on thermal imaging, clinical examination, and echo color Doppler imaging were very consistent. Infrared functional imaging consistently and accurately indicated that 25 men had no symptomatic varicocele. No control on spermatic activity was done, because we aimed to assess whether impaired thermoregulation was associated with varicocele.
According to our experience, clinical examination is affected by low sensibility and specificity. Therefore, clinical examination alone cannot adequately diagnose small and subclinical varicocele. US/CDU represent the "gold standard" method and a well tolerated imaging modality for evaluation of varicocele; nevertheless one of its disadvantages is that it chiefly depends on experience and interpretation of examiners.
Despite its low specificity and inability to distinguish between varicocele and other scrotal pathology, we emphasize that infrared digital thermography is a feasible and low cost diagnostic tool for varicocele; thanks to its high sensitivity, we suggest the use of scrotal thermography in screening programme in the assessment of subclinical varicocele.

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The Highly Focalized Thermotherapy in the Treatment of Solid Tumors: Temperature Monitoring Using Thermography

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SUMMARY

The use of hyperthermia in the tumor treatment is based on the well-established concept that heat has selective lethal effects on tumor tissues. A new hyperthermia technique, the Highly Focalized Thermotherapy (HFT), was developed in an attempt to localize the heat in the tumor. The aim of the present study was to evaluate the capability of monitoring the temperature variation by using the HFT in a melanoma mice model, through thermography. B16F10 melanoma mice (C56BL6) were injected with a Ferrimagnetic Cement and exposed to a high frequency magnetic field to generate heat within the tumor. The animal body temperature was monitored through a thermal camera FLIR A325, after removing the fur in the area of the tumor. Through thermography, the skin temperature was assessed and logged its maximum value. The HFT application in the melanoma mice model resulted in a temperature increase in the tumor. Comparing the initial tumor temperature with the tumor treatment temperature, there was an increase of 5-6 ºC in the first 5-10 minutes, whereas the body temperature showed only a limited increase (2-3 ºC). In this superficial melanoma model, the animal's temperature can be monitored using a thermographic camera. It is possible to measure the temperature variation, simultaneously, in the whole body and in the tumor, during the treatment, preventing unwanted heat effects in other tissues.

1. INTRODUCTION

THyperthermia, in the tumour treatment, is based on the well-established concept that heat has selective lethal effects on tumour tissues (2). Nowadays, many techniques are available to produce hyperthermia, but they are generally limited by the in-ability to selective target the tumour cells, with subsequent risk of affecting adjacent healthy tissues (2, 4, 5). In an attempt to solve this limitation, a new hyperthermia technique was developed, the Highly Focalized Thermotherapy (HFT). This new methodology is based on the concept of the Magnetically Mediated Hyperthermia (MMH) (6). The technique consists in the direct injection of an experimental material, the Ferrimagnetic Cement (FC) within the tumour and then the exposition to a high frequency magnetic field (HFMF). The aim is to increase the tumour tempera-ture, based on the principle that a magnetic particle can generate heat, under a HFMF. Heat is than dissi-pated throughout the tumour tissues. With this ap-proach we pretend to localize the heat in the tumour region, to the intended temperature (4 to 10 ºC upper them the initial temperature), without damaging nor-mal tissue.

The temperature monitoring during the treatment is crucial, because at Higher temperatures, up to 56 ºC, will produce the unwanted "thermo-ablation", yield-ing widespread necrosis, coagulation or carbonization (3).

In superficial tumors such as the melanoma, the tumor temperature variation can probably be moni-tored through a termographic camera that will be a non invasive method for the temperature monitoring during the HFT treatment.

The aim of the present study was to evaluate the capability of thermography to monitor the temperature variation in a melanoma mice model during the HFT treatment.

2. METHODS

2.1 Tumor induction

The experimental tumours were induced by subcu-taneous inoculation of B16F10 melanoma cells (2 x 10^5 cells/80µl culture medium) in the C57BL6 animals dorsal lumbosacral region. Tumours grew freely until they reached approximately 10 mm in diameter (corresponding to ≈ 520 mm^3 in volume), which was observed 15 days after inoculation.

2.2 HFT treatment

FC is a calcium silicate cement that, with a determined powder/water ratio, a paste can be obtained (7). The FC paste was injected in the tumor and, 48h latter, animals were exposed to the HFMF (frequency 10 kHz) created by a vertical coil (diameter 110 mm, 12 turns), using the induction system High Frequency Electronic Furnace K10/RV (CALAMARI and Milan, Italy).

2.3 Temperature monitoring

The animal body temperature was monitored through a thermal camera, FLIR A325, and analyzed using the software ThermaCAM™ Researcher Professional 2.9. The control of the HFMF strength was manually adjusted, so that the desired temperature of the tumor was kept constant. To allow a more accu-rate body temperature measurement using thermography, the fur that covers the animal's body was removed in the tumors area. The camera color pallet range was set from 19.5 to 43 ºC, and the area to be evaluated, defined as a circle within the software, logged the maximum value.

3. RESULTS

The HFT application in the melanoma mice model resulted in a temperature increase in the tumor. It was observed, through the thermographic image that the initial tumour temperature varies between 30 and 35 ºC and the animal's body temperature showed values between 27 and 31 ºC, depending on the animal (Figs. 1A and 3A). It is important to note that the animal all body fur was not removed and this certainly interferes with temperature lecture, due to the fur isolation of the temperature and to the different emissivity, and this is the major explication for the temperature discrepancy between the tumor and the animal's body. However, comparing the initial tumor temperature with the tumor treatment temperature, there was an increase of 5-6 ºC in the first 5-10 minutes, whereas the body temperature showed only a limited increase (2-3 ºC). When the desired temperature was reached, it was maintained during all the treatment period, by controlling the magnetic field intensity (Fig. 2).
The temperature increase during the HFMF exposition is confirmed in all animals, independent of its initial temperature, as seen in figs. 1B and 3B. It was also evaluated the capacity to increase the initial tumor temperature, more than the 6 ºC, and it was possible by the augmentation of the HFMF intensity in 2-3minutes (Fig. 3C). It is possible to increase the tumor temperature 9-10ºC above the initial temperature.

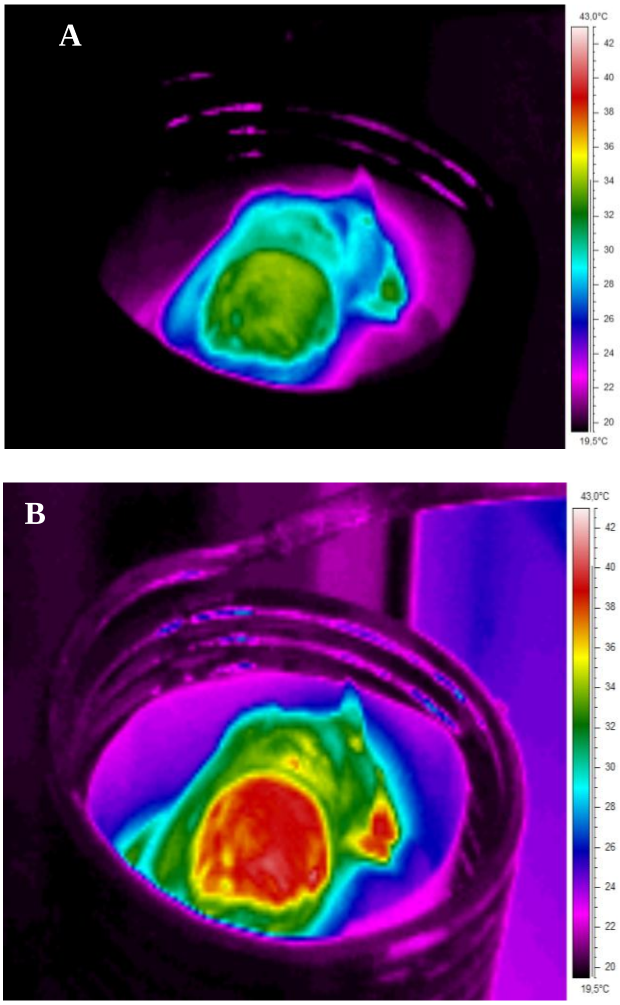

Fig. 1 - Animal thermographic image. A) Initial state temperature - before the HFMF exposure. B) During the treatment - 30 minutes of exposure to the HFMF.

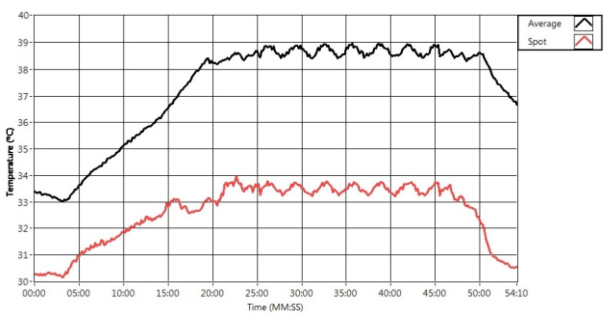

Fig. 2 - Time/temperature monitoring during the animal's HFMF exposition. Tumor area and the point (spot) in the animal's body far from the tumor.

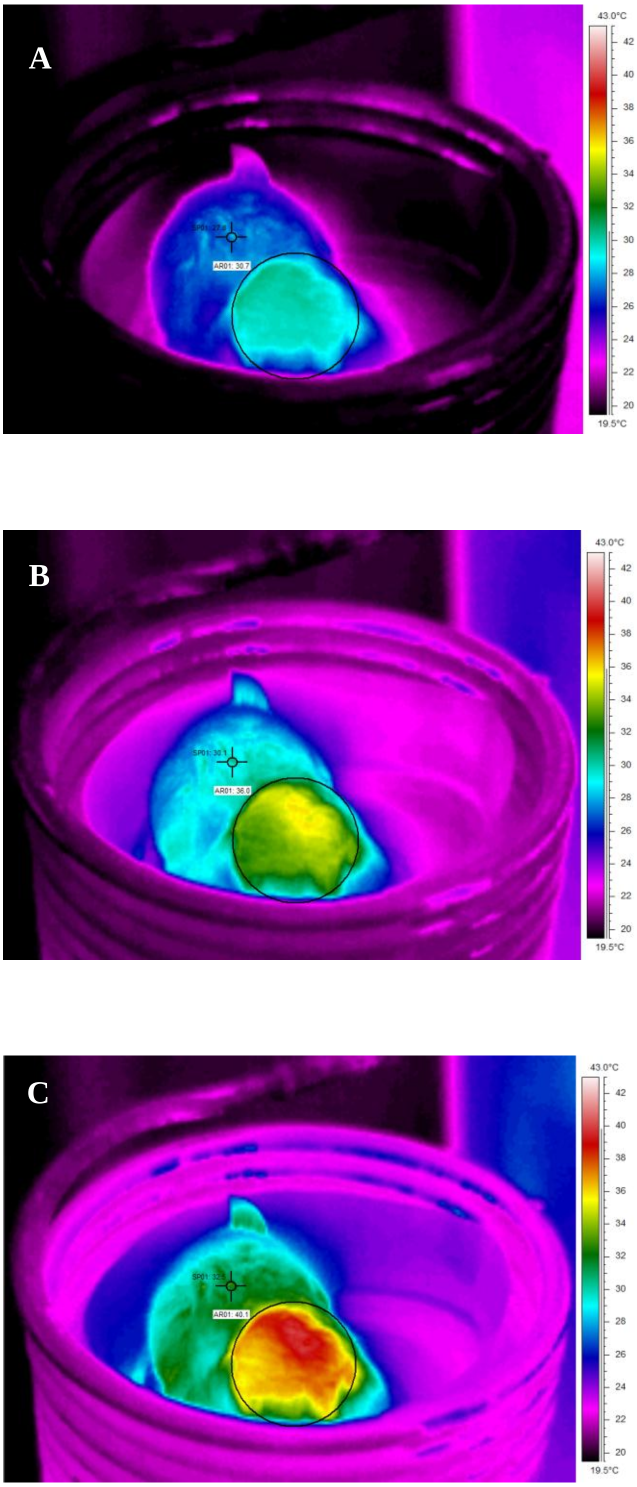

Fig. 3 - Animal thermographic image. The software used with the thermographic camera allows the determination of defined temperature points (spot) or areas.
A) Initial - area 30.7 ºC, spot 27.8 ºC.
B) During the treatment - area 36 ºC, spot 30.1 ºC.
C) It is possible to increase the tumor temperature through the augmentation of the magnetic field intensity. Area 40.1 ºC and spot 32.5 ºC.

4. CONCLUSIONS

In this superficial melanoma model, the animal's temperature can be monitored using a thermographic camera. With this methodology, it is possible to measure the temperature variation, simultaneously, in the whole body and in the tumor, during the treatment. Since energy deposition in tissues as well as cooling by blood flow are difficult to model, a good thermometry control is always needed in clinical practice. With the thermographic camera used in this study, it is possible to determine the temperature distribution in the tumor, the tumors average temperature, selected points in the image field and the temperature evolution along the time, just throughout the surface observations. This is essential to control the tumor temperature during the treatment period. In some studies it was used an optical temperature probe inserted intramuscularly near to the tumor, or within the tumor, near to the injection site of the magnetic particles. The disadvantages are that the temperature measured doesn't correspond to the real tumor temperature, is necessary skin opening and the leakage caused in the gelatinous melanoma tumor parenchyma increases the variability in tumor volumes (Saito 2008). The only limitations of the thermographic camera, is the tumor location. In the melanoma model and in a mammary tumor model (1), superficial tumors, this methodology has a great potential as a thermometry control method. In deeper location tumors, is necessary to use thermometry probes, which are invasive and give us just a temperature point and not the real temperature of the entire tumor.

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Thermography as an Alternative Tool to Determine Pressure Distribution on the Stump of Transfemoral Amputees

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SUMMARY

Lower limb amputation is a highly disabling condition affecting among others, mobility, activities of the daily and overall quality of life of the amputee. Prosthesis are custom made medical device intended to mimic the lost limb function, composed of several components, including a custom made socket, worn directly over the stump, usually made individually by hand to fit each individual stump. The socket is a crucial component, responsible for the load transfer between the prosthesis and the stump, control and stability of the prosthesis. The quality of the socket fit is crucial for the comfort, function, and energy consumption when walking with prosthesis. Despite this fact, the process of designing, producing and adapting a socket is usually a manual process, highly dependent on the experience of the prosthetist and on the individual and subjective perception of load reported by the amputee, dependent on a trial/error process to achieve a better fit, resulting in a costly process due to the number of visits to the workshop, as well as the number of prosthetics sockets that may have to be produced. The assessment of the stump/socket interface and pressure distribution is of paramount importance and the possibility of assessing the variables on a clinical setting on normal walking conditions, represents an important step forward on prosthetic production and rehabilitation. In this study the possibility of using thermography as a pressure distribution indicator is analyzed. The authors concluded that thermography may be a good indicator of force patterns within the socket walls and stump, allowing the possibility to determine among others the type of prosthetic socket, and therefore could be used as a tool on prosthetic production/rehabilitation. Further investigation is in course regarding the study of the stump/socket interface on lower limb amputees.

1. INTRODUCTION

1.1 Lower Limb Amputation

Lower Limb Amputation (LLA) is a highly disabling condition affecting the ability to stand up, walk, run and perform daily life activities involving ambulation. The leading cause for lower limb amputation on developed countries is dysvascular disease, commonly associated with diabetes; however traumatic injuries, cancer and congenital deficiencies are also commonly reported.

Besides affecting walking performance, the increased load on the non-amputated side, is thought to cause additional blood flow deficits in persons with vascular disease (4), back and leg pain (5) and premature wear and tear and arthritis on a long term basis because of the increased ground reaction forces. The effect of lower limb amputation on vascular disease is exacerbated by the common comorbidities that are associated and the impact of overloading the remaining limb. These combined factors result on diminished quality of life and activity levels. The altered weight bearing patterns can be also related to comfort and pressure distribution on the stump, when wearing prosthesis. Most frequently reported problems that had led to reduction in quality of life were heat/sweating in the prosthetic socket (72%), sores/skin irritation from the socket (62%), inability to walk in woods and fields (61%) and inability to walk quickly (59%). Close to half were troubled by stump pain (51%), phantom limb pain (48%), back pain (47%) and pain in the other leg (46%) (5).

It is estimated that on USA, in the year 2005, 1.6 million persons were living with the loss of a limb.

Of these subjects, 38% had an amputation secondary to dysvascular disease with a comorbid diagnosis of diabetes mellitus. It is projected that the number of people living with the loss of a limb will be more than double by the year 2050, in a figure of 3.6 million (1). The leading cause for amputation is also reported frequently. Severe peripheral arterial disease indicating critical ischemia has been found in 1.2% of a general population aged 60 years and in almost 5% of primary care patients aged 65 years (2).
In 2009 the data reported by ACSS - Administração Central do Sistema de Saúde, regarding amputation in Portugal is summarized on the table 1.

Table 1 - Amputations in Portugal 2009 (ICD-9M)

Total (GDH 113,114,213,285)	
Men **(mean age** 70 years old)	**1963 (66%)**
Women (**mean age** 78 years old)	**991 (34%)**

Source: ACSS *Administração Central do Sistema de Saúde database* (http://www.acss.min-saude.pt)

1.2 Prosthesis and Rehabilitation Outcome

Transfemoral prosthesis – Fig. 1 are custom made medical devices, intended to substitute the limb by replacing the limb part and mimicking the function of the knee and foot. The device is connected to the reminiscent limb by a socket, custom made to fit each individual stump; this interface has to be designed properly to achieve efficient load transmission, stability and provide sufficient control for the mobility expected when walking.
Supporting body weight in static and dynamic conditions is one of the main functions of the lower limb. Symmetrical weight shifting over the limbs during stance and gait is a relevant clinical problem for lower limb amputees. Due to amputation of one limb the center of gravity is shifted laterally to the side of the no amputated limb, a shift that is not fully compensated by the mass of the prosthesis. However, the commonly reported increase in vertical loading on the non-amputated side is not only related to the difference between the weight of the prosthesis and the weight of the anatomical segment. Other factors, such as pain and/or postural instability are probably responsible for the asymmetrical weight bearing during stance and gait (4).
The prosthetic socket – Fig. 2 is the component where all the forces acting on the body and from the ground interact. The socket should be adapted to fit the stump shape and must be properly contoured and relieved for functioning muscles.
A good prosthetic socket should therefore the following criteria:
a) Stabilizing pressure should be applied on the skeletal structures as much as possible and areas avoided where functioning muscles exist;
b) Functioning muscles, where possible, should be stretched to slightly greater than rest length for maximum power;
c) Force is best tolerated if it is distributed over the largest available area, reducing therefore problems derived from high localized pressure;
d) Properly applied pressure is well tolerated by neurovascular structures;

Regardless of the fitting method employed, the socket for any amputee must provide the same overall functional characteristics, including comfortable weight bearing, stability in the stance phase of gait, a narrow-based gait, and a swing phase as normal as possible consistent with the residual function available to the amputee. These characteristics will provide the format for a description of transfemoral sockets (7).
The socket fit is a key factor and determines the comfort of the amputee when standing, walking or performing everyday activities, as well as the ability to control the device. In the absence of a snug comfortable fit, the amputee may experience discomfort, pain and resulting in friction wounds and walking is then a process less effective in terms of energy consumption (2) The aim of the prosthetic rehabilitation is to provide for the amputees an early return to independent daily activities and mobility with lower limb prosthesis in their own environment. The comfort and satisfactory pressure distribution over the stump plays an important role on the prosthetic rehabilitation process, quality of life and performance the activities of the daily living. Despite the importance of this part of the process, it is usually achieved by a trial/error process, and the socket fitting process includes questioning the patient to assess the perceived pressure and comfort/discomfort zones, listening to unsolicited verbal reports of discomfort from the patient, making visual observations of tissue colors and contact pressures through the clear walls of a check socket, and using the finger or an object as a probe to estimate pressure magnitudes.
An understanding of the load bearing on the socket is of particular relevance to most transfemo-ral amputees because the main pain and discomfort they experience are related to the interaction between the socket and the residual limb. The function of the prosthesis may influence the effects of the applied forces on the residual limb and affect

the amputee's perception of comfort and the degree of control of movement of prosthesis is also dependent on the ability of the amputee to transmit the appropriate forces through the socket.
For a sound understanding of these forces and moments applied on the residual limb, it is essential that the loads measured in experimental conditions reflect those produced during the daily life of trans-femoral amputees. The objective of the present study is to describe a possible way of assessing pressure distribution on the socket of transfemoral amputee during everyday situations and on clinical conditions.

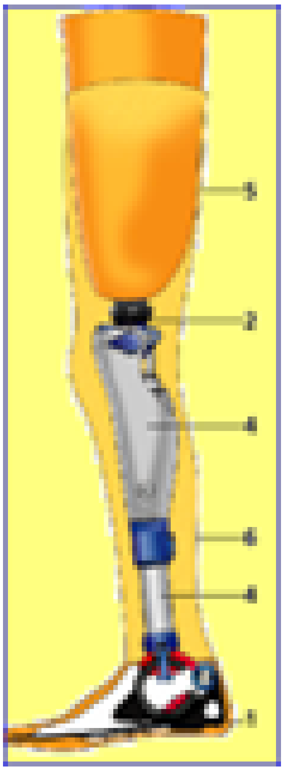

Fig. 1 - Transfemoral prosthesis - constituted by a socket, adaptors and tube prosthetic knee and prosthetic feet (8).

Fig. 2 - Examples of prosthetic sockets (coronal view) - CAT/CAM type and a Quadrilateral type.

1.3 The stump/socket interface and possible pressure measurement process

The basic principles for socket design vary from either distributing most of the load over specific load-bearing areas or more uniformly distributing the load over the entire limb. The skin and the underlying soft tissues of the residual limb are not particularly adapted to the high pressures, shear stress, abrasive relative motions, and the other physical irritations encountered at the prosthetic socket interface. No matter what kind of design, designers are interested in understanding the load-transfer pattern. This knowledge will help designers to evaluate the quality of fitting and to enhance their understanding of the underlying biomechanical rationale. Many studies have been conducted to evaluate and quantify the load distribution on the residuum by either clinical measurements or computational modeling.
In order to design a good socket fit with optimal mechanical load distributions, it is critical to understand how the residual limb tissues respond to the external loads and other physical phenomena at the interface (6). Pressure measurements within prosthetic sockets have been addressed by several authors including the use of transducers, their placement at the prosthetic interface, as well as the associated data acquisition and conditioning approach. An ideal system should be able to continually monitor real interfacial stresses; both pressure and shear, without significant interference to the original interface conditions (6).A variety of transducers have been developed for socket pressure measurements.
However the techniques for placement of transducers at the residual limb or socket interface can be divided into two categories. They are either inserted between the skin and the liner/socket, or positioned within or through the socket and/or the liner. Only thin sensors are suitable for insertion between the skin and socket. In this particular case mounting is relatively easy and it is not necessary to damage the prosthesis. However, for many of these sensors, interference is unavoidable from their protrusions into the socket volume, because of their finite thickness. Positioning the transducers within or through the socket with the sensing surface being flush with the skin would make the thickness of the transducer becomes less critical. For such mounting, holes would need to be made on the experimental sockets to recess the transducers (6). Commercial systems have been designed such as the Rincoe Socket Fitting System, Tekscan F-Socket Pressure Measurement System, and Novel Pliance 16P System. The F-socket (type 9810 or 9811) transducer is a force-sensing system particularly

designed to use with lower limb amputees. This type of technologies are potentially very interesting to use on the prosthetic fitting process, however they still pose some limitations. The main requisite for such an application may be described as follows: non-invasive, non-intrusive, ease to use on clinical/production setting, reliable and allowing for a close normal walking conditions assessment. Thermography is a possible technique as it is noninvasive and nonintrusive technique, relatively easy to use on clinical setting.

2. METHODS

The subject, a 48 years old traumatic transfemoral amputee, walked for 10 minutes in a crosswalk at a comfortable speed (4m/s); during this time we were able to simulate a normal walk of approximately 700m – Figure 6. For the experiments it was used the thermal camera FLIR® A325 with a special resolution of 320x240 pixels and a thermal sensitivity of 68 mK. The images were taken before and after the exercise, both to the subject and to the prosthetic socket.

3. RESULTS AND DISCUSSION

The thermal images of the amputee stump after ten minutes walking revealed extremely low temperatures in the distal end - Figure 3, as well as an uneven heat distribution pattern. This may be explained by the fact that the stump is experiencing circumferential or clamp uneven pressure, on the proximal region, just by being inside the socket, which is an abnormal pattern of pressure to the limb possibly causing disturbance on the blood flow. The low temperature in the distal end of the stump clearly demonstrates that there was no contact or friction with the prosthesis. We can expect that lower limb amputees, due to the biomechanics characteristics of the prosthetic sockets, may experience circumferential or clamp type forces, as well as frictional, rotational and distal bearing forces over the stump, which are very abnormal patterns to the skin and tissues. The end pressure will be the sum of the stabilizing pressure pre imposed on the socket, creating vacuum inside the socket continuously and the pressure imposed by the forces associated with walking, namely on the stance phase. It is also interesting to see that the image of the inner socket walls also show the same temperature distribution, as the correspondent stump - Figure 4. These are coincident with the expected pressure points on the stump/socket interface as the recruited areas for weight bearing on the quadrilateral type socket are all located on proximal region of the stump/socket, namely over the medial, posterior and anterior portions of the stump/socket. According to this, it is also possible to distinguish that the socket that is being used by the amputee is of the Quadrilateral type. Another important finding is the high temperature recorded in the supporting zones - Figures 5; once again this was also observed in the prosthesis and maybe an indicator of areas where the socket walls are tighter and create extra pressure on the stump. Figure 6 shows a picture of the setup, camera and amputee. Also, from the thermal results, one can clear identify the areas of the socket where the contact with the body is more intense, which naturally results in a temperature increase, as it reduces the thermal resistance. Therefore thermography seems to be a very useful tool to help the fine tuning of the socket to the stump, as to give the better comfort to the amputee.

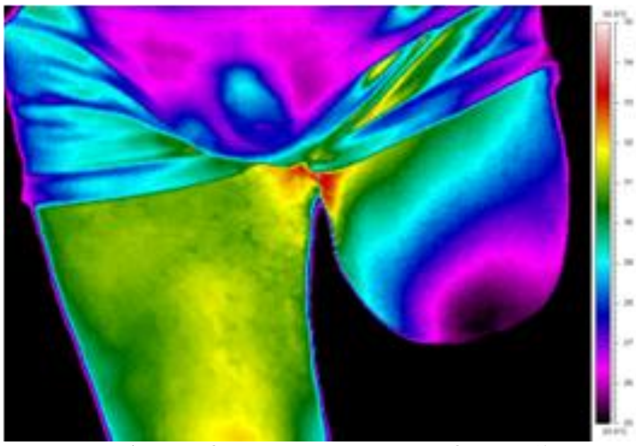

Fig. 3 - Subject, front view 10 min after walking.

The anterior distal end of the stump is indicating temperatures between 20 C° to 25 C°.

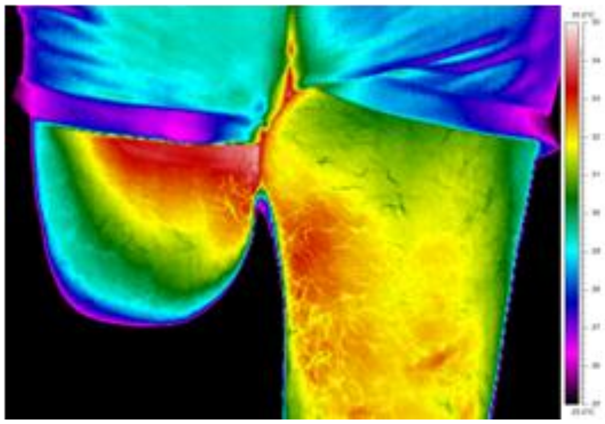

Fig. 4 - Subject, rear view (zone of load support).

Whereas on the distal proximal region the temperature levels raise up to 34 C° - 35 C°.
These differences are a strong indicator of how the overall pressure is being distributed over the stump after a 10 min walk, and may be used to assess the possible best fitting socket and socket type.

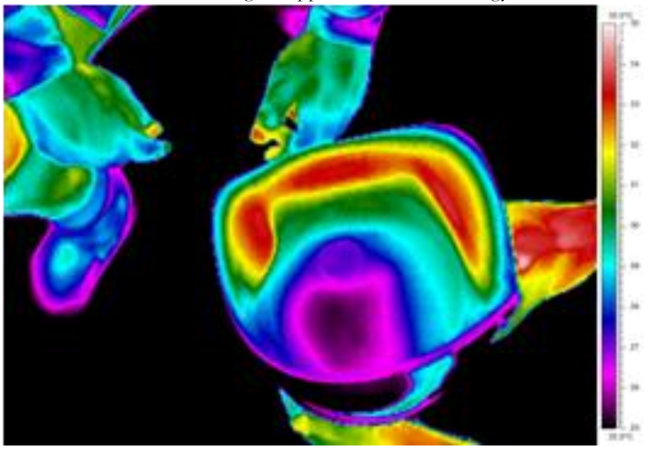

Fig. 5 - The thermal patterns on the prosthesis.

On the socket walls the same heat distribution is observed, indicating that the patterns obtained by thermography are congruent.

Fig. 6 - The walk exercise and the heat recording set-up.

4 CONCLUSIONS

The use of thermography as a possible tool to assess pressure distribution patterns over the amputee stump was analyzed on a single subject, conveniently recruited from the amputee population attending CRPG – *Centro de Reabilitacao Profissional de Gaia*. The subject, a transfemoral traumatic amputee, was a very experienced prosthetic walker and at the time of the study self-reported to be comfortable with the prosthesis. On the day to day the lower limb amputees are expected to compensate the absence of a segment of the lower limb, with a mechanical device (custom made medical device) which is fitted individually to the stump. The forces generated between the stump and the socket are known to be responsible for the lack of comfort, blisters and friction wounds among others, leading to a decrease on mobility function and sometimes prosthetic abandonment. Therefore the design of a mechanically sound interface between the socket and the stump is crucial on prosthetic rehabilitation. The availability of a simple, non-intrusive assessment method, applicable on a rehabilitation setting could help greatly the effort of producing a prosthetic socket, usually a very long and costly process. Thermography may be of help on this process as an indicator and further studies are being developed to evaluate it applicability on a routine clinical practice. However the authors would like to highlight that other variables should also be addressed when analyzing the stump socket interface, such as the effective pressure on the skin and friction, the moisture, muscle activity among others.

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Thermal Effect during Ketamine Anaesthesia in Laboratorial Mice

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SUMMARY

Ketamine is an anaesthetic and analgesic agent used frequently in research and clinical practice. However, this drug is related with memory deficits. These deficits are dependent of the temperature. So, body temperature is an important parameter to monitor during anesthesia. Determination of body temperature by traditional means, such rectal thermometer, is stressful to animals, and extremely time consuming. Thermography may be a rapid non-invasive method to determine mice superficial body temperatures without the need to insert thermometers, thermocouples or implantable microchips. Therefore the purpose of this study was to evaluate thermography as noninvasive method for monitoring thermal superficial changes during ketamine anaesthesia in laboratory animals. To achieve this aim, four adult mice were anaesthetized with ketamine (150 mg/kg) and their body temperature was measured continuously during anaesthesia and recovery of the animals. Thermal measures were conducted using a FLIR long infrared camera with a spatial resolution of 320x240 pixels, a thermal sensitivity of 68 mK. Our results showed that tail temperature decreased during anaesthesia, as we expected. In summary, this work showed that thermography showed to be a good, fast and easy method to evaluate the thermal distribution in living beings. Moreover, this work suggested that thermography can be used for developing better and more effective types of anaesthesia.

1. INTRODUCTION

Most clinical procedures in veterinary medicine as well as in humane medicine have to be performed using anaesthesia. Ketamine, a non-competitive glutamate N-methyl-d-aspartate acid receptor antagonist, is an anaesthetic and analgesic agent used frequently in research and clinical practice (6). More specifically, this drug is used, in human medicine, in painful diagnostic procedures, traumatic and hypovolemic shock and burn situations (1, 7, 8). In veterinary medicine and research, ketamine is frequently used as part of the anaesthetic protocol, combined with other drugs in high variety of surgeries and short procedures (5). However, this drug can trigger neuro-degeneration and memory deficits (4, 11). Cell death at a neurological level may have serious implications for the learning capacity and memory. It was reported that these deficits in memory are dependent of the temperature (3). Room temperature of the 21°C may exert neuroprotection but 25°C is a potential stressful event that increases brain vulnerability and may potentiate ketamine-induced deficit (3). In other way, hypo-thermia may lead to death of animals during anaesthesia. Furthermore, it was reported that high doses of ketamine may cause hypothermia, indicating an involvement of the N-methyl-D-aspartate receptor in thermoregulation pathway (10).

Body temperature is an important parameter to monitor during anesthesia. Determination of body temperature by traditional means is stressful to animals, and extremely time consuming. Conventionally the core body temperature of mice has been measured by either the insertion of a thermometer into the anus of the mice or insertion of a thermocouple via the anus into the large intestine (9, 13). Thermography is a rapid non-invasive method to determine mice superficial body temperatures without the need to insert ther-mometers, thermocouples or implantable microchips. Therefore the purpose of this study was to evaluate thermography as noninvasive method for monitoring thermal superficial changes during ketamine anaesthesia in mice.

2. METHODS

2.1 Animals

Four 12 months of age, male C57BL/6 mice bred in the animal facility of the institute (F1-F2 offspring of animals bought from Charles River, Barcelona, Spain) were used. The mice were housed with con-trolled temperature (21º) and relative humidity at 55%. Lights were on a 12/12h cycle, with lights off at 17.00h. The animals were housed in groups of three to five mice per cage (Makrolon type II cage, Tecniplast, Dias de Sousa, Alcochete, Portugal) (Fig. 1) and it received a commercial pellet diet (4RF25-GLP Mucedola, SRL, Settimo Milanese, Italy) and water ad libitum. Each cage was provided with standard corncob litter (Probiológica, Lisbon, Portugal), a piece of tissue paper and a cardboard tube. The mice were allowed to acclimate to the facilities at least one week prior to the commencement of the study.

2.2 Anaesthesia

Ketamine (Imalgéne® Merial, Portugal; 100mg ml-1) was used for anaesthesia. Standard physiological sa-line 0.9% (Soro Fisiologico, Braun Vet, Portugal) was used for diluting the drug (to ease handling small volumes).

Fig. 1 - Type II cage with mice.

The mice were weighed using an electronic scale and the drug dosage calculated for each animal. By holding the mice firmly by the base of the tail, the mice were placed on the lid of the cage. The thumb and index finger of the left hand secured the skin of the neck and lifted the animal while the palm and third finger of the same hand held the tail. The ani-mals were maintained in dorsal recumbence during the administration of the drug. Ketamine was administered as a single intraperitoneal (i.p.) injection (150mg/kg). Intraperitoneal administration was per-formed lateral to the midline next to the umbilicus. The needle (15mm / 25 gauge) was inserted in an angle of 45º to the abdominal wall in the lower left quadrant of the abdomen (Fig. 2). Injection and restraint were always performed by the same person. After i.p. injection, each animal was placed alone on a blanket with circular acrylic protection until it lost its righting reflex. After this lost, the animal was placed in dorsal recumbence. The time to loss of righting reflex and duration of anesthesia were rec-orded. The time point to recovery of anesthesia was defined as a recovery of righting reflex.

2.3 Thermal Measures

Tail temperature was measured continuously dur-ing induction, maintenance and recovery of the anaesthesia.

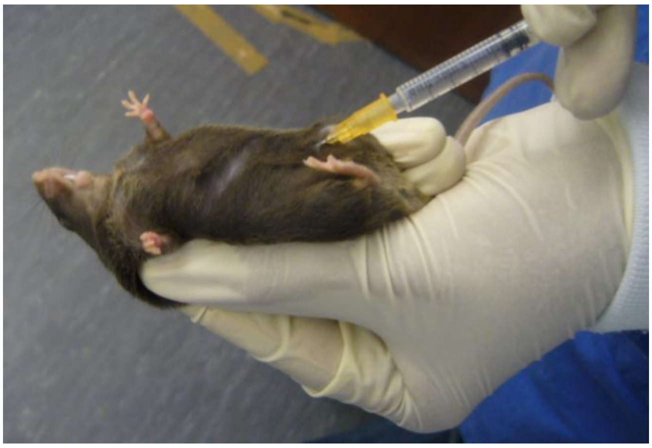

Fig. 2 - Intraperitoneal injection administration.

Thermal measures were conducted using a FLIR long infrared camera (A325) with a spatial resolution of 320x240 pixels and a thermal sensitivity of 68 mK (Fig. 3). All the measures were conducted re-cording one image per second and analyzed posteriorly.

During induction of anaesthesia animals were placed in a transparent cilinder. The room temperature was 21ºC.

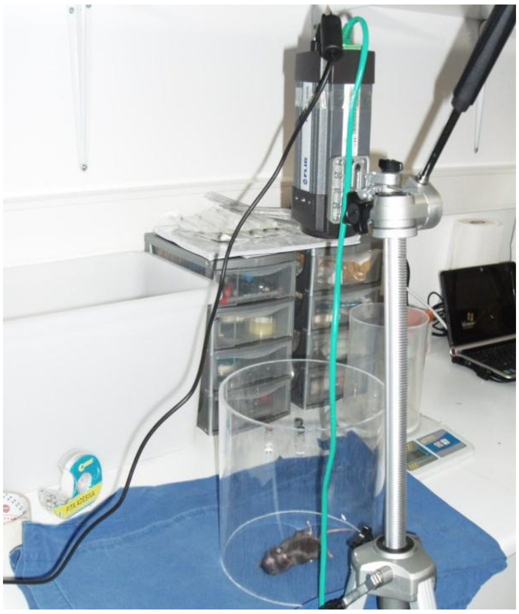

Fig. 3 - Thermal image acquisition setup and camera view.

2.4 Data analysis

The recorded thermal sequences were processed with the ThermaCam™ researcher Pro 2.10 software from FLIR. In these sequences a straight line was drawn perpendicular to the mice tail (Fig. 4) and the maximum temperature along the line over the time was exported to Microsoft Office Excel 2003 (Microsoft Corporation, U.K.). Since the ambient temperature was always lower than the mice tail, the maximum temperature along the line was always correspondent to the mice tail.

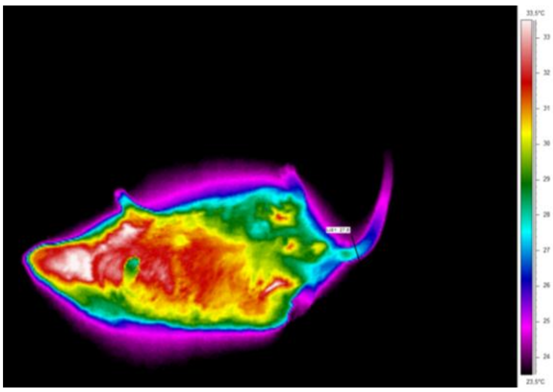

Fig. 4 - Thermal image processing with line maximum temperature, 10mm from the tail base.

Six time points were defined for temperature analyses: immediately after i.p. injection (time 0), 1, 5, 10 and 15 minutes after injection, and immediately before recovery. The temperatures measured in these time points were compared between them. All results were analyzed by using Microsoft Office Excel 2003 for data management and SPSS 16.0 for Windows (Apache Software Foundation, Forest Hill, MD) for statistical analysis. Firstly, data was tested for normality and homogeneities of variances. Para-metric tests (one-way ANOVA with Bonferroni post hoc tests) were used if data fulfilled this assumption.
Data was expressed as means ± standard deviations. $P<0.05$ was considered statistically significant.

3. RESULTS

All animals lost the consciousness. The time to loss of righting reflex was 1.83±0.75 minutes and mice were unconsciousness for 30.5±5.75 minutes. As it was expected, these results showed that ketamine is an effective anaesthetic agent for laboratory animals. The time that the animals were unconsciousness is sufficient to perform a several short procedures in mice, such as collect blood, biopsies, inoculations, surgical implantation, aseptically urine collection among other things. Ketamine is however routinely used combined with several drugs to achieve longer times of anaesthesia and reduce side effects.
This work showed that tail temperature decreased significantly during anesthesia, (Figs. 5, 6, 7). The temperature of the animals immediately after i.p. injection (32.35±1.60ºC) is significantly different of the temperature at times 5 (27.23±0.51ºC, $p<0.01$), 10 (25.19±0.52ºC, $p<0.01$) 15 min. (25.18±0.89ºC, $p<0.01$) after i.p injection, and at re-covery time point (25.39±0.80ºC, $p<0.01$). Moreover, no significant differences were observed between the temperature recorded at time 10 minutes and temperature immediately before animal recov-ery, showing temperature stabilization after that time point ($p=1$).

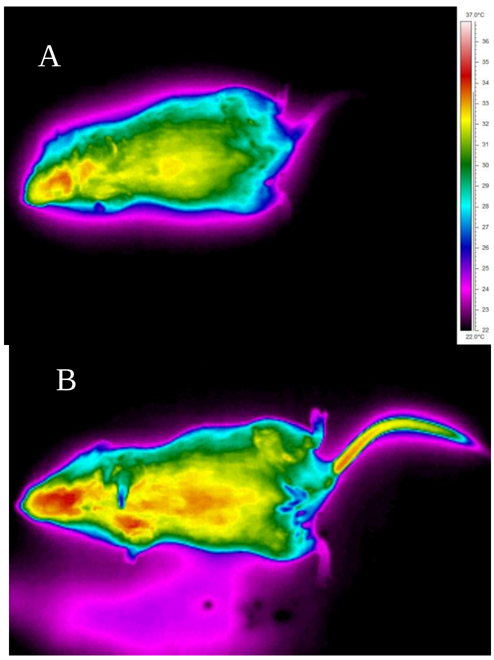

Fig. 5 - Thermal images:
A) after induction (time 0).
B) immediately before anaesthesia recovery.

In anaesthetic situations, animals decreased their metabolism and consequently the body temperature is reduced. It was reported that high doses of ketamine, an N-methyl-D-aspartate receptor antagonist, caused hypothermia (10). For thermography to be considered a good method for determining temperature in laboratory animals it should be able to detect the fall in body temperature caused by anaesthetic drugs. This paper showed that thermography can detect such drop in temperature after ketamine anaesthesia.

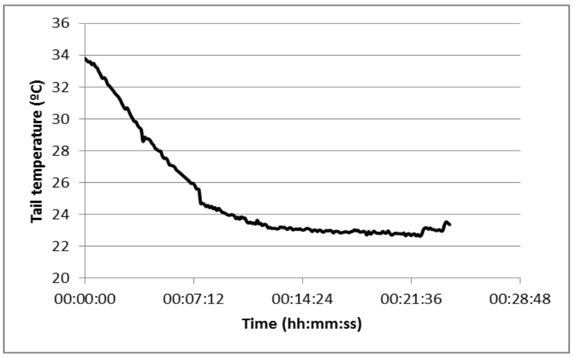

Fig. 6 - Tail temperature evolution during anaesthesia from one animal showed as an example.

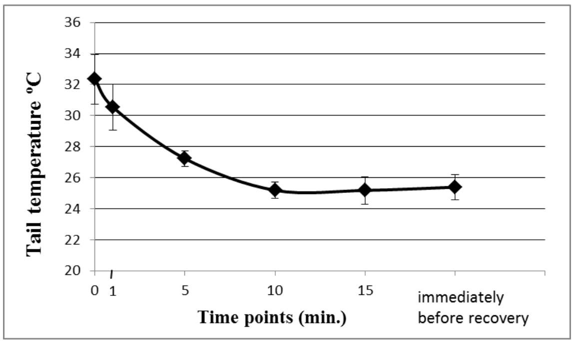

Fig. 7 - Tail temperature at different time points: 0, 1, 5, 10 and 15 minutes after i.p. injection, and immediately before recovery from all animals (n=4). Data are presented as mean±SD.

In this work we used tail temperature to evaluate the superficial body temperature. Tail is the major thermoregulatory organ in mice and it is a good indicator of superficial body temperature. Tail has a large surface to volume ratio, and it is perfused with many blood vessels, especially at the tail tip and midlength (2). More specifically, mice control their body temperature through their tails by dilating or constricting their tail blood vessels. When body temperature drops, the tail vessels shrink in diameter (vasoconstriction) thus restricting blood flow to the tail (12). Less blood flows into the tail for cooling, and body heat is conserved. This heat also can be channeled to the vital organs in order to compensate the reduction in internal body temperature caused by the slower metabolism induced by anaesthetics.

4. CONCLUSIONS

Anaesthetic agents, such as ketamine, produce a drop in superficial body temperature in mice. Thermography showed to be a valid, fast and easy method to evaluate the thermal distribution in living beings. Moreover, this work demonstrated that thermography can be used for developing better and more effective types of anaesthesia in laboratory an-imals.

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Thermography of Facial Skin Temperature in Healthy Subjects During Cooling of the Face with Hilotherapy

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SUMMARY

Background: Hilotherapy (in which the face is cooled by a temperature-regulated, water-cooled mask at 15ºC) may be more effective than standard cryotherapy (using cold packs) in reducing swelling and pain after facial surgery. No data exist, however, on the speed of cooling during the application of the hilotherapy mask, and the actual skin temperatures achieved across the face are also unknown. We investigated a facial cooling procedure using a hilotherapy mask in 3 healthy control subjects using infrared thermography. In one of the subjects, we also studied cooling of the face using an ice compress.
Methods: The hilotherapy mask was applied to the face and set to cool in continuous mode at a temperature of 15ºC. Anterior, left lateral and right lateral thermograms of the face were recorded prior to cooling and 5, 10, 20 and 30 minutes after the commencement of the cooling procedure. The mask was briefly removed from the face to allow thermograms to be captured at each measurement time-point. A further set of thermograms was recorded 5 minutes after the cooling procedure had ended. After a 30 minute re-stabilisation period, the cooling process was repeated in one subject using the ice compress.
Analysis: Temperature data from the left lateral thermograms was plotted using four anatomical regions of interest (ROIs).
Results: The smallest drop in median skin temperature during the hilotherapy cooling procedure was observed at the most superior ROI (7°C), whereas the greatest drop in median temperature was recorded from the most inferior ROI (9.8°C). The maximum skin cooling achieved with the ice compress was 4.9°C (at the most inferior ROI).
Conclusions: Infrared thermography is an effective tool in the evaluation of facial cryotherapy for the reduction of pain and swelling after maxillofacial surgery. Our pilot data show that hilotherapy cools facial skin more effectively than an ice compress. The greatest skin cooling with hilotherapy over 30 minutes was achieved at the inferior part of the face. Further work is required with both healthy control subjects and surgical patients to determine the optimum cooling configuration with hilotherapy.

1. BACKGROUND

Facial cooling has been demonstrated to reduce pain and swelling after maxillofacial surgery, leading to im-proved patient satisfaction and shorter hospital stays. Maximal skin vasoconstriction occurs at a skin temperature of 15ºC (1). Rana et. al. (3) showed that hilotherapy (in which the face is cooled by a temperature-regulated, water-cooled mask at 15ºC) may be more effective than standard cryotherapy (using cold packs) in reducing swelling and pain after facial surgery.
Moro et. al. (2) found that hilotherapy was more effective at reducing swelling than ice-pack application in most areas of the face, but they found hilotherapy to be less effective in limiting swelling between the external canthus and tragus – an area not fully enclosed by the hilotherapy mask.
No data exist on the speed of cooling during the ap-plication of the hilotherapy mask, and the actual skin temperatures achieved across the face are also unknown.
In order to better understand the performance of hilotherapy, we monitored a facial cooling procedure using the hilotherapy mask in three healthy control sub-jects using infrared thermography. In one of the subjects, we also studied cooling of the face using an ice compress.

2. METHOD

Three healthy adult control subjects (1 female, 2 male) gave informed consent prior to participating in the measurements.

Each subject avoided smoking, hot food, alcohol and caffeinated drinks for one hour prior to the investigation, and rested in the thermography laboratory for 15 minutes at a room temperature of 23ºC prior to imag-ing. Thermography was performed using an A320G Thermacam imager (FLIR Systems, West Malling, UK) with an ethernet connection to a PC running FLIR Thermacam Researcher software. The A320G is an uncooled focal plane array imager sensitive across the 7-14 μm waveband. The thermal imager was recently quality-assured against a blackbody source traceable to the International Temperature Scale of 1990 (4). No camera readings differed from the source temperature by more than 0.3°C across the range of facial skin temperature. Prior to measurement, the thermal imager was operated for one hour to ensure the microbolometer detector gave stable temperature readings.

For each subject, the hilotherapy mask was applied to the face and set to cool in continuous mode at a temperature of 15ºC. Anterior, left lateral and right lateral thermograms of the face were recorded prior to cooling and 5, 10, 20 and 30 minutes after the commencement of the cooling procedure. The mask was briefly removed from the face to allow thermograms to be captured at each measurement time-point. A further set of thermograms was recorded 5 minutes after the cooling procedure had ended. After a 30 minute re-stabilisation period, the cooling process was repeated in one of the male subjects using the ice compress.

Fig. 1 shows a sequence of left lateral thermograms monitoring cooling using the hilotherapy mask in the female subject.

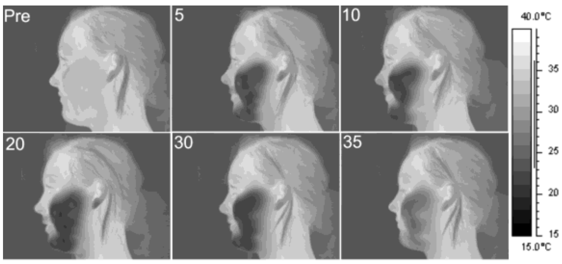

Fig. 1 - Thirty-minute cooling sequence using the hilotherapy mask in a female subject. The 35-minute time-point is 5 minutes after cessation of cooling.

3. ANALYSIS

Temperature data from the left lateral thermograms was plotted using four anatomical regions of interest (ROIs). These regions represented areas of anatomical significance when making the bone cuts for standard maxillary and mandibular osteotomies for orthognathic corrections. The ROIs were adapted from the linear measurements along the face made by Moro et. al. in their assessment of change in oedema and swelling in response to cooling. The four ROIs are shown in fig. 2. Region 1 was the most superior ROI, with region 4 being the most inferior.

4. RESULTS

Facial temperature from the four ROIs during the hi-lotherapy cooling procedure is plotted in figures 3 to 6. Data shown are median, maximum and minimum temperature from the 3 subjects. The 35-minute time-point was 5 minutes after the cessation of cooling. Skin cooling was observed at all four ROIs. For re-gions 1 to 3, maximum cooling occurred at 20 minutes and there was a subsequent small rise in skin temperature during the final 10 minutes of the cooling procedure. At region 4, skin temperature reduced throughout the entire 30 minutes of the cooling procedure. Compared to baseline, the smallest drop in median skin temperature during the cooling procedure was observed at region 1 (7°C), whereas the greatest drop in median temperature was recorded from region 4 (9.8°C). The lowest median skin temperature recorded was 24.3°C (after 20 minutes from region 2).

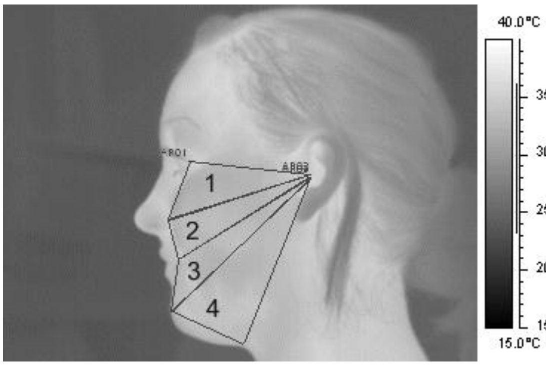

Fig. 2 - Four regions of interest for extracting temperature data from the thermograms.

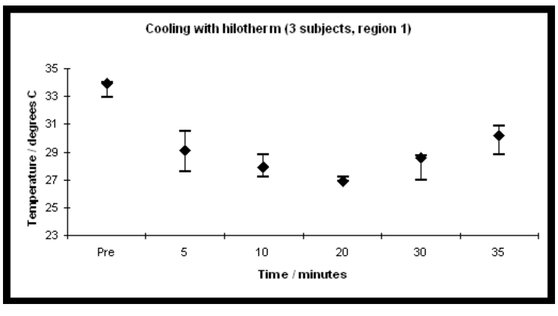

Fig. 3 - Cooling with hilotherm: 3 subjects, region 1.

Fig. 7 and fig. 8 show the skin temperatures for subject 3 during cooling with hilotherapy and an ice compress respectively. The maximum skin cooling achieved with the ice compress was 4.9°C (after 20 mins at region 4), compared to a maximum skin cooling of 10.2°C (after 30 mins, also at region 4) using hilotherapy. The maximum skin cooling achieved at region 1 using the ice compress was only 0.5°C.

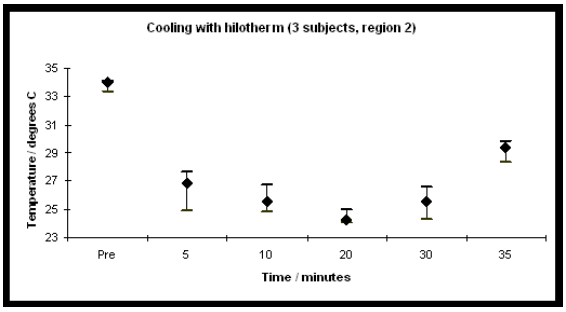

Fig.4 - Cooling with hilotherm: 3 subjects, region 2.

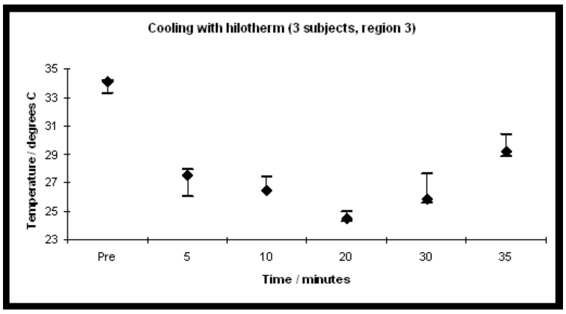

Fig. 5 - Cooling with hilotherm: 3 subjects, region 3.

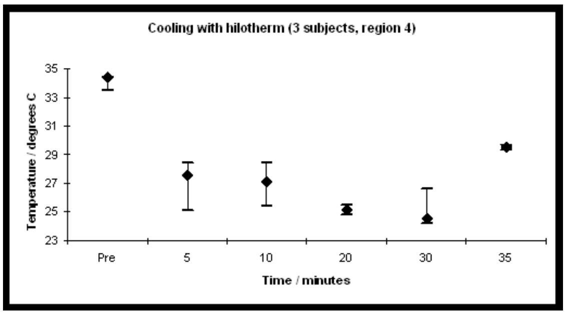

Fig. 6 - Cooling with hilotherm: 3 subjects, region 4.

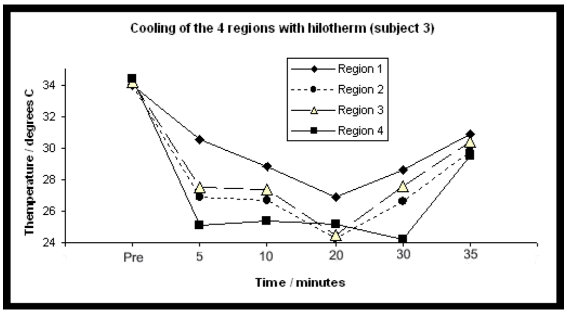

Fig. 7 - Thirty-minute cooling sequence using hilotherm in subject 3.

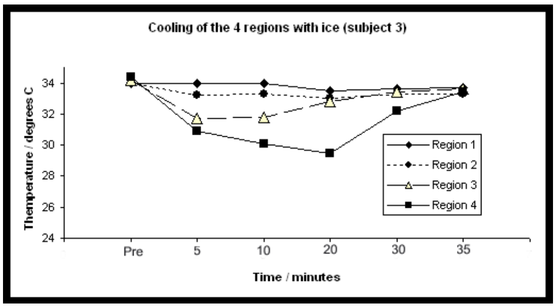

Fig. 8 - Thirty-minute cooling sequence using an ice compress in subject 3.

5. CONCLUSIONS

Infrared thermography is a useful method to monitor facial cooling with cryotherapy techniques.
Our data show that hilotherapy cools facial skin effectively, particularly in the more inferior parts of the face. Our results from the most superior region of interest suggest that this area is cooled at least 2.5°C less than the three more inferior ROIs. This observation is in keeping with the findings of Moro et. al (2) that hilotherapy was less effective at limiting swelling between the external canthus and tragus (which is not an area entirely enclosed by the hilotherapy mask).
We saw evidence from ROIs 1 – 3 that, with the mask set to 15°C, maximal cooling is achieved at 20 minutes. After this time the skin temperature rose slightly, suggesting a process of autoregulation. At ROI 4, however, skin temperature continued to fall until cooling ceased at 30 minutes.
The lowest median skin temperature observed of 24.3°C was 9.3°C higher than the mask coolant water temperature; further work is required to investigate if lower coolant temperatures and/or longer cooling procedures could achieve lower skin temperatures.
In the subject who also underwent cryotherapy with an ice compress, hilotherapy was markedly more effective than the ice compress at cooling all facial skin regions.
The Hilotherm mask is a promising device for reproducible cooling of the face after maxillofacial surgery. Further work is now required in both healthy control subjects and surgical patients to investigate the opti-mum cooling configuration for hilotherapy.

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Infrared Thermography in Plastic Surgery: A Comparative Study of Pre and Post - Operatory Abdominal Skin Circulation after Different Techniques – The Effect of Undermining

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SUMMARY

The authors related a prospective study of the abdominal skin circulation after three different types of abdominal plastic surgery with infrared thermography (before and after surgery). They conclude that Lipoabdominoplasty was the less aggressive surgery, followed by the Abdominoplasty with preservation of the superficial fascia. The Classic Abdominoplasty, even with poor undermining, was the technique that destroyed the most abdominal perforated vessels, with the biggest rate of complication in the post operatory.

1. INTRODUCTION

Abdominal plastic surgery has suffered many alterations since its beginning. A revolution started in the eighties with the liposuction introduced by Illouz (3) and his posterior Abdominoplasty without undermining. Actually, authors as Avelar (1) and Saldanha (4) have been disseminated the moderns Abdominoplasties, as the Lipoabdominoplasty, with little undermining.
Infrared Thermography is a method that captures heat alterations of the skin with the infrared spectrum, with a special camera, making possible the study of the skin vascularization and function. It can even precede Doppler's sound, and have been developed and studied by many authors, as Brioschi (2), for different medical specialties.
However, there are few references in the literature about studies of the skin micro circulation to compare surgeries.

2. METHODS

In this paper we studied with the infrared thermography twelve patients preliminarily. They had been submitted before into different types of surgeries, with different surgeons, and were compared into their vascular patterns. After, we studied prospectively 4 groups (10 patients each) before and after:
1) Lipoabdominoplasty (LAP),
2) Abdominoplasty with preservation of the superficial fascia (APSF) and
3) Modified Classic Abdominoplasty (CAP), with little undermining. The fourth group was the control (CT).
The patients were studied at the temperature of 20º Celsius, before and after the use of ice over the skin to suppress the hot spots, that are the images of the perforated vessels of the abdominal wall. The camera had a sensibility of 0.08º Celsius and collected the images sequentially.
In the prospective group, the examination was made before and after each surgery (never before 3 months post operatively).
The IR camera used is shown in fig. 1.

Fig. 1 - Infrared photographic camera - (IR) T400 (FLIR® Co, Boston, USA). Software ThermaCam Reporter (FLIR Co, Boston, USA).

The perforated vessels were market in the abdominal wall (Fig. 2) and compared before and after surgery (number and position).

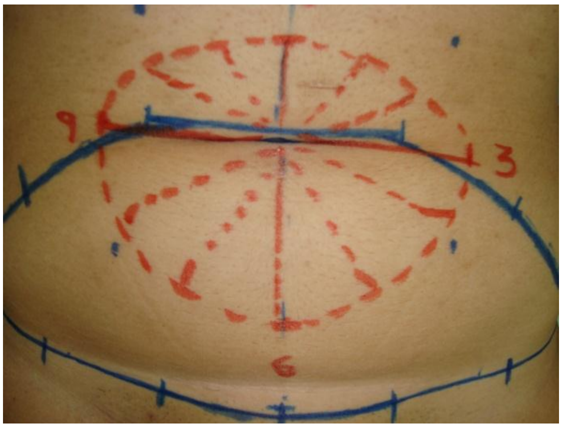

Fig. 2 - Abdominal wall marked before surgery, with the perforated vessels showed.

The results were evaluated quantitatively (number of perforator vessels) and qualitatively (capacity of maintaining skin thermoregulatory function by the termogram pattern) with the control group and between the groups.
For the quantitative results, the statistic tests used were ANOVA and Tukey. For the qualitative results, the spectrum of the color was used to classify each patient (decrescent order: red, yellow, green, sky blue, dark blue and pink).

3. RESULTS

At the preliminary study there was no possibility to establish a circulatory pattern, probably because the first groups were heterogeneous and very small. At the prospective study the 3 groups were homogeneous with the control pre operatively (F=1.6683 and p = 0.1910) and heterogeneous post operatively (F = 22.0968 and p = 0.0000). This means that the surgery was the agent of the changes.
The LAP patients had the biggest preservation in number of perforated vessels (mean 11.8 before surgery and 10.8 after surgery). They also had the best quality of thermographic images and were the only group that could be compared with the control (mean 12.1), with low rates of complications. They maintained 91.52% of the perforated vessels.
The APSF group had few complications too, compared with LAP group. They maintained a reasonable thermoregulatory function (color *spectrum*), although the number of the perforator had decreased, maintaining 65.46% of the perforator (mean 10.4 before and 6.6 after surgery)
The CAP group had the biggest destruction in perforator vessels and the worst thermoregulatory function, with the highest complication rate. They only maintained 49.01% of the perforated vessels in the post operatory (mean 10.2 pre and 5 post operatively). In the figs. 3 and 4 we can see an example of the decreasing perforator vessels number observed at this group after the surgery.
The general results, as the complications, are showed at the fig. 5 and table 1.

Fig. 3 - Pre-operative patient with the perforated vessels marked at the abdominal wall.

Fig. 4 - Post operative patient after a Classical Abdominoplasty, with the perfurated vessels marked.

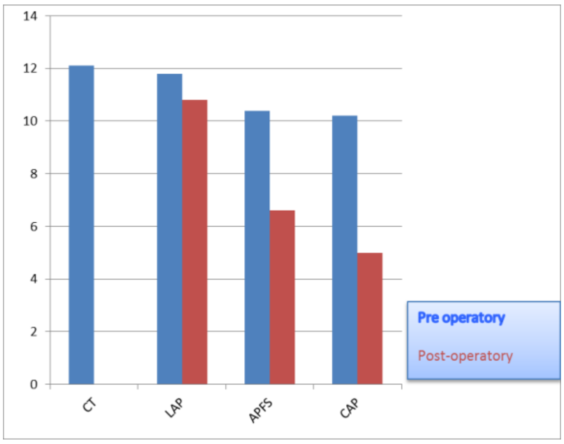

Fig. 5 - Average distribution of perforated vessels for each group studied before and after the surgeries, comparing with the control group (CT).
Pre operatory – first column, Post-operatory – second column
LAP= Lipoabdominoplasty
APFS= Abdominoplasty with preservation of the superficial fascia
APC= Classic Abdominoplasty with little undermining

Table 1. Distribution of the complications for each group studied.

COMPLICACIONES	LAP	APFS	APC
Hematoma	0	0	0
Serome	0	0	3
Open wound	0	1	0
Infection	0	0	0
Reoperation	0	0	1
Hypertrophic scar	0	1	1
Fibrosis	1	0	1
Bad position of the scars	1	0	0
Necrosis	0	0	0
Insensibility	0	0	2

LAP= Lipoabdominoplasty
APFS= Abdominoplasty with preservation of the superficial fascia
APC= Classic Abdominoplasty with little undermining

Statistically, also, only the groups LAP and control (CT) were similar (p=0.5797).
The group APFS was closer the group CAP (p= 0.4033), although it have been better aesthetic and functional results.
The group CAP was the most different than the control (p=0.0001)
These results can be observed at the table 2.

Table 2. Statistic Test (Tukey) used for comparing groups.

Tukey 's TEST				
Group	{1} 12,100	{2} 10,800	{3} 6,6000	{4} 5,0000
CT		0.579735	0.000181	0.000159
LAP	0.579735		0.001210	0.000165
APFS	**0.000181**	0.001210		0.403304
CAP	**0.000159**	0.000165	0.403304	

LAP= Lipoabdominoplasty
APFS= Abdominoplasty with preservation of the superficial fascia
APC= Classic Abdominoplasty with little undermining

4. CONCLUSIONS

The infrared thermography is an objective, simple and useful method of the evaluation of the abdominal skin vascularization and function.
There were decrease in perforator vessel's number and thermoregulatory function, crescent in the groups: LAP, APSF y CAP.
The only group compared with the control was the LAP that preserved the most vessels and the skin function.
The CAP group had the biggest complication rate, whereas the others were comparable and low.
The APSF is an alternative to the patients who cannot have a LAP, with good preservation of the circulation and thermoregulatory function, with low complication rates.
Other studies are necessary to evaluate the aesthetic or not aesthetic possible changes after functional post-operative modifications, even though the LAP group had showed the best results and the thermography could measures indirectly its best skin metabolism.

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Infrared Thermography Assessment of Infantile Hemangioma Treatment by Propranolol

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SUMMARY

Infantile hemangiomas (IH), is one of the most common benign soft tissue tumours in childhood, it affects 1-2% of neonates and 10-12% of children up to the first year of life. Although most IH are small and self-limiting and in most cases, naturally resolve between 7 – 10 years of age, they can in some situations be dangerous for the surrounding tissues and organs. In such cases treatment should be taken into consideration, including pharmacotherapy, laser surgery and cryosurgery - surgical treatment has limited value. Since 2008 numerous reports have confirmed the anti-proliferative effect of propranolol in treatment of IH. In this paper we present our initial experience of infrared thermography used in diagnosis and treatment monitoring IH in children treated by propranolol. According to the length of treatment with propranolol, patients were divided into 2 groups. In both groups we have observed a decrease of mean temperature, which correlated with a significant reduction in size and symptoms of the hemangiomas.
This pilot study indicates that quantitative infrared thermography can be used to assess the temperature and the size of hemangiomas. It could become a method of choice in the initial assessment and followed up by hard to reach hemangiomas in such localizations as eyelid, nose, lip, etc. Thermographic monitoring could also be used to determine the effective length of treatment with propranolol. A controlled trial of this treatment using the additional temperature assessment is required to substantiate these results. While the results in this study are positive they are still preliminary and need more verification on a larger scale.

1. INTRODUCTION

Infantile hemangiomas (IH) are common benign soft tissue tumours of childhood, affecting 1-2% of neonates and 10 -12% of children up to a first year of life (1). The head and neck region is the most frequently affected area (60%), followed by the trunk (25%) and the extremities (15%) (2, 3). The pathogenesis of infantile hemangioma is unknown (4). Hemangiomas commonly pass through three phases. The first is a growth period (proliferative phase), the second – stability phase and followed by the third phase - spontaneous regression (involution). In 70-90% cases IH resolves naturally between 7 – 10 years of age (5).
Although most IH are small and self-limiting they can cause severe damage to organs and create serious complications depending on their localization. Ulceration is one of the most common complications leading to pain, disfigurement and functional impairment. Hemangiomas, complicated by ulceration or bleeding are an indication for early treatment. In infants and children surgical treatment has limited value. Treatment options for complicated IH include oral steroids, laser surgery, cryosurgery and in life threatening cases cyclophosphamide or interferon may be used (6).
In 2008, Leaunte-Labreze and al. (7) described observations of the anti-proliferative effect of propranolol in IH and published their initial report of propranolol as an effective treatment of IH. Since then, numerous reports have confirmed this as an effective treatment. Propranolol, a beta blocking agent actually has been reported, by several investigators, to be an excellent treatment, reducing blood flow to the lesion and therefore accelerating the healing process. Beta-blockers without alfa-

antagonist effects such as propranolol inhibit the vasodilatation mediated by adrenaline via beta-receptors (8). Propranolol treatment in hemangioma is associated with visible change in colour and palpable softening of the IH lesion (9). It appears that propranolol now plays a major role in the treatment of hemangioma (10, 11, 12).
In the diagnosis of IH, Doppler ultrasonography, magnetic resonance, computerized tomography and angiography may be used to evaluate the extension of involvement.The purpose of this study is to present our initial experience of infrared thermography used in diagnosis and treatment monitoring of IH in children treated by propranolol.

2. METHODS

Thermographic images of infantile hemangiomas were recorded in children under the care of The Hemangioma and Naevus Clinic at the Department of Oncological Surgery of Children and Adolescents, at the Mother and Child Institute in Warsaw. All the children were already involved in the propranolol therapy program. ECG's, echocardiographic studies, biochemical blood studies and Doppler ultrasound studies were performed in all cases.
According to the length of treatment with propranolol the patients were divided into 2 groups:
Group I - 6 children (2 boys, 4 girls - average age of 7 months), were examined using infrared imaging before starting propranolol treatment or during the first follow-up visit (after 6 weeks of treatment). Group II - 28 children (7 girls, 21 boys - average age of 15 months) were examined using infrared imaging after an extended period of propranolol treatment (min 4 months up to 18 months), usually successful, with regression of their clinical symptoms.
The range of investigations employed were, E.C.G. echocardiography, biochemical studies and Doppler ultrasound. Infrared thermography of the affected areas of body was performed using a calibrated FLIR T640 infrared camera in a stable environment (21-23ºC). This camera also provides a simultaneous visible image of the lesion. All images were analysed using FLIR Quick Report software.

3. RESULTS

The hemangioma lesions were located in many different areas of the body, mostly on a face and neck but some on the arms and trunk of the body. Where possible the thermograms were recorded to include reference areas on the contra-lateral side of the body, or alternatively an adjacent area - clear of the lesion for comparison. The mean temperature of the affected area and of the reference (normal) areas of the skin was subtracted as expressed as delta temperature.
In group 1 with 6 patients mean temperature decreases in 6 – 8 weeks: 0.9ºC (-0.3ºC - 2.5ºC).
In group 2 with 28 patients who undergo longer duration therapy (min 4 months, max 18 months) mean decrease in temperature: 0.47ºC (0.2ºC – 5.1ºC). A high proportion of this group had a significant reduction in size and symptoms of the hemangiomas.
The difference in average temperatures between an area measured within the hemangioma and an area measured within a symmetrical body part or an area adjacent to the hemangioma was in group I -1.3˚C, in group II -0.45˚C (Figs 1,2).

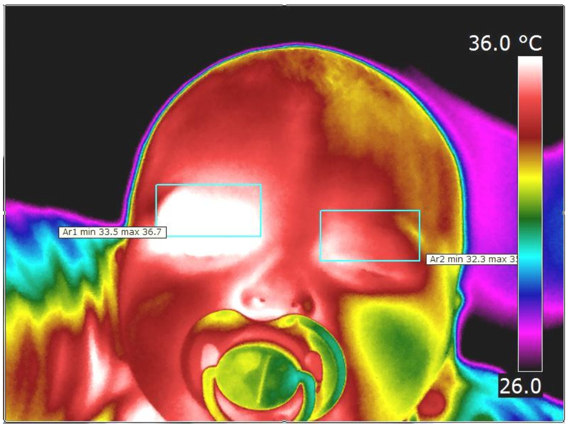

Fig. 1 - 2-months old infant with an infantile hemangioma of the right upper lid before treatment. The lesion is compressing the eyeball - this is a difficult location to assess blood flow using Doppler ultrasound. The difference in average temperatures between symmetric areas is 1.5ºC.

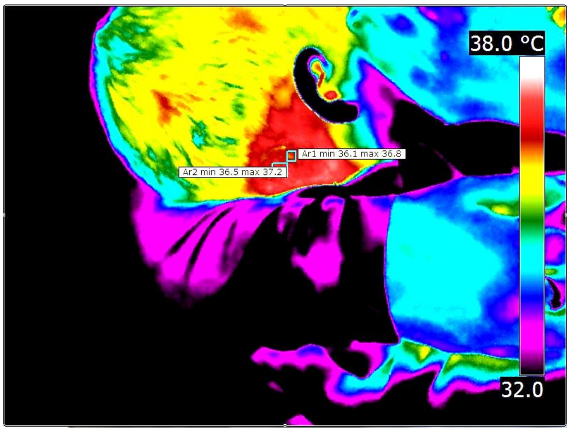

Fig. 2 - 9-months old infant with an infantile hemangioma of the skin in the area of the mastoid process after 4 months of propranolol treatment. There are visible atrophic foci, the difference between average temperatures is 0.5ºC.

4. DISCUSSION

Infrared thermal imaging is a non-invasive procedure for mapping skin temperature distribution of the human body. Considerable progress has been made over the last 20 years in modern infrared imaging used in medical applications (13, 14, 15). Infrared thermography can be used to assess the temperature of hemangiomas, and of the lesion size in metric units (by using special software). Because of the diversity of these hemangiomas, their location, age of children and the progress of the healing process (atrophy of the hemangioma) it has been found that the comparison of average temperatures between an area registered within the hemangioma and an area registered within a symmetrical body part is the most reliable method to describe the treatment effectiveness. In cases of an unfavourable location of the hemangioma (i.e. nose area, forearm), it is more objective to compare temperatures between the hemangioma and an equivalent area of adjacent, healthy tissue.

In the children in this study, the hemangiomas and their treatment outcome were also measured using Doppler ultrasound for blood flow assessment. In very active infants, with a hemangioma located on the eyelid, nose or lip, usually being inflamed, Doppler ultrasound is very difficult to perform, and therefore less reliable. Infrared thermography can become the method of choice in the initial assessment and follow up in those difficult locations with hemangiomas.

This preliminary study has shown that the variety and complexity of the different hemangioma lesions has not presented problems for thermographic assessment being a non-contact technique. The more commonly used ultrasound technique in some locations such as eyelid or mouth of a young child can be very difficult to perform. The decrease in temperature of the lesions with the propranolol therapy has been accompanied by a reduction in size and symptoms. The speed of image capture with thermography, and the ability to simultaneously capture a visual image of the lesion is a great advantage, and one which is very convenient with very young children. A controlled trial of this treatment using the additional temperature assessment is required to substantiate these results.

These results remain preliminary, and further studies are needed to verify the use of this technique on a larger scale.

5. CONCLUSIONS

The conclusions of this study were:

1. Infrared thermography used for the measurement of skin temperature can be a helpful diagnostic method in monitoring and assessment of propranolol treatment efficacy, irrespective of the location and size of the hemangioma.
2. Thermographic monitoring allows a more accurate determination of propranolol treatment length.
3. Infrared imaging is also useful in follow up assessments of hemangiomas after completion of propranolol treatment.

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Facial Imprints of Autonomic Contagion in Mother and Child: A Thermal Imaging Study

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SUMMARY

The present study aimed at investigating whether maternal empathy is accompanied by a synchrony in autonomic responses. We simultaneously recorded, in an ecological context with contact free methodology, the facial thermal imprints of mother and child, while the former observed the latter when involved in a distressing situation. The results showed a situation-specific parallelism between mothers' and children's facial temperature variations, providing preliminary evidence for a direct affective sharing involving autonomic responding. These findings support a multidimensional approach for the comprehension of emotional parent–child relationships. Thermal infrared imaging offers the possibility of recording non-verbal interactions among individuals, thus paving the way to new studies and methodologies in neuropsychology.

1. INTRODUCTION

Seeing one's own offspring in distressing situations is a rather ordinary occurrence in everyday life. A sense of empathy with the child's feelings helps parents to understand the child's needs and to provide congruent responses. In fact, a mother's ability to empathically share offspring's emotional feelings in distressing situations is considered integral to the creation of primary affective bonds and a healthy socio-emotional development (4, 17, 32, 37, 41, 42, 48). What neurobiological mechanism subtends maternal empathy in humans? In particular, does sharing of autonomic arousal accompany a mother's affective sharing of her offspring's distress?

Autonomically-mediated visceral responses are proposed to be strictly related to the experience of emotional feelings (10, 11, 12, 22, 23, 29, 31, 47). The sympathetic and parasympathetic divisions of the au-tonomic nervous system represent the principal channels of interaction between the brain and bodily organs, and have complementary roles in the achievement of homeostasis and the regulation of physiological responses to emotional stimuli (5, 10, 24). It is therefore plausible that the vicarious response of empathy, generally referred to as a common neural coding of the perception of one's own and the other individual's feelings underpinning a sharing of af-fective experiences (1, 13, 18, 19, 40, 44), also embodies a direct sharing of changes in body physiology between the involved individuals (10, 11, 12, 13, 40).

The present study is an extension of a previous one aimed at investigating whether a mother's empathic sharing of her offspring's distress is accompanied by physiological sharing of autonomic responses (16). For this purpose, facial thermal imprints of mother and child dyads were simultaneously recorded in an ecological context while mothers observed their children when involved in a distressing situation.

We used thermal infrared (IR) imaging which esti-mates variations in autonomic activity reflected by cutaneous temperature modulations by means of recording the thermal infrared signals spontaneously released by the human body (20, 34, 38, 39, 43). Facial temperature is mediated and regulated by sympathetic and parasympathetic activity, which works to preserve the body homeostasis in the human physical and psychological functioning (2), and therefore is especially active when emotional stimuli are present in the proximal environment (29).

2. METHODS

2.1 Participants

Thirteen mothers (age 31-46 years) and their typically developing biological children (5 male, age 38-42 months) participated in the experiment. Two out of 13 mother-child dyads were excluded from further data analysis, since the toy was not broken during the experiment (see Procedure section). Inclusion criterion for both mothers and children was the ab-sence of any overt physical, psychiatric or psychological disease. All participants observed standard preparation rules for thermal imaging.
The study was approved by the local Ethics Committee. Written informed consent was obtained from all participants after full explanation of the pro-cedure of the study.

2.2 Procedure

Prior to testing, each subject was left to acclima-tize for 10 to 20 minutes to the experimental room and to allow the baseline skin temperature to stabilize. The recording rooms were set at standardized temperature (23 °C), humidity (50 - 60%), and without direct ventilation. The subjects comfortably sat on a chair during both acclimatization and measurement periods, without any restriction to body movement.
Before the start of the experiment the children underwent an adequate familiarization period for psy-chological habituation to the setting and the experi-menter, first in presence of their mothers, followed by neutral interaction with the experimenter alone.
After a neutral baseline period of interactive activities with the experimenter, children were presented with a potential stressful experience elicited by the "mishap paradigm" (7). More specifically, children were invited to play with a toy, which was previously manipulated to break on the child's hands when playing with it, thus suggesting that the child accidentally broke the toy. The toy was introduced by the experimenter as her own favorite.
Distinct phases could be distinguished in the paradigm:
1) "presentation" (the experimenter demon-strated the toy);
2) "playing" (the child played with the toy, while the experimenter left the room for 1 minute);
3) "mishap" (child "broke" the toy);
4) "re-entrance" of the experimenter (the experimenter did not say anything for 30 seconds and merely looked at the broken toy);
5) "soothing" of the child (the experimenter cheerfully indicated that the toy could be fixed and that the breaking was not the child's fault).
Mothers were invited to observe their children in interaction with the experimenter through a one-way mirror from a separated room, while naive about the specific content of the experiment.

2.3 Materials and data acquisition

Thermal IR imaging was performed by means of two digital thermal cameras (FLIR SC3000, FlirSystems, Sweden), with a Focal Plane Array of 320 x 240 QWIP detectors, capable of collecting the thermal ra-diation in the 8-9 μm band, with a 0.02 second time resolution, and 0.02 K temperature sensitivity. The thermal camera response was blackbody-calibrated to null noise-effects related to the sensor drift/shift dy-namics and optical artifacts. Thermal images of the faces of the mother and the child were simultaneously acquired along the whole experimental paradigm. Sampling rate for thermal imaging was set at 10 frame/sec.
Behavioral recordings of the children took place through two remote-controlled cameras (Canon Vc-C50iR). Video-signals were sent to two video-recorders (BR-JVC) and the resulting movies were subsequently mixed by a Pinnacle system (Liquid 6) to have a two- or three-split image. Subsequently, the movies were processed in a video reading lab by specialized software (Interact Plus, Mangold) that allows to code behavior in synchrony with the ongoing mov-ies of the children during the experiment.
The toy presented to the children in the "mishap paradigm" was a black and white colored robot with a height of approximately 20 cm. When turning on the robot with a switch on its back it started to walk and play music. Both hands of the robot could be opened and closed by means of pressing/relieving a button. The hands of the robot were prepared to break when manipulated by the child. The robot could be repaired only by the experimenter. During neutral interaction between the experimenter and the child, other toys were presented, such as a puzzle, a magic wand, 3-D book.

2.4 Behavioral data analysis

Behavioral and verbal signs of children's distress during the experiment were observed according to a reliable coding system used in previous research and in the same context (7, 27, 28). According to this scheme, the child's behavior is coded according to 5 main categories (gaze direction, facial expression, bodily tension, actions and verbalizations) and various parameters (frequency, duration, latency) by two independent raters. Following from the notion that different combinations of signs may be indicative of distress, in previous studies of guilt and shame reactions to mishap paradigm and task failure (28, 33) distress has been scored categorically by restricting the number of criterion signs to five (eye/face, head/body, arms/hands, action and verbal). Thus, in the mishap and entrance phase, distress in response to mishap was defined "absent" if the child was not affected by the mishap in any way, "low" if the child showed behaviors included in one of the five codified signs, "medium" if the child showed behaviors included in two or three of the five codified signs, and "high" if the child showed behaviors included in at least four of the five codified signs.

2.5 Thermal data analysis

A visual inspection of the changes in facial ther-mal imprints in 10 mother-child dyads was performed to qualitatively investigate the autonomic responses of mother and child throughout the experiment.

This visual analysis was followed by a quantita-tive estimation of temperature variations in relevant facial regions of interest in 11 mother-child dyads.

Thermal facial imprints and variations in cuta-neous temperature of facial regions of interest in chil-dren and their mothers were analyzed using custom-made Matlab programs (http://www.mathworks.com). To chase a cluster of pixels corresponding to the same region on the face, we corrected, whenever possible, for translation of the face in the thermograms, which arose from body movements before analyzing changes in facial skin temperature. In case of marked rotation of the head, we skipped to the next frame in which the subjects restored their initial position. We corrected for the displacement between images frame by frame using anatomical landmarkers based on the subject's nose profile (15).

In order to quantify thermal variations and their correlation between children and their mothers, changes in cutaneous temperature for the nasal tip. This region was selected according to previous studies in humans as well as primates (30, 36, 43) as associated with the activation of the sympathetic nervous system by emotional or distressing stimuli (30, 34, 35, 36, 43). More precisely, thermal changes of the nasal tip may reflect sympathetic alpha-adrenergic vasomotor effects. Furthermore, sympathetic stimulation of the blood vessels can also have smaller vasodilatory effects via cholinergic and beta-adrenergic receptor action (45).

First, we assessed at the intra-individual level whether the facial skin temperature did not vary significantly or presented drifts during a 90 second baseline period immediately preceding the experiment, thus providing evidence for proper acclimatization of subjects. Second, in order to investigate the presence and timing for the change in skin temperatures following stimulus presentation (i.e. the onset of the experimental phases), we carried out multiple comparison tests between the 10-second pre-stimulus period (from 10 to 0 s before stimulus presentation) and each of the six 10-second post-stimulus periods. Analysis of variance (ANOVA) results rejected the hypothesis of equality of the means of the distributions. Dunnett's t-test showed that stimulus-related skin temperature variations occurred within the first 10 seconds and lasted from 20 to 30 seconds for the mishap, entrance and soothing phase. Therefore, for further analysis of the individual mother-child dyads as well as of the group data, we decided to take into account 5 representative frames for each experimental phase in which emotional modulation took place (mishap, entrance, soothing), as closest in time as possible to 6, 12, 18, 24, 30 seconds after the beginning of each phase. This proce-dure also allowed to deal efficiently with the partici-pants' motion and vocalizations in the ecological experimental setting by excluding frames affected by short-lasting motion or vocalization artifacts. Thus, a total of 15 frames (data points) were obtained for each participant for the analysis of the experimental phases. Similarly, 15 frames (each frame taken every about 5 seconds, and not affected by the above-mentioned short-lasting artifacts) from a neutral baseline period of 90 seconds immediately preceding the experiment were obtained.

The nasal tip temperatures of the children were manually extracted from the available thermal images. For extraction of the mothers' nasal tip temperature, a tracking algorithm was applied to the thermal videos to ensure the proper localization of the defined facial ROI (nasal vestibule area) on each of the processed frames of the experimental phases (baseline, mishap, entrance, soothing). The tracking algorithm is based on the 2-D cross-correlation between a template re-gion, chosen by the user on the initial frame, and a similar ROI in a wider searching region, expected to contain the desired template in each of the following frames. ROI average temperature distributions were computed in order to extract the time courses. For analysis, ROI average temperatures of the mothers were extracted at the time points corresponding in time to those of the selected thermal images in the children.

In order to verify whether there was a significant modulation of skin temperature in children and their mothers during the experimental phases and the base-line period in these facial region of interest,

group ANOVAs were performed with the thermal values at the 15 selected time points according to the procedure described above in the facial region of interest as within-subject variable.
Group correlation analyses (Pearson coefficient) analysis was performed on the thermal time courses of the determined region of interest for the experimental phases in which the emotional modulation took place (mishap, entrance, soothing) investigating quantitatively whether the individual mother-child dyads showed a synchronicity in autonomic activity. In order to verify whether correlations between au-tonomic parameters were specific for the experimental phases, that is, situation specific, the same procedure was applied to a baseline period of neutral interaction between the experimenter and child immediately preceding the experiment. In order to standardize the individual time courses, the thermal value of each selected data point in the time course was converted to a z-score. Subsequently, the standardized individual thermal time courses were averaged separately for the children and the mothers. Correlation analysis was performed between the averaged time courses of the children and the mothers.

2.6 Control analysis

In order to account for the possibility that the observed thermal variations in an empathic situation could reflect respiratory alterations, the mothers' temperature dynamics of the nasal tip were correlated with respiratory alterations.
For the extraction of the breathing signal, a tracking algorithm was applied to the thermal videos to ensure the proper localization of the defined facial ROI (nasal vestibule area) on each of the processed frames of the experimental phases (mishap, entrance, soothing). The tracking algorithm is based on the 2-D cross-correlation between a template region, chosen by the user on the initial frame, and a similar ROI in a wider searching region, expected to contain the desired template in each of the following frames. ROI average temperature distributions were computed in order to extract the time courses of the nasal breathing signal of the participating mothers. Once the breathing signal was extracted and opportunely band-pass filtered (0.25-0.6 Hz), the duration of breathing cycles (in seconds) was evaluated using an algorithm based on zero-crossing detection of the de-trended breathing signals. The obtained breathing cycle series were smoothed using a moving average (span of 8 signal samples). Data extraction and following analysis were developed by homemade Matlab algorithms (the Matworks Inc.).

Prior to the computation of Pearson correlation coefficients, we followed the same procedure as described above for calculating the correlation between facial temperature dynamics of mothers and their children. Thus, for every mother we took into account the respiratory cycle duration at 5 equally distributed time points for each of the experimental phases (mishap, entrance, soothing). Then, correlations between the resulting 15 data points representing the duration of breathing cycles and the 15 data points representing the nasal tip temperature were computed for the individual mothers.
A group analysis was also performed. In order to standardize the individual respiratory series, the value of each of the 15 data points was converted to a z-score. Subsequently, the standardized individual res-piratory time series were averaged for the group of mothers. Correlations were calculated between the average nasal tip temperatures and average respiratory cycle durations. Furthermore, multiple regression analysis was performed with both nasal tip thermal signal of the children and mothers' respiratory activity as independent variables, and nasal tip thermal signal of the mothers as dependent variable.
In order to verify whether there were significant respiratory alterations in the mothers during the experimental phases, a group ANOVA was performed with the 15 respiratory cycle duration values as within-subject variable.

3. RESULTS

3.1 Behavioral results

As expected, behavioral data confirmed a significant increase of children's distress during the experimental phases, that is, after the mishap. According to the categorical scores, distress levels across the chil-dren varied between medium and high.

3.2 Visual analysis of facial thermal imprints

A visual inspection of the changes in facial ther-mal imprints was performed to investigate the pres-ence of appreciable signs of autonomic responses of mother and child throughout the experiment.
As to the child, no appreciable modulations were detected regarding facial skin temperature distribution during the presentation and playing phase. However, after the mishap (i.e. after the breaking of the toy), a sympathetic reaction could be observed, reflected by a sudden and wide-spread decrease of face temperature, especially in the maxillary area and nasal tip as previously found in human as well as

macaques (30, 34, 35, 36, 43). This sympathetic reaction was accompanied by sudomotor response (34), which is in the maxillary area likely regulated by sympathetic postganglionic cholinergic activity, whereas the decreased skin temperature in the nasal tip could reflect peripheral vasoconstriction due to alpha-adrenergic activity. These sympathetic responses were maintained after the entrance of the experimenter. During the soothing phase, the sudomotor re-sponse in the maxillary area was initially maintained, whereas the temperature of the nasal tip soon in-creased, likely reflecting a withdrawal of the sympathetic alpha-adrenergic vasoconstrictor effect. This initial response was followed by a more generalized face temperature increase and the extinction of the sudomotor response, up to re-establishing the baseline state. Moreover, an over-response of nasal tip temperature was observed, compared to the start of the experiment.

Concerning the mother, no appreciable modula-tion of skin temperature distribution was detected during the presentation and playing phase. After the mishap as well as after the entrance of the experimenter, the same thermal variations observed in the child were detected in the mother, although more intensely in both cases. During the soothing phase, the mother showed a gradual and generalized increase of facial temperature with extinction of the sudomotor response in the maxillary area, re-establishing the baseline state. Moreover, like the child, she showed an over response of nasal tip temperature, compared to the start of the experiment.

3.3 Mother and child in synchrony

ANOVAs with the temperature values of the faci-al region of interest (nasal tip) at the different time points as within-subject variable showed a significant modulation of temperature during the emotionally charged experimental phases (mishap, entrance, soothing) for the child [$F(14,140) = 5.605$, $p < 0.001$] as well as for the mother [$F(14,140) = 2.339$, $p < 0.01$]. No significant modulation of temperature was detected during the baseline period, neither for the child [nasal tip $p > 0.9$], nor for the mother [nasal tip $p > 0.4$].

Group analyses for the phases in which the emo-tional modulation took place (mishap, entrance, soothing) showed significant positive correlation coefficients between thermal fluctuations of mother and child for the nasal tip ($r = 0.87$, $p < 0.0001$). With respect to the neutral baseline condition, no significant correlation could be found at the group level for the nasal tip ($r = 0.13$, $p > 0.6$), suggesting that the observed parallelism in thermal variations between mother and child also at the group level was specific for situations with an emotional valence. Example of mother-child dyad temperature variation is shown in fig. 1. Group results are graphically presented in fig. 2.

3.4 Control analysis for respiratory effects on thermal variations

Correlation analyses investigating the relationship be-tween thermal variations on the nasal tip and

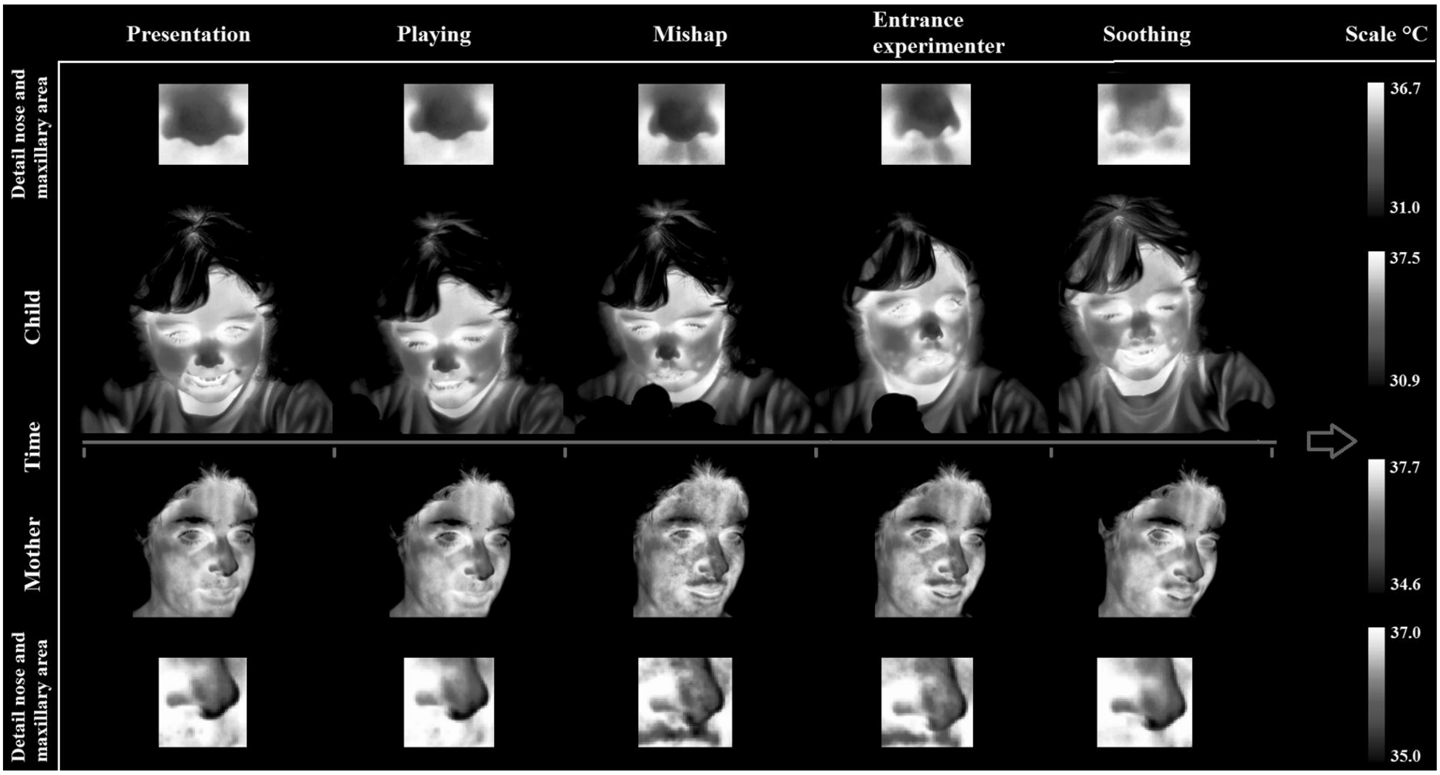
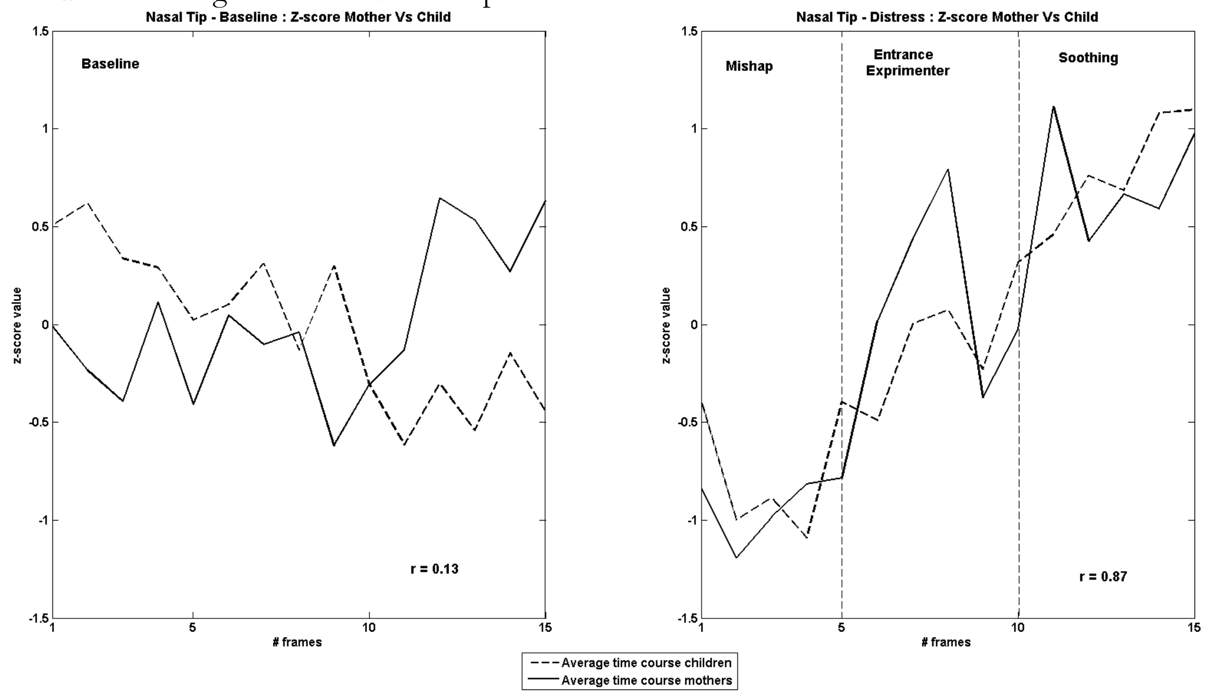


Fig. 1 - Facial thermal imprint of one of the mother-child dyad (adapted from 16).

Fig. 2 - Graphical representation of group temperature variations of the nasal tip area during the experimental phases as well as during the neutral baseline period.



nasal respiratory variations in the individual mothers did not yield significant correlations ($p > 0.05$). Group analysis confirmed the lack of a correlation between nasal temperature dynamics and respiratory activity in the mothers ($p > 0.7$). Furthermore, a multiple re-gression analysis showed that nasal tip temperature variations in the mothers were statistically independ-ent from the mothers' respiratory activity (Beta = 0.02, $t = -0.17$, $p > 0.8$), whereas the relationship between nasal tip temperature variations in the mothers and those in the children remained signifi-cant (Beta = 0.91, $t = 7.963$, $p < 0.001$). ANOVAs with the respiratory cycle duration values as a within-subject variable failed to show a significant modulation of respiratory activity in the mothers during the experimental phases ($p > 0.1$).

4. CONCLUSIONS

The present study provides two main results. First, facial thermal imprints of the mothers suggest that observation of their child's experience of distress in-duced significant emotional arousal mediated by the autonomic nervous system. The facial thermal modu-lations observed in the mothers were surprisingly similar to those observed in the child. Second, facial thermal modulations of the mothers correlated with corresponding modulations of their children at the in-dividual as well as at the group level. Control analyses showed that the thermal variations observed in the mothers in an empathic situation are unlikely to reflect respiratory alterations or other short-lasting artefacts throughout the experiment. Although both vasomotor and respiratory activity could be modulated by emotional stimuli, facial thermal variations were statistically independent from mothers' respiration and no significant alterations of respiratory activity were detected in the mothers during the experimental phases. Furthermore, segments in the thermal time courses corrupted by motion or vocalization artefacts were excluded from quantitative data analysis and would not be able to explain the observed parallelism between mother and child. Thus, mother-child dyads showed a significant and situation-specific synchronicity between the autonomic reactions individually exhibited by each partner.

These results, showing a synchronism between mothers' and children's autonomic responses, offer ra-ther direct evidence for the affective aspect of empathy as an embodied vicarious process. The findings are also consistent with the notion that both the psychological and the neural components of emotional feelings are essentially integrated with autonomic-visceral changes (8, 9, 10, 11, 12, 22, 23, 29, 31, 47).

The present study provides reliable measures of autonomic responses recorded simultaneously for both distressed children and their empathizing mothers, without the disadvantages of most of the physiological methods when applied to psychological domain, including the poor practicability and psychologically demanding character of the meas-urement equipment. By means of thermal IR imaging, physiological correlates of emotional reactions were investigated in an interactive and ecological experimental context without interfering with spontaneous behaviour and without age restrictions (30, 36, 43). This ecological

context has the advantage of obtaining more valid and generalizable data than those collected in fake laboratory settings. This also suggests important applications of the thermal IR imaging technique for providing data that add to developmental, comparative and evolutionary research on emotion in humans as well as non-human individuals (3, 13).
Some other issues should be noted. Although the present results show plausible evidence for emotional sharing between mother and child, testing whether similar patterns of physiological responses emerged in the mother if she had broken the toy herself, could properly support this evidence. Likewise, testing the mothers against other categories of people could sup-port the "maternal" nature of this emotional sharing. Differences both in intensity and in synchrony of au-tonomic responses could be expected between moth-ers and other groups. Differences should also be ex-pected between women who are the mothers of the observed children and women who are not, the latter supposed to be less emotionally tied to the child or to be less familiar with the child's typical behavioral signs of distress. In sum, based on our results, further studies using relevant control groups are encouraged in order to test specific hypotheses.
Furthermore, mimicry of facial muscular responses have been found predictive for self-reported empathic experiences and are related with variations in facial temperature as well (21, 25, 46). It would be a relevant issue for future studies to integrate these different types of measurements in order to gain more insight in the interrelationship between empathic re-sponses at different levels, like motor, autonomic and experiential (26).
In conclusion, the present results pave the way for a more comprehensive approach to the investigation of the neurobiological basis of emotional parent-child relationships as a multidimensional phenomenon. Supporting the hypothesis that empathy embodies a direct sharing of visceral-autonomic responses, we found a close and specific parallelism between the au-tonomic variations of mothers observing their children in a distressing situation and those occurring in children themselves. Since this sharing is assumed to represent the most basic and direct level of empathy (14), the present results provide reasonable evidence for a crucial and still poorly explored aspect of the phenomenon under scrutiny.
Finally, because of the contact-free nature of thermal infrared (IR) imaging, its successful application in the context of psychological research suggests that it could be particularly useful in investigating the neuro-biological basis of behavior, especially in populations difficult to involve in controlled and artificial experi-mental settings, like children. It also allows to study people in ecological settings without interfering with spontaneous behavior, providing more valid and gen-eralizable results.

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Reliability and Reproducibility of Skin Temperature of Overweight Subjects by an Infrared Thermography Software Designed for Human Beings

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SUMMARY

<u>Introduction</u>: The technical improvement and new applications of Infrared Thermography (IRT) with healthy subjects should be accompanied by results about the reproducibility of IRT measurements in different popula-tion groups. In addition, there is a remarkable necessity of a larger supply on software to analyze IRT images of human beings.
Therefore, the objectives of this study were: firstly, to investigate the reproducibility of skin temperature (Tsk) on overweight and obese subjects using IRT in different Regions of Interest (ROI), moments and side-to-side differences (ΔT); and secondly, to check the reliability of a new software called Termotracker®, specialized on the analysis of IRT images of human beings.
<u>Methods</u>: 22 overweight and obese males (11) and females (11) (age: 41,51±7,76 years; height: 1,65±0,09 m; weight: 82,41±11,81 Kg; BMI: 30,17±2,58 kg/m²) were assessed in two consecutive thermograms (5 seconds in-between) by the same observer, using an infrared camera (FLIR T335, Sweden) to get 4 IRT images from the whole body. 11 ROI were selected using Termotracker® to analyze its reproducibility and reliability through Intra-class Correlation Coefficient (ICC) and Coefficient of Variation (CV) values.
<u>Results</u>: The reproducibility of the side-to-side differences (ΔT) between two consecutive thermograms was very high in all ROIs (Mean ICC = 0,989), and excellent between two computers (Mean ICC = 0,998). The re-liability of the software was very high in all the ROIs (Mean ICC = 0,999). Intra-examiner reliability analysing the same subjects in two consecutive thermograms was also very high (Mean ICC = 0,997). CV values of the different ROIs were around 2%.
<u>Conclusions</u>: Skin temperature on overweight subjects had an excellent reproducibility for consecutive ther-mograms. The reproducibility of thermal asymmetries (ΔT) was also good but it had the influence of several factors that should be further investigated. Termotracker® reached excellent reliability results and it is a relia-ble and objective software to analyse IRT images of humans beings.

1. INTRODUCTION

Infrared Thermography (IRT) is a technique, which allows us to get rapidly and non-invasive thermal images from objects or human beings. Since the first applications of IRT on humans in the medical sector in 1950's and early 1960's (3, 25), this technique has underwent different and fluctuant stages, from the increasing interest in the 1970's and 1980's, to the rejection during the 1990's due to the lack of methodological standards and poor quality of the imaging systems (11). Nowadays, IRT is facing a new revival due to the technical improvements, which are paving the way for new applications (13, 14, 24).
Even if IRT has been widely used in pathological conditions, there are much less data available from healthy subjects (35). Moreover, the increase of interest on the application of IRT, not only in the medical sector but also in other fields as the physical activity with healthy subjects, makes more necessary to increase the knowledge concern-ing the factors affecting the application of IRT on humans (5, 24, 35), as well as the reproducibility of IRT measurements in different potential groups of application as children, elderly, overweight, disabled, or physically active subjects.

Overweight people represent a growing population group worldwide, mainly in occidental countries (5). Although IRT has been used on overweight and obese people –from the detection of some pathologies as diabetes (10, 29) to cellulite assessment (19)- few is known about the reproducibility of IRT measurements in overweight and obese subjects.
Ring has recently defended and described the new features of IRT technology and the improvement on standardization protocols (24). Nevertheless, most of research groups keep on analyzing IRT images using the software packages provide by the camera manufacturers, which are mainly created for industrial or architectural purposes, rarely adapted to human analysis (17). Therefore, there is a remarkable necessity of a larger supply on software to analyze IRT images of human beings.
The aims of the present study were: firstly, to investigate the reproducibility of skin temperature on overweight and obese subjects through IRT in different body regions, moments and thermal asymmetries (ΔT); and secondly, to check the reliability of the new software called Termotracker®, specialized on the analysis of IRT images of human beings and created by the research group of the Faculty of Phys-ical Activity and Sport Sciences-INEF from the Technical University of Madrid with the collabora-tion of several institutions.

2. METHODS

2.1 Subjects

A total of twenty-two overweight and obese right-handed males (11) and females (11) (age: 41.51±7.76 years; height: 1.65±0.09 m; weight: 82.41±11.81 Kg; BMI: 30.17±2.58 kg/m²) exercising at least 2 times per week, took part of the study. They did not report any orthopedic limitation or diseases, consumption of medicaments or drugs.
Subjects were previously asked to avoid a list of factors affecting skin temperature on their daily activity (i.e. alcohol or tobacco consumption, applica-tion of creams or ointments, or physical activity) in the 24 hours before the test an signed a writing con-sent for participating in the study. During the accli-matization period, they were asked to answer a ques-tionnaire to know the existence of any possible influence factor affecting IRT results. The project was previously approved by the Ethics Committee of the Technical University of Madrid, following the principles outlined by the World Medical Assembly Declaration of Helsinki.

2.2 IRT evaluation

The evaluation took place in a laboratory with stand-ardized conditions (Temperature = 23.55±1.19ºC; Humidity = 46.59±4.08%; and Atmospheric Pressure = 942.69±3.03 mb/hPa) following guidelines of the European Association of Thermology (EAT) (2).
Whole body skin temperatures (Tsk) of each subject were recorded in four IRT images (Anterior and Posterior of Upper and Lower body) – as it is shown in figure 1- in two consecutive thermograms (5 seconds in-between) by the same observer. We decided to separate both thermograms just with 5 seconds in order to minimize the influence of factors that could affect the skin temperature records, as others authors have described in their studies (35).

2.3 Equipment

All thermal images were taken by an infrared camera (FLIR T335®, FLIR Systems, Danderyd, Sweden) with thermal sensitivity of 50mK, a wide range of temperature from -20 °C to +120 °C, spectrum range of 7.5-13 μm, resolution of 320 x 240 pixels, emis-sivity set at 0.98 (Steketee et al. 1973) and an accu-racy of ± 2%. The environmental conditions were controlled by a BAR-908-HG portable weather sta-tion (Oregon® Scientific, USA). Moreover, we use a tripod Hama Omega Premium II (semiprofessional Tripod 62.5-148 cm) and a “Roll-up" 125 x 206 cm to obtain a homogeneous background behind the subjects. We used also a "step" with marks for fixing the standing protocol position and raising slightly the subject from the floor surface. IRT images were transferred to a laptop Sony® VAIO Y11S1E/S (Sony, Japan). The IRT images were analyzed using the IRT software Termotracker® (pemaGROUP, Madrid, Spain) and statistic analyses were made through SPSS version 20.0 for Mac (IBM® Corpo-ration, Armonk, NY, USA).

2.4 Software

Termotracker® (pemaGROUP, Madrid, Spain) is a software for analysing IRT images of human beings, which was created by the Thermography research group of the Faculty of Physical Activity and Sport Sciences-INEF from the Technical University of Madrid with the collaboration of several institutions, as TS Company (Madrid, Spain), Spanish National Research Council (CSIC, Spain) or Alava Ingenieros (Madrid, Spain). The software is able to analyse the 4 IRT images of a subject (Anterior and Posterior, Upper and Lower body) dividing automatically each IRT image in Regions of

Interest (ROI) based on ar-ticular and muscular areas of the human anatomical structure (as it is shown in fig. 1) Termotracker® recognises a total of 78 ROI by a feature called "artificial vision" and based on an algorithm that identi-fies the subject shape and anatomical key points to automatically trace the ROIs, without requiring any external marker, which are often used by other authors in literature (6, 28). Termotracker® extracts from the total of pixels of each ROI the maximum, minimum and mean temperature with standard deviation (SD). The images can be organised in folders, ROI can be handily modified and the results can be transferred to an excel file. For this study, we decide to use 11 ROI: abdominal, right and left thigh union of several ROI, right and left anterior knee, right and left chest, right and left calf, back and lumbar ROI marked on the fig. 2. We decided to select only these ROIs because of their relevance and size, and to reduce the amount of information. All images were assessed in two different laptops with the same software.

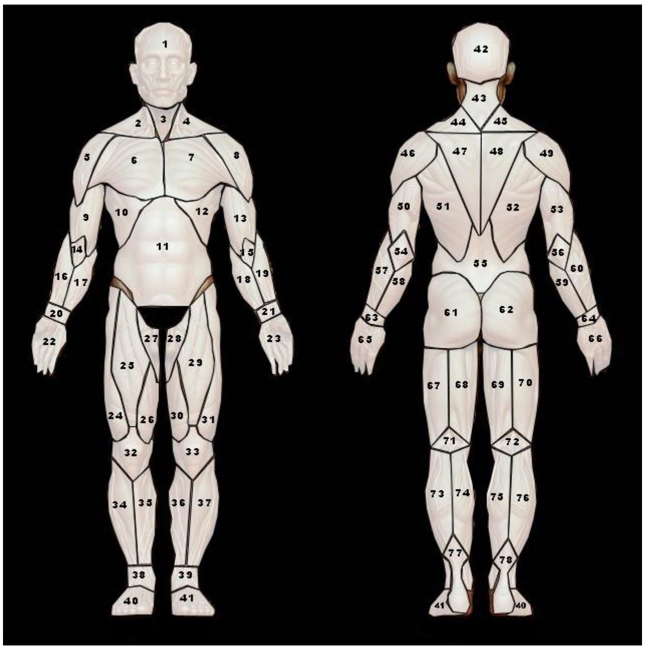

Fig. 1 - Distribution of the 78 Regions of Interest (ROI) made by Termotracker® software by analysing IRT images.

2.5 Statistics

Kolmogorov-Smirnov tests were used in order to verify the normality of the dependent variables and to determine the use of parametric or nonparametric statistics. The results indicated a normal frequency distribution, therefore parametric statistics were applied.

A two-way mixed model was used to determine: the Intra-class Correlations Coefficient (ICC) consider-ing the obtained data from two different computers (reliability of the software); the intra-examiner relia-bility (two thermograms of all subjects by the same researcher); and the reproducibility of thermal asymmetries between bilateral ROIs (ΔT) (obtained by two computers from two different thermograms). Coefficient of Variation (CV) (SD/mean * 100) was also used to analyze the dispersion of the data. In addition, Bland-Altman plots were calculated to show the intra-examiner agreement and the disper-sion of all readings with 95% agreement limits. Pearson Correlation Coefficient was calculated in order to describe the correlation of ΔT results be-tween 1st and 2nd thermogram. The level of signifi-cance was set at $\alpha=0.05$.

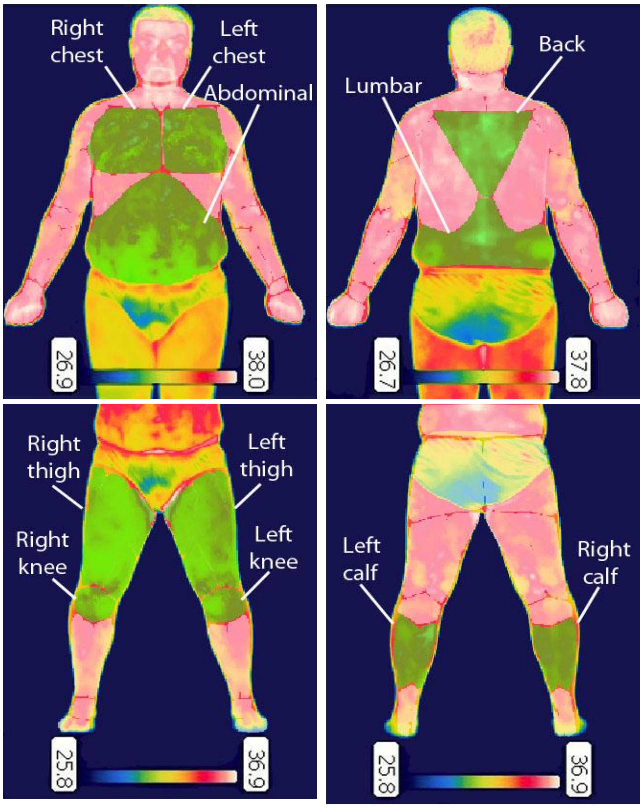

Fig. 2 - Anterior and Posterior IRT iamges of Upper and Lower body with the ROI selected by Termotracker® and analysed in this study (n=22).

3. RESULTS

Coefficients of Variation (CV) were calculated (see table 1) showing higher CV on the upper body ROIs (i.e. right and left chest, lumbar and ab-dominal) and lower CV on the lower body (i.e. right and left calf). Nevertheless, the CV results were ranged between 1.20% and 3.10% in both thermo-grams, with a CV mean value of 2.08% for the Thermogram 1, and 2.13% for Thermogram 2.

Concerning the side-to-side differences (ΔT) between bilateral ROI (see table 2), the bigger asymmetry was found on the knee, with a result of (ΔT = 0.13±0.38). Despite the fact of all subjects

Table 1. Mean temperatures with minimal and maximal values, standard deviations (SD) and coefficient of variation (CV) of each Region of Interest (ROI) on Thermogram 1 and Thermogram 2 (n=22)

	Skin temperature Thermogram 1			Skin temperature Thermogram 2		
ROI	Mean±SD	(min-max)	CV (%)	Mean±SD	(min-max)	CV (%)
Abdominal	31.05±1.33	(27.55-33.38)	2.45	31.00±1.37	(27.00-33.29)	2.83
Right Thigh	30.27±1.34	(26.59-31.78)	1.68	30.26±1.34	(26.59-31.84)	1.66
Left Thigh	30.35±1.38	(26.69-32.32)	1.79	30.34±1.40	(26.71-32.34)	1.83
Right Knee	30.11±1.18	(27.77-32.38)	1.83	30.13±1.21	(27.75-32.40)	1.88
Left Knee	30.25±1.30	(27.06-32.64)	1.89	30.26±1.32	(27.04-32.72)	1.92
Right Chest	31.49±1.16	(28.69-33.66)	3.09	31.54±1.13	(28.89-33.57)	3.10
Left Chest	31.42±1.16	(28.39-33.55)	2.96	31.46±1.13	(28.54-33.49)	2.96
Right Calf	30.79±1.08	(28.68-32.50)	1.20	30.79±1.06	(28.69-32.40)	1.20
Left Calf	30.88±1.12	(28.44-32.61)	1.25	30.87±1.11	(28.53-32.53)	1.24
Back	31.62±1.17	(28.82-33.65)	1.77	31.65±1.14	(29.03-33.66)	1.73
Lumbar	30.83±1.42	(27.79-33.08)	2.95	30.84±1.40	(27.95-33.08)	3.04
Mean±ST			2.08±0.68			2.13±0.72

were right handed, the results of ΔT show warmer skin temperatures in the left ROIs excepting the chest, were the right side was hotter than the left (ΔT = 0.08±0.22). Pearson Correlation Coefficient of ΔT results between thermogram 1 and thermogram 2 were very high ($r > 0.98$ in all bilateral ROIs; $p < .001$)
Intra-class Correlation Coefficients (ICC) analysis is summarized in table 3. On the one hand, the Intra-class Correlation Coefficients (ICC) from the analy-sis of the IRT images in two different computers was very high in all the ROIs (mean ICC = 0.999); on the other hand, the intra-examiner reliability using the software to analyse two consecutive thermograms of the same subjects was also very high (mean ICC = 0. 997). The lowest ICC value was found on the Abdominal ROI (ICC = 0.987). More-over, Figs. 3 and 4 show the Bland-Altman mean difference plots, which can be used to visualize the overall degree of agreement. In this case, they corre-spond to intra-examiner agreement between both thermograms (fig. 3) and both computers (fig. 4), with only 4.13% and 3.30% of all readings falling outside the 95% agreement limits respectively.
In table 4 the side-to-side differences (ΔT) results are summarized considering bilateral ROIs. The outcomes point out the high level of agreement between both computers (mean ICC = 0.998). Likewise, the reproducibility of ΔT between two consecutive themograms was also very high in all ROIs (mean ICC = 0.989), despite they were the lowest values compared with other reliability and reproducibility results (see table 5).

Table 2. Mean temperatures and standard deviations (SD) of thermal asymmetries (*ΔT*) –side to side temperature differences- of the Thermogram 1 and Thermogram 2. Pearson Correlation Coefficient between both Thermograms and p value **p < .001 (n=22)

	ΔT of ROI			
	Thermogram 1	Thermogram 2		
ROI	Mean±SD	Mean±SD	Pearson	P value
Thigh	-0.09±0.23	-0.08±0.23	0.998**	0.000
Knee	-0.13±0.39	-0.13±0.38	0.994**	0.000
Chest	0.07±0.23	0.08±0.22	0.986**	0.000
Calf	-0.09±0.33	-0.08±0.31	0.997**	0.000

4. DISCUSSION

Even if skin temperature is supposed to be constant along the time (9), or symmet-rical on both sides of the body in terms of skin temperature (18, 33), the list of factors affecting the skin temperature is so large (23), that a lack of feasibility on Tsk records could be considered one of the weakest points of IRT.
Therefore, working on the improvement of IRT for a wider application consists not only on making better cameras with advanced features, but also on deepen our knowledge about skin temperature, and how it behaves depending on the interaction with extrinsic and intrinsic factors. Among the enormous quantity of further work left to do, this study pre-tends to take two small steps forward: firstly, to analyse the reliability and reproducibility of IRT in a special population group, as overweight and obese people; and secondly, examining the reliability of a

specific software created to analyse IRT images of human beings.

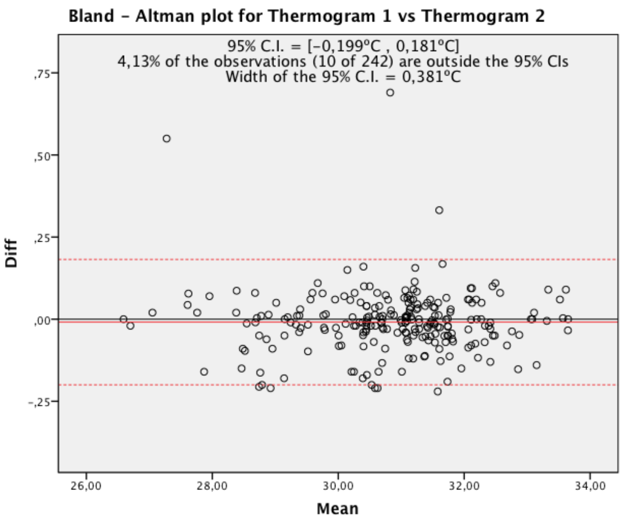

Fig. 3 - Bland – Altman plots for intra-examiner agreement between the same observed in two thermograms, 4.13% of all readings done fell outside the 95% agreement limits.

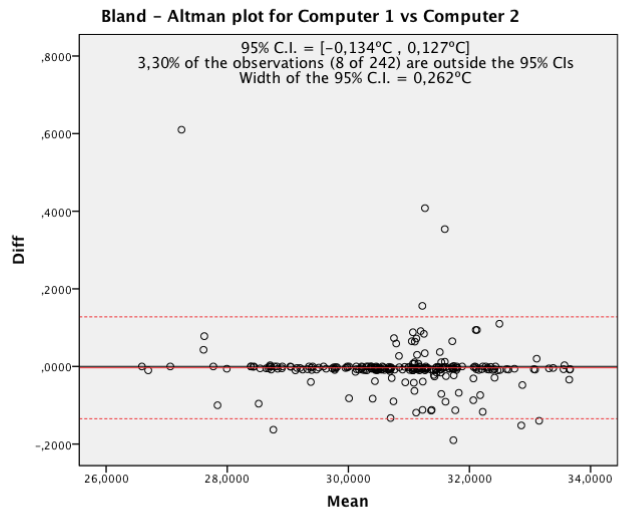

Fig. 4 - Bland – Altman plots for intra-examiner agreement between the same software in two computers. 3.30% of all readings done fell outside the 95% agreement limits.

Concerning the first objective, IRT reliability has been studied in several works, both with patients (6, 12, 28, 31) and healthy subjects (16, 21, 35). So far, most of the studies cited above reached ICC results ranged between 0.4 and 0.9. However, some of them reported the influence of factors as technical errors, the physiological variability from one day to other (35), or the existence of anterior injuries (12). Consequently, we decided to use only one examiner, following a standardised protocol based on the guidelines of the EAT (2) with healthy subjects in two consecutive thermo-grams, separated by just 5 seconds in order to avoid the potential influence of those factors. According to the Littlejohn (16) classification of ICC values (poor: 0 – 0.39, Fair: 0.40 – 0.59, Good: 0.60 – 0.79 and Excellent: 0.80 – 1.0), our results showed excellent ICC values between the two consecutive thermograms (mean ICC = 0.997), what is almost perfect.

Table 4. Intra-class Correlation Coefficients (ICC) and their mean with Standard Deviation (SD) in two different computers with the same software Termotracker® and in two different thermograms for each Region of Interest (ROI) (n=22)

ROI	Software reliability (two computers)	Intra-examiner reliability (two thermograms)
Abdominal	0.997	0.987
Right Thigh	1	0.998
Left Thigh	1	0.999
Right Knee	0.999	0.998
Left Knee	0.999	0.999
Right Chest	0.999	0.997
Left Chest	0.999	0.998
Right Calf	0.999	0.998
Left Calf	0.999	0.999
Back	1	0.998
Lumbar	0.999	0.998
Mean±SD	0.999±0.001	0.997±0.003

Table 5. Intra-class Correlation Coefficients (ICC) and their mean with Standard Deviation (SD) for the reproducibility of thermal asymmetries (*∆T*) of the bilateral Regions of Interest (ROI) in two different computers with the same software Termotracker® and in two different thermograms (n=22)

	Reproducibility of ΔT	
ΔT of ROI	Software	Thermogram
Thigh	0.998	0.980
Knee	0.998	0.994
Chest	0.996	0.985
Calf	0.999	0.996
Mean±SD	0.998±0.001	0.989±0.008

In addition, we took into account the growing use of thermal asymmetries in the application of IRT on humans (7, 18, 33, 34) to calculate the side-to-side differences (ΔT) in the selected bilateral ROIs. In that case, our reproducibility results of bilateral ΔT for two consecutive thermograms, if somehow

Table 6. Mean, minimal, maximal values of Intra-class Correlation Coefficients (ICC) with Standard Deviation (SD) for the reliability of the software and the examiner and the reproducibility of thermal asymmetries (*ΔT*) in two different computers with the same software Termotracker® and in two different thermograms (n=22)

	Min	Max	Mean	SD
Intra-examiner reliability (between two computers)	0.997	1.000	0.999	0.001
Intra-examiner reliability (between two thermograms)	0.987	0.999	0.997	0.003
Intra-examiner reliability (between two days) (Zaproudina et al. 2008) (n=16)	**0.080**	**0.780**	**0.880**	**0.210**
Reproducibility of ΔT (between two computers)	0.996	0.999	0.998	0.001
Reproducibility of ΔT (between two thermograms)	0.980	0.996	0.989	0.008
Reproducibility of ΔT (between two days) (Zaproudina et al. 2008) (n=16)	**-0.010**	**0.830**	**0.400**	**0.220**

slightly lower compared with the absolute Tsk values, were still excellent, with an ICC mean of 0.989. The highest results correspond to the calf and knee, reaching chest and thigh lower values. This difference could be related to the ROI size, but fur-ther investigations with more time between thermo-grams are required to check this tendency.

According to the second objective, we examined the reliability of a software created to analyse IRT images. Some authors reported inter-examiner variations (22, 35), due in some cases to the difficulty of selecting man-ually the areas of the ROIs (2). Therefore, in addition to the efforts done on creating standardised protocols and guidelines (2, 23, 27), it should be suitable to develop specific and automatic software able to manage with this difficult task. Termotracker® is a new software with a computer vision algorithm, which automatically identifies the body shape and the regions of interest from the IRT images, providing a database with the main data of the con-sidered ROIs. The results of reliability and reproduc-ibility reached in this study by the software Termotracker are almost perfect (between 0.998 and 0.999) –table 5-. By comparing the results with those ob-tained by Zaproudina et al. (35) (see table 6), the higher reliability even in ICC intra-examiner results could be due to this automatic process to identify ROI, task done in other studies by the observer (6, 12, 28). This automation of determining the areas of each ROI improves the IRT reliability, making possible a faster and more efficient IRT analysis of the thermograms from human beings. These results should be expected to be perfect (ICC = 1.0), but the few imperfections showed in figure 4 should be improved by removing some random parameters from the computer vision algorithms implemented in Thermotracker®.

In addition, the use of coefficients of variation (CV) showed a small dispersion of the Tsk in all ROIs. Our results are better than those reported by Zaproudina et al. (35), which indicated CV lower than 10%. Our CV mean values of 2.08% and 2.13% -Thermograms 1 and 2 respectively- reinforce the good data obtained on the reproducibility results. Likewise, Bland-Altman plots showed good results of intra-examiner agreement, with only 4.13% of the readings out of the 95% agreement limits between Thermograms 1 and 2, and 3.30% in the case of intra-examiner agreement between computer 1 and 2.

The distribution of skin temperatures showed warmer temperatures in the upper body ROIs, as back and right and left chest. The abdominal ROI will be supposed to be among or close to these values; but it reached lower Tsk values, which could be justify by the remarkable isolating effect of the sub-cutaneous fat in this body area (26). Colder temperatures are show on distal ROI as thighs or knees –table 1.

In general terms, the results of this study are coin-cident with those of Owens et al. (20) and Burnham et al. (4) with ICC over 0.9, but both au-thors did not used IRT cameras, but a handheld thermographic scanner and Infrared Skin Ther-mometer respectively. Other studies examining inter and intra-examiner reliability of IRT cameras reached good results (6, 12, 16, 21, 28, 31, 35), but none took as sample of overweight subjects, and reached so excellent ICC results like the ones showed in our study. Moreover, among the new technological features (15, 30, 31) and similar softwares (Murawski et al. 2003), Termotracker® seems to be one of the firsts IRT software created to analyse IRT images of human beings, which reported excellent reliability results. Nonethe-less, it should be improved until reaching ICC values of 1, to ensure an automatically perfect analysis of the considered ROIs in IRT images.

5. CONCLUSIONS

Skin temperature on overweight subjects has an excellent reproducibility for consecutive thermograms. The reproducibility of thermal asymmetries (ΔT) is also good but could be influenced by several factors that should be further investigated. The high reliability results of the software suggest the im-portance of using specific software to analyses IRT images on humans, eliminating the likely human error of drawing each ROI and improving the efficiency and objectivity of a technique with a high potential of application on humans. So that, we conclude that Termotracker® is a reliable and objective software to analyse IRT images of humans beings.

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Thermographic Evolution of Bone Temperature Evolution

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SUMMARY

Dental implants present very high long term success rates due to, among other factors, an adequate and atraumatic implant bed preparation or osteotomy. Osteotomy is a surgical procedure of bone removal where strong inflammatory reactions and trauma are present. During bone drilling, if the temperature reaches 47ºC or more for 1 minute, irreversible osteonecrosis will occur, depending on its extension on temperature magnitude and time of exposure to the thermal agent. To simulate the human jaw, fresh porcine femora of uniform density were used. To measure the temperature during bone drilling, a FLIR A325 thermal camera was used with a close-up lenses (25µm/pixel), recording one image per second. Different parameters regarding drilling speed, drilling depth, pressure applied to the drill and continuous vs intermittent drilling can induce different bone temperatures. In bone like structures a simple thermal camera is not adequate to measure temperature changes since these are extremely high and localized in very small portions of material. Therefore the use of a close-up lenses is crucial.

1. INTRODUCTION

Built primarily from collagen molecules, mineral crystals, water and ions (1) bone is a specialized connective tissue (2) that provides diverse mechanical, bio-logical and chemical functions such as structural support, protection and storage of healing cells, and mineral ion homeostasis (3).
The bone is made up of bone cells and extra-cellular matrix. The matrix consists of two types of materials - organic and inorganic. The organic matrix is formed by collagen, which represents 30-35% of the dry weight of the bone. The inorganic matrix is primarily calcium and phosphorus salts, especially hydroxyapatite [Ca10 (PO4) 6 (OH) 2] and constitutes approximately 65-70% of the dry weight of the bone. There are three main bone cell-types:
1. Osteoblasts – concerned with ossification, these cells are rich in alkaline phosphatase, glycolytic enzymes and phosphorylases.
2. Osteocytes – these are mature bone cells which vary in activity, rich in glycogen and PAS positive granules, and may assume the form of an osteoclast or reticulocyte.
3. Osteoclasts – these are multi-nucleate mesen-chymal cells concerned with bone resorption, containing glycolytic acid hydrolases, collagenases and acid phosphatase enzymes (4,5).

At the macrostructure level, bone is distinguished into the cortical (or compact) and cancellous (or trabecular) types (3). Comparison of cortical and cancellous bone demon-strates a similar matrix structure and composition, but vastly different masses, with cortical bone hav-ing a greater mass-to-volume ratio. The differences in mechanical properties between cortical and can-cellous bone are due to the differences in architec-ture, even though the composition and materials are the same. The thick and dense arrangement allows cortical bone to have a much higher resistance to torsional and bending forces, whereas cancellous bone provides greater resilience and shock absorp-tion. In general, cancellous bone is much more met-abolically active and is remodeled more often than cortical bone (6).
Cortical and cancellous bone can be made up of either woven or lamellar bone. Woven bone, some-times referred as primary bone, is seen in embryonic bone and is later resorbed and replaced by lamellar, or secondary, bone. Woven bone has a greater rate of metabolic activity compared with lamellar bone (7).
It has been demonstrated the importance of heat generation during bone drilling. About 500 BC, in his theory and practice of medicine, Hippocrates suggested that cooling should be applied to the tre-phine when disks of bone were removed from the skull (8). Necrosis around pins inserted into bone was noticed by Gillies, which he attributed to drilling heat (9).

Osseointegrated dental implants present very high long term success rates due to, among other factors, an adequate and atraumatic implant bed preparation or osteotomy (10, 11). Osteotomy is a surgical procedure of bone removal where strong inflammatory reactions and trauma are present (12). Drilling causes not only a mechanical trauma, but also a considerable thermal damage to the surrounding bone, being this the most harmful factor regarding this tissue (13). After the im-plant bed preparation and placement of the implant in its final position, several cellular and molecular events occur as a response of the wound healing process (14). Because of the low thermal conductivity of bone, heat generated during drilling is not quickly dissi-pated remaining around drill holes or osteotomies. If the temperature reaches 47ºC or more for 1 minute, irreversible osteonecrosis (15) will occur depending its extension on temper-ature magnitude and time of exposure to the thermal agent (16). Consequently, denatura-tion of alkaline phosphatase takes place (14, 15, 17, 18, 19) preventing the implant from osseointegration (15). Several factors have been described as being responsible for the temperature rising during osteotomy for implant bed preparation such as: drill speed (13, 20), pressure applied to the drill (21), drilling depth (22), irrigation (23, 24) and continuous vs intermittent perforation (24).

2. METHODS

2.1 Bone preparation

To simulate the human jaw, fresh porcine femora of uniform density and with a cortical thickness of 3-4mm were used. The porcine and canine bones best resemble human samples (25).

2.2 Drilling

All drillings were performed with the W&H Osseoset 100 dental implant motor using a 13mm long and 2mm wide cylindrical drill in new condition, running at 100 rpm with a constant load of 2.0 kg. All drilling was performed by the same surgeon.

2.3 Thermography

In order to measure the temperature during bone drilling, a FLIR A325 thermal camera was used with a close-up lenses (25µm/pixel), recording one image per second. The tests were recorded at 30Hz and analyzed af-ter using two softwares: the FLIR® thermaCAM™ Researcher 2.10 and a custom application developed in LabVIEW®.

3. RESULTS

3.1 Direct readings

When different parameters (drilling speed, drilling depth, pressure applied to the drill and continuous vs intermittent drilling) were used during bone drilling, significant differences were found regarding bone temperature. Because the aim of this study was to access if thermography is a valid method to evaluate bone temperature evolution during dental implant bed preparation, we defined a single drilling speed, with a constant pressure and without irrigation fluid.
In bone like structures, a simple thermal camera is not adequate to measure temperature changes since these are extremely high and localized in very small portions of material. Therefore, the use of a close-up lenses is crucial, which is easily demonstrated comparing fig. 1 with fig. 2, where the maximum temperatures differed more than 30ºC. (80ºC to 110ºC).

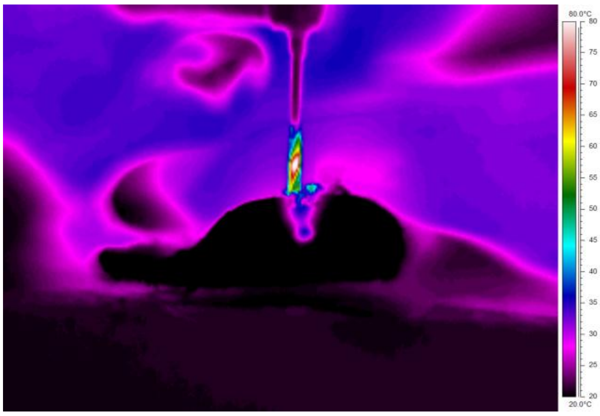

Fig. 1 - Hole drilling starting point, without close-up lenses.

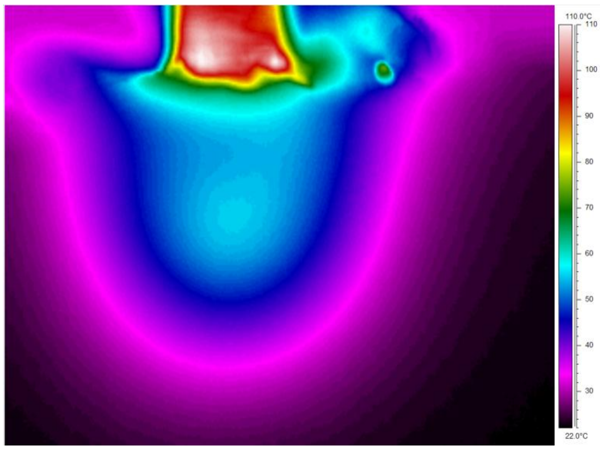

Fig. 2 - Hole drilling starting point, with close-up lenses.

As expected, during the drilling procedure, the maximum temperature was recorded in the middle of the wall. The highest temperature registered during a 15 second drilling period was 113 ±2ºC.
In what concerns to temperature patterns, these were very symmetrical along the drilling depth. This enabled another representation of the data and also other conclusions.

Fig. 3 - Temperature distribution at the end of drilling process.

3.2 Processed data

Because of the enormous symmetry in thermal patterns, it was possible to analyze only the drilling axis. Therefore, a custom application developed in LabVIEW® was used, in order to extract the temperature line that was placed in the center of the hole (Fig. 4).

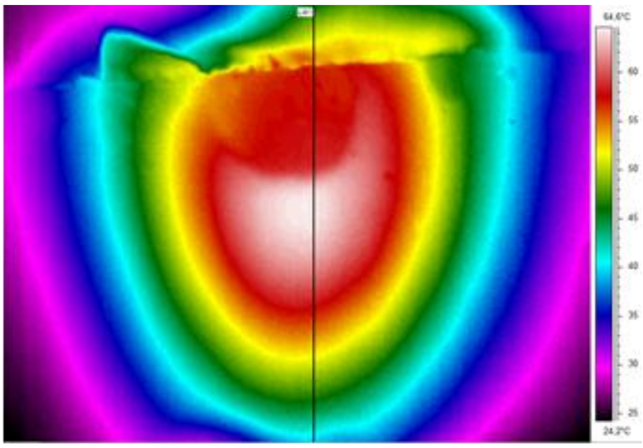

Fig. 4 - Line to analyze through time.

At each frame (recordings took place at 30Hz) and after extracting the temperature line in the center of the drill, that same line was inserted in a buffer. Then a new image was constructed, with the X axis being the time in seconds, Y the position along the drill and lastly the color representing temperature values (Fig. 5).

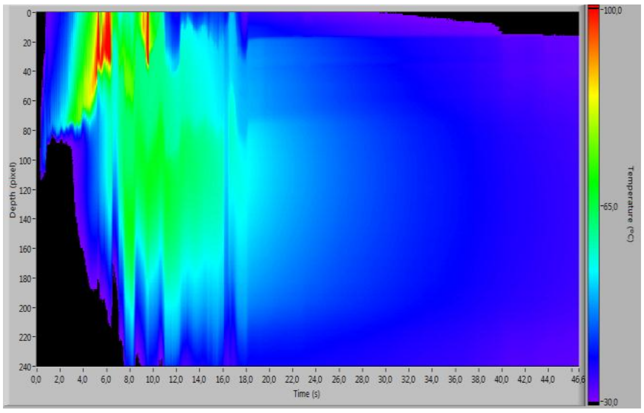

Fig. 5 - Temperature evolution (100-33 ºC).

4. DISCUSSION

During these tests, extremely high temperatures were observed, with a maximum registered of 113ºC. Considering 45º - 46ºC as the highest bone temperature before osteonecrosis occurs, bone was more than 15 seconds above 65ºC and more than 20 seconds with temperatures above recommendation (Fig. 6).
Like in all measurements with thermography also in bone drilling procedures there are inherent errors. The error of a missed estimation of the emissivity could lead to highly doubtful temperature values. This setting can be easily corrected by performing some tests with a fast response thermocouple or a RTD sensor, has a feedback for the thermal measures. There are even some references for this setting like (26).

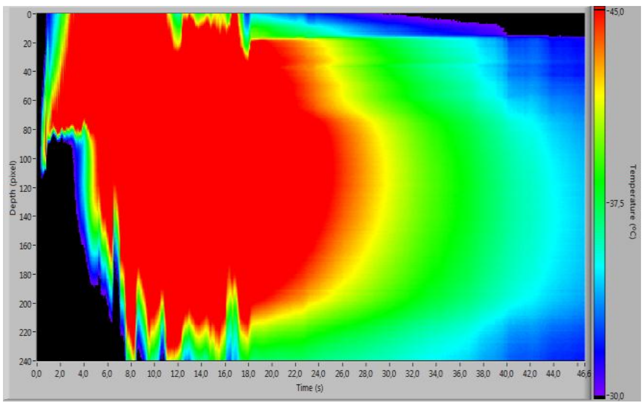

Fig. 6 - Temperature evolution (45-33 ºC).

The use of a simple thermal camera showed to be insufficient to measure the temperature of the bone during drilling procedures. To achieve a correct thermal reading is necessary to have several pixels at the same temperature to prevent neighborhood errors. Since the object of interest is relatively small, (15x15mm) a macro lenses should be required. This way, the region of interest fills the entire image and the amount of infrared radiation that reach a sensor

of the microbolometer is very resemble to their neighbor and, therefore, neighborhood errors are minimum.
One of the problems of using a macro lenses is the sensitivity to the movement during the drilling procedure; the result is illustrated in figures 5 and 6 where is visible some irregularity in the temperature border profile. In order to correct this, some extra post processing is required or, otherwise, the use of a support to firmly secure the bone sample is advisable.
Evaluating just the peak temperature is not enough, as is also extremely important to assess the temperature curves to estimate the complete bone damage. The post processing presented in figs. 5 and 6 demonstrate the alarming of unexpected high temperatures and sustenance over time.
Despite bone drilling procedures without liquid refrigeration are not recommended, under specific surgical protocols, there are implant manufacturers that advocate dry drilling perforations; these situations can be firmly reproduced in laboratory and the direct readings with thermography are enough. On the other hand, liquid refrigeration procedures cannot. Regarding this, alternative refreshing is required in a way that it does not affect the infrared radiation but able to maintain the cooling capacity of the saline solution.

5. CONCLUSION

Maximum caution must be taken during dental implant osteotomy in order to avoid bone damage that could lead to osteonecrosis and, therefore, implant failure.
The results of this study clearly indicate that a better comprehension of the drilling procedure is required so it may be determined what are the best and saffer drilling protocols.
Thermography showed to be the perfect tool to access the temperature changes and patterns during bone drilling maneuvers.
It is also necessary to develop a device that allows assessing bone drilling temperatures when liquid refrigeration is used. For example, in order to try to reproduce the same cooling capacity, a fast and directed stream of air could be an effective substitute for liquid cooling, even if the volume of air per minute could be difficult to estimate.
Further investigations are necessary to fully understand the temperature distribution and patterns during bone drilling procedures.

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Effect of Yoga and Swimming on Body Temperature of Pregnant Women

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SUMMARY

Introduction: Physical activity for pregnant women should be controlled and adapted in order to minimize the risk of loss of balance and fetal trauma (Davies, Wolfe, Mottola, y MacKinnon, 2003). Non-invasive technologies are required for understanding better the effects of physical activity on pregnant women. Infrared thermography allows, remotely, securely and without any contact, to measure and display accurate temperatures on the human skin.
Methods: We studied the effect of two different organized physical activities on the skin temperature (Tsk) of 28 volunteer 31-weeks-pregnant women (Yoga: n=14; Swimming: n=14). Two sets of six thermograms (Anterior and Posterior of the Upper and Lower limbs, and Left and Right Lateral Upper body) were registered by a T335 FLIR infrared camera: the first after 10 minutes of acclimatization to the room conditions and before the physical activity, and the second within the ten minutes after finishing the physical activity.
Results: Because of the significant difference in general Tsk of the women in the first assessment ($t(26) = 9.21$; $p < 0.05$) probably due to increased use of creams ($\chi2(1) = 9.33$; $p < 0.05$), lower room temperatures ($t(26) = 4.00$; $p < 0.05$) and humidity ($t(26) = 7.49$; $p < 0.05$) in the yoga group, only the increment of Tsk between pre- and post-activity measurements were considered for the analysis of the data. Our results indicate (see Table 8) that general Tsk were significantly reduced after swim-ming ($t(13) = 11,60$; $p < 0.05$) and non-significantly increased after the yoga practice ($t(13) = -1,19$; $p = 0.25$). This tendency was similar in all the body areas in the Swim group and more heterogeneous after the yoga practice with non significant differences in the limbs and significant differences in the trunk areas (including breast and belly).
Conclusions: The results point out a significant reduction of Tsk of expectant mothers after aquatic activity even in the breast and belly areas, probably due to inadequate water temperature although the values of Tsk does not appear to be hazardous to the fetus. Practicing yoga during pregnancy slightly increases the Tsk in the whole body maybe because of the characteristics of the activity.

1. INTRODUCTION

Nowadays, physical and sport practice has become a daily occurrence, which defines each society. International institutions recommend the promotion of Physical Activity (33) as one of the best ways to prevent some of the most frequent health problems of the population (32). Therefore, in countries where women are treated equally by society, exercise has become part of everyday life of many women, even during pregnancy, the women's stage in which occur the most important physiological and psycho-logical adaptations. Everyday there is a greater number of women who wish (14) to continue training during their pregnancy.

1.1 Pregnancy and Physical Activity

The prescription of exercise in pregnant women has varied depending on available scientific information (1, 19, 29). The large number of anatomical, biological and psycholog-ical changes that occur in women during pregnancy (17, 35) and the individual differences on these changes (30), make difficult to reach a consensus on the volume, intensity, and kind of exercise to be prescribed for pregnant woman.
However, several studies (12, 18, 22, 26, 28) indicate that moderate exercise dur-ing a healthy pregnancy

can have physical and psychological benefits in pregnant women and offer little risk to the fetus.
Effects of physical activity in pregnant women have been studied through their influence on different organs and systems of the pregnant woman taking into account different parameters:
1) heart rate is significantly higher in pregnant women who are physically active; however, blood pressure helds similar parameters in pregnant and non-pregnant women (37);
2) ventilation change for physiological, mechanical and chemical reasons (13, 34, 36);
3) metabolism yield to different results (18);
4) temperature has been a major concern of physical exercise during pregnancy because hyperthermia produced by an excessive exercise may cause problems in the fetus development (16, 18).

A recent study (15) concluded that temperature of pregnant women did not increase significantly during or after exercise (36.5 vs. 36.7 °C). The methods used for assessing temperature were electronic thermometers located in the selected area and inside the ear canal. None of the pregnant women approached their body temperature to dangerous levels while practicing low-impact exercise. We can conclude that low intensity aerobic exercise at about 70% of maximum heart rate seems to be safe for the fetus in terms of risk by maternal hyperthermia.
Other works (5) have investigated the effects of exercise on the oxygen and substrate delivery to the interphase, which can exceed 50% during exercise; however, regular bouts of sustained exercise may improve oxygen and substrate delivery at rest. Additionally, Clapp stated that the type of maternal carbohydrate intake and food intake frequency can also influence the substrate availability of the fetus through their effects on maternal blood glucose and insulin levels, concluding that exercise in early and mid pregnancy stimulates placental growth while the relative amount of exercise in late pregnancy determines its effect on late fetal growth. On the other hand, low-glycemic diets decrease growth rate and size at birth while high-glycemic food sources increase it.

1.2 Thermography health and pregnancy

In the field of medicine, infrared thermography is considered as a diagnostic tool for pathologies as breast cancer (11), deep vein thrombosis (7), lateral epicondylitis (3), stress fractures (10), rheumatic diseases (6, 8, 23), reflex sympathetic dystrophy (4), dermatological diseases (31), fever detection (9, 21) or Diabetes (25).

There are some significant changes during pregnancy related to physical activity as increased maternal and fetal body temperature that may pose a hypothetical risk of exercise during pregnancy (19). Several physiological mechanisms maintain thermal balance during exercise of moderate intensity, one of them is the increased blood flow to the skin level in acral areas and reduced on the trunk and proximal extremities (2).
In this paper, we will attempt to use infrared thermography to study the effects of physical activity on body temperature of pregnant women.

2. METHODS

2.1 Sample

The study sample consisted of 28 physically active pregnant women divided into two groups: half of them were engaged in low intensity yoga (n = 14) and the other half (n=14) practiced an aquatic activity (Swim) specifically designed for pregnant women.

2.2 Equipment

Thermograms were recorded with a T335 FLIR® in-frared camera (FLIR® Systems, Sweden). Maximal and averaged Tsk were extracted from each consid-ered Region Of Interest (ROI) with the software ThermaCAM Reporter 6 provided by the camera manufacturers. The environmental conditions were controlled by a BAR-908-HG® portable weather sta-tion (Oregon Scientific, USA).

2.3 Data collection

Before the training session, subjects remained in the data collection room at least for 10 minutes dressing only underwear for adapting to the room conditions before collecting the first thermogram series. During the acclimatizing time, subject fulfilled a questionnaire about incidence factors on thermography and personal data for required in the study and signed the informed consent to participate in the study. Subjects proceed directly to the data collection room drying the skin without rubbing for second thermograms se-ries within the 10 minutes after the activity.
The study protocol was approved by the Ethics Committee of the Technical University of Madrid following the principles outlined by the World Medical Assembly Declaration of Helsinki.
Six thermograms were registered before and after the workout in both activities (fig. 1): Dorsal (20 ROI), Ventral (19 ROI) and Left- and Right-Lateral

(2 x 12 ROI) in Upper Body, and Dorsal (16 ROI) and Ventral (12 ROI) Lower Body. Yoga data were registered in May by 11:00 AM in one of the rooms of a Yoga Center while water activities data were collected in July by 9:45 AM in a changing room attached to the swimming pool.

2.4 Analysis of the data

For data analysis, initial region of interest (ROI) where grouped into "areas" and, later, the areas into "zones" for better management and subsequent interpretation of the data. The grouping criteria are summarized in Table 1.

Table 1. Criteria for areas and zones establishment.

ZONE	Areas Included	# of ROI
LOWER LIMB	Right and Left Thigh	6
	Right and Left Leg	5
	Right and Left Knee	2
	Right and Left Ankle	1
UPPER LIMB	Right and Left Forearm	4
	Right and Left Arm	2
	Right and Left Elbow	2
	Right and Left Wrist	2
TRUNK	Right and Left Trapezium	2
	Right and Left Rips	1
	Neck	2
	Right and Left Shoulder	2
	Dorsal	5
	Lumbar	3
BELLY	Abdomen	5
BREAST	Right and Left Breast	2

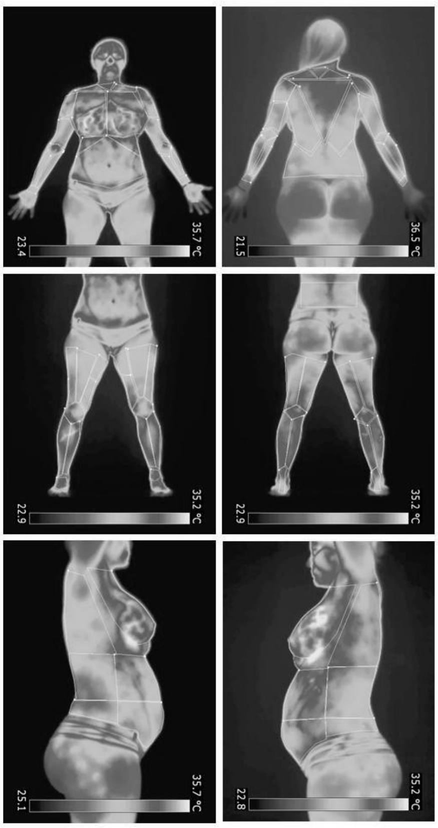

Fig. 1 - Location of the ROI in each thermogram.

The data are given as the means ± Standard Deviations (SD). Only mean Tsk values are exposed in order to reduce the number and size of tables.
The normality of the data distribution for each dependent variable was tested with the Kolmogorov-Smirnov method. Student t-tests for independent samples were run to compare quantitative Tsk data between Yoga and Swim groups, Student t-test for paired samples for comparing pre- and post-exercise results, and Chi-square test (χ^2) were applied for dichotomic variables (Yes-No). The statistical significance was set at $\alpha = 0.05$ in the software SPSS 15.0.

3. RESULTS

As can be seen in Tables 2 and 3, it was registered an increased use of creams ($\chi2(1) = 9.33$; $p < 0.05$) , lower drugs consume ($\chi2(1) = 7.04$; $p < 0.05$), lower room temperatures ($t(26) = 4.00$; $p < 0.05$) and lower humidity ($t(26) = 7.49$; $p < 0.05$) in the yoga group; however, the weeks of gestation of both samples were similar.
Averaged Tsk values for each considered area before and after the physical activity are listed in Table 4. Significant differences by physical activity (all of them $p<0.05$) were recorded in most of the areas except for the breast and the abdominal areas with lower Tsk before exercise in the Yoga group.

Table 2 - Atmospheric conditions and weeks of gestation for activity (** $p < 0.05$; ns = non-significant differences).

	Temperature (**)		Humidity (**) Week (ns)			
	Mean	SD	Mean	SD	Mean	SD
Swim	36.3%	1.1	27.4 ºC	0.7	33.5	1.6
Yoga	27.2 %	4.4	25.1 ºC	2.1	29.5	7.5

It is worth noting that, after the physical activity practice, significant differences were found on breast ($t(26) = -7.21$; $p < 0.05$), abdominal ($t(26) = -5.96$; $p < 0.05$), and belly ($t(26) = -5.88$; $p < 0.05$) with lower Tsk in the Swim group, as also happen with the rest of the areas except wrists, thighs, legs and knees (all of them $p < 0.05$).
Finally, our results indicate (see Table 7) that General Tsk were significantly reduced after swimming ($\Delta TskS = -3.30 \pm 0.43$ ºC; $t(13) = 11{,}60$; $p < 0.05$) and non-significantly increased after the yoga practice ($\Delta TskY = 0.21 \pm 0.55$ ºC; $t(13) = -1{,}19$; $p = 0.25$). This tendency was similar for all the body areas in the Swim group and more heterogeneous after the yoga practice with non-

significant differences in the limbs and sig-nificant differences in the trunk areas (including breast and belly).

Table 3 - Influence factors for activity (** p < 0.05; ns = non-significant differences).

		SWIM	YOGA
Creams	NO	12	4
**	YES	2	10
Therapy	NO	14	13
(ns)	YES	0	1
Coffee	NO	12	11
(ns)	YES	2	3
Alcohol	NO	12	14
(ns)	YES	2	0
Tobaco	NO	14	14
(ns)	YES	0	0
UVA Rays	NO	14	14
(ns)	YES	0	0
Drugs	NO	3	10
**	YES	11	4
Shower	NO	9	5
(ns)	YES	5	9

Table 4 - Tsk values (ºC) on the considered area previous to perform the activity (** p < 0.05; ns = non-significant differences). Left = L; Right = R.

	Swim		Yoga		
	Mean	SD	Mean	SD	Dif.
R. Thigh	30.03	0.75	27.07	1.14	**
L. Thigh	30.07	0.65	26.98	0.72	**
R. Leg	29.92	0.67	26.80	1.30	**
L. Leg	30.06	0.77	26.49	1.33	**
R. Knee	30.48	1.52	26.83	1.28	**
L. Knee	30.92	1.06	27.86	1.22	**
R. Ankle	30.94	0.93	25.19	2.07	**
L. Ankle	30.88	0.98	26.60	1.30	**
Lumbar	31.38	0.96	29.21	1.07	**
R. Forearm	33.61	0.72	31.38	1.51	**
L. Forearm	33.16	0.75	31.22	1.39	**
R. Arm	32.44	0.95	30.55	1.20	**
L. Arm	31.95	1.13	30.44	0.82	**
Ant. Trunk	32.75	1.00	31.33	0.90	**
Post. Trunk	32.32	1.19	31.37	1.11	**
R. Elbow	32.65	0.86	30.63	0.80	**
L. Elbow	32.38	1.02	30.41	0.79	**
Abdominal	34.82	0.73	34.50	1.54	ns
R. Wrist	33.43	0.61	29.55	1.79	**
L. Wrist	33.19	0.81	28.98	2.18	**
Breast	33.22	0.74	32.67	0.68	ns
Belly	32.41	1.22	30.97	0.98	**
General	31.96	0.77	29.46	0.66	**

Tables 5 and 6 provide data about the Tsk of the main zones considered, showing results congruent with those of their corresponding areas. We can point out that General Tsk recorded before practicing the activity (TskSWIM = 31.96 ± 0.77 ºC vs. TskYOGA = 29.46 ± 0.66 ºC) were significantly higher for the Swim group ($t(26) = 9.21$; $p < 0.05$) and after exercise (TskSWIM = 28.65 ± 1.31 ºC vs. TskYOGA = 29.67 ± 0.53 ºC) they became significantly lower in the Swim group ($t(26) = -2.70$; $p < 0.05$).

Table 5 - Tsk values (ºC) on the considered zones previous to perform the activity (** p < 0.05; ns = non-significant differences).

	Swim		Yoga		
	Mean	SD	Mean	SD	Dif.
Lower Limb	30.41	0.81	26.73	0.99	**
Trunk	32.66	0.95	31.41	0.85	**
Upper Limb	32.85	0.81	30.39	1.02	**
Breast	33.22	0.74	32.67	0.68	ns
Belly	32.41	1.22	30.97	0.98	**
General	31.96	0.77	29.46	0.66	**

Table 6. Tsk values (ºC) on the considered area previous to perform the activity (** p < 0.05; ns = non-significant differences).

	Swim		Yoga		
	Mean	SD	Mean	SD	Dif.
Lower Limb	27.09	1.40	26.51	0.51	ns
Trunk	29.45	1.35	31.86	0.73	**
Upper Limb	29.40	1.57	30.77	0.96	**
Breast	30.52	1.17	33.19	0.74	**
Belly	29.25	1.29	31.73	0.91	**
General	28.65	1.31	29.67	0.53	**

Table 7. Increment of Tsk (ΔTsk = Tsk Post-Pre exercise in ºC) on the considered zones (** p < 0.05; ns = non-significant differences).

	Swim		Yoga	
	Mean	SD	Mean	SD
Lower Limb	- 3.32 **	1.28	- 0.21 ns	0.90
Trunk	- 3.21 **	0.94	0.45 **	0.60
Upper Limb	- 3.45 **	1.44	0.38 ns	1.11
Breast	- 2.70 **	0.92	0.52 **	0.44
Belly	- 3.15 **	1.11	0.77 **	0.54
General	- 3.31 **	1.07	0.21 ns	0.66

4. DISCUSSION

It has been previously studied the effect of low-impact exercise on pregnant women (15). Aerobic exercises at 70% of maximum heart rate increased the temperature of the mother, but ap-pear to be safe in terms of risk of maternal hyperthermia. In the study by Larson, the measurement from pregnant women temperature was conducted by an ear thermometer, but works done with different methods of measuring body temperature obtained similar results.(24)

Our thermographic data show that pregnant women Tsk is not greatly increased after exercise; moreover, with swimming even decreased, probably due to the aquatic environment in which the activity is conducted at an approximate temperature of 27.5 ºC and with physical characteristics (i.e. head conductivity) that facilitates the corporal heat loss while the subject is immersed into the water.

Data from this study should be considered with caution because the environmental conditions of tem-perature and humidity during data collection are not the optimal to be used as reference values, especially the data from the Swim group, that were recorded in summer with an average room temperature of 27.4 °C. According to Ring & Ammer (24) the optimal temperature of room for a thermography should be between 18 and 22 °C. We are sure that those temperature conditions have influenced in the recorded Tsk for the Swim group.

In this sense, humidity is also an important factor that may have influenced our results, since the collection of data on the Swim group was carried out in a locker room attached to the pool, where the moisture content (36.3%) was significantly greater than in the Yoga center (27.2%).

Other factors could have influenced the recorded Tsk and they were recorded in the initial questionnaire. It has been found evidence of the influence of the creams on the infrared emission of the skin (27). In the case of pregnant of the Yoga group, the application of creams was significantly higher (71.4% of pregnant women) compared with 14.5% of those who practiced aquatic activities. This may be one of the reasons why Tsk from Yoga group, both pre-and post-exercise, were so low. We also found significantly higher drug consumption in the Swim group (78.6%) compared with the Yoga group (only 28.6%). We ignore the type of drugs consumed and whether they could have a thermogenic effect or could have induced an increased peripheral blood flow, but this factor could be contributing, together with the higher humidity and room temperature, to differences on initial Tsk values of pregnant women from both groups.

The results point out a significant reduction of Tsk of expectant mothers practicing aquatic activities even in the breast and belly areas, probably due to inadequate water temperature and the low-intensity characteristics of the activity performed, although the values of Tsk does not appear to be hazardous to the fetus. More studies about the influence of water temperature and the amount and intensity of the aquatic activities on the recovery of the normal temperature processes after aquatic exercise should be conducted not only with pregnant women but also with normal swimmers.

Practicing yoga during pregnancy slightly increased the Tsk in the whole body probably due to the characteristics of the activity (low intensity and controlled movements, many of them in sitting or lying positions).

Due to the lack of optimal conditions during the collection of the data, and in order to reduce the im-pact of the influence factors (i.e. creams usage and drugs consumption) we decided to use ΔTsk (Tsk before exercise – Tsk after exercise) instead of direct Tsk data for discussing the influence of the practice physical activity on the Tsk of the pregnant women.

In Swim group, the belly Tsk and other body zones significantly decreases with respect to the before exercise values, with maximal descents of -3.45 ºC on the upper limbs and minimal on the breast (ΔTsk = -2.70 ºC) and belly (ΔTsk = -3.15 ºC). One must bear in mind that the activities of this group are done into a swimming pool and they should be considered the above mentioned characteristics of the water for heat conduction. Also should be noted that chest and belly are covered by the swimsuit. Additionally, the lower Tsk descent may be the result of the mechanisms of temperature compensation ex-pressed by (18) as a way to maintain the temperature of the fetus.

In Yoga, the area with a higher Tsk increase after exercise is the belly (ΔTsk = 0.77 °C) followed by the breast (ΔTsk = 0.52 °C), both of them statistically significant values. In general, Tsk after practicing Yoga tends to non-significantly increase on 0.21 °C. Legs are the single body zone with a non-significant lower Tsk after exercise (ΔTsk = -0.21 ºC). We think that this Tsk descent could be due to the sitting position hold during Yoga practice, which get in contact the legs with the floor, reduces the activity of the legs, and slightly and temporary blocks the blood flow on this area.

In general, we can see that the significant reduc-tion of the Tsk after swimming was -3.31 ºC and after yoga the Tsk increased non-significantly by 0.21 ºC (Table 7). If we compare the general and belly Tsk after swimming (28.65 ºC and 29.25 ºC respectively) with the Tsk of those areas in the Yoga group before exercise (29.46 ºC and 30.97 ºC respectively), they are quite similar. That could support the idea that the significant descent of Tsk after practicing aquatic activity is not so dangerous; however, practicing the activity in a slightly warmer swimming pool could promote a lower loss of Tsk on those areas. On the other hand, we should also consider that in summer time the descent of Tsk generated by the aquatic activity could refresh the mother helping her to withstand better the effects of heat during the summer.

5. CONCLUSIONS

From our work we can conclude that thermography can be applied for its simplicity and safety of assesing the Tsk of the pregnant population practicing physical activity, but in order to obtain optimal results the environmental variables and certain factors that may influence the Tsk record must be controlled.

The Tsk of the belly was significantly reduced af-ter practicing the aquatic activity in -3.31 ºC and was non-significantly increased after practicing yoga in 0.21 ºC. Even though the descent of Tsk after swimming is quite drastic, not appear to be dangerous for the well-being of the fetus; however, it is suggested to perform aquatic activities in water warmer than normal in order to minimize the heat loss at the end of the activity.

Practicing yoga during pregnancy slightly increases the Tsk in the whole body probably due to the characteristics of the activity.

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Legality Associated with the Use of Infrared Thermal Imaging in Veterinary Medicine

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SUMMARY

Infrared thermography has been used in veterinary medicine since the early 1960's. In the 1970's and 1980's, significant scientific advances were made in both human and veterinary medicine. The purpose of this presentation is to make everyone aware that the USDA-APHIS (United States Department of Agriculture and Animal Public Health Inspection Service) has used thermography since early 1970's to help enforce the Horse Protection Act of 1970. In the 1990's APHIS took a position that physical examination was sufficient for diagnosis of abuse and discontinued the regular use of thermography for enforcing the Horse Protection Act. A recent ruling by a federal judge has prompted APHIS again consider the use of thermography as a means for additional documentation if the horse was sored or not. The efficacy and practicality for the use of thermography has been demonstrated in numerous clinical and research studies as a diagnostic tool for veterinary medicine.

1. INTRODUCTION

In 1970 the Horse Protection Act was passed by the United States Congress to ban the use of chemical and mechanical means of "soring" of horses. It was common practice in the 1960's and 1970's, with Tennessee Walking Horses, to use mechanical devices (boots, rollers, chains) on the horse's front legs to enhance their performances. Chains of various weights were applied to the mid pastern region of the thoracic limbs for the purpose of causing exaggerated limb action during show. There was also some evidence that mustard oil was applied to the skin of the mid pastern to further enhance the horse's performance. Use of these devices induced irritation of the skin, causing inflammation with scarring in the pastern areas.

To prevent this abuse, the Horse Protection Act was passed. Just to use physical examination, including digital palpation, was not a reliable enough source to prosecute the horse owner or the trainer in a court of law. This lack of reliable information obtained by physical examination of the horse prompted the USDA-APHIS (United State Department of Agriculture and Animal Public Health Inspection Services) to fund studies for the diagnosis of "soring". Thermal imaging was then used by Nelson and Osheim in Iowa (1) and Purohit et. al (2, 3, 4) at Auburn University to perform studies for the diagnosis of inflammatory processes in horses in response to various chemical and physical factors.

2. MATERIALS AND METHODS:

Early studies were done using thermography to establish normal thermal patterns of the horses and specific attention was directed towards thoracic and pelvic limbs. During these studies, standards were established for the use of infrared thermography in veterinary medicine. Auburn University studies were also done to document thermographically assisted diagnosis of various inflammatory processes.

3. RESULTS

Auburn University studies resulted in revision of the Horse Protection Act in 1983. This revision was also followed by implementation of new guidelines imposed by the USDA-APHIS. Along with physical examination and evaluation of horses for show purposes, thermography was also used by USDA-APHIS services as a diagnostic aid for detecting cutaneous inflammatory reaction to the horse's' limbs. Over time, use of thermography was discontinued and horse inspection for horse shows was again done by physical examination that also included digital palpation.

Since the 1970's to the present day, prosecution of owners and trainers accused of soring horses has been attempted. APHIS had taken a position in the early 1990's that palpation by itself is sufficiently reliable to accurately determine whether a horse has been sored or not. In some cases, horses that were banned from showing were a cause of litigation in federal courts. Recent rulings by Federal Law Judge Peter M. Davenport questioned whether palpation alone was sufficient "scientific" means to allow expressing an expert opinion. (5). He cited a Supreme Court case which set forth four factors to determine that reliability. He used thermography references of published papers in veterinary medicine. Because of his recent ruling, APHIS lost the court case. USDA-APHIS now wishes to reinstitute the use of thermography as an additional means to document if the horse was sored or not.

4. DISCUSSION

The efficacy of non-contact, electronic infrared thermography has been demonstrated in numerous clinical settings and research studies as a diagnostic tool for veterinary medicine. Sometimes it is very difficult to use radiology, ultrasonography, or magnetic resonance imaging for large animals like horses and cattle (bulls). These procedures require direct contact with the animal, and in some cases the animal must be under general anesthesia to perform these tests. Thermography which can be performed in an unsedated animal has been very helpful as a preliminary diagnostic tool in many clinical cases. Painful conditions associated with peripheral neurovascular and neuromuscular injuries can be easily diagnosed by thermography.

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The Use of Thermography to Evaluate Back Musculoskeletal Responses of Young Racehorses to Training

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SUMMARY

Thermography has been used for the diagnosis of skin temperature variations caused by overloads of the musculoskeletal system. The present study was aimed to evaluate the efficiency of thermography in monitoring musculoskeletal system response to increasing intensity of back overloads during racehorses training cycle. The thermographic examinations of 20 racehorses' back were performed at Partynice Racing Track (Poland) every 3 weeks in twelve sessions during a period of 10 months. The back was divided into 5 areas: thoracic vertebrae (T), lumbar vertebrae (L), sacroiliac join (SIJ), and symmetric sides of the thoracic vertebrae area left side (ML) right side (MR). From each area the average temperature was measured. For statistic analyses the nonparametric Kruskal - Wallis test was used. An increase in the training intensity resulted in significant decreases in average temperature differences between T and L, T and SIJ, T and ML and T and MR. Constant training overloads of the musculoskeletal system under demanding exercise resulted in increased blood circulation of a back. The analysis of the surface temperature distribution over the horse's back will allow to develop a model of blood circulation within this area in intensive training cycle. It will help specialists, breeders and veterinarians to analyse the fundamentals in physiological response of the musculoskeletal system to intensity of training. These results provide additional support for the continued study on the equine thermography.

1. INTRODUCTION

Constant overloads of equine musculoskeletal system can cause abnormalities associated with painful conditions or diseases, leading to loss of performance (9). Back pathologies are mainly associated with soft tissue injures or spinal stress fractures (7). They are often variable clinically manifested from overt lameness, pain on palpation, to gait alterations or behavioural changes (3, 10).

Back overloads can be associated with the physical demands of musculoskeletal system in response to training (16). It can also be caused by the type of training, skills of the rider or badly fitting saddle (2, 6, 18). The detection and monitoring of back physiological overloads is particularly important for racehorses put under extreme physical training demands. Immediate diagnosis might help to maintain their health, what influences their further racing career.

Thermography as a noninvasive diagnostic imag-ing tool, measures emitted heat by radiation from the body surface. The heat is generated continuously through the body, and spread to the skin. The skin take it is heat from the local circulatory system and from the tissues metabolism, providing information about tissue physiology. Variations on skin temperature are due to change in the local circulation, caused by stress of musculoskeletal system (21).

Results from previous studies indicated that the determination of the body surface temperature distribution of racehorses can be used to determine the injury of the musculosceletal system (22). Thermography has been successfully used for the diagnosis of back abnormalities associated with: neuromuscular disease of the thoracolumbar region and inflammation of spinous processes (5, 17, 20, 23).

The map of surface temperature of the horses' back has been previous described (12, 19). Whereas changes of back surface temperature distribution in response to training cycle has not been yet investigated. The pre-sent study was aimed to evaluate the efficiency of thermography in monitoring musculoskeletal system response to increasing intensity of back overloads during racehorses training cycle.

2. METHODS

2.1 Study population and data collection

Measurements were obtained from 20 clinically healthy racehorses of two breeds (12 Polish Half Breed and 8 Arabians) aged 3 years. All horses were in trained at Partynice Racing Track (Poland) for 10 months and participated regularly in flat races. The horses were housed in individual stalls with common management and training regimes. The training type and its intensity were taken into considerations. None of the racehorses had diagnosed injuries of the back.
Series of thermographic images were obtained from the dorsal view of the extension of the vertebral column including thoracic, lumbar and sacroiliac joint area every 3 weeks in twelve sessions for a period of 10 months between January and October 2011. The distance of the camera from the animal was set for all readings at 1.5 m. The applied protocol for thermal imaging was identical as previously described by Hoogmoed et al., (2000). Horses were examined at rest before daily exercise. Dirt and mud present in the scanning field area was brushed away before examina-tions. Approximately 10 minutes was allowed to pass before scanning to ensure the transient heat generated by brushing had subsided before obtaining baseline measurements. Thermographic examinations were consistent with international veterinary standards (15). During the research horses were subject to gradual increase of the training intensity: light (January-February), medium (March-April) intensive (May-June), light due to racing break (July), high (August-October). For all readings thermograpic camera VarioCAM 640 x 480 was used. The analyses of thermograms were conducted with IRBIS Version 3 Professional software program. In each session the ambient temperature was measured. To minimize the effect of environmental factors, such as sun light, draft, thermal images were performed within an enclosed barn (21).

2.2 Statistical analysis

The back which includes axial skeleton form wither to sacroiliac joint was divided into 5 areas: thoracic vertebrae (T), lumbar vertebrae (L), sacroiliac joint (SIJ), and symmetric sides of thoracic vertebrae area: left side of the muscles (ML); right side of the muscles (MR) (Fig. 1). A nonparametric Kruskal-Wallis and post-hoc test was used to evaluate the average temperature of particular areas and differences between T-L, T-SIJ, T-ML, T-MR and incensement of training intensity. To determine the effect of ambient temperature on the body surface temperature the linear regression analysis were used.

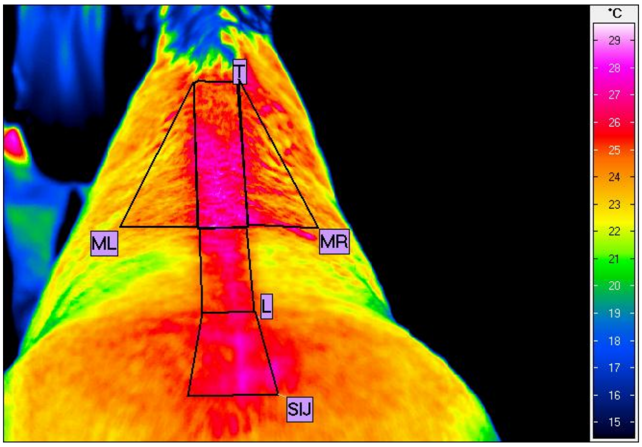

Fig.1 - Thermographic image of the horse's back, dorsal view with included areas: T – thoracic vertebrae area, L - lumbar vertebrae, SIJ - sacroiliac joint, ML - left side of the muscles, MR - right side of the muscles.

3. RESULTS

In twelve sessions, the average temperatures meas-ured in areas T;L;SIJ;ML;MR ranged between 19.3°C – 32.8°C with the lowest temperatures found in IIIrd session and the highest in XIth session. Within meas-ured areas in all sessions the significant highest aver-age temperatures values (21.8°C – 33.2°C) were found in T area. The average temperatures of L, SIJ, ML and MR area did not differed significantly from each other in all sessions (Table.1).

Table 1 - The average temperature of measured areas in each session

Nr of session	Area average temperature $[\bar{x}]$				
	T[1]	L[1]	SIJ[1]	ML[1]	MR[1]
I	23.2 a	21.4 b	21.3 b	21.4 b	21.4 b
II	23.8 a	21.9 b	21.9 b	21.6 b	21.7 b
III	21.8 a	19.8 b	19.8 b	19.3 b	19.3 b
IV	24.4 a	22.9	22.4 b	22.4 b	22.6 b
V	26.6 a	25.4 b	25.0 b	25.0 b	25.0 b
VI	29.4 a	28.8 b	28.5 b	28.6 b	28.5 b
VII	29.2 a	28.3 b	28.1 b	28.3 b	28.3 b
VIII	32.8 a	32.3 b	31.9 b	32.4 b	32.3 b
IX	31.6 a	31.0 b	30.7 b	31.2 b	31.1 b
X	31.3 a	30.4 b	30.2 b	30.9 b	30.7 b
XI	33.2 a	32.9 b	32.7 b	33.0	32.8 b
XII	31.7 a	31.0	30.8 b	31.1	31.0

[1] T, L, SIJ, ML, MR – in Fig. 1
a,b - significant differences at $p < 0.05$

The results of measured areas determined analyzes of the average temperature difference between T-L, T-SIJ, T-ML and T-MR due to increasing intensity of training cycle in all twelve sessions (example Fig.2).

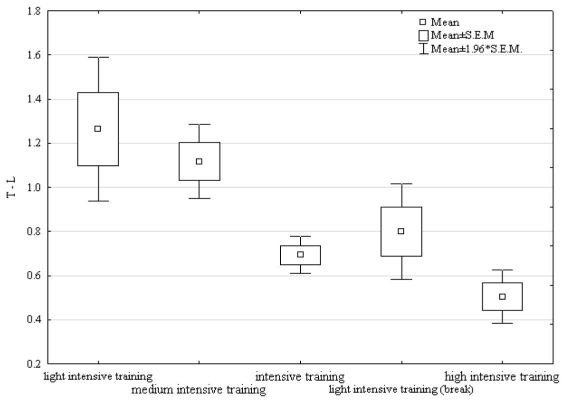

Fig. 2 - Average temperature differences between T-L area for level of intensive training.

Incensement of the training intensity, caused de-crease the average temperature difference between T and L area (H = 22.143, $p<0.001$) (fig.2); T and SIJ area (H = 21.453, $p<0.001$); T and ML area (H = 47.466, $p<0.001$); T and MR area (H = 40.218, $p<0.001$) (Table 2).
The highest average temperature differences were indicated between T-ML areas in light intensive training (Table 2).

Table 2. Average temperature differences between measured area for level of intensity training.

Areas	Light intensive training	Medium intensive training	Intensive training	Light intensive training	High intensive training
T-L	1.3 a	1.3	0.7 a	0.8 a	0.5 a
T-SIJ	1.3 a	1.4	0.9 a	0.9	0.6 a
T-ML	1.4 a	1.4	0.5 a	0.3 a	0.4 a
T-MR	1.4 a	1.4	0.6 a	0.4 a	0.5 a

a - significant differences at $p < 0.05$

The ambient temperature from Ist till XIIth sessions had increasing tendency and ranged between 6°C – 21.1°C. The lowest ambient temperature was record-ed in IIIed and the highest in XIIth session. There was a high correlation between ambient temperature and surface temperature distribution of measured areas (Fig. 3).

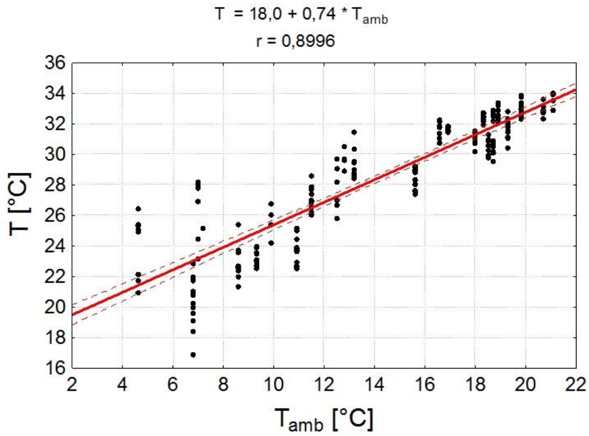

Fig. 3 - Correlation between average temperatures of T area and ambient temperature (T_{amb}).

To eliminate influence of an ambient temperature, temperature differences of measured areas were determined according to the formula: $\Delta T_i = T_i - (a + b \cdot T_{amb}$. Parameters a and b were recorded from correlation diagrams (Fig. 3 and Table 3). As an example for T area the formula was $\Delta T_T = T_T - (18.0 + 0.74 \cdot T_{amb})$.

Table 3 - Parameters of temperature regressive model.

Area	a	b	r
T	18.0	0.74	0.900
L	15.6	0.83	0.885
SIJ	15.3	0.84	0.908
ML	14.8	0.88	0.895
MR	15.0	0.87	0.896

The body surface temperature of measured areas was significantly influenced by training compare to ambient temperature from IIIed session for T,L and SIJ and from IVth session for ML and MR. In the Ist, IIed and VIIth session the ambient temperature signifi-cantly influenced on measured areas temperature (Table 4).

Table 4 - Temperature differences (^{0}C) of measured areas influenced by training intensity, with eliminated ambient temperature.

Area	Nr of session											
	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
	Light it[1]			Medium it[1]			it[1]			Light it[1]	High it[1]	
T	-1.7	2.3	0.5^x	0.5^x	0.4^x	1.8^x	1.2	0.2^x	0.0^x	0.4^x	0.3^x	0.0^x
L	2.0	2.7	0.7^x	0.6^x	0.5^x	2.4^x	1.2	0.4^x	0.1^x	0.3^x	0.4^x	0.0^x
SIJ	1.8	2.5	0.4^x	0.4^x	0.4^x	2.3^x	1.2	$0,2^x$	0.0^x	0.3^x	0.4^x	0.0^x
ML	1.6	2.8	0.6	0.6^x	0.4^x	2.3^x	1.3	0.4^x	0.3^x	0.7^x	0.3^x	0.0^x
MR	1.7	2.8	0.8	0.7^x	0.3^x	2.2^x	1.3	0.2^x	0.1^x	0.6^x	0.2^x	0.1^x
T_{amb}	9.3^x	10.9	6	8.6	11.5	13.2	15.6	18.6	19.3	18	21.1	18.7

4. DISSCUSION

Thermography was used to characterize the horses back surface temperature distribution changes in the response to increasing training intensity. There was

a high average temperature differences between T–L; T-SIJ; T-ML and T-MR, at the beginning of the training cycle. Gradual incensement in training intensity caused a decrease of average temperature differences between measured areas. Previous research characterised the surface temperature distribution of the back, with increased temperatures along the midline of the back with symmetrical lowering temperature on the either side (12). Similar conclusions had Tunley & Hanson (19), who generated a thermographic map of the thoracolumbar region. Horses spine, was divided into 6 horizontal lines along which the temperatures were measured. All graphs indicated increased temperature along the midline of the spine, with a fall of 3°C on either side of the midline. A possible explanation is a high number of superficial subcuticular blood vessels in that area (17).
In other papers, the body thermographic measurements were used in respect to sport and racing type of performance. The surface temperature examination of the entire body of the horses was used as an indicator of physiological state of a horse's health and was helpful in assessing the level of exercises in preparation of the horse to training. It was additionally concluded that the thermograms documenting the changes of the horses' surface temperatures resulting from the exercise, could be useful in the evaluation of the work of individual parts of the body in sport performance (11). Also present study, indicated influence of increasing training intensity on changes of back temperature distribution.
High average temperatures differences between T-L, T-SIJ, T–ML, T-MR at the beginning of the training cycle could be associated with riding techniques mainly in trot. It has been found that the weight of the rider in trot increases strain only in T area. Significantly highest load on the horse's back was at the sitting trot (2112 N), followed by the rising trot (2056 N) and the two-point seat (1688 N) (14). Also saddles analyzed for the pressure distribution over the thoracic vertebrae during movement, indicated the highest pressure at trot (13). Therefore thermal image assessment of the dynamic interaction between saddle and back of the horse showed not only the heat generated in areas of greater interaction with the saddle, but also the physiological effects of riding on the back of the horse (1, 24).
Gradual increase in training intensity caused a decrease in average temperature differences between the T-L, T-SIJ, T-ML, T-MR areas. This confirms results from previous studies which indicated that strains and overloads of the musculoskeletal system under demanding exercise resulted in increased blood circulation that can predispose later injuries (4). Training intensity caused defensive adaptation processes by increasing blood circulation of individual areas in response to constant training overloads.

5. CONCLUSION

Ten months of regular thermographic examinations of 20 racehorses allowed to localize and follow the average temperature changes of a horse's back in response to increasing intensity of training. Therefore surface temperature distribution of a healthy horse depends on thermoregulation of the organism influenced by individual traits of a horse and the way it is performed.
The analysis of the surface temperature distribution over the horse's back will allow to develop a model of normal blood circulation within this area in the intensive training. It will help specialists, breeders and veterinarians to analyse the fundamentals in physiological response of the musculoskeletal system to intensity of training.
Regular thermography analyzes will enable horse's back overloads to be monitored and facilitate identification of pathological condition during the training cycle. This will allow to select appropriate training programmes to achieve and maintain optimal horse performance and keep horses' performing on that level. With the veterinarians and breeders working together new heights in performance can be reached when training and conditional diagnosis are combined.
The development of the infra-red technology and better availability of this type of equipment should contribute to more extensive use of this diagnostics, applicable not only to horses, but also to other animals.

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Effect of High Regional Nerve Blocks on the Thermographic Patterns in the Limbs of Horses

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1. INTRODUCTION

It is often difficult to judge the effectiveness of a high regional nerve block (i.e., anesthesia of the median, ulnar, peroneal, or tibial nerve) in the horse. After a high regional nerve block, skin can be tested for loss of sensation at a specific site on the limb for each nerve, but this method of testing may yield erroneous information for several reasons: (1) the horse may be stoic and show little reaction to noxious stimulation of skin, (2) the region of skin desensitized may vary somewhat among horses, and (3) some horses react violently to the slightest provocation, making a positive reaction to skin testing difficult to interpret. A positive response to a nerve block (i.e., resolution of lameness) is good evidence that the nerve was actually anaesthetized, but a negative response may mean that the source of pain causing lameness was not in the region supplied by that nerve or that anesthesia of the nerve was not achieved; the accuracy of a lameness examination depends upon the ability to make this distinction.

Thermography studies done on the thoracic (front) and pelvic (back) limbs of horses before and after neuroectomies showed that posterior digital nerve neuroectomy had a significant increase in heat patterns in the areas supplied by the nerves. (1, 2, 3) Sensory – sympathetic dermatome patterns of the cervical regions in horses were determined by using 0.5% mepivacaine hydrochloride as a local anesthesia in horses (4, 5). Thermography provided the evidence of the individual cervical nerve block.

The nerves of the skin are mainly divided into two categories: sensory and autonomic. The sensory nerves are for transmission of the sensation of temperature, pain, itch, light, touch, pressure, and proprioception; whereas the autonomic nervous system controls the tone of cutaneous blood vessels and skin glands.

We reasoned that neurological control of blood vessels in skin is interrupted when the nerve supplying blood vessels is anaesthetized and that those blood vessels would dilate in response to nerve block. Dilation of blood vessels increased flow flow to skin, in turn causing an increase in skin temperature, which can be detected on thermography (6). The primary objective of this study was to demonstrate that thermography can be used to accurately predict whether or not a high regional nerve block was successfully performed.

2. METHODS

Six horses ranging in age from 15 to 21 years were selected for this study. A digital infrared camera (Flir B360) was used to record thermal images. Images of the front leg were taken from the forearm and hoof and posterior leg images from the stifle to hoof. The anterior, posterior, and lateral images were taken to provide thermal mapping of the dermatome regions related the specific nerve block. Average temperature of the dermatome regions were determined by using Flir software (Flir Reporter 8.5). A baseline thermographic image was recorded prior to each perineural injection of mepivacaine HCL of the ulnar, median, peroneal, or tibial nerves. A total of 20mL of mepivacaine HCL was administered perineurally using a 20-gauge, 1.5 inch hypodermic needle. Thermography patterns of the all limbs of each horse were obtained immediate post injection and at 15 minute intervals for one hour post injection. A sham treatment, injection of saline for each site was also performed on separate occasions to determine the effect of potential injection site irritation, if any.

3. RESULTS/DISCUSSION

In response to regional nerve block, two responses were produced. First, blocking the sympathetic portion caused increased thermal (heat) patterns due to vasodilation, and second, the area of insensitivity was produced by the sensory portion of the nerve block. Increased thermal gradients were consistent in all nerve blocked areas. Thermography can be used to determine the accuracy of a high regional nerve block, and the area can be easily demarked. Results of a thermographic evaluation of the limbs is at least as accurate as testing for skin sensation to determine the accuracy of a high regional nerve block and may be a safer method of making this determination.

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Thermography and Oral Pathology

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1. INTRODUCTION

The purpose of this study is to illustrate the clinical use of thermography in identifying asymptomatic dental (oral) pathology. A common cause of dental (oral) infection and inflammation found in this study is in fact due to a common dental procedure, a root canal. Unless the region becomes abscessed, usually over a longer period of time, we are completely unaware that there is an issue.

For years, a debate has brewed between those, who are proponents of root canals, and those, who see root canals as a potential health threat. Current convention is to save a tooth at any cost. Despite multiple research studies that link root-canal treated teeth to cancer and other chronic disease, the majority of people, even health care professionals, do not pay enough attention to dental health. With thermographic imaging, we can identify areas of suspected inflammation and infection because they present with heat. Once an area of concern is identified, it needs further investigation and resolution.

2. MATERIALS AND METHODS

Study population consisted of 20 patients (2 males and 18 females, aged from 42 to 63 years) that visited Thermography Clinic in Toronto, Ontario, Canada with variable complaints. All patients were evaluated with IR imaging and followed up with dental examination that included x-ray and examination of the oral cavity. Patients were followed up with additional dental examinations for up to one year.

Patients were evaluated with FLIR A-320 Infra Red camera, with examination guidelines followed, as set forth by the International Academy of Clinical Thermology.

The IR imaging finding results were summarized. Quantitative variables were described using summary statistics (means, medians, and standard deviations, minimum and maximum values, table 1). Categorical variables were summarized by giving frequency distributions. Percent of patients with at least one IR imaging finding confirmed by subsequent dental evaluations was the primary endpoint in this study (fig. 1).

Table 1 - Demographic and Evaluation Characteristics

Parameter	Study Participants (N=20)
Age (years),	
Mean (SD)	52.4(6.7)
Median	51.5
Min-Max	42.0 – 63.0
Gender, n (%)	
Females	18 (90%)
Males	2 (10%)
Type of Exam, n (%)	
Total Body Scan	2 (10%)
Breast Scan & Facial	13 (65%)
Facial	5 (25%)
Presence of Symptoms, n (%)	
Symptoms Present	6 (30%)
No Symptoms	14 (70%)
Number of Months Until First Dental Exam,	
N	20
Mean (SD)	0.7(0.6)
Median	1.0
Min-Max	0 – 2
Number of Months Until Second Dental Exam,	
N	10
Mean (SD)	4.7(2.3)
Median	4.5
Min-Max	2 – 8

SD=standard deviation, Min=Minimum; Max=Maximum

3. RESULTS

Twenty patients with age ranging from 42 to 63 years (mean age ± SD is 52.4 ± 6.7 y.o.) participated in this study. Eighteen (90%) patients were females. Two patients (10%) had total body scan performed; thirteen patients (65%) had both breast and facial scans, and 5 patients (25%) had a facial scan only. Fourteen patients (70%) did not have any symptoms related to dental pathology. The number of oral cavity findings ("spots") per patient ranged from 1 to 4 (mean ± SD is 2.1 ± 1.1). Most of patients had 1 (40%) or 2 (30%) dental cavity findings (table 2). Following the thermography evaluations, eight subjects (40%) had a dental follow-up exam in less than a month, 12 subjects (40%) had such an exam in 1-2 months. Ten subjects (50%) subsequently had another dental exam; seven of these subjects saw the dentist within the following 6 months. In eleven subjects, (55%), thermographic findings were confirmed during the first follow-up dental exam. In fourteen subjects with 1-2 detected spots, six subjects (42.9%) had confirmed results. Five out of six subjects (83.3%) with 3-4 spots received such confirmation. During the second follow-up dental exam, thermographic findings were confirmed in all 10 subjects evaluated. Notably, in 7 of these subjects results of the first dental evaluations were not confirmatory. When both first and second dental evaluations are take into account, thermographic findings when confirmed at least once in 18 our 20 subjects. The high confirmation rate (90%) indicates strong correlation between thermographic and dental exams (table 3).

Table 2 - Thermographic Findings

Parameter	Study Participants (N=20)
Number of Spots , Mean (SD)	2.1(1.1)
Median	2.0
Min-Max	1 – 4
Number of Spots, n (%)	
1	8 (40%)
2	6 (30%)
3	3 (15%)
4	3 (15%)

SD=standard deviation, Min=Minimum; Max=Maximum

4. DISCUSSION

Pain acts as a warning system that something is wrong. Unless the region becomes abscessed, usually over a longer period of time, we are completely unaware that something is going on. When a patient has no symptoms of pain or discomfort, the assumption is that all is well. If an infection in the area does develop, we have no way of knowing this, as the pain receptors in that area have been removed as in case of root canal treated teeth. If an abscess develops, it will be taken care of – usually as an emergency – but by then, infection could have been setting in for many years and could have already contributed to the development of other health issues. Chronic inflammation has been accepted as “the silent killer” that leads to chronic disease, heart disease, and cancer. Root canals are inherently susceptible to infection and inflammation.

Over the years at our clinic, we have imaged thousands of women using infrared thermography. In many cases, we have clearly seen cases of inflammation in the dental area using this heat sensing technology. Many of these cases are caused by a low-grade infection and inflammation and have, through further testing, been attributed to dental or oral issues, such as issues related to root-canal treated teeth. Invariably, some cases are very subtle, even asymptomatic for many years, but these cases slowly and continuously affect peoples’ health. With thermographic imaging, we can identify areas of suspected inflammation and infection because they present with heat. Once an area of concern is identified, it needs further investigation and resolution. People living with a chronic source of infection and inflammation will eventually find that their immunity is affected. In some cases, this chronic inflammation and infection will actually promote the growth of malignancy. The natural defense mechanism to fight malignant development is impaired since their immune system is busy dealing with inflammation that has no chance of resolving on its own. The only way this problem can be resolved is by identifying and removing the cause. The infected area has to be properly dealt with before the body can be restored to health.

5. CONCLUSION

The IR imaging procedure provided enormous information about the physiological processes through examining the temperature of the facial area that can be related to the internal process of inflammation or irritation. The early signs provided by the IR imaging can be used as a prognostic indicator in detecting oral and or dental pathology. The merits of a non-invasive IR imaging modality are important in identifying early stages of inflammation not visible by other imaging modalities. The high confirmation rate (90%) indicates strong correlation between thermographic and dental exams.

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connection between oral pathology and chronic disease which eventually led to this study.

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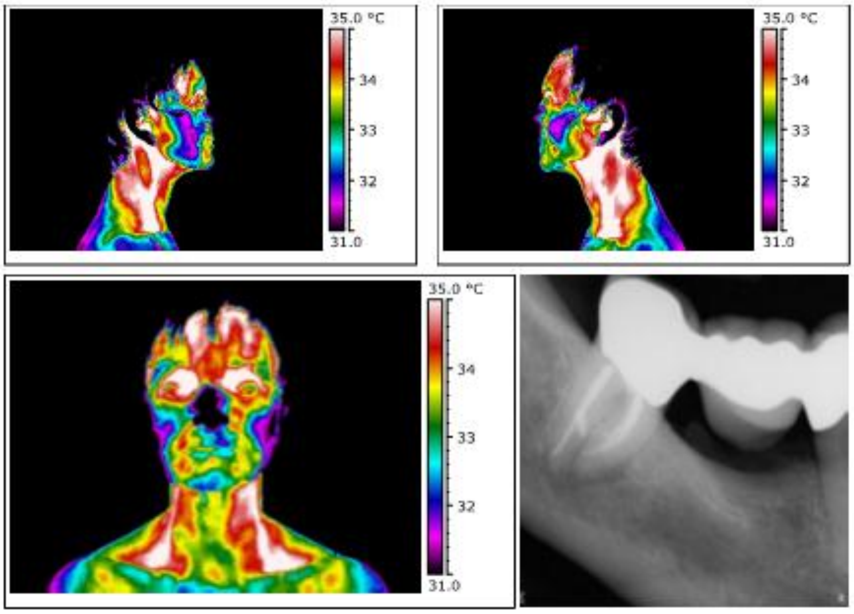
Table 3 - Confirmation of Thermographic Findings by Dental Evaluations

Number of Subjects Stratified by Number of Spots n (%)	Confirmed by 1st Dental Exam	Confirmed by at Least One Dental Exam
1 Spot: N=8	4 (50%)	7 (87.5%)
2 Spots: N=6	2 (33.3%)	5 (83.3%)
3 Spots: N=3	3 (100%)	3 (100%)
4 Spots: N=3	2 (66.7%)	3 (100%)
All Subjects: N=20	11 (55%)	19 (90%)



Initial Thermography performed in June of 2010.

(L)TMJ ΔT = 0.5 °C and Hyperthermia in the region of 1st-2nd premolar.

Dental Exam – no abnormalities,
Bite Splint was done.
Patient refused any additional dental work.

In February of 2011 patient complained of sensitivity on chewing in the lower right side.

Exam showed gingival inflammation and furcation involvement of 7mm pocket. Extraction was performed.

Fig. 1 – Example thermograms.

Infrared Imaging of the Crânio-Cervico-Mandibular Complex in Bruxism Patients

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SUMMARY

Many authors have suggested the existence of a functional dependence between the cervical muscle and mastication muscles. In the sequence of this functional dependence postural, changes, specially in the head and neck, can influence certain neuronal-muscular patterns leading to the development temporomandibular disorders. The existing of hyperactivity of the mastication muscle in bruxism patients can originate areas of neuro muscular sensibility, that can be detected by thermography with asymmetric thermogram patterns. It is therefore important to evaluate the existing differences of head and neck posture in bruxism patients and asymptomatic individuals and the respective correlation of the thermographic patterns.
The sample of the present study consisted on 32 individuals (16 bruxism patient and 16 asymptomatic individuals) students of the Dental Faculty of Porto University with ages between 22-26 years old. A clinical examination was made in order to diagnose the presence of signs and symptoms of bruxism. The thermographic evaluation was made using the thermographic camera Flir® A325.
The ΔT of thermography showed assymetric patterns in the temporomandibular joint and within most of the muscles of the cranio-cervic-mandibular complex.
Infrared imaging technique can be a complement method of diagnostic in temporomandibular disorders, when evaluating the possible association of specific muscles of the cranio-cervico-mandibular complex with an increased muscular activity seen in bruxism patients.

1. INTRODUCTION

Human body posture control is maintained by the somatosensory, vestibular and visual systems, integrated within the locomotor and central nervous systems (1).
Besides all these mechanisms of feed-back and feed-forward, the stomatognatic system (SS) plays also an important role in posture control. Stomatognatic system is a functional unit characterized by several structures such as: skeletal components (maxilla and mandible), dental arches, soft tissues (salivary glands, nervous and vascular supplies), the temporomandibular joint (TMJ) and masticatory muscles (1, 2). TMJ works as muscular and ligamentary connector between the cranium and all the cervical region, forming the cranio-cervico-mandibular complex (CCMC) (1).
In the sequence of this functional dependence between cervical region and SS, postural changes, specially in the head and neck, can influence certain cranio-cervical neuronal-muscular patterns leading to the development temporomandibular disorders (TMD)(3-6). The presence of TMD may also contribute to postural changes (3-6) The most common posture disorder observed in TMD patients is a forward head position, usually associated with shortening of the posterior cervical muscles and length of the anterior cervical muscles (7-9).
According to the American Academy of Orofacial Pain, bruxism is a "psychophysiological disorder that can be defined as diurnal or nocturnal tooth contact parafunctional activity, such as clenching and grinding" (10). This parafunctional activity take to a situation of hyperactivity of the mastication muscle that can originate areas of neuro-muscular sensibility that can be detected by thermography with asymmetric thermogram patterns (6, 8, 9, 11-14).
Thermography involves the detection of infrared radiation that can be directly correlated with the temperature distribution of a defined body region and appears as a non-radiating, non-contact and non-invasive analysis tool which provides informations on the basis of temperature patterns and evaluation of temperature asymmetry (12, 14-18).

2. MATERIALS AND METHODS

The sample of the present study consisted on 32 individuals (16 bruxism patient and 16 asymptomatic individuals) students of the Dental Faculty of Porto University with ages between 22-26 years old. The study protocol was approved by the Ethics Committee of the Dental Faculty of Porto University and informed consent was given to all participants.
A clinical examination was made in order to diagnose the presence of signs and symptoms of bruxism. The thermographic evaluation was performed using the thermographic camera FLIR® A325 with a resolution of 320x240 pixels, a measurement accuracy of ±0,2C□ and thermal sensitivity □ 0,07□ C. Thermograms were recorded at 30Hz and informatical analyzed with ThermaCAM Researcher Professional® 2.10.software.
Data were submitted to statistical analysis by Wilcoxon-Mann-Whitney test at a 5% significance level.

2.1 Infrared Imaging Capture Protocol

The thermograms capture was made before the clinical examination and it was performed indoor and the temperature was stabilized to 21°C. Infrared camera was placed on a tripod and positioned approximately 1.5m and looking perpendicular to the patient. Thermal images were obtained in right and left view and in dorsal view and while this procedure all electronic equipment was kept clear of the volunteers. Before image capture the volunteers were requested to follow certain instructions such as: avoiding cosmetics, avoiding exercise and non-smoking 4 hours before the procedure. Besides, all volunteers remained quiet and rest for 15 minutes for thermal equilibrium, male participants were asked to record thermograms without their t-shirts while female participants were asked to use a sleeveless, avoiding this way skin marks from clothes.

3. RESULTS

The group of bruxism patients reported an average temperature variation of: 0.681; 0.613; 0.500; 0.344 and 0.625°C in muscles temporal, masseter, trapezius, sternocleidomastoid and TMJ, respectively (Table 1). Control group showed for the same group of muscles, an average temperature variation between right and left side of: 0.263; 0.394; 0.294; 0.231 and 0.369 °C (Table 2).

Table 1 - Descriptive statistics of ΔT between right and left side: control group.

	Control Group				
°C	Temporal	Masseter	Trapezius	Sternocleidomastoideu	TMJ
Min	0.40	0.40	0.20	0.00	0.40
Max	1.40	1.20	0.80	0.70	1.10
Mean	0.681	0.613	0.500	0.344	0.625
Std. Deviation	0.2889	0.2247	0.1826	0.1861	0.1693

The temperature variation differences registed between the two groups in study was statiscally significant in all muscles and TMJ. Temporal, masseter, trapezius, sternocleidomastoid muscles and TMJ registed values of p= 0.001, p=0.005, p=0.029, p=0.021 and p=0.014, respectively.

Table 2 - Descriptive statistics of ΔT between right and left side: bruxers group.

	Bruxers Group				
°C	Temporal	Masseter	Trapezius	Sternocleidomastoideu	TMJ
Min	0.00	0.10	0.00	0.00	0.10
Max	0.70	1.30	1.10	0.4	2.00
Mean	0.263	0.394	0.294	0.231	0.369
Std. Deviation	0.1893	0.3396	0.3214	0.1360	0.4729

4. DISCUSSION

Some authors had study the relationship between the activity of mastication muscles and head posture using the electromiography (EMG) and came to the conclusion that variations in head position could lead to a highest muscular activity, specially of the temporal and masseter muscles (19, 20). The consequences of a permanent muscle hyperactivity can have effects not only in mastication muscles but also in cranio-cervico-mandibular complex (CCCM) due to the common innervation of trigeminal complex (21).
Body temperature control is regulated by the central nervous system and in healthy individuals is available in symmetric patherns (13, 14, 22). The hyperactivity of the mastication muscle in bruxism patients can originate areas of neuro muscular sensibility, which can be detected by thermography with asymmetric thermogram patterns (6, 8, 9, 11-14).
In this investigation we considered that a ΔT ≥0.36 between right and left sides could be an evidence of a strong level of an unusual thermic pathern (22).

The results achieved allowed to verify that there are clear differences of ΔT average values between the same muscles in the two different groups in study. These differences were statistically significant. Temporal and masseter muscle showed a statistical difference more relevant. Trapezius and sternocleidomastoid muscle present the lowest statistically significant differences of ΔT between bruxism and asymptomatic groups. Trapezius muscle showed up as the postural muscle with the lowest value of significance ΔT (p=0.029).

No references in literature of investigations involving bruxism patients and the study of thermal patherns could be found. However, there are some studies that establish the deep relation between the presence of TMD and asymmetric patterns of the CCCM (15, 23, 24).

There are various auxiliary tools for diagnosis of TMD such as: computerized tomography, arthrotomography, arthroscopy and magnetic resonance (25). However, these methods are radiating, expensive and some of them invasive.

In contrast to the abovementioned auxiliary diagnosis methods, thermography analysis is a non-radiating, non-contact and non-invasive analysis tool (13-15, 18, 19, 22).

5. CONCLUSION

The thermography can be a complement method of diagnostic in temporomandibular disorders and prevention of pathologies when evaluating the possible association of specific muscles of the cranio-cervico-mandibular complex with an increased muscular activity seen in bruxism patients. Never the less more studies are needed whit higher samples in order to clarify this situation.

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Evaluation of the Masticatory Muscles Temperature by Thermal Imaging During Mastication

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1. INTRODUCTION

The mastication is the first step in the digestion process and has as an objective prepare the food for the swallowing process and procession by the digestive system. (1-3) The masticatory sequence begins with the introduction of the food in the oral cavity, and ends with the swallowing of the bolus (2, 4, 5). Each masticatory sequence is a set of masticatory cycles, each cycle is composed by a opening, closing, and side movements (2, 4). The rhythm is the main characteristic of the mastication process (4). The masticatory rhythm is generated by the Central Pattern Generator, that active a motor program, and coordinate the mandibular, tongue and facial muscles movements. (1, 4).

There are a lot of methods that can be used for the study and analysis of the mastication function, one of those methods is the surface electromyography, that records the bioelectrical potentials of the masticatory muscles, trough electrodes placed in the skin surface(4-6). These bioelectrical potentials are related with the strength developed by the muscle during the mastication. So surface electromyography is a widely used method in studies that relate the muscle activity in the masticatory process (4-6).

Infrared termography has been used in medical applications to evaluate cutaneous blood flow adaptation during a specific function like in swimming were it was possible to observe significant variations in the cutaneous temperature according to swimming styles (7).

This work had as main goal, to study the application of infrared termography in the mastication process and to see a possible correlation beetween the values obtained with the electromigraphy.

2. MATERIALS AND METHODS

This study has involved 7 young individuals, with an average age of 22.4 years old (SP +/- 1.173) the maximum age was 25 years old, and the minimum 22 years age. As exclusion criteria: 3th molars mallpositioned, orthodontic treatment, orofacial lesions, malocclusion Class III, sintomatology and/or symptoms of temporomandibular disorders. To aid screening the presence of temporomandibular disorders, was used the Research Diagnostic Criteria for Temporomandibular Disorders (RDC), translated into Portuguese.

The selection of ten individuals started with a sample of 25, among which the differences were calculated from records of the masseter electromyography during chewing of a slice of carrot. Five subjects were chosen with differences of potential bioeléctricos less than 10 micro-volts between the right and left masseter. And two who had differences of more than 25 micro-volts between the muscle of the right and left side.

The bioelectrical potentials were recorded bilaterally in the anterior temporal and masseter muscles. The electromyographic equipment used was the BioEMG II of BioResearch® with BioPak software for Windows. The surface electrodes used were the BioFlex® from BioResearch (Ref : 800-251-2315). To place the electrodes the skin was cleaned with alcohol, and then the position for placement of the electrodes was determined by muscular palpation and the electrodes were arranged parallel to the longitudinal direction of the muscle fibers, with firm pressure (Fig 1). The ground wire was placed in the lateral-cervical triangle of the neck. For the EMG records, it was analysed the first four seconds of EMG for each food in each head position. The software used, allowed to calculate the average in micro-volts of those first four seconds for each muscle and this was the value used for the results.

Thermal images were performed using the thermographic camera Flir® A325, were further interpretation of the thermographic patterns were realized with a software analysis system – ThermaCAM Researcher Professional.

Fig. 1 - Surface electromyography of jaw muscles with eletroelectromyographic equipment BioEMG II of BioResearch ®.

To obtain the images of thermography, subjects were seated in a chair, placing the camera sideways to each participant. A thermal image was obtained at rest position in lateral, right and left view of the participants (Fig. 2). The subjects were instructed to chew three slices of carrot without having the indication of chewing to a specific side. After completing this task, another thermal image was obtained of lateral, right and left view of the participants (Fig 3).

Thermal images were performed using the thermographic camera Flir® A325, were further interpretation of the thermographic patterns were realized with a software analysis system – ThermaCAM Researcher Professional.

Fig. 2 - Subject at rest position before mastication were infrared thermography examination took place.

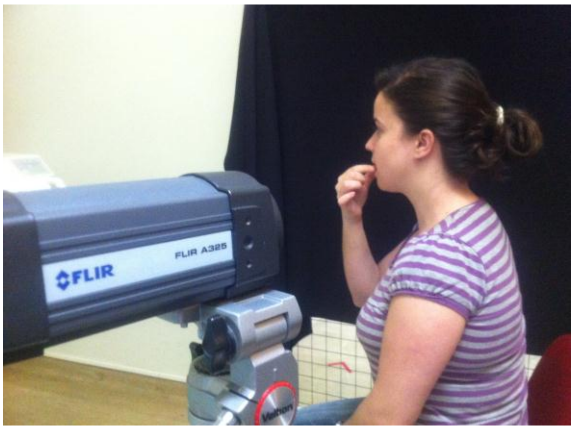

Fig. 3 - Camera Flir A325 capturing thermal images during mastication.

3. RESULTS

The different ranges of electromyography values that exist don´t have direct relation with the thermal images obtained. Regardless of the differences that exist in terms of electromyography in the masticatory muscles, namely the masseter and temporal right and left side, these differences do not appear in temperature recorded by the infrared thermography. The facial thermograms obtained at the end of mastication are very similar between participants even when there was differences in the bioelectric potential of the masseter and temporal. The subjects with higher electromyography values do not have higher infrared images.

Regarding the temperature difference between the right and left sides, what happens is that participants with the left side is the preferred side, do not exhibit, invariably, temperatures in left ATM, masseter and temporalis higher than the structures of the right side (tables 1, 2, 3).

Table 1 - Temperature registed before mastication.

Subject	Temperature before mastication °C					
	Left TMJ	Right TMJ	Left Temporal	Right Temporal	Left Masseter	Right Masseter
1	35.4	35.2	36	36	34.4	34.3
2	35	35.5	35.8	35.6	35.5	35.1
3	34.9	36.1	35.4	35.5	35.8	35.9
4	34.8	35.4	35.5	35.7	34.2	34.7
5	35	35.3	34.9	35.3	35.2	34.8
6	35.1	35.5	36	36.1	34.6	34.6
7	35.8	35.9	36.2	35.9	35.9	35.6

Table 2 - Temperature after mastication.

Subject	Temperature after mastication °C					
	Left ATM	Right ATM	Left Temporal	Right Temporal	Left Masseter	Right Masseter
1	35.3	35	36	35.9	34.4	34.2
2	34.9	35.5	35.7	35.5	35.4	35.2
3	35.3	35.6	35.1	35.6	35.7	35.7
4	34.8	35.2	35.5	35.6	34	34.4
5	34.9	35.2	34.9	35.4	35.3	34.9
6	35	35.1	36	36	34.9	35
7	35.6	35.8	35.9	35.8	35.6	35.5

Table 3 - Electromiographic values of each masticatory muscle

Subject	Electromiographyc values µV			
	Left Temporal	Right Temporal	Left Masseter	Right Masseter
1	42.6	28.1	32.3	41.5
2	37.9	30.5	57.3	47.3
3	61.5	49.5	54.7	44.9
4	44.4	39.4	36.8	35.1
5	26.6	25.4	38.8	43.3
6	55.2	33.4	59.2	30.0
7	32.5	36.2	59.3	33.4

4. DISCUSSION

A complete assessment of the orofacial region was obtained with the thermal images, allowing the visualization of determinant structures during mastication, like the TMJ and the jaw elevator muscles. The information obtained showed no asymmetric pattern, before and after mastication, this can be due to the fact that the time concuming during mastication was very short, lasting 1.5min. Like wise in most cases the temperature before mastication is higher than the temperature recorded after chewing. With the thermal images we can evaluate the cutaneuos temperatures of the aboved mentioned structures were the surface temperature is high at the rest position and then reaches lower values at the end of mastication, possiblt due to the fact that the blood supply is "shifted" from the surface to deeper structures that are active and therefore the skin surface notes a lower value of temperature.

5. CONCLUSION

Infrared thermography is a noninvasive, nonionizing diagnostic method that can complement the evaluation of orofacial structures involved in the process of mastication, that are related with the overloading of these anatomic zones. Further studies should me made with the time of 20 minutes of mastication representing an ideal meal; this should be done also testing different food consistency.

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Diagnostic Evaluation of Chronic Venous Insufficiency Cases Using Thermal Imaging

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SUMMARY

The use of infrared thermography in surgery of Varicose Veins on the inferior limbs is presented. The study was executed at Polytechnic Institute of Bragança and at the Regional Hospital of Bragança, Portugal. The most suitable steps to measure with this technology were determined prior to the clinical studies, where a minimum waiting time of 10 minutes was determined for each individual to reach thermal equilibrium. Both inferior limbs were compared for each patient and it was found that in 75% of the cases there was an aggravation of the healthier leg. In one of the cases residual veins appear. It was concluded that regular thermographic exams on post-operatory allow a closer follow up of the recovery of the operated limb, as well as the evolution of the non-operated limb.

1. INTRODUCTION

This study show the early exploration phase for Varicose Veins cases recommended for safenectomy at the Surgery Department of the ULS Bragança Hospital, Portugal. This work involved preliminary tests to develop an appropriate experimental protocol to study the inferior limbs, and analyze clinical cases with the support of the Surgery Department at the Bragança Hospital, Portugal.

One of the most common manifestations of venous insufficiency, or venous reflux are Varicose Veins. They are the source of aching pain and discomfort and may require medically necessary treatment, being the most extreme the surgical option the removal, or closing off, the affected vein. Surgical option accounts for the severity of the symptoms, the type of vein and the source of venous reflux. Clinical examination is also supported by blood exams, Eco-Doppler soundings or other imaging studies in order to accurately assess all of the sites of venous reflux.

Blood flow can be assessed by many methods including the washout technique, laser Doppler flowmetry, and medical infrared thermal imaging. Of those, infrared thermography has the advantages of being noninvasive, fast, reliable, contactless, and capable of producing multiple recordings at short time intervals. It is also absolutely safe for patients and medical staff (1, 3).

The aim of this work is the exploratory use of infrared thermography within venous insufficiency cases. Thermography visualization was made at the inferior limbs where cases of varicose veins were monitored over time with a camera FLIR® T365 model.

The most adequate steps to measure with this technology were determined prior to the clinical studies. A team of engineers and medical doctors evaluated the thermographic images for a better analysis and interpretation of the results.

With this work, it was found that the thermography was a very useful technique in this particular pathology, being easy to handle and reliable in diagnosis. From this technique we were able to verify whether the surgery had been successful or not, and identify varicose veins that had not been identified earlier with standard Eco-Doppler exam.

1.1 Varicose Veins

The normal way the saphenous vein works is by allowing blood to flow from the lower leg to the heart (a simple pipe or conduit use). Venous valves stop the backward flow of blood once it is pushed forward by muscles or gravity. Unfortunately, valves can become damaged allowing backward flow, creating pools in the lower leg and causing swelling as well as other problems. The term used by physicians for this abnormal state is chronic venous insufficiency (CVI). Another sign that there is abnormal back-ward blood flow in the lower leg is the presence of varicose veins, in which they are often seen as dilated vein branches coming off the saphenous vein and easily seen beneath the skin (2).

1.2 Saphenectomy or Shaphenous Venous Stripping

Standard open varicose vein surgery has been used to treat uncomplicated varicose veins for over 100 years. The specific techniques of the operation have been subject to regular, and often cyclical, change over the years. However, the essential aim of the operation, to ligate and disconnect the great (GSV) or small saphenous vein (SSV) at its junction with the deep venous system has remained constant (4).
The traditional surgical treatment for venous insufficiency of the saphenous vein involves two primary goals. The first is to eliminate backward blood flow (reflux) in the saphenous vein and its tributaries. The second is to remove unsightly and protruding varicose veins through tiny incisions (phlebectomy). Improvement to the method over the years has allowed most procedures to be done on an outpatient basis.
Saphenous vein stripping involves making a small incision at the level of the groin to expose the beginning of the saphenous vein and its branches, and a separate incision at or near the level of the knee. A wire stripper is then inserted into the vein and the vein is disconnected at these two incisions. The vein is attached to the wire stripper and is pulled (ripped) from where it lies. Thus the term "stripping" of the vein was what it came to be called. Small separate skin cuts (incisions) over the areas of abnormal vein dilation are made along the thigh or calf for removal of branch varicose veins that were not attached to the main trunk of the saphenous vein or where not removed at the time of stripping.
Compression bandaging is used from the ankle to the level of the thigh for several days to reduce the amount of bruising and discomfort from the procedure. The patient is allowed to walk to comfort levels immediately after surgery with instructions for leg elevation when discomfort develops and when retiring to bed. This procedure can be often based using local anesthesia but more normally has been performed in an ambulatory setting with either a general or spinal anesthetic (2).

2. METHODS

A particular protocol for a FLIR®, model T365, camera (Fig. 1) was developed for this pathology. This protocol differs from Bagavathiappan et al. (1) because functional tests were also included to enhance physical limitations provoked by the disease and are better captured by thermography.

Fig. 1 - Camera FLIR®, T365 model.

The determination of the experimental protocols results on the adaptation of the existing protocols, which consist in a set of steps and cares such as caution on the application of lotions, avoiding excessive sun exposure, shaving or exercise. Those are some of the examples to be avoided before a thermographic exam.
The subjects were placed at rest for a period of 10 minutes in a controlled temperature room in order to conclude acclimatization process.
A black background was also used to avoid temperature contamination of the surroundings and the capture of images was made from multiple angles. It was considered an emissivity of 0.98, the relative humidity (50%) and the distance from camera to the object (0.50 m).

2.1 Distance and angle from the camera to the object

The infrared thermal camera was positioned 0.50 m away from the limb and the images were taken in three views: anterior, posterior and lateral. As the images are from a curved surface (limb) several images – parallel to the surface - are necessary to fully capture the emitted radiation.

2.2 Exploratory Tests and Methodology

The exploratory tests were made in four healthy subjects, of approximately 20 years old, providing a reference for neutral situation. The tests were performed in a horizontal position, where the leg was at rest, and then vertically.

Initial measurements of lower extremities of the healthy patients showed normal skin surface temperature. The thermography protocol followed was:

1. Turn on the camera and leave it to calibrate for 5 - 7 minutes;
2. Leave the subject rest with the lower limbs to acclimate (remove all the clothes of this area) in a room for 10 minutes;
3. Put the black background behind de limb;
4. Leave the camera 0.50 m to the subject;
5. Collect images from multiple angles.

The results presented of the healthy subjects are only of the right leg since does not distinguish differences between the two relevant.

3. RESULTS AND DISCUSSION

The preliminary tests were able to provide a reference for neutral situation. In Fig. 2 there are four healthy subjects. It is observed uniform temperature variations along the surface.

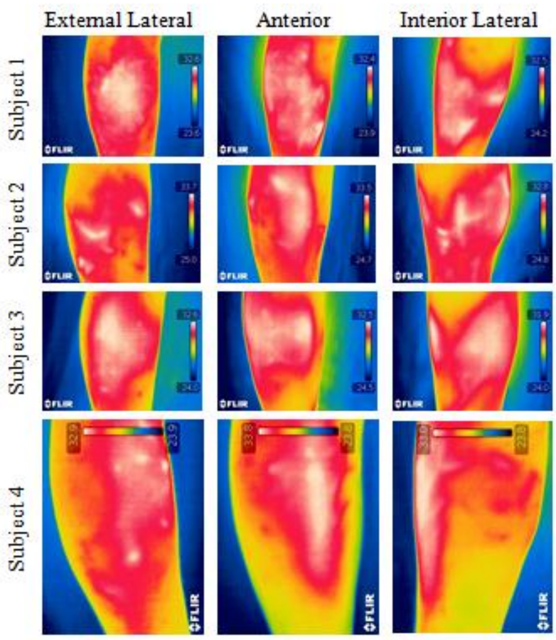

Fig. 2 - Right inferior limb of the healthy subjects in the anterior and lateral views.

Four clinical cases are presented: one male and three females, with Varicose Veins pathology identified in only one leg – with surgical recommendation. Exams in both legs with standard procedure produced the same information for the leg with the pathology. However, thermography clearly unveiled – or highlighted – additional Varicose Veins in the considered healthy legs, not identified by clinical examination or by imaging methods commonly used in clinical practice. This early identification of venous pathology demonstrates the advantages of the Thermal Imaging as a quickly, inexpensive and noninvasive diagnostic tool, and could lead to other course of treatments avoiding radical solutions such as Saphenectomy.

3.1 Clinical Case 1

The patient was a 61-year-old female with recur-rent varicose veins. This patient had undergone a saphenectomy. A possible duplication of the saphenous vein complicated the venous system of the right leg leading the patient to a second surgery. Images were collected with the patient laid and standing up. When the patient was at rest one do not observe the same temperatures as standing (fig. 3). While lying, the blood flow is smaller, being that one of the characteristics of the varicose veins. Then, when the patient stands upright position, blood flow increases because there are no competent valves that can control the flow.

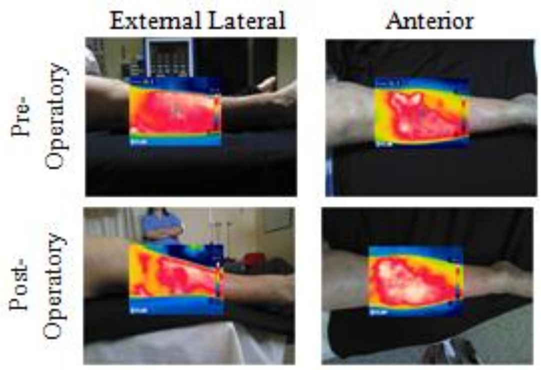

Fig. 3 - Inferior right limb before and after surgery at rest.

In this case it was not possible to identify pathology when the patient was at rest. However, the results confirmed the venous pathology and the recur-rent varicose veins when the patient was standing. It was possible identify with the thermographic exam the same findings the Eco-Doppler exam. In the post-operatory images (Fig. 4) it is possible to observe residual veins that are a common complication of the surgical treatment. An alternative hypothesis refers to the ill marking of the veins in pre-operatory exam. Thus an intra-operatory exam would be a way to ensure the success of the surgery when the marking is not completed. The images of the post-operation were collected 39 days after the surgery.
In this case there was an aggravation of the healthy leg (Fig. 5) that may be due to overload in the leg while the operated leg recovers from the surgery.

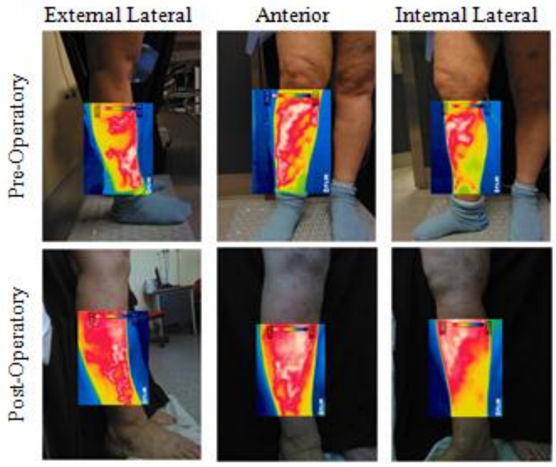

Fig. 4 - Affected limb (right leg) of the clinical case 1 before and after surgery.

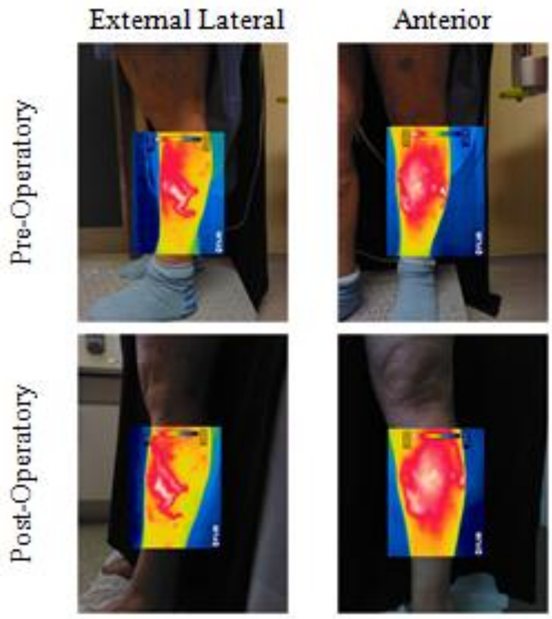

Fig. 5 - Right inferior limb not indicated for surgery. Identification of pathology in the external lateral face of the limb.

The images of the pre and post-operatory were not taken always at the same distance and angles but approximate values of the vein dimension were determined by simple triangulation. One of the varicose veins of the healthy leg (Fig. 6) increased of 232% ± 5%.

3.2 Clinical Case 2

An 18 year-old male with a visible dilatation of the vein of the inferior left limb. The images were collected in pre-ambulatory environment, and in this case it was possible to identify abnormal temperature areas even when the patient was at rest (Fig. 7).

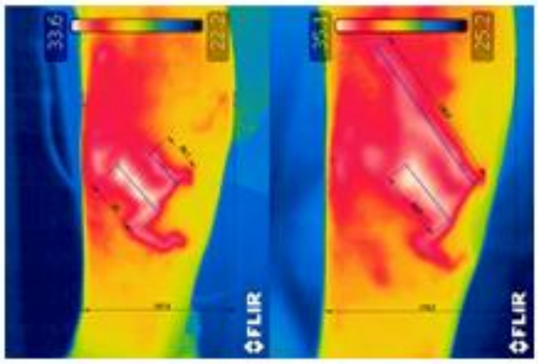

Fig. 6 - Left leg. Varicose veins compared before and after the surgery to the right leg.

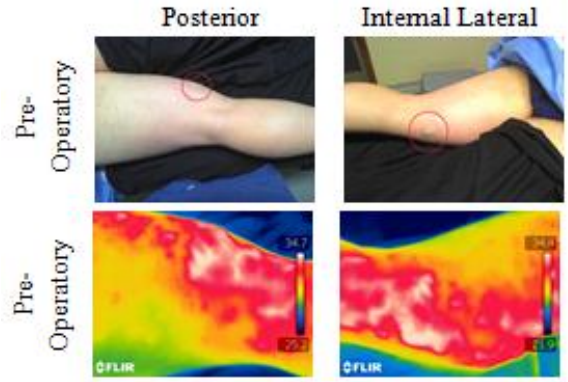

Fig. 7 - Affected limb (left leg) of the clinical case 2 before surgery (Original and thermal images).

When the patient was standing the pathology was better visualized because of the increase of the blood flow (as previous mentioned in 3.1). The affected area was only in the internal part of the leg, so the results presented are only of the area that presented this pathology. The images of the post-operation were collected 39 days after the surgery.

Although not being common in younger people, this pathology may be presented in people with genetic predisposition or with high intensity of sport activity, our case.

The pathology is evident and consistent with the Eco-Doppler. The saphenectomy intended to solve the main trunk of the saphenous vein. From a medical point of view the surgery was successful (Fig. 8). It was also possible to identify varicose veins in the healthy leg (Fig. 9) where the Eco-Doppler had not identified any abnormality.

In this case the increase of the varicosity of the healthy leg (Fig. 9) was 4.3% within our margin of error. In this case we cannot conclude that there was an increase of the varicose vein in the healthy leg.

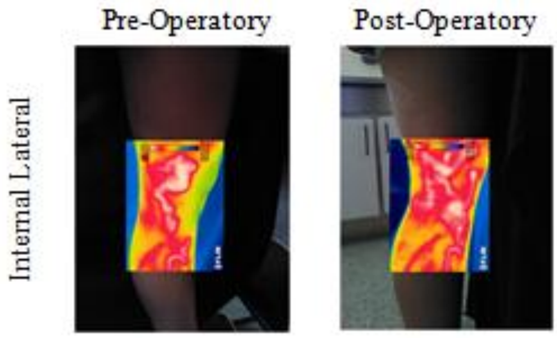

Fig. 8 - Left inferior limb before and after surgery only in the lateral view.

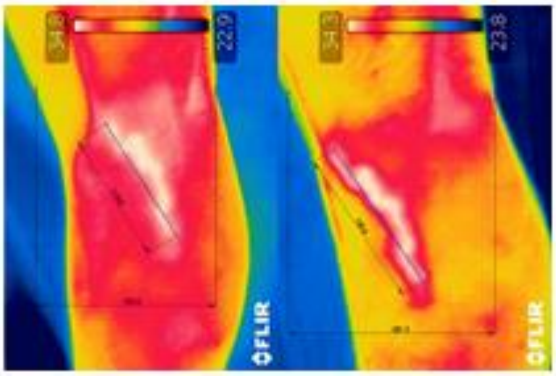

Fig. 9 - Right leg. Varicose vein compared before and after the surgery to the left leg.

3.3 Clinical Case 3

The third clinical case was of a 60-year-old female indicated for a saphenectomy in the left inferior limb. The most evident vein was located in the posterior face of the limb. In Fig. 10 it is visible the vein with the thermographic exam confirming the pathology. The images of the post-operation were collected 18 days after the surgery, and it is well perceptible the improvement of the area presenting a more uniform temperature of the intervene area.
There is an improvement on the posterior face of the limb. At the post-operatory consult the patient claimed to feel well and free of pain.

3.4 Clinical Case 4

A 62 year-old female with indication of surgery to the right inferior limb. In this case it was possible to see through the thermal images the pathology very clearly even when the patient was lying (Fig. 11). Then, the venous pressure is more passive, as the pressure of the blood is lower in the veins to venous return.
The post-operatory images were collect 17 days after the surgery.

Undoubtly, the best position to visualized and diagnose varicose veins is when the patient is standing (Fig. 12). This is another case in which there was a significant improvement in the leg after surgery, observing in the post-operatory a uniform surface temperature. Given that these images were collected 17 days after surgery, we can also speak on the expertise of the surgeon.

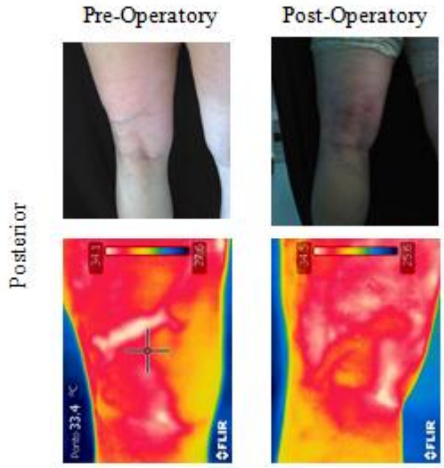

Fig. 10 - Left inferior limb before and after surgery.

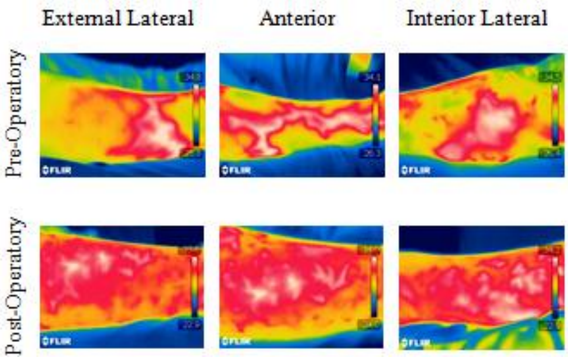

Fig. 11 - Right inferior limb before and after surgery.

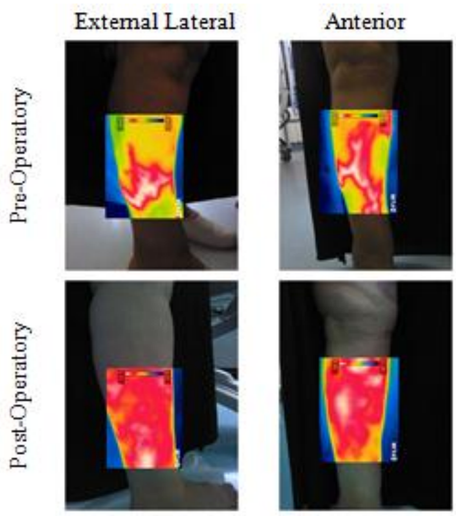

Fig. 12 - Right inferior limb indicated for surgery (pre and post-operatory).

In this case was also possible to identify pathology in the healthy leg (Fig. 13). However the angle of capture of the images in the pre-operatory wasn't exactly the same than the post-operatory therefore is not possible to conclude if there is an evolution of the varicose vein.

3.5 Marking of varicose veins

In some clinical cases, the opportunity arose to collect images while the surgeon was marking the varicose veins with a marker. In Fig. 14 we observe a surgeon tagging the leg with a marker. In this case the surgeon was guided by Eco-Doppler information and touch (by palpation of the leg). We observe that the markings are consistent with the warmer spots on the leg.

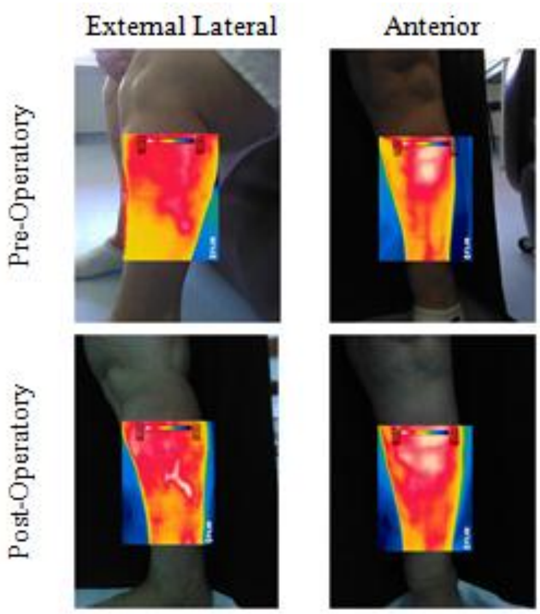

Fig. 13 - Left inferior limb not indicated for surgery, before and after the operation of the right leg.

The marking is done with the patient standing, but it can be considered doing with the patient lying with thermography as a diagnostic support.
In the point of view of a surgeon, in the case 1 there were some varicosities spots to mark. In the future to help avoid these types of flaws, thermography can be a very useful technique in the support of the pre-operatory exam. It would be also a great support technique as a intra-operatory exam (Figs 15-16), helping the surgeon to evaluate the result of the surgery.

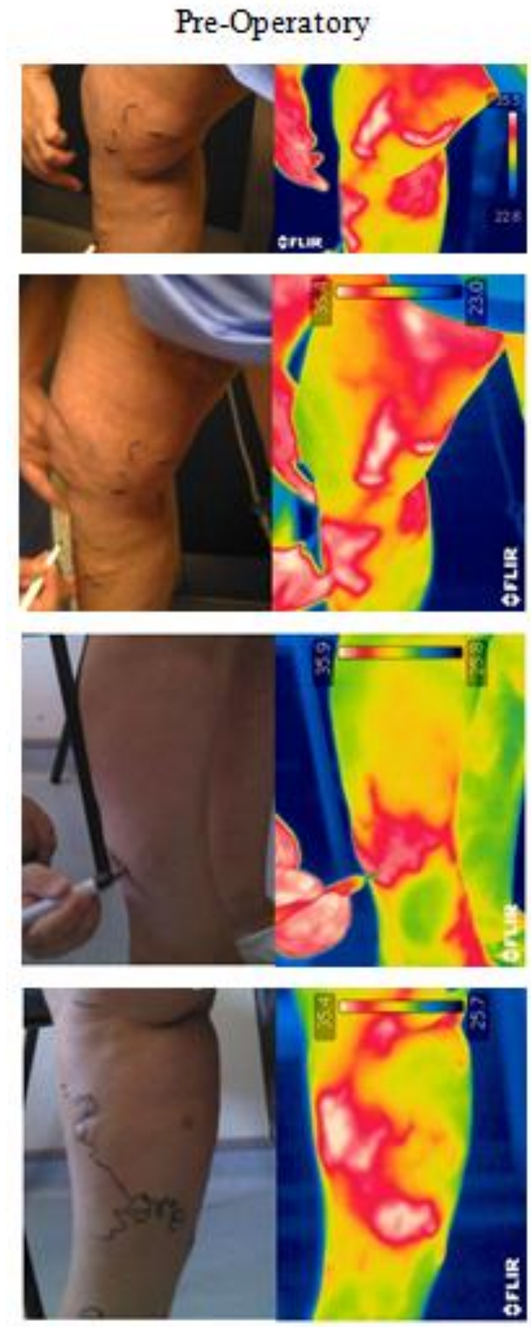

Fig. 14 - Marking of the varicose veins in the pre-operatory exam.

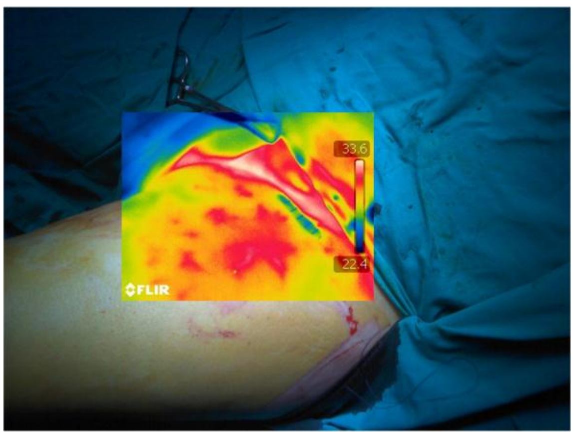

Fig. 15 - Intra-Operatory thermography exam.

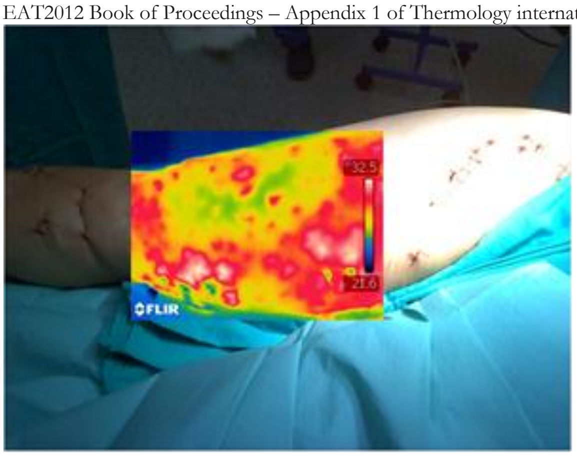

Fig. 16 - Intra-Operatory thermography exam of a saphenectomy surgery.

3.6 Discussion

Analyzing all the images collected on the lower limbs of healthy subjects and clinical cases came to the conclusion that the collection of data when the patient is at rest may also be relevant. In healthy subjects was not perceptive because did not exist pathology. However, in clinical cases it was found that it was possible to observe varicose veins at rest. Factors such as distance, angle, capturing light, or other factors that weren't determined for lack of time, may be involved in data collection. It was found that in a standing position the pathology is better visualized: the blood flow increases, and the pressure in the veins, due to poor venous return, is more evident.
Except for case three, it was noted the worsening of varicose veins identified in the healthy limb.

The success of the surgery depends primarily on factors as:
1. The expertise of those who operate;
2. The duration of the surgery;
3. The ability to visually evaluate.

The recovery of the surgery depends mainly of three factors:
1. The illness (the severity of the pathology, such as case 1 in which there are complications to the appearance of residual vein, or the existence of genetic predisposition, as in case 2);
2. The patient (the care that the patient have after surgery for a good recovery, i.e., an active life, not sedentary, avoid excessive sun exposure, avoid sitting or standing positions for long periods of time, good diet, etc.);
3. The expertise of the surgeon (ability to evaluate and verify the results in the intra-operatory, the expertise of those who operate, the visual diagnosis of who marks the pathology, etc.).

4. CONCLUSIONS

In this work it was proposed exploratory testing using thermography. For this it was learned to master the technique, the handling of the camera, as well as processing and interpretation of results, thus achieving a suitable experimental protocol.
It was concluded that the ideal position for the collection of data was standing even for healthy patients as the ill patients. In clinical cases it was more evident that the best position to collect images was standing because of the pressure exerted in the veins.
Other factors such as distance to the object and the camera's shooting mode were defined. Angles to capture images were defined and the use of black surfaces for better image capture. The use of the black background allowed to mitigate contamination from other sources, such as reflection light.
The creation of thermography protocol was effective in collecting data, and the result of the captured images and the diagnosis using this technique - satisfactory. The technique proved to be reliable for the diagnosis of the pathology being possible to assess the success of the surgery. Through this it was possible to identify varicose veins that were not previously detected in the Eco-Doppler exam.
Through thermography it was observed the worsening of varicose veins that were not identified in the healthy limb. This increase may have been caused by overloading while the operated leg recovered from surgery. It was also noted that this technique could be very effective in marking varicose veins since the difficulty of visually evaluate can influence the marking, and thus compromise the success of the surgery.
In addition to the factors that may compromise the surgery it is also considered the disease. The patient may have a genetic predisposition for the dis-ease. Recovery from surgery depends on the disease, the patient and the care that this have after the surgery (and once again the expertise of those who operate).

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