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Thermologic investigations in plants

Thermal Imaging to assist in the diagnosis of Carpal Tunnel Syndrome

Infrared Cold Water Autonomic Functional Stress Testing for CRPS

14th Congress of the Polish Association of Thermology: Abstracts

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Contents (INHALTSVERZEICHNIS)

Thermologic investigations in three groups of plants - How much temperature difference to expect ?

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SUMMARY

Thermologic investigations of plants become more popular due to lighter handheld cameras and decreasing prices of them. This paper gives a survey about the thermologic effects one may expect. To make comparisons easier, corresponding experiments are divided into three groups: (i) Monitoring injuries, infection, and cellular freezing with temperature differences usually below 1 K, sometimes 2 K; (ii) Phototropic and solar tracking plants which try to gain as much (or sometimes less) radiation energy by turning to the light or following the sun on its transit (up to 5 K); (iii) Thermogenic plants that use special metabolic tricks to develop heat instead of chemical energy, to warm up their blossoms, evaporate odor molecules and attract pollinators (up to 35 K). These effects may endure a few hours, some days or a week. Some flowers even regulate their metabolism on a level comparing to small mammals or hummingbirds.

KEYWORDS: Plant diseases and freezing, Phototropic and solar tracking plants, Thermogenic and thermoregulating plants

THERMOLOGISCHE UNTERSUCHUNGEN AN DREI GRUPPEN VON PFLANZEN – WELCHE TEMPERATURUNTERSCHIEDE KANN MAN ERWARTEN?

Thermologische Untersuchungen an Pflanzen werden immer populärer durch leichtere Kameras und sinkende Preise. Diese Arbeit gibt einen Überblick über die thermischen Effekte, die man erwarten kann. Um den Vergleich zu erleichtern, werden die Untersuchungsobjekte in drei Gruppen eingeteilt: (i) Verletzungen, Infektionen und Gefrieren von Pflanzen (weniger als 1 K, ganz selten bis 2 K); (ii) Phototrope und der Sonnenrichtung folgende Blüten, die versuchen, möglichst viel (in seltenen Fällen möglichst wenig) Strahlungsenergie aufzunehmen (bis etwa 5 K); (iii) Thermogene Pflanzen, die besondere Stoffwechselwege nutzen, statt chemischer Energie Wärme zu bilden und ihre Blüten aufzuheizen, Duftstoffe zu verbreiten und Bestäuber anzulocken. Diese thermogenen Effekte können Stunden, Tage und sogar eine Woche dauern. Manche Pflanzen halten dabei ihren Stoffwechsel auf einem mit kleinen Säugetieren oder Kolibris vergleichbaren Niveau.

Schlüsselwörter: Pflanzenkrankheiten, Photo- und Heliotropismus, Thermogene und thermoregulierende Pflanzen

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Introduction

Comparing botany with human or veterinary medicine, it seems to be a neglected field for infrared thermology. Of course, stationary equipment typical of thermography in former times and restricted to laboratories or medical wards reduced the interest of botanists for this technique of investigation. Only recently, handheld instruments became available at a reasonable prize, so that flexible laboratory set-ups and outside experiments became possible. For a first approximate survey of the interest distribution in the various fields of application one may ask the internet. A search on Google Scholar for the application of IR thermography to plants and flowers in just biological journals (excluding those of human and veterinarian medicine) gave an astonishing picture: since the year 2000 about 670 papers were published on animals, humans, flowers and plants combined with "Infrared thermography", showing a percentage of 9.5 % for flowers alone and 32.6 % for flowers and plants. Including also medical journals as an important field for thermography yielded about 1760 papers and reduced the figures for flowers alone and for both to half. Physical, chemical and industrial applications were not included in this consideration. Confounding of "plants" as kind of factories or energy and water supply was more or less excluded by the choice of the journals.

The present paper intends to show which temperature differences are to be expected in various experiments. It is divided in three sections showing in the first part investigations of plant infections with elevations of less than one or two degrees due to a reduced transpiration (and thus reduced cooling) or a leakage of cell material with an increased cooling. Freezing of water in the intercellular spaces of plants produces so-called "exotherms" which are approximately in the same range and typical for freezing.

The second part describes experiments with heliotropic or even solar-tracking plants which orientate their flowers (and sometimes leaves) in an appropriate direction to collect as much light as possible for photosynthesis or flowering. Or, they are following the sun in its transit to have an even larger efficiency. Here, the light and especially the sun and, of course, the special form of the blossoms, are the driving forces resulting in temperatures several degrees above ambient.

The third section is quite different from the first two sections and deals with thermogenic plants. Several times during evolution such plants developed which use a special form of metabolism while flowering to increase the temperature and attract pollinators. Several rewards for them are the result of the diversity of the blossoms. In this case the blossoms often are rather large, attractive, bad to pleasant smelling and active for a few hours, some days or even a week. Differences vary between a few degrees up to more than 35 K. They certainly offer the most spectacular results for infrared thermography.

Part 1: Cellular effects zero to around two degrees

The first group of plant investigations with thermology bring small effects. Usual temperature differences are below 1 K. But as they are significant for the material, one could superscribe this section with "Seeing is believing. Imaging techniques to monitor plant health", a title adapted from L. Chaerle and D. Van Der Straeten, pioneers of such investigations [1]. In their review article they show – among others – infection of tobacco plants (*Nicotiana* spp.) with tobacco mosaic virus (TMV). These infections become visible in the infrared range for spots of hypersensitive reactions after 2.5 days. As the temperature increases by +0.4 K 6 days later, the cells at the infection site have died, and the temperature returns to that of the leaf in total. Similarly, thermography can visualize spontaneous cell death in specific transgenes like bacterio-opsin in tobacco. The left thermography in **Figure 1** indicates cell death spreading from the leaf bases along the main veins and the side ones into the leaf. The yellow colour (+ 0.6 K) is due to a reduced transpiration. The blue spots (-0.8 K) are the result of cellular material leaking to the surface and cooling by evaporation [1].

Salicylic acid (SA) and some of its analogs are known for closing or partly closing stomata, plant structures regulating evaporation, thus inducing reduced water loss and temperature increase. These effects are – again - shown on tobacco plants in **Figure 2**. The upper row presents an uninfluenced control leaf, an SA treated leaf, and one treated with an SA-inactive analog. The bottom row leaves were treated with a combination of an SA analog plus a blocker, with the SA analog, and with the inactive analog, both from above. Effects were an increase in temperature of up to +0.8 K after 4 to 5 hours for SA and +0.5 K for one of its analogs. After the initial peak both levelled to +0.45 K after 7 hours. Four hours later the influence began to decrease and became approximately zero [2].

We have learned from our gardens that plants are more or less sensitive to frost and that ever-greens have possibilities to withstand wintry stresses. As water molecules are relatively misarranged in water complexes, water does not freeze at 0 °C. When absolutely free of freezing nuclei, it is possible to cool it down to –38 °C. Plants use similar tricks and form very small amounts of crystal nuclei inside the cell. Thus, freezing happens not within the cells, but in the intercellular spaces and this reduces the amount of water inside the cells and increases the concentration of freeze protecting substances step by step. In this way ever-greens, like rhododendrons, can stand wintry temperatures of –30 °C without damage.

R.S. Pearce shows thermologic investigations on plant freezing in a botanical briefing "Plant Freezing and Damage" and states that freezing of water as an exothermic effect is easily seen in "infrared video thermography (IRVT)" [3]. As an example he presents 3 holly leaves (*Ilex* spp.) freezing in a controlled environment with droplets of water on the surface for external freezing (**Figure 3**). They produce exotherms of +1.2, +0.7 and +0.3 K for leaves 1 to 3. Moreover, blue/white areas in leaves 1 and 2 (in A) and 3 (in B) are due to a small exotherm at the beginning of cooling. These pictures clearly indicate that the nucleation starts at the droplets for leaf 2 and 3 and at the black arrow in leaf 1. The intensive yellow/brownish colour of leaves 2 and 3 results from water drawn out of the cells and frozen externally. It should be noted that the registration temperature was shifted downwards by –0.3 °C between the two pictures (time gap 156 s) so that a 2-degrees span could be maintained [3].

In a more recent paper it was shown that freezing in plants proceeds from the stem into the leaf basis and then along the main veins (and sometimes up to the third-order lateral veins) by exothermic effects which occur with velocities between 0.3 and 4.7 cm s^{-1}. This again proves that – in this case – Infrared Differential Thermal Analysis (IDTA) is a highly effective method to follow the small exotherms combined with freezing [4].

In further thermologic experiments two kinds of wild turfgrass were taken from the field, washed, and the roots were excised and prepared for the investigation. After acclimatization and a root regrowth plants were placed in a room whose temperature could be lowered every 3 min at a rate of 0.5 °C. The plants were inoculated each with 3 drops of 5 μl ice-nucleating bacteria (*Pseudomonas syringae*). The infrared radiometer was set at a span of 2 K and allowed to follow the freezing events in turfgrass. Due to the high water content in the leaves the exotherm could be about +2 °C, while the effects in the roots were much smaller with up to +0.5 °C. After finishing freezing, tissue IR colours returned to their initial values. Freezing in roots proceeded at several centimetres in approximately 1 min, confirming the values of Hacker and colleagues [4]. The order of freezing was: first roots, then crowns and finally leaves. None of the plants survived the treatment and was able to grow again in normal soil [5].

It is known that the observed increase in leaf temperature is mainly due to stomata closure and thus a reduced or even stopped transpiration. Thus, the cooling effect of water is hampered and the temperatures increase, already seen in the section about freezing of water in plants. In this paper dry and wet reference surfaces were taken as estimates for the evaporation [6]. Petroleum jelly was applied to the sur-

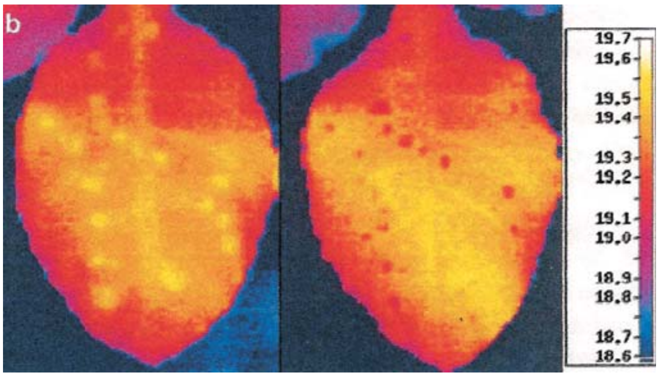

Figure 1
Infection of tobacco leaves with tobacco mosaic virus. 2.5 days after the infection (PI) the temperatures rises by +0.4 K. Six days later the cells at the infected sites are dead, they show darker spots of lower temperature [1].
Reprinted from [1] with permission from Elsevier.

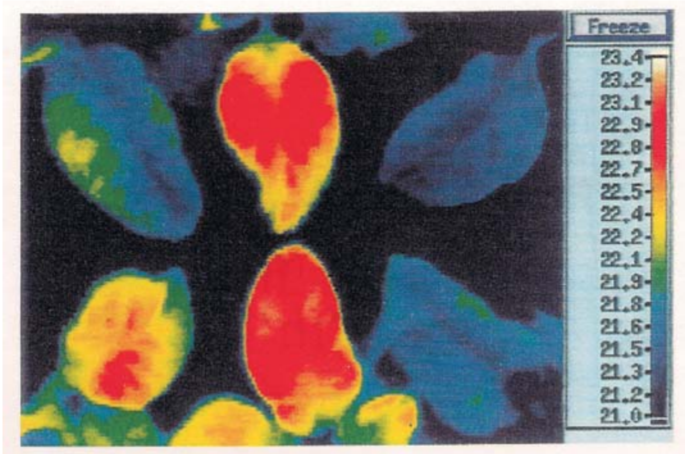

Figure 2
In the upper line a control leaf, an SA treated and a 4-HBA treated leaf of tobacco plants are shown, in the lower line leaves treated with a combination of 2,6-DHBA and SHAM, treated with 2,6 DHBA alone and with 3-HBA [2].
HBA = hydroxybenzoic acid; DHBA = dihydroxybenzoic acid; SA = salicylic acid; SHAM = salicylhydroxamic acid. 3- and 4-HBA are known to be ineffective in temperature effects.
Reprinted from [2] with permission from Springer.

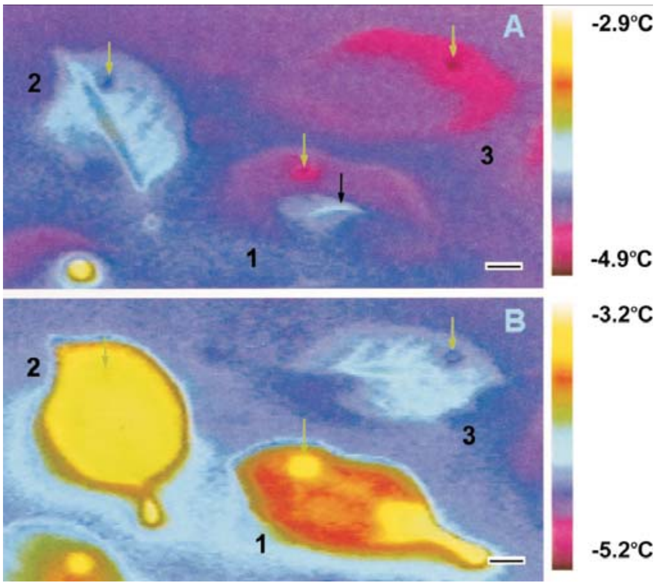

Figure 3
IR thermography of freezing holly leaves (Ilex spec.) by controlled cooling. The bluish colours indicate areas of initial minor exotherms after ice formation, yellow-brownish colours where water was drawn out of the cells and froze extracellularly [3]. For further information see text.
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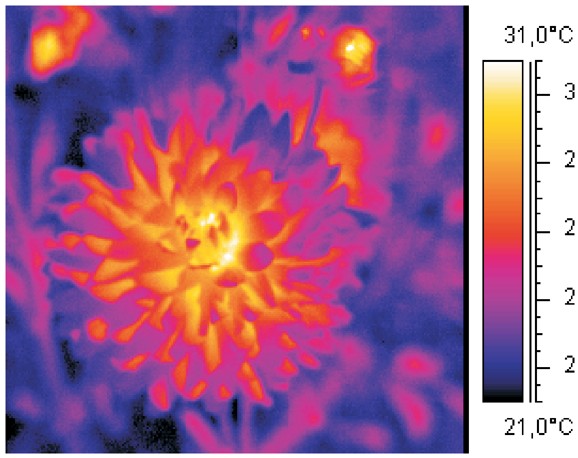

Figure 4
IR thermogram of a red-orange Dahlia (Gräfin Cosel) under full sun. The scale was put to the maximum temperature (31.0 °C) so that the light seems to glow out of the centre of the blossom. ÄT amounted to 8.2 K [7].
Reprinted from [7] with permission from Elsevier.

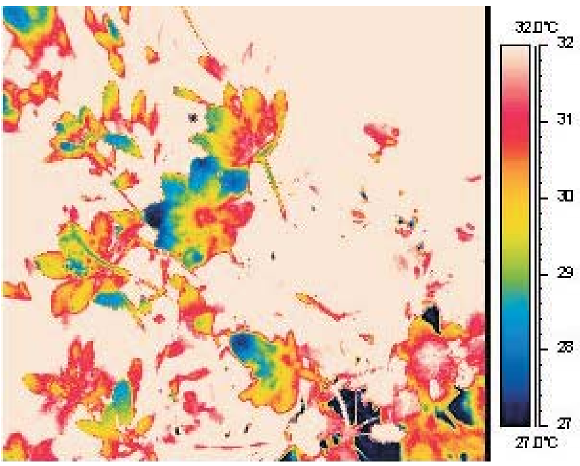

Figure 5 (left**)**
Thermal image of solar tracking blossoms of *Dryas octopetala* directed to the sun around noon in the Berlin Botanical Garden. Blossoms in different states of development are detectable in the image. The two blossoms in the centre show the energy effects best [8]
Reprinted from [8] with permission from Springer.

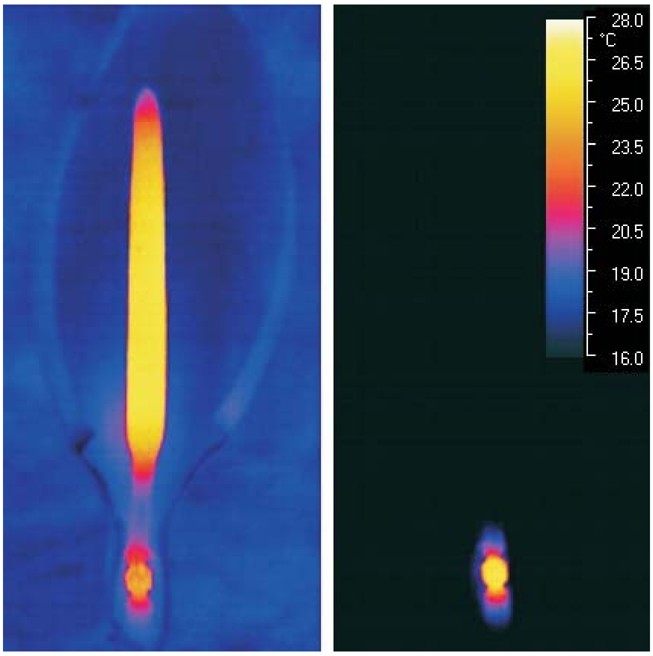

Figure 6
Thermal image of an *Arum concinnatum* blossom in the field with clearly indicated thermogenic appendix and male florets. The front part of the spathe was cut open.
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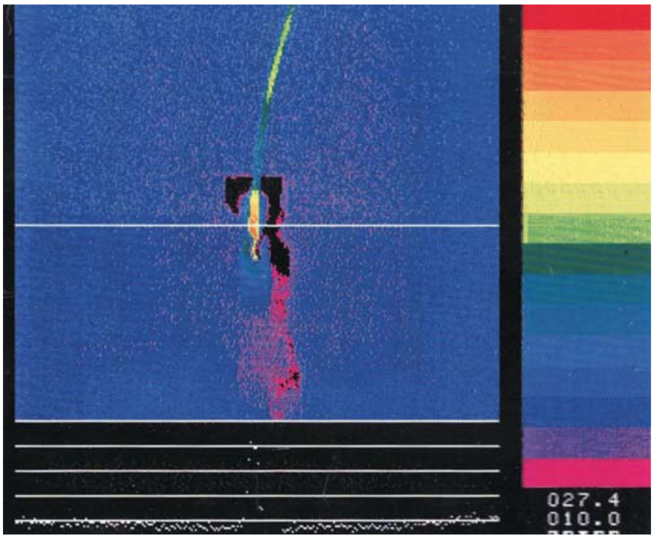

Figure 7
Thermographic image of a voodoo lily *Sauromatum guttatum* at 20 °C ambient temperature. From top to bottom: the appendix, the upper part of the male florets; below the floral chamber and the widely opened and downwards curled spathe are clearly seen. The curve in the black field below the image represents the indicated transect (temperature curve) through the male florets. Adapted from [21]

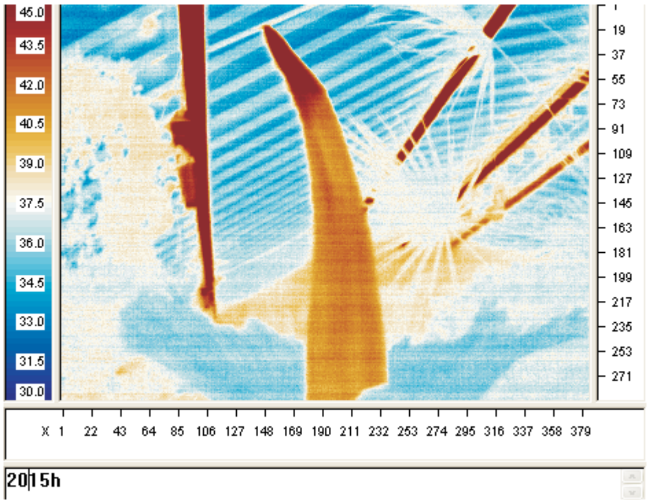

Figure 8
IR thermogram of the Titan arum *Amorphophallus titanum* at the time of maximum heat production. In the beginning of the thermogenic period the top of the appendix (about 60 cm from the blue rim of the spathe) heats to about 36 °C. Then the heat production dissipates slowly downwards to the whole appendix. It is at room temperature in the next morning.
The brown lines in the picture are hot water tubes at the ceiling of the greenhouse, the white structures leaves of other plants.The temperature at the left scale is not calibrated

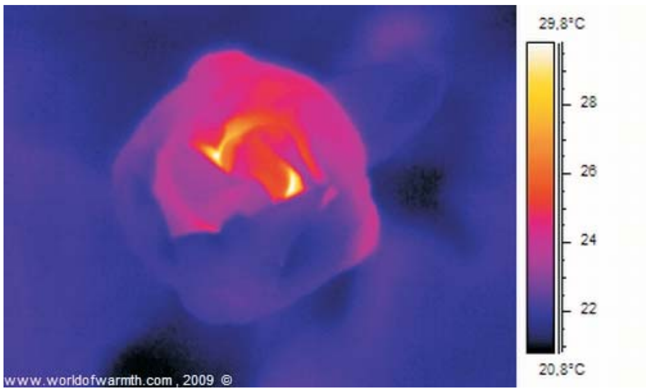

Figure 9
Blossom of the Sacred Lotus *Nelumbo nucifera* in the Zoological Garden of Rotterdam. The warmest visible parts are near to 30 °C, while the outer sepals are near to 23 °C. The receptacle inside the shielding leaves is considerably higher in temperature. With courtesy of A. Vlooswijk, worldofwarmth (2009).

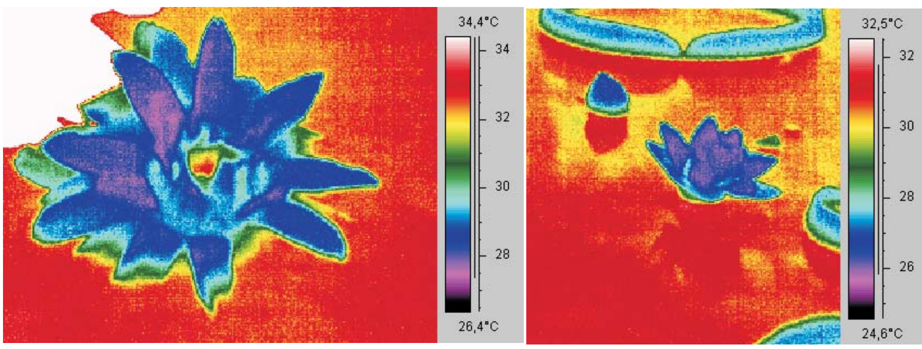

Figure 10
Thermographic images of a fully opened *V. cruziana* blossom (left) and a composition of a partly opened blossom, a bud left behind it, a leaf with rim and insections to release rainwater in the back centre and two smaller leaves in front. Please observe the warmer thermal reflections of the objects. The temperature in the blossom (left) shows 33.5 °C or 9.5 K against air, the upright leaves around 28 °C [27]. Reprinted from [27] with permission from Elsevier

face of the plants for non-transpiring (dry) leaves; wet leaves were sprayed with water. Investigations were run on sunlit and shaded parts of grapevine plants, in which the stomata were open (sunlit) or more or less closed. Here, thermal imaging showed its great advantage over IR thermometry as the latter gave one particular temperature point only at a time while thermography renders a manifold including even reference temperatures. Moreover, this is without any contact with the leaves as in gas - exchange measurements or porometry.

Part 2: Energy gain from the Sun

The objects in the second group also receive a temperature increase by a special "treatment": exposure to solar radiation. The increases vary considerably with the time of the day, the orientation towards the sun, the anatomical structures of the blossoms and their colours, just to name a few of the reasons [7,8]. Making thermographic investigations on a sunny late-summer day in the Botanical Garden of Berlin on more than 40 different plants at 21 °C ambient temperature gave the following results: The maximum and minimum temperatures of the blossoms amount in the mean to 29.4 ± 2.6 °C and 23.1 ± 2.4 °C, resp., their difference to 6.0 ± 2.2 °C.

The top values are found in the Chinese Lantern (*Physalis alkekengi*) with 37.5 °C and English Marigold (*Calendula officinalis*) with 33.3 °C; the lowest values of 18,0 °C for a sunflower (*Helianthus annuus*) and 19.2 °C for the Willow Leaf sunflower (*Helianthus salicifolius*); with a mean ÄT of 6.3 and 10.7 °C, respectively. The medians of the three values are 29.7, 23.0 and 5.7 °C, respectively, only slightly deviating from the means. It shows that the temperature of the flowers span independently of the maximum or minimum values.

It is well known that plants and especially flowers turn to the light or remain in a position where they can collect as much energy for photosynthesis as possible, or, just opposite in dry and hot areas to harvest the least energy possible to avoid overheating and water loss for evaporative cooling. To this latter group belong the so-called compass plants which orientate their flat leaves in a strictly vertical, mainly East-West orientation and additionally their midrib to the South. Thus their leaves collect much radiation in the early morning and the late afternoon and nearly nothing at noon. The Prickly Lettuce *Lactuca serriola* as an European Compass Plant was included in the present investigations showing leaf temperatures 2 to 3 °C lower than in the rest of the plant or of plants in their neighbourhood [7,8].

Constant temperature gradients exist also within the surface of the blossom. In a Garden Zinnia (*Zinnia elegans*) a temperature difference of 5.5 K was found along a line of only 0.6 cm (9.2 K cm^{-1}) between the centre and the petals or even 12.8 K cm^{-1} in their exposed cylindrically dark receptacle. Such differences are permanent there and induce high rates of flowing heat. A difference of even 8.2 °C is seen in a Dahlia in full sun giving the impression that the flower glows from the inside **(Figure 4)**.

The effect between full sun and complete shade was investigated in some flowers. Sometimes clouds, sometimes a cardboard served for shading for the possibility to determine the cooling or heating rates in the plant. For this end, a second value was read after one minute. At a gradient of nearly 10 K to the ambient there was a decrease of about 2.5 K in one minute. For both rates – cooling down from the maximum or heating up from the minimum value – the specific rates were about 0.3 to 0.4 K K^{-1} min^{-1} [7,8].

To expand the time of the research in late summer, spring plants were also monitored thermographically. The Far East Amur Adonis (*Adonis amurensis*) blooms approximately 10 cm above the snow. It orientates its blossoms more or less directly to the zenith, a position that brings optimal gain of energy when it is kept during the day and the blossom does not turn. The blossom heats up to about 10 K above ambient in days with about + 0 °C just above the snow. The same holds true for the stem of the plant and the brownish litter of last year's leaves at the bottom so that an empty surface is melted into the snow giving a plus of energy for the ground and the roots of the plant. At the same time, the bowl shaped form of the blossoms focuses the radiation to the sexual structures of the blossom and protects them and possible visitors against the wind [7,8].

Even more attractive is the white bloomed Mountain Aven (*Dryas octopetala*) in the early summer, a plant well known from Alpine mountains and the Arctic region. It is also bowl shaped but tracks the sun mainly during noon. Its blossoms show focus temperatures 3 to 4 K higher than the white, bowl forming petals and 15 K higher than the air temperature [9] (**Figure 5**). Similarly, arctic poppy blossoms (*Papaver radicatum*) track the sun in Polar Regions as long as it is above the horizon, that means 24 h in the extreme. The excess temperature reaches 7 K. It was observed that arctic mosquitoes rested in these blossoms although there was no nectar reward for this behaviour. In Dryas mosquitoes remained fivefold longer in the blossom than would be necessary to exhaust all nectar. This means that the increased temperature and not only the food reward were essential [9-14].

Perhaps the best-known solar tracker is the Sunflower *Helianthus annuus* which turns – as a young flower – with the sun to collect a maximum of energy from the sun, but attains a stationary position looking East/North East with age to avoid overheating of pollen and seeds. If one plots the inclination angle of the flat blossom against the horizon and additionally the position of the sun during the sun's transit as a function of daytime, one finds a perfect coincidence of the two curves with a time lag of about two hours [8]. Even more astonishing: during the night the blossom returns at first to an upright position and then bends down to meet the sun in the morning at the right place and with a nearly correct angle.

The advantage heliotropic blossoms may draw from this behaviour, especially in extreme alpine and arctic environments, is a quicker ripening of blossoms and pollen, longer visits of pollinators, special rewards for them in form of energy, elevated local temperatures and thus a stronger metabolism and an increased development of their ovaries [9,10,14].

Part 3: Thermogenic Plants

The third group of plants playing an important role in the energy spectrum discussed here is the thermogenic ones which heat up their flowers or inflorescences (blossoms comprising many small male and female florets), produce odors which range from pungent and nauseating to pleasant like fruit salads to attract pollinators, and have a store of rewards for them. Pollinators may be insects, especially beetles, birds and bats. The plants span a range from a few centimetres up to the largest inflorescence known in the world, the Titan Arum Lily *Amorphophallus titanum* with up to 3 m height and more than 2 m diameter.

The temperature differences of the hot plant parts against ambient may be astonishingly high with 30 K for *Philodendron selloum* thermoregulating its temperature between 37 and 44 °C [15] or even 35 K for the Eastern Skunk Cabbage *Symplocarpus foetidus* regulating its spadix temperature between 22.7 and 26.2 °C, when the ambient temperature drops down to –10 °C [16]. But sometimes, the temperature differences in thermogenic plants are so small that they cannot be detected as temperature increases because of larger cooling rates due to evaporation. In these cases one has to perform indirect calorimetry to find an increased gas metabolism and know that thermogenesis is proceeding.

Arum concinnatum, a Mediterranean form of Arum, was intensively studied in Cretian olive groves by R.S. Seymour from Adelaide. It looks similar to the popular European *A. maculatum* and *A. italicum* with a large attractive spathe, a long extended appendix and in the floral chamber from top to bottom spines to block the escape of pollinators, then male and finally female florets. At 19:00 the appendix was at 26.5, the weaker thermogenic male florets at 23 and the spathe at 18.2 °C (**Figure 6**). At 10:00 next morning the appendix is no longer metabolically active while the male florets show a further episode of up to 10 K difference [17-19].

About 30 different plants of the Aroid group were investigated for their maximum temperatures as a function of the active volume [20]. By "active volume" is meant that cylinder which carries the male florets as the main source of heat production. The volume ranges from 0.62 to 53.38 cm^3, the male zone length from 1.8 to 17 cm and the temperature difference from 1.2 to 15.1 °C. A mathematical model of heat conduction between the isolated cylinders and the environment gave good results assuming a conductive heat transfer alone or a convective plus radiative heat loss. For these calculations a mean heat production of 29.5 mW g^{-1} was assumed [20]. The temperature differences show that further interesting effects can be studied here with IR thermography.

An easy to breed thermogenic aroid plant is the voodoo lily *Sauromatum guttatum* sold in Europe by Dutch gardeners in hundreds of pieces. They come as corms of 100 to 300 g, are stored at 6 °C until a suitable time and grow at room temperatures without soil and water in a fortnight to the flowering state. The shoot develops to a height of 50 to 70 cm and the weight of the corm decreases by a few percent due to starch metabolism and water loss. The floral chamber in the lower part of the spadix contains from the bottom to the top: the female florets, the club-shaped organs and the male florets. On the day of flowering the beautifully designed spathe opens and folds back, exposing the red-brown appendix as the upper part of the spadix and the upper rim of the male florets. At this time the female florets are receptive and the truly horrible smell is released to attract pollinators. Simultaneously, the appendix temperature rises 5 to 10 K above ambient, which might be easily detected by touching. The difference against the spathe is even higher (> 10 K) due to its evaporative cooling. The maximum is seen by thermography directly at the upper rim of the male florets, a second weaker one along 10 cm up the appendix (**Figure 7**). This heat production starts before sun-rise and ends at noon. This "metabolic explosion" is accompanied by a corresponding weight loss of 30 % within a short time [21,22].

While members of the Arum family can be investigated by the dozen, there are rare possibilities for thermologic experiments with some other plants. One of these plants is the Titan arum *Amorphophallus titanum*, which only blossoms at a special age and then only every several years. In the years between, the corm develops leaves. It is the biggest inflorescence of the World with heights up to 3 m and diameters at about 2.50 m. It flowered for the first time in the Berlin Botanical Garden in April 2009 for three days only. Unfolding its spathe in the early afternoon, it exposed its huge appendix early in the evening.

Simultaneously, its metabolism rose rapidly and reached its maximum at 20:15 (**Figure 8**). From then it declined slowly during the night until morning. The appendix remained neutral the next day and started to bend down the third day. Through the thermal episode the plant temperature was followed by a fixed infrared camera with pictures every 15 min. The obtained temperature scale of the camera had to be corrected by the equation $T_{object} = 1.29\ T_{camera} – 22.30$. Maximum temperatures were thus around 36 °C, and the greenhouse temperature at night 24 °C (I. Lamprecht, R.S. Seymour, in preparation)

Although many thermogenic plants are highly attractive in their appearance, two of the most beautiful thermogenic plants will be discussed at the end of this part: the giant water lily *Victoria cruziana* and the Sacred Lotus *Nelumbo nucifera*, both imported to our greenhouses from the tropics. Their flowers are large and interesting and their fragrance even for the human nose pleasant or at least tolerable. In the case of *Victoria* this smell is a mixture between tropical fruit salad and pine-apple. For lotus it is foul smelling [23] and "benzene-like, heavy, sweetish, medicinal" [24].

The experiments on the Sacred Lotus *Nelumbo nucifera* occurred in a large outdoor pond in the Botanic Gardens at

Adelaide, Australia. They were mainly aimed at the thermogenic and especially at the thermoregulating metabolism of the Lotus plants and used thermal sensors and respirometry as well as direct calorimetry. The principal idea was to invert a commercial double-walled wine cooler over the flower and thermostat it externally. This method was used with other plants also and is well documented in the literature (for instance in [15,16,25,26]). Air was sucked along the flower and determined by a paramagnetic oxygen analyser. In a similar way, direct calorimetry was performed on the whole blossom *in situ*. In this way, rather complex information was gathered about metabolism and temperature and clearly showed circadian structures and the phenomenon of thermoregulation during the night.

The Sacred Lotus has a 2 to 4 day thermoregulating period that keeps the blossom temperature between 30 and 36 °C, even if the ambient values drop to 10 °C or increases well above 40 °C (**Figure 9)**. The oxygen consumption during the night rises up to fivefold and returns to normal values with daylight. Higher temperatures at noon are reduced by evaporative cooling, just as we do by sweating. The adaptation is not straight forward but sluggish so that undershoots and overshoots in temperature occur [26].

Victoria cruziana (and also *V. amazonica*) is better known for its gargantuan leaves with a diameter of up to 2 m than for its beautiful flowers as they start to open in the evening and develop their charm at midnight. Originally, *Victoria* grows in the Amazon and its affluents in calm waters, ox-bow lakes or flooded green lands. *V. cruziana* prefers cooler water in Argentina and Paraguay. Both *Victoria* plants have been cultivated around the world for more than 150 years, outside or otherwise inside of greenhouses in botanical gardens. In contrast to *A. titanum* they shift leaves and blossoms alternating for many months. The present investigations were carried out in the Botanical Garden of Berlin in a greenhouse pond of 30 °C, a humidity always near to 100 % (so that evaporative effects might be neglected) and normal light regime. All IR and usual thermometry were performed directly in or at the edge of the pond [27].

The *Victoria* bud increases its metabolism in the morning and comes to the "metabolic explosion" in the afternoon. It widely opens its beautiful flowers in the following night and attracts beetles to pollinate the fertile female florets in the floral chamber. In the early next morning, the tunnel to the floral chamber closes and imprisons the beetles until the following afternoon. The temperature shows a second maximum, the tunnel opens and releases the pollinators. They pass by the male structures along their way out and strip off the shed pollen. Infrared thermograms of the blossom and the huge leaves were taken in the evening with a hand-held AGEMA 570 Pro camera. They showed 33.5 °C in the upper tunnel entrance, 30.9 °C on the upper paracarpels and the inner stamens surrounded by a circle of outer stamens between 27 and 29.5 °C (**Figure 10**). Air temperature was 24.0 °C all the time, water temperature around 30 °C and the distance between flower and water surface between 5 and 10 cm. The maximum temperature difference inside the floral chamber was 11 K against ambient air [27].

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Investigation of a method of Thermal Imaging with the potential to assist in the diagnosis of Carpal Tunnel Syndrome

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SUMMARY

BACKGROUND AND AIMS.: It has been suggested that thermal imaging may provide alternative appropriate diagnostic information for Carpal Tunnel Syndrome (CTS). The aims of this study are to investigate the optimum method of data collection from thermal images of subjects with CTS, establish base line thermographic reference data in subjects with CTS, measure the effect of a thermal washout on these patients and compare pre/post surgery baseline thermographic data to assess the effects of surgery.

METHODS: Patients who had a diagnosis of CTS and were waiting for decompression surgery were recruited. The study involved two data collection sessions, the first immediately before decompression surgery, the second 6 weeks after the operation. A baseline image was taken, cooling using a Cryo/Cuff took place, following removal of the Cryo/Cuff temperature data were sampled during rewarming. Data from pre and post operative images were extracted by mapping three areas defined on screen by using thermally inert markers.

RESULTS: The most clinically significant results were seen in the temperature change in the distal portion of the 2nd and 5th digits of the symptomatic hand. The same difference was not seen in the proximal portion of the same digits or in the asymptomatic hand. The greatest increase in post operative temperature of the distal portion of the digits occurred in the 2nd digit which is supplied by the median nerve compared to the smaller increase in temperature in the 5th digit which is supplied by the ulnar nerve.

DISCUSSION: Considering the underlying pathology where the median nerve is primarily affected in CTS this could have significant diagnostic implications. There would appear to be clinical implications in these findings with potential for this method to be developed further as a diagnostic thermal imaging test which would be better tolerated and more readily available than nerve conduction studies thus reducing waiting times for diagnostic testing to confirm CTS.

KEY WORDS: Carpal Tunnel Syndrome, Thermal imaging, Anatomical markers, Thermal washout, Surgical decompression

INFRAROTTHERMOGRAPHIE VOR UND NACH WÄRMENTZUG KANN MÖGLICHERWEISE DIE DIAGNOSE "KARPALTUNNELSYNDROM" UNTERSTÜTZEN

HINTERGRUND UND ZIEL: Es wurde diskutiert, dass die Infrarotthermographie möglicher Weise alternativ diagnostische Informationen beim Vorliegen eines Karpaltunnelsdyndroms (KTS) liefern kann. Das Ziel dieser Untersuchung war es die optimale Methode der Datenerfassung von Patienten mit Karpaltunnelsyndrom zu finden, eine Datenbank mit Referenz-Wärmebildern von Personen mit KTS aufzubauen, den Effekt eines kurzen Wärmeemtszugs im Sinne eines thermischen "Auswaschens" bei diesen Personen zu untersuchen und durch Vergleich der Wärmebilder vor und nach chirurgischer Therapie die Wirkung der Operation zu beurteilen.

METHODE: Patienten, welche die Diagnose KTS erhalten hatten und auf die Dekompressionsoperation warteten, wurden in die Untersuchung aufgenommen. Die Studie führte zwei Datenerfassungssitzungen durch, die Erste unmittelbar vor der Entlastungsoperation und die Zweite 6 Wochen nach der Operation. Nachdem ein Ausgangsthermogramm aufgezeichnet worden war, wurde mittels eines Cryo/Cuff der betroffenen Hand Wärme entzogen und während der Wiedererwärmung wurden neuerlich Temperaturdaten erfasst. Die Daten von drei mittels thermisch inerten Markern definerten Messarealen wurden aus den Wärmebildern vor und nach der Operation extrahiert.

ERGEBNISSE: Die Temperaturänderungen an den distalen Abschnitten des 2 und 5 Fingers der symptomatischen Hand wurden klinische relevante Ergebnisse gefunden. Kein derartiger Temperaturunterschied wurden an den proximalen Anteilen der untersuchen Finger oder an der asymptomatischen Hand gesehen. Postoperativ fand sich am Zeigefinger, der vom N.medianus versorgt ist, die deutlichste Zunahme der Hautetmperatur, während im vom N.ulnaris innervierten Kleinfinger die geringste Temperatursteigerung beobachtet wurde.

DISCUSSION: Da der N.medianus die betroffenen nervale Struktur beim KTS darstelle, könntem die Ergebnisse relevante Auswirkungen für die diagnostische Abklärung des KTS besitzen. Die Weiterentwicklung der vorgestellten Methode könnte eine diagnostischer Thermographietest sein, der vom Patienten besser toleriert wird, rascher zur Verfügung steht und so die Wartezeiten für eine elektrophysiologische Abklärung zur Bestätigung eines KTS veringern könnte.

SCHLÜSSELWÖRTER: Karpaltunnelsyndrom, Thermographie, anatomische Marker, Wärmeentzug, chirurgische Dekompression

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Introduction

Carpal Tunnel Syndrome (CTS) is a common and debilitating condition which although non life threatening can seriously restrict participation in activities of daily living, and impact negatively on quality of life. CTS is the most common entrapment neuropathy in humans and is often associated with repetitive low loading activities such as typing. Electrophysiologically confirmed cases would suggest an annual UK incidence of 120 per 100,000 in females and 60 per 100,000 in males [1]. It occurs at the wrist when the Median nerve becomes compressed as it passes through the Carpal Tunnel. Diagnosis is usually made by history, clinical examination and nerve conduction studies. Nerve conduction studies involve activating peripheral nerves electrically over several points and measuring the responses obtained [2]. Although long term side effects have not been reported nerve conduction studies are uncomfortable, are a specialist procedure and therefore have traditionally had along waiting time.However recent changes in the NHS particularly the 18 week rule have dramatically improved waiting times

It has been suggested that thermal imaging may provide alternative appropriate diagnostic information for this condition[3,4]. The advantage of this method is that the information is obtained without any invasive procedures. One of the early papers on the use of thermography in CTS was very positive in its findings. Herrick & Herrick. [5] demonstrated that in 55 CTS patients decreased vascular heat emission occurred over the Median nerve distribution in the hand and that the thermograms demonstrated 97% specificity and 100% sensitivity for detecting CTS. Despite these very positive findings a number of other papers at the time found equivocal results and were less enthusiastic about the use of thermography in diagnosing CTS.

So, Olney, Aminoff [6] demonstrated in their study of 22 CTS patients that 12 (55%) had abnormal thermograms. They reported that the thenar-hypothenar temperature gradient was altered in some patients with CTS, usually in the direction of a relative warming of the median innervated digits. They pointed out that this could be caused by a relative warming of the median innervated digits or by cooling of the little finger and in most cases it was impossible to tell which was responsible. They also found that the sensitivity of thermography was similar between patients with unilateral and bilateral problems and concluded that thermography was not helpful for diagnosing CTS. Similarly Reilly et al [7] who studied 23 patients with CTS found that there was no clear diagnostic pattern in CTS and concluded that nerve conduction studies should remain the cornerstone of diagnosis in CTS.

In contrast to these studies Tchou et al [8] who studied 61 patients with unilateral CTS and 40 healthy control subjects found that 57/61 CTS patients demonstrated abnormal thermogams and only 1 healthy control subject demonstrated an abnormality. In this paper an abnormality was defined as a temperature increase of >1degree Celcius. This study supported the usefulness of thermography in unilateral CTS but found that its usefulness was limited in bilateral cases because the interpretation of test results is dependant on differences between affected and un-affected sides. Giordano et al [9] reported on 40 CTS patients (45 hands studied as some were bilateral) and 30 healthy control subjects who all showed normal thermal patterns. In the CTS patients there was a decreased temperature over the thenar eminence in 43/45 hands. They concluded that thermography could be considered as an additional source of data in CTS but may not replace other instrumental procedures. Ammer [3] and more recently Ming [4] investigated infrared thermography proposing that it can confirm the presence of CTS. Ammer [3] proposed that a temperature difference greater than 1 degree Celsius was considered an indicator of nerve entrapment.

This study will investigate temperature measurements recorded from an infrared thermal imaging camera from the hands of patients with carpal tunnel syndrome (CTS) who are referred for carpal tunnel decompression surgery.

The aims of this study are as follows:

1. To investigate the optimum method of data collection from thermal images of subjects with Carpal Tunnel Syndrome

2. Establish base line thermographic reference data in subjects with Carpal Tunnel Syndrome (CTS) and measure the effect of a thermal washout on these patients.

3. Compare pre/post surgery baseline thermographic data to assess the effects of surgery.

Method

Setting

National Health Service (NHS) Orthopaedic Outpatients Clinic and Day Care Unit: Lancashire Teaching Hospitals NHS Foundation Trust

Participants

Patients who had a diagnosis of carpal tunnel syndrome and who were on the waiting list for decompression surgery were recruited. The pathway for patients recruited to the study is outlined in Figure 1. The eligibility criteria for entry to the study are outlined below.

Inclusion Criteria

- Patients waiting for surgical carpal tunnel decompression

Exclusion Criteria

- Cold intolerance/ hypersensitivity
- Vascular disease including, Raynaud's disease, Buerger's disease, Cryoglobinaemia, Peripheral vascular disease
- Previous surgery of the upper limb, cervical spine or for CTS on the side of planned surgery
- Pregnancy
- Abnormal illness behaviour

These exclusion criteria ensured that no participants were knowingly at risk from the cold stimulus and that the problem they presented with was of a benign origin. [10,11,12]. (See Table 1)

Definition of Region of Interest

Ten small thermally inert markers were placed on anatomical landmarks in order to define the region of interest (ROI) for later analyses based on Ammer & Melnizky [13] and Selfe et al [14]. These were located as follows

- Scaphoid & Pisiform
- 2 & 5 metacarpal heads
- Lateral and medial distal interphalangeal joint lines of the 2 & 5 digits
- Tip 2 & 5 digits

Thermal Washout procedure

Prior to the baseline temperature measurement of the wrist and hands being taken the exposed limbs were allowed to equilibrate to the room temperature of a mean 22.7°C (20.2-23.3C) away from localised sources of heat, sunlight or draughts, for 15 minutes [10,11,12]. The baseline temperature measurement was then taken with the Thermo Vision A40M thermal imaging camera (Flir Systems, Danderyd, Sweden). Immediately, following the baseline temperature reading the Hand and Wrist Cryo/Cuff (Aircast, Summit NJ, USA) was applied bilaterally for 3 minutes. For standardisation the Cryo/Cuff filled with cold water and ice was elevated to 40cm above the hand as it is reported that this produces 30mm Hg of compression [15] see figure 2. More aggressive procedures for cooling such as the use of crushed ice or ice water immersion in order to induce differences in cold response between groups are available. However, as these patients had confirmed diagnoses and their problems were severe enough to warrant surgery we did not consider that such procedures could be justified ethically. The procedures used were developed through pilot study testing and did induce a measurable response to cold.

Figure 1
Study pathway

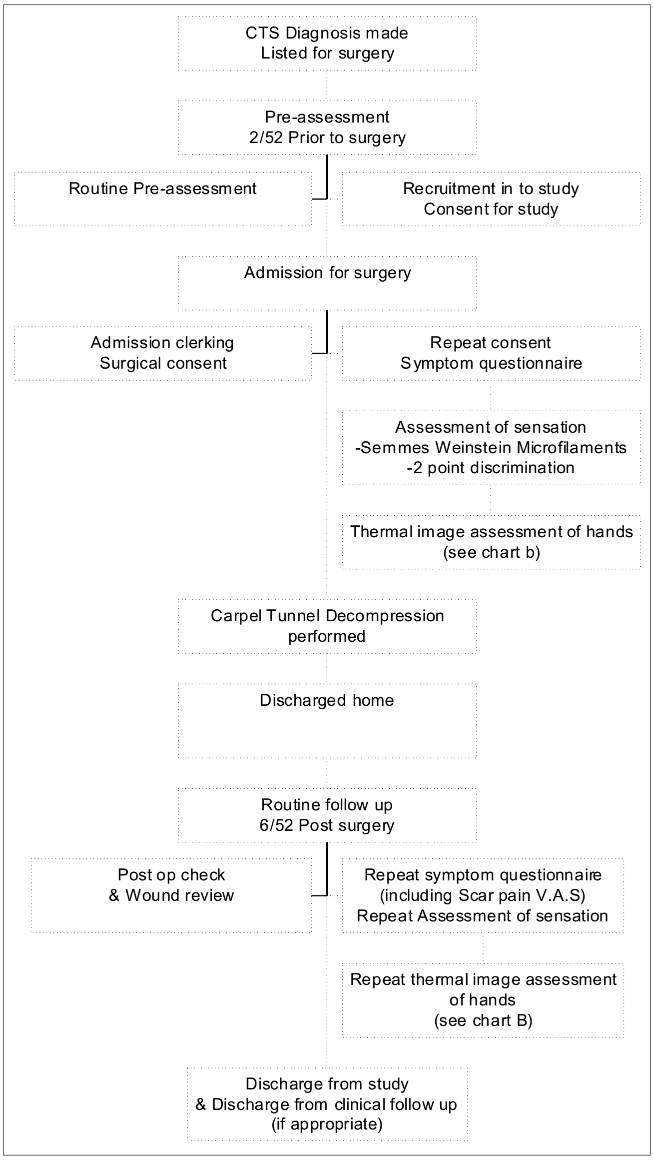


Figure 2
Patient positioned with Cryo cuff in place.

Thermographic measurements were taken with subjects in a stable relaxed sitting position with forearms supinated on a table adjusted to a comfortable height in front of the patient. The thermal camera was focused on the palms of the hands and aligned parallel with the skin. Once the subject and camera were positioned in the correct experimental setup the first temperature measurement was taken, this was used as the baseline. Following removal of the Cryo/Cuff temperature data were sampled at a rate of 1 image per minute for 20 minutes.

Participant preparation

Patients who had been admitted to the study underwent routine pre-surgery assessment and consent for their surgery at the initial out patient appointment. Following this and whilst waiting for their surgery some of them underwent nerve conduction studies. Patients were requested not to have any alcoholic drinks, drinks with a high caffeine content (coffee, Coke), smoke or take part in vigorous exercise before their appointment. [10,11,12]. Each patient completed a questionnaire whilst they were waiting which covered past medical history relevant to the study and a symptoms questionnaire [16]. Any jewellery worn on the hands was removed where possible. On the day of surgery a verbal repeat of the patients consent was obtained and a full explanation of the study given in order to ensure continued co-operation and address any questions that the patient had.

Data Collection

The study involved two data collection sessions. The first was carried out on the day case surgical unit on the day of and prior to the decompression surgery. The procedure outlined in Figure 4 was adhered to for each patient. Prior to each imaging sequence the ambient room temperature was noted. Patients were encouraged to remain as still as possible during the procedure in order to minimise patient movement and so improve accuracy of data collection. Patients were then returned to the waiting area to await their surgery.

The second data collection session took place at 6 weeks after the operation in the Outpatient Department when the patient attended for the routine post operation follow up consultation. At this time they were initially seen by the clinical team to assess their recovery from surgery. They repeated their symptom questionnaire and completed a scar pain questionnaire. Finally the markers were reapplied, a baseline image was recorded, the Cryo/cuff was applied for three minutes and the thermal imaging sequence of both hands was repeated as described previously. This completed each patient's involvement in the study. All data were recorded on a laptop computer for later analysis.

Data Analysis

Data from the pre and post operative images were extracted by mapping three areas which were defined on screen by using the thermally inert markers

- the palm,
- the distal portion of the 2 digit
- the distal portion of the 5 digit

A rectangle was mapped between the markers over the scaphoid, pisiform, 2^{nd} & 5^{th} metacarpal heads to obtain data which was used to calculate a mean temperature for the palm on each image.

A triangular area was mapped between the markers over the lateral and medial borders of the distal inter-phalangeal joint lines of the 2^{nd} digit and the tip of the 2nd digit to obtain data which was used to calculate a mean temperature for the distal portion of the 2^{nd} digit on each image.

A triangular area was mapped between the markers over the lateral and medial borders of the distal inter-phalangeal joint lines of the 5^{th} digit and the tip of the 5^{th} digit to obtain data which was used to calculate a mean temperature for the distal portion of the 5^{th} digit on each image. See figure 3

Data were then used to plot graphs of temperature changes pre and post surgery of each designated area. Data from incomplete studies were excluded from the final results.

Figure 3
Demonstration of thermal image with areas between markers defined for data collection.

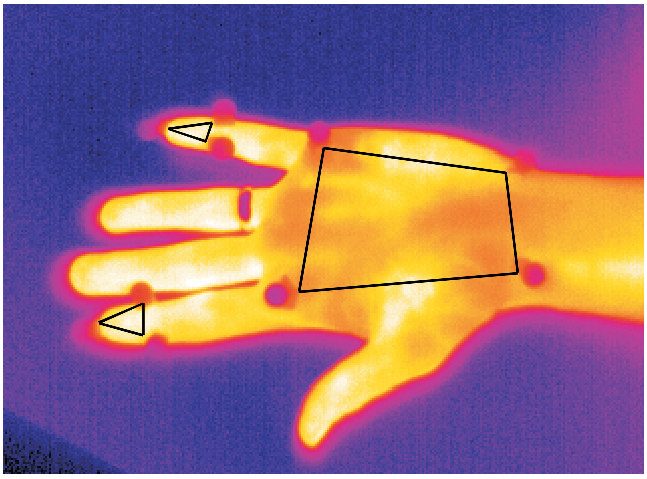


Figure 4
Thermal imaging

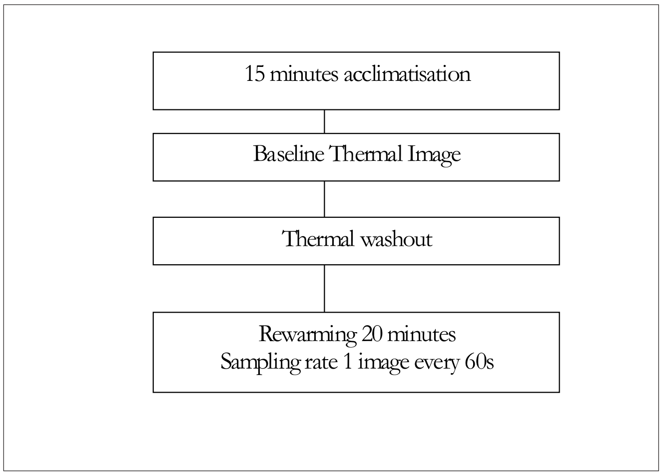


Table 1
Biographical data

Number of patients	Number of males	Number of females	Age range	Mean age	Number with bilateral symptoms?	Number with previous decompression surgery of contralateral hand?	Number that completed study?
17	6	8	34-81yrs	54.7yrs	7	7	14

Reason for drop out – 2 did not attend follow up appointments, 1 was unable to tolerate thermal washout procedure.

Results

On analysis of the baseline temperature measurements we found no difference between the areas of the hand innervated by the median nerve and that innervated by the ulnar nerve. This applied to both the measurements taken pre operatively and those taken at 6 weeks post operatively. Mean values recorded for distal finger temperature only varied between 32.2°C and 32.6°C.

Comparison of the rate of re-warming following thermal washout was also assessed. As expected from the work by Ammer & Melnizky [13] it was found that following decompression of the median nerve that the finger tips re-warmed quicker (graph 1). These findings were most marked in the 2nd distal finger (median nerve), over the first four minutes of re-warming the post operative temperature was approximately 2°C higher than in the pre operative hand (actual values of 1.7-2.3°C).

Similar changes were seen in the 5th distal finger (ulnar nerve) but to a lesser extent with the post operative hand (graph 2).

These temperature changes are clinically significant, previous work by Ammer [3] has shown a 1°C change in temperature diagnostic of nerve injury. However there was not found to be a statistically significant temperature change between the pre and post operative measurements.

Symptom severity and function were both assessed using the self administered questionnaire devised by Levine et al.[16] both symptom severity and function are given a score out of 5, with 5 being the worst score and 1 being the best. Both scores were better following surgery, with symptom severity improving from 3.1 to 1.8 and functional status improving from 2.5 to 1.7. (table 2)

Sensation and power were also measured at the pre and post operative assessments. Sensation was assessed using Semmes-Weinstein monofilaments and the smallest monofilament detectable by the patient was recorded. Measurements were taken at the index finger tip (median nerve), little finger tip (ulnar nerve) and the dorsal 1st webspace (radial nerve). Power was assessed using a dynamometer to assess grip strength and the best value of 3 attempts was

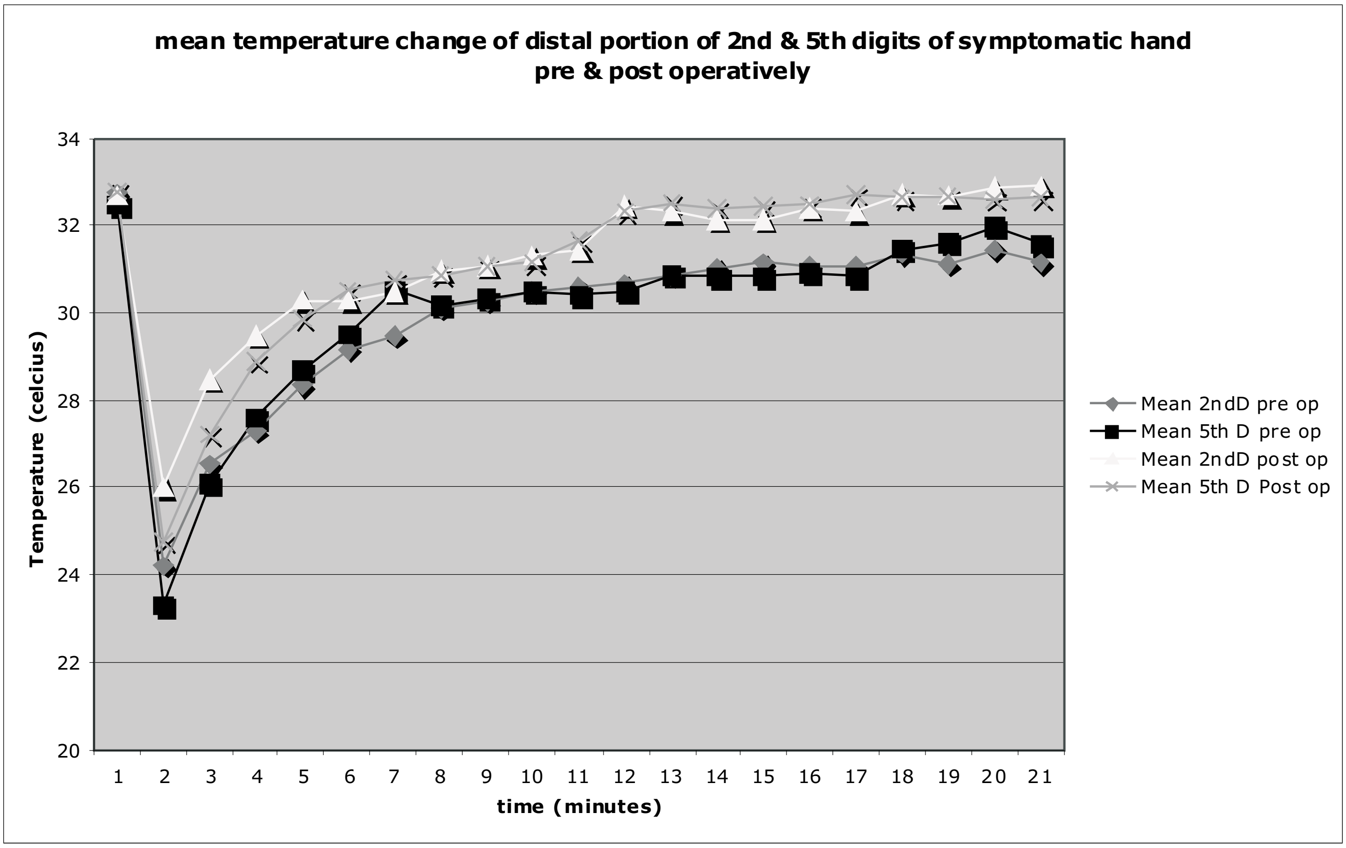


Table 2
Symptom severity and functional status

	Pre operative values	Post operative values	P value
Symptom severity score	3.1	1.8	0.0002*
Functional status	2.5	1.7	0.0096*

*paired T test

recorded. Both sensation and power were found to have improved slightly at the post operative assessment, but the results were not statistically significant.

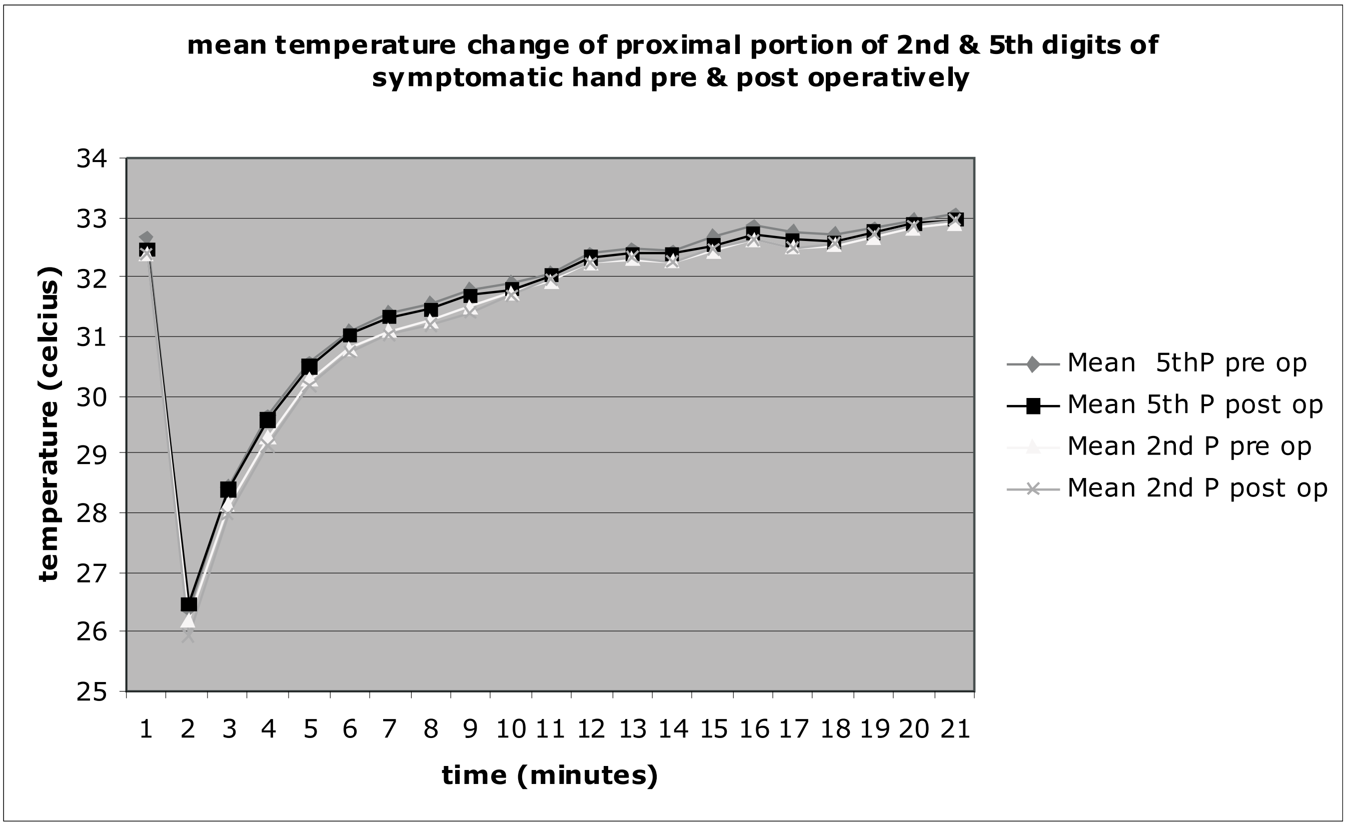
Discussion

The main finding of our study is the increased rate of re-warming observed in the hand following decompression of the median nerve. This pattern was observed most strongly in the region of the hand innervated by the median nerve, but also occurred in the area innervated by the ulna nerve. We suspect that the cause of this improved re-warming is the restoration of median nerve function in particular the sensory pathways following surgical decompression.

Although the pathology of carpal tunnel syndrome is secondary to compression of the median nerve, we have also observed temperature changes in the ulnar nerve innervation region. We think the reason that the improved re-warming occurs throughout the hand is secondary to the blood flow. Unlike sensation, the blood flow is not limited to the areas innervated by the median nerve. Therefore any increase in blood supply to rewarm the median nerve innervation will rewarm the whole hand.

Previous authors [3,4,5,6,7,8,9,13] have looked at the use of thermography to diagnose carpal tunnel syndrome with mixed results. Our study does not show any role for thermography alone, as there were no identifiable changes in baseline temperature. However thermography used to assess re-warming of the hand following thermal washout did identify differences in the rate of hand re-warming before and after nerve decompression. We feel that this is a potential clinical application for thermography and warrants further investigation. Although thermal imaging as performed in this study requires specialist equipment and skills, it could if needed be simplified to allow it to be performed by a health care worker in an out patient environment.

From a practical perspective collection of data was difficult due to the movement of the digits during imaging. Immobilisation of the patient in relation to length of examination, 20 minutes re-warming, proved to be a problem. Curling of fingers was observed over time as patients relaxed during imaging. This resulted in the area between the markers and therefore available for imaging varying and although patients were encouraged to stay as still as possible this would inevitably have had an effect on the accuracy of



data collected due to the surface area imaged being altered by this movement. The use of some form of restraint e.g. strapping digits to the table top with adhesive tape was considered but this was dismissed as likely to restrict blood flow to the area under investigation and therefore be equally likely to compromise accuracy of data collected. The use of a pillow beneath the forearms and hands to improve comfort and therefore improve immobilisation was also considered but again was dismissed as it could potentially raise skin temperature by warming the dorsal aspect of the hands and forearms.

These results of this study confirm the findings of So, Olney and Aminoff [4] in that it was difficult to determine whether the observed temperature differences were due to warming post operatively or cooling pre operatively. Although this finding is important the neuro-physiological explanation for this lies outside the remit of this paper, however, future researchers should be aware of this issue. This is an area which requires further research once a method of controlling for temperature differences between the median and ulnar innervated digits is devised.

The asymptomatic wrist was imaged as a control but several patients had undergone previous surgery whilst others had simultaneous bilateral symptoms to a lesser degree in the contralateral wrist. The presence of bilateral pathology should be considered carefully when designing future studies of this type.

Conclusion

There would appear to be potential clinical implications in these findings. Like Tchou et al [8] this study appears to support the usefulness of thermography in unilateral CTS but confirms that bilateral cases are an important confounding factor. It would appear that with further research using a healthy control group of a similar age range these findings could be supported and further knowledge acquired with the purpose of establishing a normal temperature range of the distal portion of the digits using this method. There is potential for this method to be developed further as a diagnostic thermal imaging test which would be better tolerated than nerve conduction studies and would be more readily available thus reducing waiting times for diagnostic testing to confirm CTS.

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Sensitivity, Specificity and Predictive Value of Infrared Cold Water Autonomic Functional Stress Testing As Compared with Modified IASP Criteria for CRPS

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SUMMARY

BACKGROUND: Complex Regional Pain Syndrome is a potentially disabling condition characterized by regional pain that is often disproportionate to, or occurs in the absence of, an identifiable inciting event. The condition is associated with hyperalgesia, allodynia, spontaneous pain, abnormal sudo- and vasomotor activity, passive movement disorders and trophic changes of nails and hair.

Complex Regional Pain Syndrome is characteristically diagnosed using modified International Association for the Study of Pain (IASP) criteria. The diagnosis is complicated by neuropathic and somatic conditions that often mimic this syndrome. Validation studies (internal and external) of the IASP criteria for CRPS are problematic. Such difficulties in diagnosis can result in insufficient or excessive treatments that 1) may be inappropriate given the current understanding of the pathophysiology, 2) incur significant burden to patients, and 3) impact the nature and economics of healthcare provision. In light of this, we posit that the use of cold water immersion autonomic stress testing, as part of a functional infrared thermographic (fIR) methodology, may improve extant diagnostic capability and reduce inherent problems and burdens.

STUDY DESIGN: Retrospective file review.

SETTING: Colorado Infrared Imaging Center, Denver, Colorado

OBJECTIVE: To determine sensitivity, specificity, positive and negative predictive values, receiver operating characteristic analysis and Cohen's kappa index of concordance for cold water autonomic functional stress testing utilizing real time dynamic subtraction IR imaging medical software. The cold water autonomic functional stress test index was compared with modified IASP research criteria for evaluation of CRPS.

PARTICIPANTS: One hundred forty-three (n=143) consecutive patients referred to Colorado Infrared Imaging Center for evaluation of presumptive CRPS/RSD utilizing *functional* infrared imaging (*f*)IR that included cold water autonomic functional stress testing as part of the IR battery of tests performed during (*f*)IR imaging.

METHODS: Prior to (*f*)IR imaging each patient underwent a physical examination with particular attention paid to signs and symptoms of CRPS utilizing the modified IASP criteria. Following physical examination, (*f*)IR imaging was performed, which included, cold water autonomic functional stress testing as part of the IR test battery.

RESULTS: Sensitivity, specificity and predictive values for cold water autonomic functional stress testing in evaluating patients with CRPS was 72% sensitivity, 94% specificity, positive predictive value 82% and negative predictive value 90%. The Kappa statistical analysis (kappa index of concordance) was 0.69 (95% confidence interval: 0.55 and 0.83).

CONCLUSIONS: This study showed that cold water autonomic functional stress testing, utilizing real time dynamic subtraction imaging medical software, may be a valuable and objective infrared thermographic index that can be employed with modified IASP criteria for evaluating patients with presumptive CRPS,

KEY WORDS: Thermography, IR imaging, cold water stress testing, functional infrared imaging, autonomic stress testing, CRPS

SENSITIVITÄT, SPEZIFITÄT UND VORAUSSAGEWERT DER INFRAROTBILDER NACH KALTWASSERTESTS ALS FUNKTIONELLE UNTERSUCHUNG DES AUTONOMEN NERVENSYSTEMS FÜR DIE MODIFIZIERTEN IASP DIAGNOSEKRITERIEN DES CRPS

HINTERGRUND: Das komplexer regionale Schmerz-Syndrom (CRPS) stellt einen potentiell behindernden Zustand dar, der durch lokalen Schmerz gekennzeichnet ist, der unverhältnismäßig zum auslösenden Ereignis ist bzw. dessen auslösendes Ereignis bisweilen nicht gefunden werden kann. Das CRPS ist durch Spontanschmerz, Hyperalgesie, Allodynie, abnormale sudo- and vasomotorische Aktivtät, Bewegungstörungen und trophische Veränderungen von Nägeln und Haaren gekennzeichnet

Die Diagnose des CRPS wird typischer Weise mittels den modifizierten Kriterien der International Association for the Study of Pain (IASP) gestellt. Die Diagnose kann schwierig sein, wenn neuropathische und andere somatischen Erkrankungen vorliegen, die ein CRPS imitieren können. Interne und externe Validierungen der IASP Kriteren sind problematisch. Schwierigkeiten in der Diagnosestellung können therapeutische Über- oder Unterversorgung der Patienten bedingen, die 1) unangebracht im Lichte des derzeitigen pathophysiologischen Verständnis der Erkrankung erscheinen, 2) eine beträchtliche Belastung der Patienten darstellen und 3) Einfluss auf die Art und die Ökonomie des

Gesundheitssystems haben. Angesichts dieser Umstände sind wir der Meinung, dass die Verwendung des Kaltwassertests als funktionelle Untersuchung des autonomen Nervensystems im Rahmen einer Funktions- Infrarot-Thermographie (fIT) methodology, die vorhandenen diagnostischen Möglichkeiten verbessern und die inhärenten Probleme und Belastungen reduzieren kann.

STUDY DESIGN: Retrospektive Befundauswertung

SETTING: Colorado Infrared Imaging Center, Denver, Colorado.

ZWECK DER STUDIE: war die Bestimmung der Sensitivität, Spezifität, des positiven und negativen Voraussagewertes, einer Receiver-Operating- Characteristic Analyse und des Cohen's Kappa Index der Übereinstimmung des Kaltwasser-Funktionstests (unter Nutzung einer Echtzeit-Substraktions-Software für Infrarotbilder) für die modifizierten IASP Forschungkritereien zur Evaluierung der Diagnose CRPS.

STUDIEN-TEILNEHMER: Einhunderdreiundvierzig (n=143)aufeinanderfolgende Patienten, die an das Colorado Infrared Imaging Center zur Überprüfung eines vermuteten CRPS/RSD zugewiesen worden waren, nützten eine Funktions-Infrarot-Thermographie (fIT), die einen Kaltwasser-Funktionstest als Teil der Infrarot-Thermographie-Untersuchung beinhaltete.

METHODE:Vor der fIT wurde jeder Patient klinisch untersucht, wobei besonders Augenmerk auf Symptome und körperliche Befunde des CRPS unter Berücksichtigung der modifizierten IASP Kriterien gelegt wurde. Nach der körperlichen Untersuchung wurde die Funktions-Infrarot-Thermographie durchgeführt, die einen Kaltwasser- Funktionstest als Teil der Infrarot-Thermographie- Untersuchung beinhaltete.

ERGEBNISSE: Die diagnostische Sensitivität des Kaltwasser-Funktionstest für nach IASP-Kriterien diagnostizierte CRPS Patienten betrug 72%, die Spezifität 94%, der positive Voraussagewert 82% und der negative Voraussagewert 90%. Die Kappa statistische Analyse (Kappa Index der Übereinstimmung) ergab einen Wert von 0.69 (95% Vertrauensbereich: 0.55 bis 0.83).

SCHLUSSFOLGERUNG: Diese Studie zeigte, dass Kaltwasser-Funktionstest zur Funktionsprüfung des autonomen Nervensystems unter Nutzung einer Echtzeit-Substraktions-Software für Infrarotbilder einen wertvollen und objektiven thermographischen Index darstellen kann, der gemeinsam mit den modifizierten IASP Kriterien für die Diagnose von Patienten mit vermutetem CRPS verwendet werden sollte.

KEY WORDS: Infrarot-Thermography, Kaltwassertest, funktionelles Infrarotbild, Stress Test, autonomes Nervensystem, CRPS

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Introduction

Complex regional pain syndrome (CRPS) is a neuropathic condition that may either develop following acute trauma, including fracture, contusions that produce lesions of the peripheral or central nervous system, or occur spontaneously. CRPS involves inflammatory, [1, 2] and neuropathic and nociceptive mechanisms and, by definition, is always associated with abnormal sympathetic nervous system activity, including a characteristic triad of autonomic (e.g. - vaso- and sudomotor changes), sensory (e.g. - pain, hyperalgesia and in some cases allodynia) and motor disturbances (e.g. - paresis, tremor, dystonia).

To date, a single, encompassing diagnostic algorithm for CRPS remains lacking [3]. Rather, assessment entails the interpretation of clinical stigmata of CRPS as adopted by the Committee for Classification of Chronic Pain of the International Association for the Study of Pain (IASP), as modified by Bruehl [4, 5]. These IASP diagnostic criteria are based upon non-standardized signs and symptoms [6, 7, 8, 9], and diagnosis may be complicated by 1) the presence of symptoms that appear to be far greater than anticipated for the instigating insult, and 2) symptoms that spread proximally, and in some cases to the contralateral limb, trunk, face and although more rare, all four extremities [5, 10]. Discriminate function analyses (DFA) applied to the IASP criteria have elucidated inconsistent reliability and external validity. These studies have shown that there is significant potential for both 1) over-diagnosis due to low specificity [11, 12, 4], low inter-observer reliability [13, 14], and considerable variability in the recognition of relevant clinical signs; and 2) under-diagnosis in patients who are recovering from limb fracture and/or immobilization [15]. The use of sympatholytic agents (e.g. systemically administered adrenergic antagonists, interventional sympathetic blockade) as both diagnostic and therapeutic tools has also proven to be less than reliable, given that 1) not all patients with CRPS respond to sympatholytics; 2) other types of sympathetically-maintained pain (SMP) may be responsive to these drugs, and 3) response to sympatholytics may change consequential to the natural history of both CRPS and SMP. Given this heterogeneity of signs and symptoms, response to intervention(s) and overall presentation, a level of suspicion remains among non-sub specialists as to the validity of CRPS as a diagnosis. Such dissonance promotes problems in the clinical management of CRPS.

This conundrum, and the resultant trajectories of inappropriate diagnosis and treatment, incur significant time, cost and ultimately (if not most importantly) health burdens for the patient, and generate significant practical, ethico-legal and economic problems in the provision of sound clinical care. However, because of these inherent weaknesses in clinical criteria, the diagnostic approach should be conservative and supported by objective findings [16]. We posit that diagnosis is a foundation upon which effective and sound therapeutics are built, and thus, more reliable diagnostic capability is needed to advance understanding and treatment of CRPS. In light of this, we argue that additional forms and use(s) of objective testing will be helpful to clarify both subjective information from patients, and corroborate clinical findings to enhance diagnostic accuracy, and prudent care. Toward this end, the present study examines cold water autonomic functional stress testing, utilizing real time dynamic subtraction imaging medical software, to depict its potential value as a component of infrared thermographic assessment of CRPS in concert with the modified IASP criteria.

Methods

Study Design

A retrospective study of 143 consecutive patients referred to Colorado Infrared Imaging Center, a freestanding infrared imaging facility, over a 12 month period, who underwent *functional* infrared imaging [(*f*)IR] as part of a methodology for assessing and diagnosing CRPS. The study consisted of 89 women and 54 men ranging from 21 to 72 years of age. Disease duration of the subjects studied ranged from 1 month to16 years. The symptomatic extremities reported by the subjects are listed in Table 1.

Subjects were referred for (*f*)IR imaging by their attending physicians in order to evaluate presumptive CRPS. None of the subjects had a previous history of sympathectomy. Each subject had an initial clinical examination that followed the modified IASP research criteria for CRPS. Following clinical examination, each subject underwent (*f*)IR imaging that included cold water autonomic functional stress testing as part of the IR autonomic test battery. Subjects were imaged with a Bales Tip 50 high-resolution IR camera utilizing Bales medical imaging software. The cold water autonomic functional stress test results were retrospectively compared with the findings obtained from the clinical examination utilizing the modified IASP criteria [4], listed in Table 2.

Patient Protocol

Each subject completed a patient questionnaire (which included a pain diagram), and confirmed that they had followed pre-procedure (*f*)IR imaging protocols [17, 18] that included discontinuing vasoactive medications per published protocols. Documentation of subjects' current medications and therapies, results of previous thermographic or vascular studies, and results of any prior sympathetic or vascular interventions were obtained. Upon entering the Infrared (IR) imaging laboratory each subject dis- robed and donned a loose fitting cotton gown that covered the breasts and genitalia. Prior to the 15-minute equilibration period, a focused clinical examination was performed (see below), after which each subject was required to equilibrate body temperature in a 20° C $\pm$ 1° C environment for a minimum of 15 minutes. Following equilibration, subjects underwent (*f*)IR imaging to include 3 distinct indices: (1) quantitative/qualitative IR signatures of the region of interest (upper extremities and/or lower extremities), (2) distal thermal gradient IR signatures and (3) cold water autonomic functional stress testing. Gulevich et al. demonstrated 93% sensitivity and 89% specificity when combining the data from these 3 IR indices in evaluating patients with presumptive CRPS [19].

Table 1
Symptomatic extremities

Symptomatic Extremity	Total
Right Upper Extremity	29
Left Upper Extremity	35
Bilateral Upper Extremity	8
Right Lower Extremity	29
Left Lower Extremity	25
Bilateral Lower Extremity	1
Left Upper and Left Lower Extremity	2
Right Upper and Right Lower Extremity	2
Right Upper and Left Lower Extremity	2
Three Extremity	5
Four Extremity	5

Table 2

Modified IASP research diagnostic criteria [4]:

I. Focused history was obtained documenting any previous history of the following signs/symptoms:

Sensory: History of hyperesthesia and/or allodynia.

Vasomotor: History of thermal asymmetry, and/or skin color changes, and/or skin color asymmetry.

Sudomotor/Edema: History of edema, and/or sweating changes and/or asymmetry.

Motor/Trophic: History of decreased Range of Motion (ROM), and/or motor dysfunction (weakness, tremor, dystonia), and/or trophic changes (hair, nails, skin).

For confirmation, patient must report at least one symptom in each of the above four categories.

II. Focused clinical exam was obtained documenting current signs of abnormalities in:

Sensory: Evidence of hyperesthesia (to pinprick) and/or allodynia (to light touch and/or deep somatic pressure and/or joint movement).

Vasomotor: Evidence of temperature asymmetry and/or skin color changes and/or skin color asymmetry.

Sudomotor/Edema: Evidence of edema and/or sweating changes and/or sweating asymmetry.

Motor/Trophic: Evidence of decreased Range of Motion (ROM) and/or motor dysfunction (weakness, tremor, dystonia) and/or trophic changes (hair, nails, skin).

Patient must display at least one sign, at the time of evaluation, in two or more of the above categories.

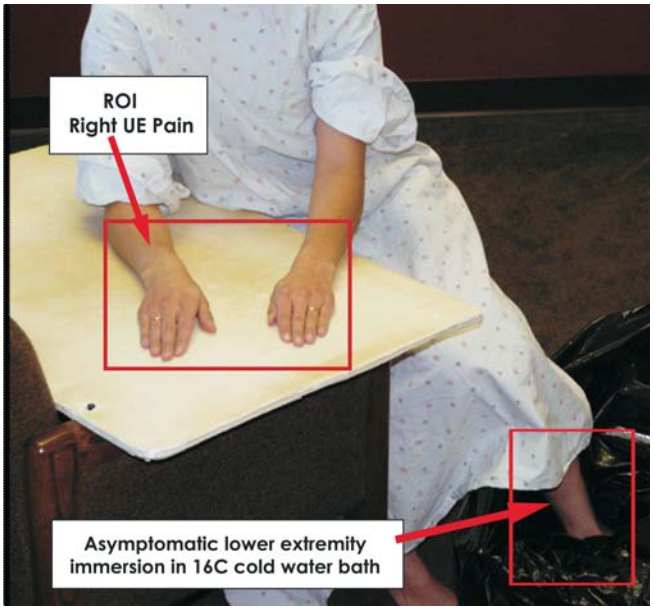
III. Must have evidence of continued pain, which is disproportionate to any inciting event.

IV. There are no other diagnoses that better explain the signs and symptoms. For the purposes of this study, all subjects were considered to have no other diagnosis that would better substantiate current clinical presentation. It should be noted that prior to being referred for (f)IR imaging most of the subjects had been evaluated by several physicians that each/all offered differing diagnostic opinions/impressions.

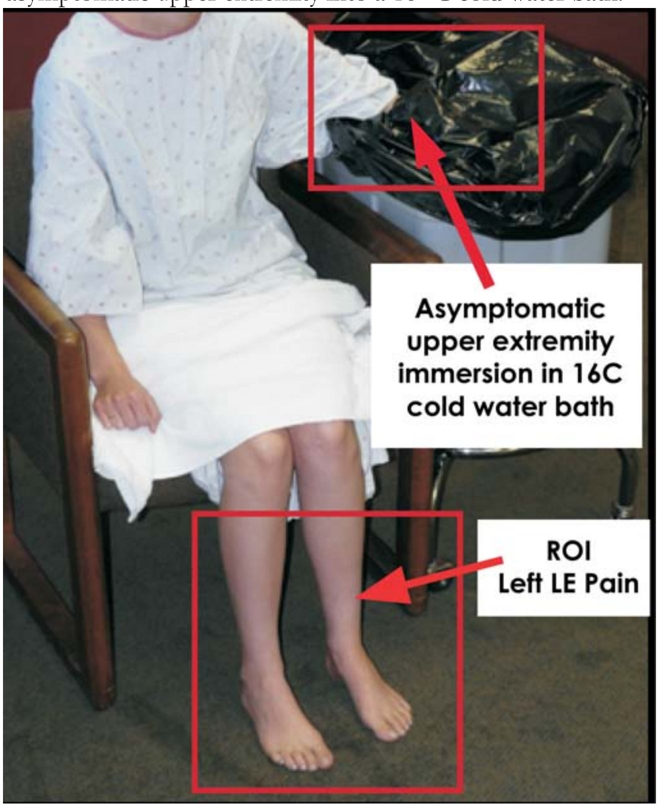
Clinical evaluation (modified IASP research criteria)

Prior to equilibration and (*f*)IR imaging, each patient underwent a clinical examination following the modified IASP research diagnostic criteria [4] for evaluating patients with presumptive CRPS. The modified IASP research criteria were utilized so as to equally balance optimal sensitivity and specificity, versus the modified IASP clinical dia- gnostic criteria that more focally maximize sensitivity.

Upper body stress test patient setup imaging the symptomatic and asymptomatic upper limbs with immersion of the left asymptomatic lower extremity into a 16° C cold water bath:



Lower body stress test patient setup imaging the symptomatic and asymptomatic lower limbs with immersion of the left asymptomatic upper extremity into a 16° C cold water bath:



Cold water autonomic functional stress testing protocol and diagnostic criteria

Cold water autonomic functional stress testing, utilizing real time, dynamic subtraction imaging (available on most medical IR software programs), was obtained following baseline high-resolution quantitative/qualitative IR images of the region of interest (i.e. upper extremities and/or lower extremities) [19, 20]. All subjects were scanned with a Bales Tip 50 IR high-resolution camera that incorporated Bales medical IR imaging software. Real-time image subtraction was achieved by choosing a starting reference image, then viewing only the differences between the re- -ference image and current image. If individual pixel temperature rises, the difference will be shown in color; if the temperature drops, the image will be displayed in shades of gray. At any time during the imaging process the user can choose to view the reference, delta or current image. All thermal data have a dynamic range of 12 bits enabling the user to view .05-degree difference in a 0-50 °C temperature range. Stress testing was performed by imaging the symptomatic and the contralateral asymptomatic extremity for five minutes while a distal asymptomatic limb was immersed in a 16° C cold-water bath. The asymptomatic distal limb is placed in a plastic bag prior to immersion into the cold water bath. At the end of the 5-minute cold water autonomic stress test imaging session, the cold water stress test image was captured and archived. The image captured includes the symptomatic distal extremity and contralateral asymptomatic distal extremity. No data is obtained from the asymptomatic extremity that was immersed in the 16°C cold water bath.

The immersion of a non-involved distal limb activates autonomic thermoregulation. If autonomic function is intact, the central vasoconstrictor reflex will initiate peripheral vascular constriction at the distal extremity of the cold-exposed limb (Fig. 1). If the autonomic vasoconstrictor reflex is inhibited, or there is autonomic failure, then an axonal vasodilatation reflex will occur, and this reflex will be evidenced by a warming of the symptomatic distal extremity (Fig. 2), and on occasion, the bilateral asymptomatic distal extremity (Fig. 3) during the five-minute cold-water stress test.

Statistical Analysis

Table 3:

	Modified IASP Exam Results		Cold Water Autonomic Functional Stress Test Results			
	Positive CRPS exam	Negative CRPS exam	True Positive	True Negative	False Positive	False Negative
Study Results	39	104	28	98	6	11

Table 4

Sensitivity = 72% (N=143; TP=28; FN=11) Sensitivity = $\frac{28}{28 + 11}$
Specificity = 94% (N=143; TN=98; FP=6) Specificity = $\frac{98}{98 + 6}$

Results

Diagnostic performance of cold water autonomic functional stress testing

Among the 143 subjects referred for (*f*)IR imaging, 39 subjects met the modified IASP research criteria for CRPS, and 104 subjects did not. Of the 104 subjects who did not meet

Figure 1
Cold water autonomic functional stress test IR signature of the upper extremities reveals the expected cooling in this patient with an intact and functioning ANS, with negative modified IASP criteria for CRPS.

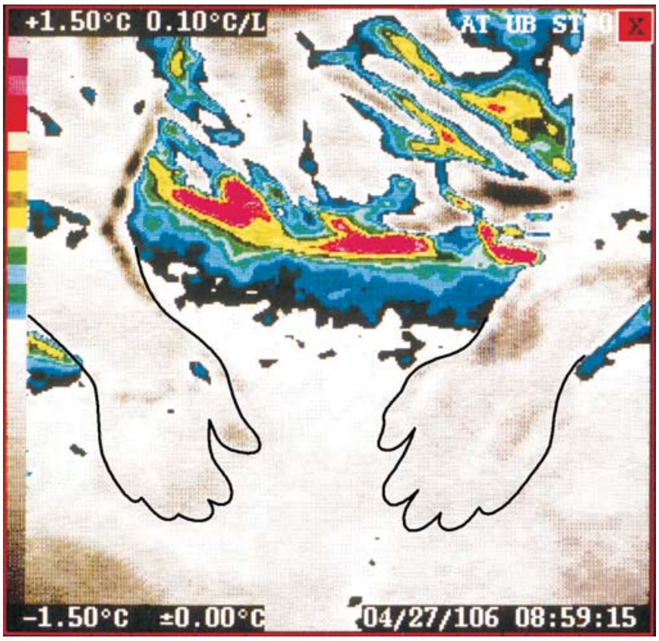


Figure 2
Cold water autonomic functional stress test IR signature of the lower extremities reveals paroxysmal warming of the right symptomatic distal extremity in a patient that met the modified IASP criteria for right lower extremity CRPS. This paroxysmal warming of the distal right symptomatic extremity is indicative of inhibition/failure of the vasoconstrictor reflex, a common finding in patients with CRPS.

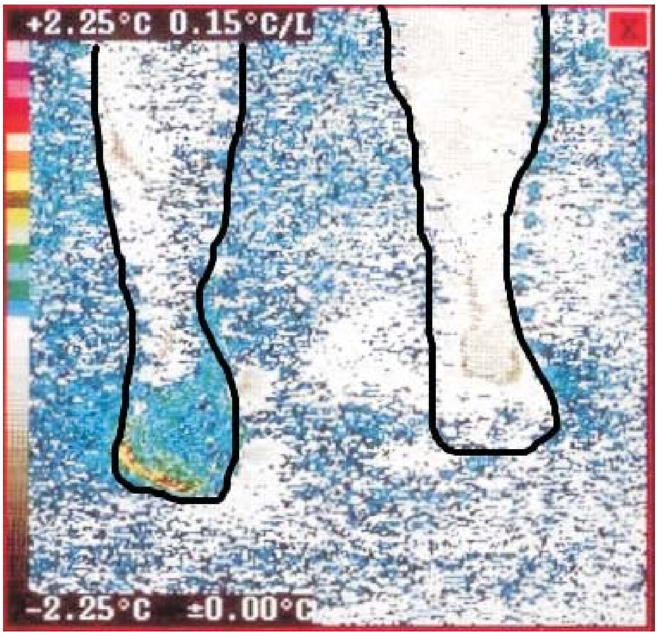


Table 4 continued

Positive Predictive Value = 82% (TP=28; FP= 6)

$$PPV = \frac{28}{28 + 6}$$

Negative Predictive Value = 90 % (TN = 98; FN = 11)

$$NPV = \frac{98}{98 + 11}$$

Table 5

KAPPA INDEX CALCULATION
$\frac{\text{observed agreement–chance agreement}}{1 - \text{chance agreement}} = \frac{N(a + d) - (n1f1 + n2f2)}{N^2 - (n1f1 + n2f2)} = \mathbf{0.69}$
Kappa index values (95% confidence interval is between 0.55 and 0.83)
0.00 - 0.2………slight agreement
0.21 - 0.4……….fair agreement
0.41 - 0.6……….moderate agreement
0.61 - 0.8……….substantial agreement
0.81- 1.0……..…almost perfect agreement

Figure3
Cold water autonomic functional stress test IR signature of the upper extremities reveals paroxysmal warming of both the right symptomatic and left asymptomatic distal extremities in a patient that met the modified IASP criteria for right upper extremity CRPS. The paroxysmal warming of both symptomatic and asymptomatic distal extremity is indicative of inhibition/failure of the vasoconstrictor reflex suggestive that ANS suppression is mediated at the central (e.g. - spinal, bulbopsinal and/or hypothalamic) level rather than in the periphery. Stress test IR signatures of the upper extremities may also represent an early indication of “spreading” CRPS into the contralateral extremity. Further research regarding this phenomenon is necessary.

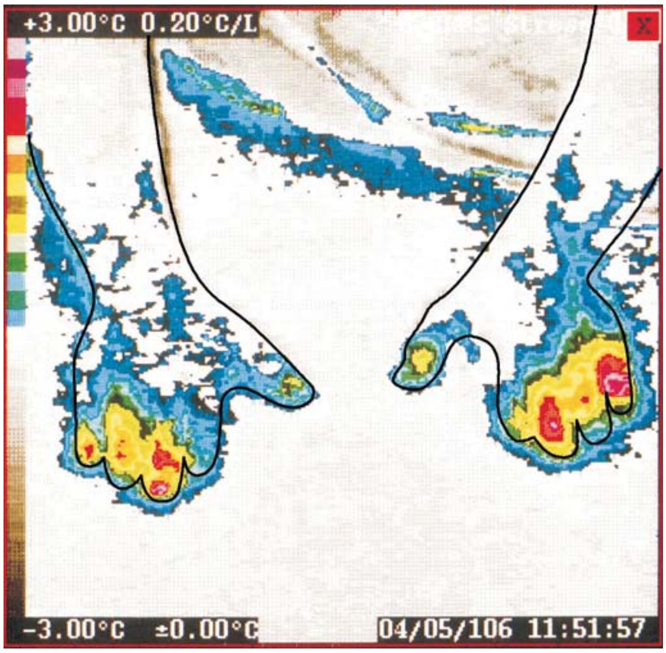


Table 6

	Modified IASP Research Diagnostic Criteria for CRPS		
Cold Water ANS Functional Stress Test	Y	N	
Y	28	6	f1: 34
N	11	98	f2: 109
	n1: 39	n2: 104	143

n1 = total true positives
n2 = total true negatives

Tabelle 7 (Y = positive test result, N= negative test result)

Subject	Cold Water Stress Test	Modified IASP Criteria	Subject	Cold Water Stress Test	Modified IASP Criteria	Subject	Cold Water Stress Test	Modified IASP Criteria
1	Y	Y	49	N	N	97	N	N
2	Y	Y	50	N	N	98	N	N
3	Y	Y	51	N	N	99	N	N
4	Y	Y	52	N	N	100	N	N
5	Y	Y	53	N	N	101	N	N
6	N	N	54	N	N	102	N	N
7	N	N	55	N	N	103	N	N
8	N	N	56	N	N	104	N	N
9	N	N	57	N	N	105	Y	Y
10	N	N	58	N	N	106	Y	Y
11	N	N	59	N	N	107	Y	Y
12	N	N	60	N	N	108	Y	Y
13	N	N	61	Y	Y	109	Y	Y
14	N	N	62	Y	Y	110	N	N
15	Y	Y	63	N	N	111	N	N
16	N	N	64	N	N	112	N	N
17	N	N	65	N	N	113	N	N
18	N	N	66	N	N	114	N	N
19	N	N	67	N	N	115	N	N
20	N	N	68	N	N	116	N	N
21	N	N	69	N	N	117	N	N
22	N	N	70	N	N	118	Y	Y
23	Y	Y	71	N	N	119	Y	Y
24	Y	Y	72	N	N	120	N	N
25	Y	Y	73	N	N	121	N	N
26	N	N	74	N	N	122	N	N
27	N	N	75	N	N	123	N	N
28	N	N	76	N	N	124	N	N
29	N	N	77	N	N	125	N	N
30	N	N	78	N	N	126	N	N
31	N	N	79	N	N	127	Y	N
32	N	N	80	N	N	128	Y	N
33	N	N	81	N	N	129	Y	N
34	N	N	82	N	N	130	Y	N
35	N	N	83	N	N	131	Y	N
36	N	N	84	N	N	132	Y	N
37	Y	Y	85	Y	Y	133	N	Y
38	Y	Y	86	Y	Y	134	N	Y
39	Y	Y	87	N	N	135	N	Y
40	Y	Y	88	N	N	136	N	Y
41	Y	Y	89	N	N	137	N	Y
42	N	N	90	N	N	138	N	Y
43	N	N	91	N	N	139	N	Y
44	N	N	92	N	N	140	N	Y
45	N	N	93	Y	Y	141	N	Y
46	Y	Y	94	N	N	142	N	Y
47	Y	Y	95	N	N	143	N	Y
48	N	N	96	N	N			

False positives and false negatives listed from 127-143 the modified IASP research criteria for CRPS, it is believed that most, if not all, of these subjects presented with autonomic phenomenon suggestive of a normal somato- autonomic reflex secondary to a peripheral pain generator(s). This is a common finding for patients whose signs and symptoms "mimic" CRPS. Of the 143 subjects who underwent cold water autonomic functional stress testing, 28 demonstrated a positive stress test result (example representes in Fig. 2 or 3), 98 subjects displayed a negative stress test result (example represented in Fig.1), 6 subjects had false positive test results and 11 subjects had false negative test results. These results indicate a sensitivity of 72% with a positive predictive value (PPV) of 82%, and a specificity of 94%, with a negative predictive value (NPV) of 90% (Tables 3&4). The Kappa Index (95% confidence interval) was 0.69, indicating substantial agreement between the modified IASP research criteria and results obtained using cold water autonomic functional stress testing (Tables 5, 6 & 7).

Discussion

Sympathetic neuronal control

Functional infrared imaging detects the thermal signature produced by changes in cutaneous blood flow regulated by central thermal and respiratory control that affect vasoconstrictor and sudomotor reflexes [21, 22]. This vasomotor activity is predominantly, but not exclusively, dependent upon hypothalamic control [21, 22]. Sympathetic pre-ganglionic neurons project to the paravertebral ganglia and synapse with post-ganglionic neurons innervating target organs [21, 22]. Postganglionic sympathetic neurons release norepinephrine and neuropeptide Y to regulate cutaneous blood flow [23]. Studies suggest that the thermoreg ulatory dysfunction in CRPS is due to central inhibition of the cutaneous sympathetic vasoconstrictor reflex [24].

Normal sympathetic neuronal response to cold stress

In a normal, asymptomatic population, there is a significant drop in temperature (vasoconstriction) that can be visualized by IR imaging utilizing computer generated temperature recordings, when an extremity is immersed in a cold water bath (temperatures ranging from 10-14° C), as compared to the thermal response in non-immersed extremities [25, 19]. Following arousal stimuli and the cold-pressor test this vasoconstrictor response is observed in asymptomatic patients and is diminished or absent in patients with CRPS [26, 27, 28]. The subsequent drop in skin temperature is the result of cutaneous vasoconstriction as mediated, in part, by the preoptic anterior hypothalamic nucleus [25]. This sympathetically-mediated, subcuta neous somato-autonomic reflex vasoconstriction shunts blood away from the skin thereby increasing the insulating capacity of subcutaneous tissues and inhibiting heat loss [29, 25, 30]. When autonomic function is intact, there is evidentiary cooling of the distal symptomatic extremity following cold water autonomic functional stress testing (Fig. 1) due to this vasoconstrictor reflex.

Hyperexcitability of polymodal C nociceptive afferents produces both orthodromic and antidromic release of tachykinins, most notably the undecapeptide substance-P, and calcitonin gene-related peptide (CGRP), from the involved nerve terminals that gives rise to rubor (i.e. - erythema) [31, 32, 22, 33]. Vasodilatation incurs a rise in surface temperature and increase in the resultant radiant heat signature. This hyperthermia is independent of sympathetic activity and is localized to the area of skin innervated by the particular C fiber(s) [34, 35, 36, 20]. Activation of functioning and intact sympathetic fibers overrides antidromic vasodilatation, producing vasoconstriction and hypothermia of the skin [37].

Abnormal sympathetic neuronal response to cold stress

In autonomic dysfunction there is warming of the distal symptomatic extremity [25, 19, 20] that may be due to inhibition/failure of the vasoconstrictor reflex [19, 26, 27, 28, 20] or adrenergic sensitization of nociceptors (viz. - up-regulation and/or increased affinity of alpha adrenergic receptors) [38] producing an axon reflex-mediated vasodilatation. This axon reflex-mediated vasodilatation is not suppressed by central inhibition of sympathetic efferent fiber activity [20]. Patients with CRPS characteristically show paradoxical warming of the skin following cold water immersion, suggestive of ANS suppression [25, 19, 20]. The paradoxical warming often occurred in both the symptomatic and asymptomatic extremity (i.e. - clinically normal side; Fig.3). This suggests that ANS suppression is mediated at the central (e.g. - spinal, bulbospinal, and/or hypothalamic) level rather than in the periphery.

Currently, the best practice algorithm for evaluating patients with presumptive CRPS is to perform a clinical examination based on the modified IASP criteria. As stated previously, there are flaws inherent to utilizing these criteria as the sole diagnostic tool. The present study demonstrates the value of objective results obtained from cold water autonomic functional stress testing, and suggests that incorporating this method within existing protocols may improve reliability in the differential diagnosis of CRPS.

Conclusion

Studies that have examined the internal and external validity of diagnostic methods used to discern CRPS suggest problems when using IASP criteria as the sole means of clinical assessment [12, 39]. The modified IASP diagnostic criteria tend to reduce the occurrence of over diagnosis; however, these methods also diminish diagnostic sensitivity [4]. The present study supports that cold water autonomic functional stress testing, utilizing real time dynamic subtraction imaging medical software, is a valuable and objective method for objectively evaluating the function of the autonomic nervous system in patients with presumptive CRPS. Cold water autonomic functional stress testing shows substantial alignment and synergy with the modified IASP criteria, and in this way, may be important to add to existing diagnostic algorithms. This methodology may also prove helpful as a screening tool for evaluating patients with suspected autonomic dysfunction.

In summary, we opine that the present results indicate that cold water autonomic functional stress testing, together with orthodox infrared thermographic images that obtain static computer generated ROI delta T's, will enhance the diagnostic validity, strengthen modified IASP criteria, and provide a basis for improved clinical care of CRPS.

Acknowledgments

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14th Congress of the Polish Association of Thermology

and

Certifying course: ”Practical application of thermography in medical diagnostics”

Zakopane, March 26 – 28, 2010

Scientific Programme

Saturday, 27th 2010

9:00-11:00 Session I
Chairmen: Prof. K. Ammer, Prof. J. Mercer

Vardasca R. (Portugal)	Barycentric warp model for hand thermal images standardisation.
Prof. Ammer K (Austria)	Cold challenge to provoke a vasospastic reaction in fingers determined by temperature measurements: A systematic review.
Vardasca T, Vardasca R (Portugal)	Hand cold stress test methods electronic evaluation and reporting.
Prof. Mercer J, de Weerd L. (Norway)	The use of infrared thermography in visualizing perfusion in the reverse sural artery (RSA) island flap preparation used in treating open of the lower extrimities.

11:30 – 13:15 Session II
Chairmen: Prof. A. Jung, Prof. E.F.J. Ring

Prof. Ring E.F.J. (United Kingdom)-	Revealing the Invisible.
Murawski P. Prof. Jung A., Dr med. Kalicki B., Dr med. Zuber J. (Poland)	Tele Med Net - medical platform for scientist and diagnostics, perspectives for thermography.

15:00- 16:00 Session III
Chairmen: Prof. B. Wiecek, Prof. A. Nica

Prof. Wiecek B., Wiecek M., Strakowski R., Owczarek G (Poland)	Application of thermography for searching people in hazard conditions.
Prof. Nica A., Mologhianu G., Murgu A. Ojoga F., Mitoiu B., Ivascu M. (Romania)	Clinical and and thermographic evaluation in the posttraumatic knee, . -
Dr Cholewka A., Prof Drzazga Z., Drop K Knefel G., Kawecki M., Nowak M. (Poland) -	Application of thermal diagnostics in hyperbaric oxygen therapy (HBO)

16:00-17:15 Training course
Chairmen: Prof. S. Klosowicz, Dr med. J. Zuber

Prof. Klosowicz S.(Poland) -	Some words about heat and temperature.
Presentation from the company VIGO	
Prof. Wiecek B. (Poland)	Comparison of cooled and uncooled cameras for biomedical applications

Abstracts

BARYCENTRIC WARP MODEL FOR HAND THERMAL IMAGES STANDARDISATION

Ricardo Vardasca

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Thermal images of hands provide clinical information. However due to the complex shape and different subject sizes. It is difficult to execute an accurate analysis. A standardisation method is needed to perform a comparison or an average of various images. The method used in this experiment is morphing triangulation, it consists of using an approximate geometrical shape similar to the capture mask, the shape is divided by anatomical regions of interest and those are triangulated based on the control points that define the model. The resultant image is generated by reverse correspondence of pixels that are obtained by equivalence based on barycentric coordinates. It will allow a scaling and alignment without scrambling the original data between different anatomical areas. This simple process of warping images is shown to meet the requirements presenting an accuracy of 98%. Standardising several hand images is possible using this technique along with extended statistical evaluation, discrimination and balancing of groups of images with minimal processing time.

COLD CHALLENGE TO PROVOKE A VASOSPASTIC REACTION IN FINGERS DETERMINED BY TEMPERATURE MEASUREMENTS: A SYSTEMATIC REVIEW

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Medical Imaging Research Group, Faculty of Advanced Technology, University of Glamorgan, Pontypridd, UK

BACKGROUND: Raynaud's Phenomenon is characterised by 3-phasic colour changes of fingers and/or toes caused by vasospam of the digital arteries due to low temperature and/or psychological stress. These colour changes may be accompanied by decreased skin temperature which can be identified by infrared thermal imaging.

OBJECTIVE: To identify procedures which address patient's preparation, temperature of the examination room, temperature and duration of the immersion bath, position of hands, time of follow-up after the cold challenge and method of evaluation

METHOD: A computer assisted literature search was performed for publications related to thermographic investigations of patients with suspected Raynaud's phenomenon in Embase, Medline, Google Scholar and the literature archive of the author.

RESULTS: Out of 170 hits in Google and 98 in Embase/ Medline, in total 50 articles and 6 reviews were included. The information on procedures performed was incomplete in the identified studies. There was a wide variation in water temperature of the immersion bath and also of duration of immersion. More than 20 different methods for evaluation of hand temperatures were reported

CONCLUSION: The description of the methodology must improve. A evidence based guideline for standard procedures of performing and evaluation of thermal images from patients with Raynaud's phenomenon is needed.

HANDS COLD STRESS TEST METHODS ELECTRONIC EVALUATION AND REPORTING

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Cold Stress Test (CST) on hands has been used as a standard in thermography for assessing Raynaud's Phenomenon (RP) for years. This test has shown to be relevant for assessing specific vascular and neurological conditions when used in combination with other provocation tests. Different temperatures of water and recovering times have been used. Three methods to grade the test have been suggested; Ring suggested in 1980 the method of areas (Method 1), where the mean temperature of fingers excluding the thumb was subtracted to the mean temperature of the dorsal palm of the hand. The index values were calculated for the thermogram before the CST and from the final one (normally 10, 15 or 20 minutes depending on the recovery), for a final index both thermograms indexes were added for each hand, in case of an index value below -2.0ºC the hand was considered hipothermic.

Ammer recently suggested two methods based on thermal gradients/profiles, one using a thermal spot of at least 16 pixels on the middle of each finger (excluding thumb) distal phalanx and another spot of the same size on a proximal region of the respective metacarpal (Method 2) computing the mean temperatures of those spots, subtracting the finger spots from the metacarpals obtaining a index per finger. The other suggested method from the same author was to draw a line composed of 4 pixels from the middle of each finger (excluding thumb) distal phalanx to the proximal part of the correspondent metacarpal (Method 3) calculating the mean temperature of each part of the line, corresponding the distal part of the line to the finger and proximal to the metacarpal, once again to obtain the index per finger by subtraction.

Is objective of this experiment to compare the three methods of assessing CST of hands, to investigate the values of thermal symmetry on healthy volunteers on recovering of CST and provide a reporting solution of the obtained results.

The CST were performed according to the Glamorgan thermogram capture protocol using exposure of 1 minute to water at temperature of 20 ºC. 10 healthy volunteers were examined. Two types of CST were recorded, one combined with mechanical provocation before and another without previous provocation. A computational application using an anthropometric model of hands was developed allowing standardization of thermal images of hands based on anatomical landmarks and preserving its thermal values per hand area of interest (AIO). This tool also produces statistical values per hand AIO's. Another complementary tool was developed implementing the three methods of assessing CST generating each statistics per minute of recovery generating a full report in PDF and DICOM formats.

The method that provides better discrimination on identifying RP is the Method 2. All methods seem to be sensitive to false positive cases of RP. This information on a full report of the three methods might be relevant on future studies of upper extremities pathological states.

THE USE OF INFRARED THERMOGRAPHY IN VISUALIZING PERFUSION IN THE REVERSE SURAL ARTERY (RSA) ISLAND FLAP PREPARATION USED IN TREATING OPEN WOUNDS OF THE LOWER EXTREMITIES.

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Soft tissue defects of the lower 1/3 tibia and dorsum of the foot present a challenging problem for plastic surgeons. The reverse sural artery (RSA) island flap has become the work horse for the closure of these defects. The flap is a so-called neurovascular flap, a flap that is based on the vascular network that accompanies a nerve. The RSA flap is harvested from the posterior side of the leg with its axis along the sural nerve and its basis approximately 5 cm above the lateral malleolus. 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. The direction of the blood flow in the flap is the reverse of normal. After transposition of the flap to the defect, the flap relies entirely for it blood supply on the perforator of the peroneal artery. However, after a 3 weeks period, vessels at the defect have made contact with the vessels in the flap. For cosmetic reasons it may be necessary to resect the skin bridge that connects the flap with the perforator This is only possible after vessels at the defect have grown into the flap and contribute to the flaps' blood supply. We demonstrate with a clinical case how infrared thermography can be used to visualize that such angiogenesis has happened and that the direction of the blood flow within the reverse sural artery flap become normalized again.

REVEALING THE INVISIBLE

EFJ Ring

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In recent years, medicine has benefited enormously from the emergence of a variety of imaging technologies. Almost every part of the electromagnetic spectrum has been used in a form of investigation. The earliest aid to medicine came from the microscope and the identification of bacteria, brought significant advances. The discovery of xrays and the emergence of radiological imaging as also made a major impact on modern medicine. Infrared radiation though identified in 1800 by Herschel, was not exploited properly until 1910, when Professor Robert Wood used an infrared film for infrared photography, which allowed some clarification of superficial blood vessels to be shown, using near infrared radiation. The advance in infrared thermal imaging came from the 1940's and subsequently wider use in the early 1960,s using electronic detectors brought passive non-contact imaging of surface temperature into many civil and medical applications.

However, infrared imaging was yet to find a new level of sensitivity and reliability that was accelerated by the advent of computing. As in many other medical imaging systems, the digital revolution has had a number of valuable attributes. One is in the use of false colour, because the human eye is limited in the number of grey shades that are naturally detected, but with false colours, even the limited 20 shades shown on the average radiology film can be increased to 200. Furthermore, it is possible to use software aids for reliable image capture, image analysis and the rapid storage and retrieval of images.

The way in which infrared thermal imaging was developed at Bath UK, for arthritis research, especially the objective measure of anti-inflammatory drugs are described. This led to a series of useful clinical trials throughout the 1970's to 1990's. These trials were based on the reduction of temperature over inflamed joints, or the assessment of changing response to thermal and mechanical stress tests, for evaluating efficacy of treatments in applied pharmacology.

The current issues around the mass screening for fever with thermal imaging are also of importance, and a clinical study of children in Warsaw has shown that standardized imaging of the face can be used, and in fact forms the basis of a new International Standard for detection for fever.

The imaging cameras have dramatically improved over the 50 years of development, and through the use of modern digital communication, it is hoped that the much needed database of normal reference thermograms for medical thermography can be achieved. This can be expected to improve education and international standardization for this technique that should increase its reliability and uptake across clinical medicine.

TELEMEDNET – MEDICAL PLATFORM FOR SCIENCE AND DIAGNOSTICS, PERSPECTIVES FOR A MEDICAL THERMOGRAPHY

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2Pediatrics and Nephrology Clinic of Military Institute of Medicine

Over the past few years, the issue of medical research has expanded the number of new issues. Phenomena such as the need to optimize the treatment process, the search for new effective methods and the need for multi-analysis of large data sets meant that specialists on issues of construction of information systems and computer algorithms, and began to look for technology to support research in these areas. Due to the large and large-data sets made it necessary to use highly advanced software solutions that can effectively support scientific research in medicine and medical economics.

The "TeleMedNet" project will be implemented by a consortium consisting of two Polish medical entities: Military Institute of Medicine (Warsaw) and the Provincial Specialist Clinical Hospital (Wroclaw). Leader of the project is Military Medical Institute.

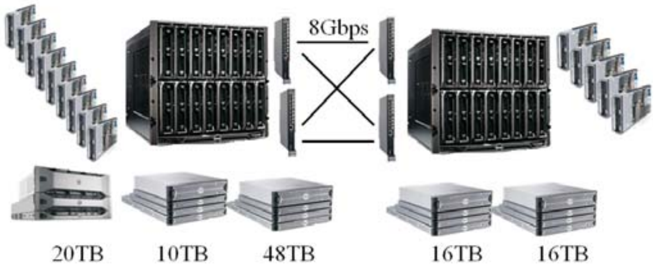
Activities conducted by the project team "TeleMedNet" aim to provide reliable infrastructure and the integration of the latest generation of computer systems. In this way, an integrated system to support action research workers and cutting-edge information and IT. Implementation of the project will conduct TeleMedNet modern scientific research in various areas of medicine based on verified clinical data. The project will produce an extensive infrastructure, which is made available to the medical scientific community to develop new lines of research in the future.

This will be achieved through:

- • The creation of infrastructure and applications to collect and store data.
- • Construction of a platform for sharing and analysis of collected data.
- Provide a safe and permanent access to infrastructure.
- Establish a database of medical costs of medical procedures.
- As a result of the project the medical scientific community will be given the resources of the safe processing and data sharing:

- Secure primary and backup localization
- Redundant, guaranteed 40(80) KVA power supply
- Redundant, synchronous internet connection (30Mbps expandable to 155Mbps)
- Full virtualization infrastructure (servers, storages, computer networks)
- Computer networks with 20 Gbps bandwidth at the backbone network
- Time server (time.wim.mil.pl)

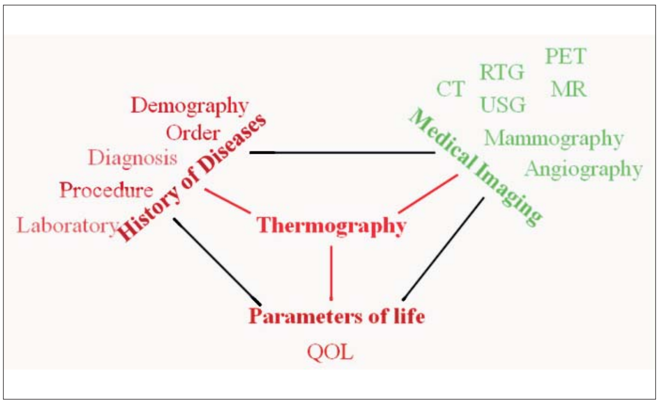
The infrastructure for collecting and processing data will be incorporated into primary and backup Data Center equipped with the infrastructure as shown.



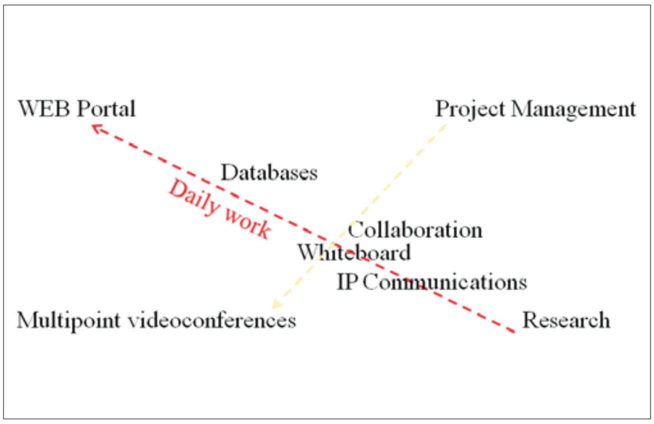
Critical elements of the data network will be connected to a fiber optic data computer network technology that uses a combination of Fiber Channel with 8Gbps bandwidth. Parallel computer network, where will be connected "customers' infrastructure, will be monitored on-line using professional equipment monitoring.

Part of the project is a development of systems for collecting medical data, including data necessary for a correct analysis of thermographic data.

The effect of system development will therefore rise to possibilities of multicriteria analysis of medical records including different types of data including medical images base on different sources.



The result of the project will also establish an infrastructure to a shared, simultaneous work of scientists and knowledge sharing. To this end, solutions are implemented to create the projects in terms of time, human resources and finance. These projects can be "discussed" with the use of many different communication techniques.



The proposed solution will also be used for routine medical research, discuss results and their presentation in the form of resources, knowledge bases and web portal
http://telemednet.wim.mil.pl.

Project facts

„TeleMedNet – medical platform for science and diagnostics" POIG.02.03.00-00-042/09	
Beneficiary	Military Institute of Medicine, Warsaw Provincial Specialist Clinical Hospital, Wroclaw
The value of the project	5 828 695,24 €
Project period	2009 – 2012
Project Manager	Lt. Col. Piotr Murawski Msc Dsc e-mail: pmurawski@wim.mil.pl

Project funded by European Regional Development Fund
"Subsidies for innovations - Investing in your future"

APPLICATION OF THERMOGRAPHY FOR SEARCHING PEOPLE IN HAZARD CONDITIONS

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In this work, we presented an algorithm and the software that allow searching people in complex, noisy and industrial environmental conditions. It can be applied in hazard situation, such as fire. The algorithm which is implemented operates in two steps. The first one is based on segmentation of thermal, monochromatic images using morphological methods and finding regional maxima that allows the image reconstruction. Then, images are binarised by thresholding and the next morphological operations are applied. This is done to separate regions glued by the small number of pixels and to recognize the vertical shape of an object. These images contain a lot of useless regions of interest, so it is necessary to select them conditionally. Regions having small areas and the long and narrow shape are eliminated. As a result, new rectangle regions of interest are created.

The next step is to calculate the parameters (image features) for regions of interest. We use I-order statistical and II-order based on concurrence-matrix parameters. In addition, we applied the wavelet transform and Run-Length matrix parameters. The last set of parameters based on temperature profile (distribution along the line) was also used. The following step of the algorithm is to select the features using Fisher coefficient which allows reducing them down to 6 the most discriminative ones. Such features are used for the classification performed by 3-layer artificial neural network. The second stage of the implemented algorithm is to connect areas having common pixels or which are located close to each other in vertical direction. Such regions are segmented once more in the way like in the first classification step. Next, the parameters are extracted and selected by Fisher coefficient and finally the people are found using the second artificial neural network. The example of working application is presented below. The software was implemented using MATLAB environment.

Figure 1.
A result of searching people, green boxes show the object correctly classified, red one – erroneous classification

CLINICAL AND THERMOGRAPHIC EVALUATION IN THE POST-TRAUMATIC KNEE

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BACKGROUND: The knee, as an intermediate joint in the kinematic chain of the lower limb, is very solicited from the mechanical, thermal and vascular point of view anatomic area. Either directly in athletes or indirectly the knee is exposed to micro and macrotrauma. Initially the knee is evaluated by the general practitioner or the orthopaedist, then by the rehabilitation specialist. The initial clinico-functional evaluation shows as a central factor the pain, then stiffness and instability, but does not measure dynamics in the vascular regenerative availability, as an essential factor in the knee rehabilitation.

AIM OF THE STUDY: The present study evaluates the dynamics of the periferial temperature, through thermal imaging and correlates it with the clinico-functional dynamics.

MATERIAL AND METHOD: We have studied a group of 25 patients with posttraumatic knee pathology: wrench, ligament rupture, meniscus fracture, tibial plateau fracture, and degenerative pathology. The patients followed a rehabilitation program, for 2 weeks, which included electrotherapy, thermotherapy, massage and kinetotherapy; they also have taken medical treatment.

The patients have been evaluated from clinical, symptomatic and functional point of view (pain, stiffness, muscular strength), radiologic (integrity of the bone structure), echografic (soft tissues integrity) and thermographic (availability of the periferic circulation).This parameters have been analyzed at the beginning and at the end of the rehabilitation program (after 2 weeks). Thermal imaging were taken on both anterior and posterior sides of the knee, according to the Glamorgan protocol-

RESULTS: The results obtained through thermographic measurements, have been correlated with the dynamics of functional evolution.

DISCUSSION: The purpose of the present study was to evaluate the dynamics of the peripheral temperature materialized through . Through biostatistic interpretation we appreciated the differences of temperature and thus we obtained an objective argument of the global clinical evolution.

APPLICATION OF THERMAL DIAGNOSTICS IN THE HYPERBARIC OXYGEN THERAPY (HBO)

Cholewka Armand[1], Drzazga Zofia[1], Katarzyna Drop[1]
Knefel Grzegorz[2], Kawecki Marek[2], Nowak Mariusz[2]

1. A. Chelkowski Institute of Physics, University of Silesia, Uniwersytecka 4, 40-007 Katowice
2. Burn Treatment Center Siemianowice Œl¹skie, Chair and Clinic of General Vascular and Transplanting Surgery, Silesian Medical University, Poland

MATERIAL AND METHODS: The investigations were carried out at the Burn Treatment Center in Siemianowice Œl¹skie.

The total study population consisted of 19 patients (7 male and 12 female) age 51 ± 15. One session of hyperbaric oxygen therapy lasted 86 minutes. The pressure of air in the chamber was 2,5 ATA. The thermograms of chosen regions of interests (ROI) were performed before and immediately after HBO in the special room outside the chamber. Temperature in the chamber during therapy as well as in the measurement room was stabilized (22,5 ±1 C).

Prior to exposure to hyperbaric oxygen as well as prior to imaging, the wound was uncovered from bandages which were wrapped in a very loose manner and then left uncovered in order to reach thermal equilibrium of ulcer with the environment. Preparation of the limb was the same for all patients.

RESULTS AND DISCUSSION: HBO can reduce the swelling and increase the leak of fluid through the damaged blood vessels what helps the oxygen to get to the damaged tissue area and improves the wound healing. It also stimulate the activity of cells creating the fibres which are usually the basal of new healthy tissue. These reactions reveal in the changes of temperature and therefore can be evaluated by thermovision. It seems that the changes of ulcered skin thermal map may be connected with improvement of microcirculation and metabolism in chosen areas that suggest a beginning of the healing process.

The result of our studies show two types of skin thermal behaviour after hyperbaric oxygenation. For most of patients suffering from trophic ulceration of tibias the mean temperature of chosen ROI decreases after hyperbaric oxygenation similarly as for all healthy people. However, the opposite effect was also observed. There were patients for whom the increase of mean temperature was observed in the whole or only in the part of the disease area.

Moreover the statistical outlines performed for studied patients suffering from *trophic ulceration* showed the significant decrease (DT=2,0°C) of temperature for 60% of patients. On the other hand the increase of mean temperature (DT=0,5°C) was observed for 40% of patients.

It follows from our studies that after hyperbaric oxygen therapy the decrease of temperature was observed more often than the increase of temperature.

However it should be noted that the HBO effects are complicated what is reflected in different temperature changes. This problem requires a deeper medical analysis.

CONCLUSIONS The significant changes of skin temperature for patients suffering from *trophic ulceration* due to stay in hyperbaric chamber were observed. It seems that thermal imaging can be useful in monitoring HBO effects.

COMPARISON OF COOLED AND UNCOOLED CAMERAS FOR BIOMEDICAL APPLICATIONS

Boguslaw Wiêcek

Institute of Electronics, Technical University of Lódz, Poland

In this paper the comparison between cooled and uncooled thermal imaging systems for biomedical applications is presented. This comparison mainly shows the difference in spectral characteristics of both solutions. The thermal uncooled microbolometer devices (Fig. 2), are only available in long wavelength spectral range. It is due to the lower detectivity. It is because low temperature object (about 300K) radiate much more of energy in the long-wavelength subband. On the other hand, the cooled cameras with much higher detectivity and sensitivity, have the very selective spectral characteristics (Fig. 1).

In cooled technology, the QWIP detectors easily allow to manufacture the multicolor devices (Fig.3). Unfortunately, QWIP has significantly lower detectivity in comparison to MCT detectors. Today the first multicolor structures using MCT are already available.

NETD is different for both technologies. Today for cooled 15mm pitch detector, it is possible to reach NETD<20mK, while 25 mm pitch microbolometer has NETD»40mK with the same optics. In addition, the time response, in the sense of integration and frame rate of the camera, is drastically worse for uncooled devices. The integration time for aSi 25mm pitch bolometr may not be lower than 10ms, while in cooled devices it can be scaled down to 50ms. It has significant impact of frame rate. The cooled systems are offered today with 20000frames/s frame rate, while the micromolomers cameras are only able to generate images at classical video speed, i.e. 25 images/s.

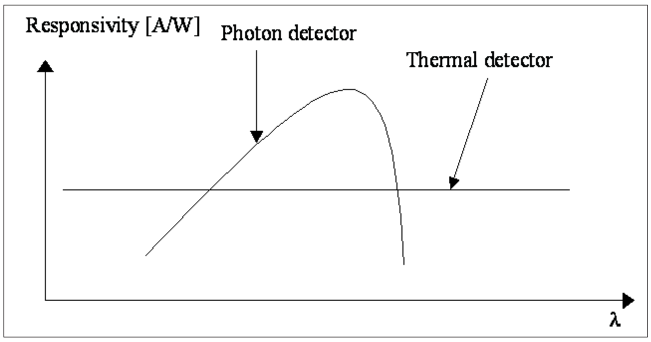


Fig. 1.
Spectral characteristics of cooled and uncooled IR detectors

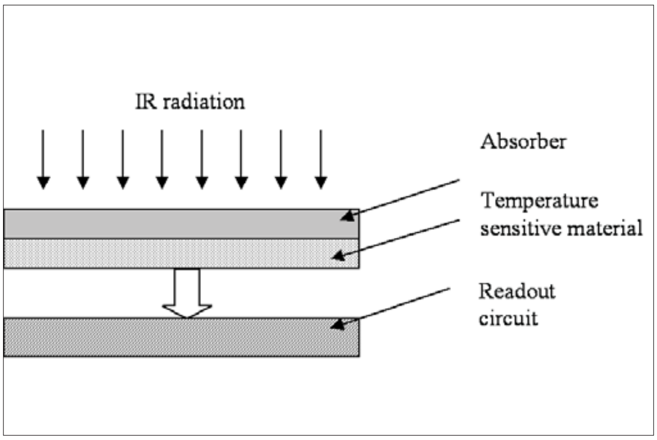


Fig. 2.
Cross-section of uncooled bolometer

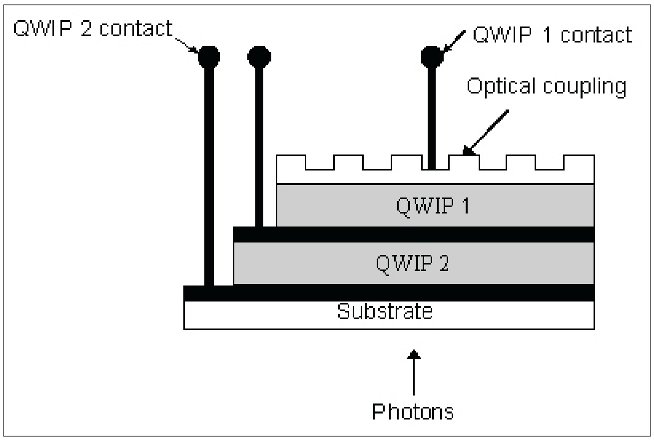


Fig. 3.
Cross-section 2-color QWIP detector

Nicholas A. Diakides, D.Sc.

Virtue, character and deed – The measure of the man

What is the measure of a man? To be sure, there is the legacy of his family and home, friends and acquaintances, and his deeds and actions. For a man of science these personal attributes of life are, of course, important, but the notion of a legacy entails a slightly different, perhaps more expansive and perdurable dimension. For the scientist, the toil that enables the "gathering of daily bread", while important to sustaining a household and family, is explicitly committed to a greater good – advancing the fund of human knowledge. Indeed, a commitment to a life in science is an overt acceptance of the notion of science in its classical definition – *scientia* – as knowledge toward some human good. Stating "…I am a scientist" is an act of profession; in so doing, one publicly accepts the philosophical foundations of science and thus claims that his labors will be conducted by a strict methodology, and bound by ethical precepts that acknowledge the iterative nature of his work and field, recognize the validity of others' work, viewpoints and contributions, and gain value from the contribution to the greater good of science's meaning and worth in the social sphere. In many ways, it is a special calling; and while many may heed the call, those who succeed – in ways that are measurable to this greater social good, are indeed a select few.

Nicholas A. Diakides was such a man. Born in Athens, Greece on December 9, 1929 to Anthony and Anastasia Diakides, both American citizens. Nicholas immigrated to the United States and subsequently became a naturalized US citizen. Attending the University of Pittsburgh, Nicholas earned a Bachelor of Science degree in chemical engineering in 1955, and a Master of Science at George Washington University in 1973. He was awarded a Doctor of Science in electrical engineering (biomedical engineering, telecommunications and computer science) from the George Washington University in 1979.

Dr. Diakides devoted the majority of his professional career to the development and assessment of sensor systems, biomedical technology, medical infrared (IR) imaging, and bioinformatics, engaging this work in a variety of governmental positions under the Office of the Secretary of Defense (OSD-S&T, DARPA, ARO, and ONR). As the director of the survivability enhancement division, U.S. Army Laboratory Command (1984-1989) and as program manager for various areas of infrared technology and electro-optics at the Army Night Vision and Electro-Optics Laboratory (1962 to 1983), he studied and developed several novel applications of IR imaging, including "smart" image processing, computer-aided detection, knowledge-based databases, IR-linked information-technology, and telemedical systems. For this work, Dr. Diakides received the Department of the Army Research and Development Achievement Award in 1973, and was presented the Commander's Award for Civilian Service by the Department of the Army for his significant contribution in military programs ranging from the creation of vision aids for night fighting to the improvement of antitank munitions' effectiveness in 1989. Moving from the government to the private sector, he established and served as president of Advanced Concepts Analysis, Inc. (1989-2009), a corporation dealing with advanced biomedical technology and innovative defense research on sensors.

Dr. Diakides was an active member of the Institute of Electrical & Electronics Engineers - Engineering in Medicine and Biology Society (IEEE-EMBS). He served as the publicity chair and member of the conference and technical program committees at the 16th annual IEEE-EMBS International Conference, Baltimore, Maryland in 1994. He organized infrared imaging-related workshops and symposia for IEEE-EMBS international conferences from 1994 to 2006, and served on a number of IEEE-USA committees, including the R&D Policy Committee (1994-2010), Healthcare Engineering Policy (1989-1994), and EMBS

Technical Committee (on imaging and imaging processing; 2005-2010). In recognition of his lifelong achievement, and commitment to the field, he was named as a Fellow of the American Institute of Medical and Biological Engineering.

As impressive as this corpus of work may be, Nicholas was a firm believer that science is not authenticated until it fulfills its social trust. In other words, it must be "…taken out of the ivory tower and given to the man on the street." Ardently committed to this public responsibility – and to that of educating the next generation of scientists, he was a prodigious author and editor, both disseminating his own work, and mentoring and shepherding the work of others. Dr. Diakides authored book chapters on "Phosphorous Screens" in *Electronics Engineers Handbook* (2nd, McGraw-Hill Book Company, 1982) and "Advances in Medical Infrared Imaging" in *Medical Infrared Imaging* (CRC Press, 2007). He served as guest editor for *IEEE EMDB Magazine* special issues on medical infrared imaging (July/August 1999, May/June 2000, November/December 2002) and was section editor of "Infrared Imaging" in the *Biomedical Engineering Handbook* (3rd Edition, CRC Press, 2006). He was the co-editor of *Medical Infrared Imaging* (CRC Press, 2007), and published more than 50 papers in the peer-reviewed scientific literature.

Yet, for Nicholas giving science "…to the man on the street" was not simply *praxis* – a classical Greek term that refers to a "doing"- it was a craft that involved, if not necessitated developing and constructing instruments that could be used as tools and implements; in the classical sense Nicholas embraced science-as-*poiesis*, an act of "creation." He was the inventor of the MedATR concept that led to the first IR-CAD for the early detection of breast abnormalities and other applications. A pioneer in the development of knowledge-based databases with standardized IR signatures validated by pathology, by 1994 and for the remainder of his exceptional career, Nicholas led an international effort to establish the use of advanced digital infrared imaging in medicine, and championed this effort as a member of the Executive Committee of the American Academy of Thermology (1998-2010).

Dr. Nicholas A. Diakides unexpectedly passed away on August 9, 2009 at his home in Falls Church, Virginia after recovering from a severe infection. He is survived by his soul mate and wife of 36 years, Mary, brother Michael Diakides and daughter, Anastasia (Tasha) Diakides. Dr. Diakides is preceded in death by his parents and his three sisters, Zoi, Maritsa and Ekaterini.

Dr. Diakides' pioneering work in the development and science of infrared imaging was instrumental in setting the groundwork for numerous advances in medical IR imaging. And thus, we are compelled to once again ask, what is the measure of a man? Achievement? Certainly important. But Nicholas Diakides was not simply a man of great achievement. He was fond of acknowledging his Greek heritage, and was proud of his personal strivings to become what Aristotle referred to as *"phronimos"* – the man of great practical wisdom. For Aristotle, practical wisdom, *phronesis*, was the fulcral virtue – both intellectual and moral, and as such dictated and directed the good in both thought and action. It extends the richness and nobility of character into each and all of the tasks in which the man is engaged. So, while we acknowledge the magnitude of Dr. Diakides' accomplishments, we stand humbled before the virtuous character and wisdom of Nicholas Diakides, the man. To quote Aristotle: "…virtue makes us aim at the right mark, and practical wisdom makes us take the right means…not in some particular respect…but about the good in life in general".[1]

Dr. Diakides will be missed, not only by his family and friends, but by those who have benefited directly and indirectly from his lifelong work in the field of IR imaging, and who have come to know the strength of his intellect, wisdom and character.

Timothy D Conwell, D.C.
Medical Director, Colorado Infrared Imaging Center

James Giordano, Ph.D., M.Phil.
Director, Center for Neurotechnology Studies Potomac Institute for Policy Studies, Arlington, VA, USA
and Senior Research Associate, Wellcome Centre for Neuroethics and Uehiro Centre for Practical Philosophy, University of Oxford, Oxford, UK

Reference

1. Aristotle. *The Nicomachean Ethics*. (Ross, D; trans). London: Oxford University Press, 1966; p.142.

News in Thermology

EAT-Webpage extended

Recently, new features were added to the EAT-Website. One of these is the **thermal image of the month**.This section presents unusual thermal images from the fields of human or veterinary medicine, which provide new insights in medical and veterinary problems.

Images to be submitted should be recorded with the rainbow palettte and a short description must explain the unique content of the image.

The section on membership was revised and states now clearly the requirements how to become a member of the EAT. It reads as follows:

Procedure for applying for EAT membership

An applicant should express his/her interest in becoming a member of the EAT by sending an email message or letter to the with copies to the and the , who have to ratify each applicant. These copies will speed up the decision process.

In your application please include your title and/or academic degree as well as your citizenship within Europe as only European academics can become ordinary members.

In addition to an email address we also need a full postal address, the latter for delivery of your copies of the journal "Thermology International".

Although optional, it will be useful if the applicant could also indicate why they wish to join the EAT.

Legal bodies such as scientific associations must declare the country where they are located and state that promoting thermology is the aim of their non profit organisation. Addresses and the optional information are the same as for individual members

The annual fee is 50.- Euro which includes a subscription to "Thermology International".

Rules for becoming a member in the EAT are available in paragraphs 4 to 7 of the EAT statutes.

Visits on the Website

Finally, the webmaster of the page and current president of the EAT Prof James Mercer, performed a statistical analyis of attendance at the webpage.

A table 1 shows, there is a constant increase of visitors at the website, starting with 22 visits/day after lauching the site in July 2009 and reached 70 daily visits by the mid of March 2010.

The visits in Februar 2010 were analysed for the country of which the visitors originate. 51 countries were be identified, for 224 hits the country remained unknown. The highest number of visitors were found for Norway (1433).The next down to rank 20 were United States (618), Romania (335) Sweden (286), Netherlands (230), Great Britain (229), Canada (208), Poland (90), Denmark (79), Brazil (73), Germany (61), India (53), Portugal (52), China (50), Australia (39), Italy (35), Kuwait (35)France(34), Turkey (33) and Austria (32.)

The analysis of search words, which brought in February 2010 visitors to the EAT-Website, were thermology (44 hits), thermography (25 hits), thermal (23 hits), european

Table 1
Visits at the EAT-website July 2009-mid of March 2010

	Average/Day					Totals				
Month	Hits	Files	Pages	Visits	Traffic	Hits	Files	Pages	Visits	Traffic
Mar 2010	458	301	191	70	20,32Mb	10549	6935	4412	1616	467,25Mb
Feb 2010	596	380	341	61	19,05Mb	16705	10642	9559	1723	533,37Mb
Jan 2010	474	297	247	50	14,71Mb	14723	26086	21652	4914	456,08Mb
2010	511	326	264	59	17,76Mb	41977	26806	21652	4914	1,42Gb
Dec 2009	383	237	215	49	15,15Mb	11889	7366	6692	1529	480,65Mb
Nov 2009	462	291	300	50	19,52Mb	13869	8739	9005	1500	585,65Mb
Oct 2009	345	210	185	44	1,53Mb	10705	6518	5745	1367	357,57Mb
Sep 2009	387	258	172	52	14,55Mb	11624	7756	5187	1564	436,49Mb
Aug 2009	317	213	146	43	13,11Mb	9840	6621	4529	1335	406,30Mb
Jul 2009	192	121	76	22	7,90Mb	5965	3767	23,67	701	244,77Mb
2009	347	221	182	43	13,65Mb	63892	40767	33518	7993	2,45 Gb
Totals	398	254	207	48	14,92Mb	14,92	105869	55168	12907	3,88 Gb

(21 hits), international (15hits) fever screening (15 hits), infrared (15 hits), thermological (14 hits), association (12 hits), imaging (10 hits) and more than 20 other terms which received less than 10 (between 9 and 2) hits. The predominant keyphrases were "fever screening and infrared thermal imaging: concerns and guideline" and "thermology international"

Merger of the German Societies

The merger of the German Society for Thermography & Regulation Medicine with the German Society of Thermology initiated in Autumn 2008, agreed by the General Assembly of the two societies in June 2009, was now finally accepted by the German Register of Associations Since January 2010 the German Society for Thermography & Regulation Medicine remaina as the sole association for medical thermology in Germany.

After this merger, this journal does not serve any longer as publication organ for German thermologists as the German Society for Thermography & RegulationMedicine has not yet decided to use Thermology international as their official publication organ

The Bergmann-Award for Thermology is now also under the patronage of the German Society for Thermography & Regulation Medicine. Submissions for this prize, which is the only around the world awarding scientific work on thermology, will be announced in due course.

Meetings

2010

19th – 21th July 2010

7th International Conference on Heat Transfer, Fluid Mechanics and Thermodynamics-HEFAT2010
Antalya, Turkey

Important dates

Final paper acceptance feedback: 1 March 2010
Early bird registration deadline: 10 March 2010
Final registration deadline: 10 May 2010

Further Information:
Prof Josua P Meyer
Chair: School of Engineering
Head: Department of Mechanical and Aeronautical Engineering, University of Pretoria, Pretoria

Tel: (012) 420 3104, Fax: (012) 362 5124
E-mail: josua.meyer@up.ac.za
Conference website: http://www.hefat.net

27-30th,July 2010

QIRT 2010 The 10th Quantitative Infrared Thermography Conference at Université Laval, Québec City, Canada

Important dates

May 20th, 2010 - Advance registration

Topics:

• State of the art and evolution in the field of infrared scanners and imaging systems allowing quantitative measurements and related data acquisition and processing.

• Integration of thermographic systems and multispectral analysis. Related problems like calibration and characterization of infrared cameras (mono and multidetector systems), emissivity determination, absorption in media, spurious radiations, three dimensionality of observed objects, certification and standardization.

• Thermal effects induced e.g. by electromagnetic fields, elastic waves or mechanical stresses.

• Application of infrared thermography to radiometry, thermometry and physical parameters identification in all fields such as (and not limited to): industrial processes, material sciences, structure and material non destructive evaluations, medicine, and biomedical science, fluid mechanics, cultural heritage, environment, food production.

Further information

QIRT 2010 Secretariat

Electrical and Computer Engineering Dept.
Université Laval, Québec (Québec)
CANADA G1V 0A6

http://qirt2010.gel.ulaval.ca

7th & 8th October 2010

The Royal Astronomical Society, Burlington House, Piccadilly, London W1J 0BQ

Two day seminars, the first onthe development and general applications of infrared imaging,and the second on infrared imaging in astronomy will be held in London. The first will be organised under the auspices of The Royal Photographic Society, Imaging Science Group, and the second by the Royal Astronomical Society.

Provisional programme for 7th October (being organised by the RPS Imaging Science Group) will include:

- Robert Wood's introduction to infrared photography
- The historical development of electronic imaging in the infrared spectrum
- Medical applications of infrared thermal imaging
- Infrared imaging for thermal physiology of animals
- Applications of infrared imaging of buildings and energy conservation
- Aerial surveys using infrared imaging
- Non-destructive testing methods with infrared imaging

Contact: Prof F Ring

Email: efring@glam.ac.uk

13th November 2010

23rd Thermological Symposium of the Austrian Society of Thermology

Venue: SAS Hotel Vienna, Austria

Deadline for Abstracts: 10thOctober 2010

Speakers:

Prof Francis Ring, UK

Dr. Kevin Howell, UK

Dr. Ricardo Vardasca, Portugal

Prof. James Mercer, Norway

Prof. Anna Jung, Poland

Prof Adriana Nica, Romania

Prof Kurt Ammer, Austria

Electronic submission is preferred and strongly suggested (Email: KAmmer 1950@aol.com)

Information
Prof K. Ammer, MD, PhD
Austrian Society of Thermology
Hernalser Hauptstr 209/14
Email: KAmmer 1950@aol.com

2011

6-8 July, 2011

17th International Conference on Thermal Engineering and Thermogrammetry (THERMO)

at the Budapest University of Technology and Economics (BME), Budapest, XI .Müegyetem rkpt.3., Hungary

THE CONFERENCE ORGANIZER:
Branch of Thermal Engineering and Thermogrammetry (TE and TGM),

Hungarian Society of Thermology (HST) at MATE,
European Association of Thermology (EAT),

CALL FOR PAPERS

The photocopy-ready papers(for CD-ROM presentation) of max. ten A4 format pages to be presented on the conference are to be submitted before 15 February, 2011. To assist the work of the Scientific Committee the authors are kindly requested to point out the aim, method and results of their work in the summary to be provided according to the typing instructions.

Notification of the acceptance of abstracts will be forwarded to the authors until 30 November, 2010. The full text of all accepted papers will be included the CD-ROM Proceedings to be presented to the participants at the Conference

Information

Prof. Dr. Imre BENKÖ,

Budapest University of Technology and Economics (BME),
Faculty of Mechanical Engineering,
H-1521 Budapest, Muegyetem rkp. 7 / D.301. Hungary

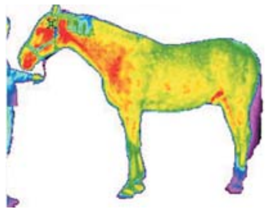
Phone/fax: +361-310-0999.E-mail: ibenko@freestart.hu

Veterinärmedizinisches Infrarot-Imaging

Schwerpunkt Pferde-Thermographie

(mit Zertifikat Stufe 1)

Kursprogramm 1. Halbjahr 2010



Veranstalter	Deutsche Gesellschaft für Thermographie und Regulationsmedizin e.V. (DGTR, gegr. 1954)
Kurstermine	15. und 16. Mai; 05. und 06. Juni; 19. und 20 Juni 2009 (jeweils Sa. und So.)
Examen	03. Juli 2010 (Sa.)
Ort	Rittergut Holdenstedt, Schlossstr. 2, 29525 Holdenstedt bei Uelzen, Lüneburger Heide
Dozenten	Prof. Dr. med. Reinhold Berz, Dr. med. vet. Andreas Feuerherdt, Armgard von der Wense

Seit 2006 bietet die DGTR in Verbindung mit der Pferdepraxis Rittergut Holdenstedt zertifizierte Kurse für equine Thermographie an. Diese Kurse basieren auf der US-amerikanischen Ausbildung und wurden für Deutschland ange-passt. An acht Ausbildungszyklen nahmen bisher mehr annähernd 75 angehende Experten für diesen Bereich teil, von denen der Großteil nach Ablegen der Prüfung das Zertifikat der DGTR erworben hat. Die DGTR bietet zusätzlich im Jahr 2010 einen zehnten Kurszyklus im zweiten Halbjahr an.

Kurs 1 15. und 16. Mai 2010

Grundlagen der veterinärmedizinischen Thermographie

Charakteristika der Infrarotabstrahlung an der Körperoberfläche

Infrarotstrahlung: physikalische Grundlagen

Die Infrarotkamera im praktischen Einsatz

Einsatzgebiete der Thermographie bei Pferden

Aufnahmestandards für die Thermographie am Pferd

Sicherheitsaspekte bei der Pferde-Thermographie Teil 1

Anatomie und Physiologie des Pferdes

Aufnahmestandards in der Praxis

Weiterbearbeitung von Messdaten am Computer

Messdaten-Management, Datenverarbeitung

Kurs 2 05. und 06. Juni 2010

Die Infrarotkamera als thermographisches Werkzeug

Besonderheiten von Infrarotkameras, Fehlmessungen und Fehlervermeidung

Demonstrationen und praktische Übungen mit der eigenen Infrarotkamera 1

Infrarotmessungen am lebenden Objekt: Wo und was wird gemessen, wie zuverlässig sind die Werte?

Sicherheitsaspekte bei der Pferde-Thermographie Teil 2

Die Beurteilung des Pferdes

Die praktische Arbeit mit der Infrarotkamera am Pferd: Standards selbst anwenden

Selbständiges Arbeiten im Stall mit Supervision: Messungen durchführen und Messwerte speichern

Realisierung veterinärmedizinischer Anforderungen in einem spezifischen Softwarepaket

Vom Messen zur Beurteilung, Schritt für Schritt

Aufbereitung der Ergebnisse, Beschreibung, Dokumentation und Erstellen eines Berichts

Präsentation der Lösungen durch die einzelnen Teilnehmer mit Feedback

Kurs 3 19. und 20 Juni 2010

Probeablegen der schriftlichen Prüfung

Besprechung der Resultate der probeweisen Theorieprü fung

Professionelle Handhabung der eigenen Infrarotkamera

Sicherheitsaspekte bei der Pferde-Thermographie Teil 3

Probeablegen der praktischen Prüfung am Pferd

Messungen durchführen, Aufbereitung der Ergebnisse bis zum Erstellen eines Berichts

Besprechung der Ergebnisse der probeweisen praktischen Prüfung

Examen 03. Juli 2010

schriftliche Prüfung

praktische Prüfung am Pferd

Erstellen eines Berichts

Die Kurse bauen aufeinander auf, daher muss ihre Reihenfolge eingehalten werden. Es ist jedoch möglich, Kursteile vom ersten mit Kursteilen vom zweiten Halbjahr 2010 oder folgenden zu kombinieren. Ebenso kann das Examen auf einen späteren Zeitpunkt verlegt werden.

Gebühren Kurse 1 bis 3 : 395 Euro zuzüglich MwSt. pro Kurs

Examen incl. Zertifikat 275 Euro zuzüglich MwSt.

Anmeldung AG Veterinärthermographie der DGTR

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Vizepräsident: Dr. med. Helmut Sauer

Kassenführer: Dr. rer. nat. Ronald Dehmlow

AG Veterinärthermographie: Frau Armgard von der Wense

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• This journal is a combined publication of the Austrian Society of Thermology and the European Association of Thermology (EAT)
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- -

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