THERMOLOGICAL STUDIES
IN REHABILITATION AND RHEUMATOLOGY USING
COMPUTERISED INFRARED IMAGING

KURT AMMER MD

PhD Overview Report

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requirements of the University of Glamorgan/Prifysgol Morgannwg
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Abstract

This overview reports 31 studies, which have been performed by the author since 1989 to define the diagnostic value of thermometry and infrared imaging in rehabilitation and rheumatology. Some investigations were designed to characterise either treatment modalities, to clarify the role of temperature measurements as a method for follow-up or treatment monitoring in certain diseases.

Thermal imaging has an important impact in assisting the diagnosis of many diseases. A relationship between temperature and clinical signs was established in the following disorders: epicondylitis (correlation of hot spots with pain provoked by firm pressure or resisted movement, and pressure threshold), complex regional pain syndrome (elevated temperature is paralleled by swelling and pain, temperature elevation of the hand after radius fracture after plaster removal predicts typical X-ray changes), thoracic outlet syndrome (high correlation of the region of paresthesia and low temperature readings), muscular inactivity, acute stage of Herpes zoster and Raynaud’s phenomenon.

Thermal imaging is of little value for the assessment of disability in patients with knee pain and of questionable value in patients with carpal tunnel syndrome or fibromyalgia. Painful tendon insertions or acupuncture points on the auricle cannot be detected by thermal imaging.

Temperature signs in epicondylitis, complex regional pain syndrome and thoracic outlet can be successfully used for treatment monitoring. This might be also the case in radiotherapy of malignant breast disease. Infrared thermography, performed immediately after physical exercise can help to identify activated muscles. The value of thermal imaging for monitoring patients with lymphedema remains questionable.

Thermometry and thermal imaging can quantify the thermoregulation response of the body to therapeutic interventions. This was expected in treatments, which accumulate or remove heat from the body. Unlike the normal rules of physics, the duration of heat treatment seems to be more important than temperature, heat capacity and mass of the heat carrier. Large disturbances in the temperature shell can be equalized if this heat phenomenon acts for only a limited time.
On the other hand as a result of these studies, it became quite clear that the heat regulatory system is connected with other regulation systems of the body. Many of these influence the perfusion of vessels, which can result in temperature changes on the surface. In addition to the circulation system, pain and muscle function are the most important links to temperature regulation. Therefore any change or therapeutic modification of these systems might be seen on thermal images.
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1. INTRODUCTION
Since the early days of medicine changes of body temperature have been recognised as signs of disease. Before the days of scientific medicine certain diseases have related heat symptoms, which are detectable by general or localised, increase or decrease of skin temperature. Hippocrates had already developed a method to visualize regions of increased skin temperature \(^1\). He used moist clay, which dried faster over hot areas of the body, and resulted in a different colour of the clay. However, the complex system of heat regulation of the human body was not well understood until the early 20th century \(^2\)^3.

1.1. Thermoregulation
Thermoregulation of homeothermic beings operates to stabilise the temperature inside the body in order to guarantee a steady temperature level for the inner organs, mainly the brain. Usually the most stable temperature is the core temperature, in contrast to the shell, which varies to equalise influences on the core temperature, which is set at 36.8 to 37.0 °C. The shell, which is represented mostly by the extremities of the body, therefore regulates heat loss and heat accumulation. This is achieved by variation of the width of the very superficial skin blood vessels, which are under the control of the sympathetic nerve system\(^2\)^3.

Two additional mechanisms are available to prevent further disturbances of the core temperature. Shivering caused by non-voluntary muscle contractions results in heat generation and is a mechanism to avoid heat loss when vasoconstriction alone cannot meet this task sufficiently. In case of overheating, sweating will provide cooling of the skin caused by evaporation of the sweat \(^2\)^3. Any failure of these regulatory mechanisms of shell temperature will result in changes of the core temperature.

With knowledge of only the basics of temperature regulation, one can anticipate that skin temperature will vary in different areas of the skin, and will change in different ambient temperatures.

1.2. Thermometry
From the view of physics heat is a form of energy. Temperature is one of 7 base units which together with mass, length, time, electric intensity, light intensity and amount of substance is used to generate the basics of the measurement and dimension system of physics \(^4\)^5. Temperature is a link between mass and heat meaning that a certain amount of heat is related either to a high mass and low temperature or vice versa.
The German physician Wunderlich established the determination of core temperature as one of the basic investigations of scientific medicine. Unfortunately, measurements of the skin (shell) temperature did not achieve a similar level of acceptance partly caused by the lack of equipment for recording or mapping the superficial temperature in extended areas of the body. Only thermal imaging can meet this challenge.

1.3. Thermal imaging

Thermal imaging is based either on the principle of heat conduction or of heat radiation. Contact measurements use heat conduction for the determination of the surface temperature. Both, the old mercury thermometer introduced for fever detection and the more modern thermistors (using the relationship between temperature and electric resistance for measurement) use heat conduction from one surface to another for the determination of temperature. Mapping skin temperature by contact thermometry needs many single elements. Therefore this approach is either restricted to rather small areas or can provide only rough information on the distribution of skin temperature.

In contrast, liquid crystal foils which also depend on heat conduction can provide good temperature maps of skin areas up to a size of 40 to 60 cm². Cholesterol crystals in such a foil change their characteristics for light reflections dependent on temperature, which results in different colours at certain temperature levels. Based on this knowledge, it becomes quite clear, that liquid crystals do not provide real temperature measurements. This technique allows only a semi-quantitative determination of skin temperature. This means that each colour of liquid crystals represents a range of temperature and does not give the figure of a certain temperature level.

The determination of infrared radiation provides temperature measurement without contact. Detectors made from rare chemical elements are used to record the infrared emission of the environment. With knowledge of the emissivity of a body or a material the surface temperature of the investigated object can be calculated. Modern equipment provides a spatial resolution of temperature of 1 mm² at a field of view of 50 x 50 cm. A temperature resolution of 0.05°C can be achieved, and 60 to 100 images/second can be recorded.

A computer achieves the processing of all this data and the image generation. Most modern equipment has the hardware for primary image processing built into the camera, but external hardware, standard for image processing since the seventies, can still be found.
In medical applications, the minimum requirements for thermal images are: grey shaded and false colour images, recording of time triggered image sequences and the definition and quantitative evaluation of regions of interest. The latter must be possible in freely defined shapes and quantitative evaluation should provide the mean temperature and the standard deviation of the defined area. Information on the number of pixels and the position of the defined area on the screen is desirable. Other features such as the preformed measurement areas being changeable in size, form and position and spot temperature measurements make the quantitative evaluation of thermal images more useful. The determination of thermal gradients (change of temperature values within an area of interest) and of the relaxation time (time for the recovery of actual temperature values to baseline readings) can be also helpful.
2. DIAGNOSTIC USE OF COMPUTERISED INFRA RED IMAGING.

In this work, 31 studies \(^9\text{-}^{39}\) have been performed since 1989 to define the diagnostic value of thermometry and infrared imaging in rehabilitation and rheumatology. Some investigations were designed to characterise either treatment modalities or to clarify the role of temperature measurements as a method for follow-up or treatment monitoring in certain diseases.

Figure 1 gives an overview on the investigated regions where thermal studies were performed.

Figure 1

Body regions where temperature measurements have been performed

The hand and the forearm were the major regional foci of these studies \(13\text{/}31\). In two studies the total body was investigated. Temperature changes over the spine and over each big joint of the extremities (shoulder, elbow, wrist, knee, ankle) with the exception of the hip joint were studied in order to establish the diagnostic value of infra red imaging.
2.1 Reliability and validity of temperature readings

The reliability of infrared thermography must be known before it can be used for the interpretation of clinical data. The use of an external black body as a reference source has been recommended since the late seventies for calibration of thermal imagers. The validity and reliability of the temperature measurements can be found in the documentation and specification of modern equipment. A drift of temperature readings over time is known to occur in older thermal scanners and can still be found in some new imaging systems. Comparisons between contact and non-contact measurements have been performed in the past and the difference in temperature determination by both techniques is well known.

Data on the reliability of positioning regions of interest and the inter- and intra-tester reliability of temperature readings from IR-thermograms were not found to be available. Therefore, the author performed a study to check the inter- and intra-operator reliability of temperature readings in infrared images.

A series of thermograms of three patients suffering from thoracic outlet syndrome were selected for the trial. Three investigators independently evaluated the thermograms by marking regions of interest on the second and the fifth finger of both hands and recorded the mean temperatures of these regions. About one week later, the same investigators repeated this procedure.

The mean intra-individual temperature differences showed a range between 0.008 ± 0.06 and 0.088 ± 0.12°C. The mean value of the inter-individual temperature differences was maximal at 0.22 ± 0.29 and minimal at 0.01 ± 0.28°C.

Our measurements presented with a good intra- and inter-rater reliability. However, the same person should perform follow-up investigations in the field of IR-thermography.

The determination of non-geometric shaped regions of interest on infrared images can be difficult. In case of the hand only one part of the total skin area innervated by a single nerve may be used to determine the temperature of the total sensory nerve distribution. Previous data to support this approach were not found in the literature. Therefore we have investigated the question whether the temperature of the index finger is correlated to the temperature of the sensory distribution of the median nerve on the dorsum of the hand.

The infrared thermograms of 52 hands were examined before and up to 5 times after a moderate cold stress test (immersion of the hands with plastic gloves for 1 minute in water...
of 20°C). Regions of interest were defined on the dorsum of each hand with respect to the distribution of sensory fibers of the median nerve (ulnar site of the thumb, 2nd and 3rd finger and the radial site of the 4th finger from the finger tips to just above the metacarpophalangeal joints) and of the ulnar nerve (ulnar site of the 4th and total of 5th finger from the fingertips to the wrist).

Regions on the index and the little finger, from the fingertips to just above the metacarpophalangeal joints were also defined. The mean temperature of these 4 regions of interest was recorded. The differences of finger temperature (df = temperature of the index (if) minus temperature of the little finger (lf)) and of nerve areas (d = temperature of the median nerve area (mt) minus the temperature of the ulnar nerve area (ut)) were calculated. Temperature values and temperature differences were correlated at each measurement time. Finally, the difference of d minus df was calculated and all results were assembled into one file.

Electrophysiologic testing of the median nerve was performed in all the hands studied. A total of 16 hands presented with a distal latency longer than 6.0msec and in 16 hands the distal latency was in the range of 4.4 to 6msec. The remaining 20 hands showed normal values for the distal latency.

Prior to the cold stress test the mean temperature of the index was 0.06 degrees higher than the mean temperature of the median nerve area. At this time the little finger presented with a mean temperature of 31.93°C compared to 32.00°C for the ulnar nerve area. Correlation coefficients of 0.98 and 0.97 indicate that these values are almost identical.

For the cumulated file the difference of d minus df was within a 95% confidence interval of -0.03 and 0.29 degrees.

We conclude from these data that the temperature of the index or the little finger is highly representative for the temperature of the sensory area of the median or ulnar nerve, respectively. Therefore, regions of interest over these fingers should be used instead of areas over the sensory distribution of the median or ulnar nerve, because these areas may be difficult to define.

Both studies have shown for the first time, that the positioning of regions of interest can be performed with high reliability. Regions placed on single fingers provide valid information for the mean temperature of the sensory area of the median or ulnar nerve respectively. Thermal imaging may therefore be regarded as a reliable and valid method for temperature measurement.
2.2. Diagnosis of certain diseases

Thermographic diagnosis of a disease can be sometimes based on the evidence of a disturbed **thermal symmetry**. In healthy subjects a symmetric distribution of temperature can be found from one side to the other 42,43 and from the core to the temperature shell resulting in a thermal gradient from the proximal to distal parts of the extremities 44. On the trunk a hot V-shape can normally be detected on the back with higher temperature readings on the neck than on the lumbar spine 45. If symmetric involvement of body regions occur, the knowledge of normal values of the affected area is useful for correct interpretation 46. The thermal index created by Ring et al. defines such normal values 47,48, although a cut-off point for low temperature values is not provided. Low temperatures are only mentioned in the thermal gradients of hand to assess Raynaud’s phenomenon.

Pattern recognition is the method of thermographic diagnosis most used in female breast diseases 49. However, so-called **hot spots**, which can also be defined as a disturbance of the symmetry of heat distribution, may be either by a change in the side-to-side symmetry or in the proximal to distal gradient. It may also have an important role for the diagnosis of muscular disorders such as epicondylitis or fibromyalgia.

2.2.1. Fibromyalgia

A high number of tender points, which may correlate well with hot spots in thermograms 50, is an essential criterion for the diagnosis of **fibromyalgia**. Data on this correlation have not been previously published.

A study in 18 patients diagnosed as fibromyalgia by the criteria of the American College of Rheumatology was made to determine the number of hot spots in these patients 11. The patient findings were compared with those of a group of healthy subjects and also a group of pain patients who did not meet the diagnostic features for fibromyalgia.

Thermograms of the regions typical for the location of tender points were recorded after acclimatization for 15 minutes to a room temperature of 24°C. Hot spots were defined as any small area being at least 0.5 degrees warmer than the surroundings. After thermography the typical sites for tenderness were tested.

As expected, the number of tender points differed significantly between fibromyalgic patients and both control groups. Furthermore the number of hot spots was higher in patients with fibromyalgia than in healthy controls. However, there were fewer hot spot
than tender points, and a general coincidence of hot spots with tender points was seldom found. Although the number of hot spots is increased in patients suffering from fibromyalgia, the number of tender points on the patient cannot be replaced by recording hot spots in thermograms.

2.2.2. Epicondylitis

Binder et al reported that hot spots over the radial aspect of the elbow are a common finding in patients suffering from so-called tennis elbow. However, a relationship between the hot spot and pressure pain threshold was not established previously.

For the definition of such a relationship, the author performed thermal images of both elbows in 45 patients with elbow pain. 10 patients were re-evaluated after treatment resulting in a total of 110 thermograms. A visual analogue scale (VAS) quantified pain on firm pressure over the lateral epicondylus performed by the investigator's thumb and pain in resisted dorsal extension of the wrist. A. Fischer pressure algometer was used to determine pain threshold of the epicondylus and of the muscle bulge 5cm distal of the epicondylus. Spot temperatures were measured at these specific areas.

For calculation of diagnostic values (sensitivity, specificity, predictive values, accuracy and odds ratio) the following parameters were defined. Hot spots were identified by pattern recognition i.e. each hot area partly or totally separated from an eventually hot area over the forearm was accepted as hot spot. In addition hot spots were defined by a temperature difference greater than 1 or 0,5 degrees, respectively. Cut off levels for pain measured by VAS were set on 10 or 0 mm. Threshold levels less than 2,5kg/cm² or 4kg/cm² were accepted for algometry.

Identified hot spots showed an odds ratio of 9,4 for pain threshold below 2,5kg/cm², of 2,15 for pain on pressure (VAS >10) and of 2,78 for pain on resisted movements (VAS > 10). A temperature difference of 0,5 degrees revealed a sensitivity of 78% and a specificity of 60,2% (odds ratio 3,42) for pain threshold less than 2,5kg/cm². Pain threshold less than 2,5kg/cm²over any measuring points was found to be a test of maximal specificity for either pain on firm digital pressure or pain in resisted movements.

This study shows clearly, that temperature changes recorded by thermal imaging have a close relationship to clinical symptoms. Therefore hot spots may be used for treatment monitoring in patients suffering from epicondylitis.

This application of thermal imaging has also been studied.
The aim of this study was to determine the value of thermography and pain threshold measurements for the documentation of the course of disease and for monitoring the treatment of patients suffering from epicondylopathy humeri radialis.

The thermal images of both elbows of 27 patients with elbow pain were recorded before and after a physical therapy series. The outcome measurements were the same as in the study described above, i.e. pain on firm pressure over the lateral epicondylus performed by the investigator's thumb and pain in resisted dorsal extension of the wrist quantified by a visual analog scale (VAS). A Fischer pressure algometer was used to determine pain threshold of the epicondylus and of the muscle bulge 5cm distal of the epicondylus. Spot temperatures were measured at these specific areas.

The number of hot spots, the temperature difference between hot spots and the surroundings, and the tenderness over the hot spots decreased after treatment.

Identified hot spots showed an odds ratio of 1.7 (95% confidence interval 0.9 to 3.2) for pain threshold below 2,5kg/cm², of 4.7 (95% confidence interval 1.9 to 11.6) for pain on pressure (VAS >0); and of 4.5 (95% confidence interval 2.0 to 10.1) for pain on resisted movement (VAS >0). A temperature difference of 1.0 degree revealed a sensitivity of 38.1% and a specificity of 81.8% for pain threshold less than 2,5kg/cm².

Hot spots identified by pattern recognition bear a high risk for low pain threshold over the epicondylus of patients with epicondylitis. With respect to the high specificity of a temperature difference of 1.0 degree, healthy subjects can clearly differentiated from patients by thermal imaging. The combined use of thermography and algometry might therefore improve the evaluation of tennis elbow. We can conclude that both methods can be recommended for treatment monitoring in epicondylitis patients.

Painful tendon insertions can be found in several regions of the upper extremities. The positive findings on thermal images of patients with elbow pain raised the question if tendon insertions in the shoulder region will produce similar thermal changes. Only few information on thermal changes of the shoulder joint is available. However, shoulder pain is a frequent problem in physical medicine, which we see in our out-patient clinic. Most of the patients present with shoulder pain originating from periarticular structures as tendons, bursae and muscles. Some patients show symptoms of a frozen shoulder.

2.2.3. Shoulder pain

The aim of this study was to identify different thermal patterns in patients with different causes of shoulder pain.
64 patients with shoulder pain (23 patients with frozen shoulder, 41 with painful tendon insertions at the shoulder) were included in the study, 16 healthy subjects served as controls. Thermograms in the anterior and the posterior view of both shoulders were performed after patient's adaptation to a room temperature of 24°C for 15 minutes. Regions of interest were defined for the deltoid muscle and the projection of the humeroscapular joint. The mean temperature of these areas was recorded. Hot spots (at least 0.5 degrees warmer than the surrounding) were identified over the trapezius, the supra - and the infraspinatus muscles in the posterior view.

A visual analogue scale quantified overall shoulder pain. Passive range of motion of both humeroscapular joints was measured and the pain threshold for pressure was recorded over the mid trapezius muscle, the supraspinatus muscle and the tuberculum majus on both sides.

In the anterior view the side-to-side difference (mean temperature of the painful shoulder minus mean temperature of the healthy side ± 95% confidence interval)) differed significantly between the 3 groups (tendopathic shoulder: 0.01 ± 0.1, frozen shoulder: -0.20 ± 0.15, healthy controls: 0.19 ± 0.1).

Range of motion was more significantly decreased in patients with frozen shoulder than tendopathic shoulder. Healthy subjects showed a significantly greater range of motion than patients with tendopathic shoulders.

Frozen shoulder is characterized by a decrease of temperature over the affected side as reported by other authors. This might be caused by lower muscular activity due to decreased range of motion. Enthesopatic changes of the shoulder joint can only be differentiated from normals by clinical testing and not by thermography because of the lack of typical thermal changes in this disease.

2.2.4. The Hand

There are several clinical disorders, which present with thermal symptoms at the human hand. In general, these changes can be either hypo- or hyperthermal. Increased skin temperature is mostly related to the inflammatory process in joints, tendon sheaths, or bursae. Normal values for the temperature of the wrist under different room temperature conditions have been described in the literature 46,48. Normal values of small finger joints (metacarpophalangeal and interphalangeal joints) have not been published previously.

Our study 15 performed at a room temperature of 24°C emphasized the difficulty to define the lower cut off level of normal values. It was shown, that arthritic joints present with
higher temperatures than healthy subjects, but patients with nerve entrapment syndromes or Raynaud’s phenomenon show lower temperatures as healthy subjects. Unfortunately, temperature readings overlap in these three groups of subjects. Early recovery from a mild cold stress can be used to confirm the presence of an inflammatory process. Only the persistence of a negative thermal gradient from the finger tip to the metacarpophalangeal joints (or the hand, respectively), not low temperature readings of the fingers on its own are diagnostic for Raynaud’s phenomenon. Therefore a correct interpretation of thermal changes of small finger joints cannot rely only on the absolute temperature values.

Temperature changes are typical signs of the complex regional pain syndrome type I, formerly called reflex sympathetic dystrophy. Before 1990 no systematic investigation on heat changes after radius fracture was published. Therefore a study was performed to show a correlation between heat emission and early x-ray changes after radius fracture, in patients who were treated by immobilization with a plaster cast.

Patients had thermograms recorded under controlled temperature conditions. The first thermogram was made two hours after removing the plaster cast and another one week later. After the second thermogram an x-ray image of both hands was performed.

Analysis of variance of the temperature difference between both sides found an increased temperature of 0.6°C on the fracture side to be a sign of increased heat emission after plaster removal. In thermograms made one week later a temperature difference from side to side of 0.63°C was calculated which was significantly different. Sums of mean temperature and two-fold standard deviation were 1.6°C after plaster removal and 1.5°C at the control after one week.

X-ray images were classified as positive or negative, while images with slight changes were added to the positive class. From the coincidence of increased heat emission of the fractured side and positive x-rays sensitivity, specificity and positive predictive value were calculated.

After plaster removal the thermal changes showed that the sensitivity of the test was 71.4%, specificity 45% and predictive value 57.6% at a temperature difference of 0.6°C: Increasing the level of temperature difference to 1.6°C decreased the sensitivity to 33%, but specificity reached 95% and predictive value 87.5%.

For thermograms one week later, a sensitivity of 61.9% was found at the temperature difference of 0.6°C. Specificity was 75% and predictive value 72.2%. At the temperature difference level of 1.5°C a sensitivity of 76.2%, specificity of 15% and predictive value of
48.5% were calculated.

In conclusion from this study it is proposed that an X-ray should be taken of both hands, if a marked heat emission of the fractured side can be detected immediately after plaster removal or if the temperature difference is still greater than 0.6°C one week later. In this way early diagnosis and successful treatment of Sudeck's disease cannot be missed.

This increased heat radiation might be used for treatment monitoring, but no study has been published until the early 1990's to support this approach.

The course of 25 patients with Sudeck's disease 17 diagnosed by typical symptoms and X-ray changes was reported in 1991. In this study, thermal images were performed before, during and after treatment. All patients showed an increased temperature over the affected limb before treatment (mean temperature difference to the opposite, unaffected side was 1.3 °C). All patients were treated with high voltage galvanic stimulation and therapeutic exercise. A few were also injected with human calcitonin. Most patients showed a temperature decrease over the affected limb after 4 weeks of treatment. The decrease correlated very well with the reduction of pain and swelling and also with the resolution of radiologic changes.

2.2.5. Hypothermia & Carpal Tunnel Syndrome

Hypothermia may be caused by a reduced blood flow due to a low muscular activity or vasoconstriction. It is well known that pain is followed by high sympathetic activity, which leads to hypothermia. In contrast, a total loss of the autonomic sympathetic control of skin vessels leads to an increase in heat emission from the skin. Most nerve entrapment syndromes can be detected by typical cool areas of skin temperature localized in the sensory distribution areas of the affected nerve. Hobbins has described a typical hypothermic pattern in early cases of carpal tunnel syndrome, which will switch over to hyperthermia in late stages of this disease 54, but quantitative data on the frequency of these patterns have not been published.

The author performed a study to determine, if patients with a distal latency of the median nerve higher than 6.0 msec present with a hyperthermic pattern 18. The thermal patterns were defined by the difference of the mean skin temperature of the median nerve innervated area minus the mean skin temperature of the ulnar nerve innervated area. A difference of at least 0.5 degrees was defined as a hyperthermic pattern. A warmer ulnar area of 0.5 degrees or more was defined as a hypothermic pattern.
Thermograms were taken of 52 hands in 26 subjects before and every 5 minutes after a moderate cold stress test (CST) for 20 minutes. In all subjects a nerve conduction test of the median nerve was performed bilaterally. Distal latency was higher than 6 msec in 15 hands (severe carpal tunnel syndrome = sC), between 4.4 and 5.8 msec in 17 hands (moderate carpal tunnel syndrome = mC), and the remaining 20 hands showed the distal latency in the normal range.

Before CST, 5 sC-hands presented with a hyperthermic and 3 hands with a hypothermic pattern. 7 hands with mC showed a warm median nerve area, 2 hands with presented with a warmer ulnar nerve area. A hyperthermic pattern was seen 4 times in the 20 healthy controls and 3 times a warmer ulnar skin area was found in this group.

10 minutes after CST 5 hands with sC, 5 hands with mC and 4 control hands showed a hyperthermic pattern. A hypothermic pattern was found in 2 sC hand, 5 mC and 4 control hands. At this time, the temperature of the median nerve area had recovered to baseline readings in 14 controls, 10 mC hands and 6 sC hands. 20 minutes after CST, the median nerve temperature has not recovered in 5 controls, 3 sC and 2 mC hands.

In conclusion, there is a slight increase of the frequency of hyperthermic patterns in patients with severe carpal tunnel syndrome indicating that the entrapment of the median nerve is followed by a loss of the autonomic function in these patients.

2.2.6. Thoracic Outlet Syndrome

Hypothermia may sometimes only be observed after provocation tests as in the case of Thoracic Outlet Syndrome (TOS) where arm raising causes pressure on the nerve. The first quantitative evaluation of thermal images for the diagnosis of the mild form of Thoracic Outlet Syndrome 19 was presented at the 4th European Congress of Thermology in Bath 1994.

Thermograms of both hands were taken before and during three different stress tests. The mean temperatures of the second and fifth finger on the same hand, representing the areas supplied by the median and ulnar nerve, were compared. A cooling of one of these fingers compared to the other proved the paresthesias and sensation of cooling in the history of the patients and reinforced the diagnosis of TOS. From the results obtained from 32 patients and 17 controls predictive values, sensitivity and specificity for clinical signs were calculated. In this first study on TOS a sensitivity of 85% and a specificity of 39% was found. In a following re-evaluation of this diagnostic procedure in 138 hands revealed a sensitivity of 90% and a specificity of 54% 55. A consecutive study showed clearly that
thermal imaging could be used successfully for the evaluation of treatment in this form of nerve entrapment 56.

2.2.7. Raynaud´s Phenomenon

Application of a cold stress test confirms the diagnosis of Raynaud´s Phenomenon by monitoring typical recovery patterns in temperature. Similar reactions can be found after exposure to vibration in patients with vibration induced cold fingers 57.

A retrospective study was conducted on 71 patients suspected of suffering from Raynaud´s phenomenon 20. The aim was to clarify, whether cold fingers before a moderate cold stress test can predict a prolonged delay (more than 20 minutes) of rewarming, as diagnostic for Raynaud´s phenomenon. The thermal gradient from the metacarpophalangeal joints to the finger tips was calculated for each finger and cold fingers were defined by a temperature difference less than -0.5 degrees. Combining the frequencies of cold fingers with Raynaud´s phenomenon, resulted in a sensitivity of 78.4, a specificity of 72.4 and diagnostic accuracy of 74.0 of cold fingers for Raynaud´s phenomenon. Based on a positive predictive value of 58.5, it was concluded, that a prolonged delay of re-warming after a cold stress test can not sufficiently be predicted by cold finger and that a cold stress test is necessary to confirm the diagnosis objectively. Additionally, an intermediate group of patients was described, which show a delay of re-warming for 10 minutes, but full temperature recovery after 20 minutes. Therefore temperature measurements should be performed previous, immediately, 10 and 20 minutes after the cold stress test to differentiate this intermediate group from patients with true Raynaud´s phenomenon.

Use of muscles is a major source of heat production in man; therefore, fully functional muscles can be detected easily in thermograms as hot areas. Low activity muscles caused by neurological deficit or by pain inhibition should result in an asymmetric thermal pattern with low temperature over non-functioning muscles. Although the relationship between handedness and temperature distribution on the forearm was reported 58, data on the correlation between temperature and muscular activity of the lower leg has not been published previously.

2.2.8. The Lower Leg

Thermograms of 50 patients with pain in one ankle joint were re-evaluated for thermal asymmetry over the lower leg 21. Thirty-eight patients showed a pathological side-to-side difference of temperature over the ankle joint in a range of -1.8 to 3.4 degrees. Thermal asymmetry of the anterior lower leg, defined as side-to-side difference greater than 0.5
degrees was observed in 54% of patients. Nearly all of these patients showed a decrease of
temperature (mean of temperature on the affected minus temperature of the healthy side: -
0.32 ± 0.78) on the symptomatic side. A similar decrease of temperature over the muscles
of the anterior lower leg was found in a small group of 10 patients with palsy of the
peroneal nerve.

Muscular inactivity should be considered as a reason for regions of low temperature in
patients with painful ankle joints.

Furthermore, paretic muscles should present with a decreased heat production after
physical exercise. To prove this effect, we compared infrared thermograms of 10 healthy
subjects and 10 patients suffering from peroneal palsy after 12 minutes of exercise 22.
Healthy subjects exercised the right leg only, while the patients performed the exercises on
the paretic side. The group of controls showed unilateral warming over the lower leg
compared to the other side, whereas the patients who presented with a pathological
asymmetry of temperatures even before training, on the affected side were always cooler.
After training the healthy leg showed higher temperature on the lower leg, whereas the
affected side showed a decrease of temperature, especially in the ankle region. Infrared
thermography, performed immediately after physical exercise can help to identify activated
muscles for the modification of the training programme.

2.2.9. Lymphedema

Another cause of low surface temperature of extremities is the occurrence of edema. As
there is a lack on systematic thermographic investigation in this condition, the temperature
distribution was determined in patients with either primary or secondary lymphedema, and
the value of thermography for monitoring treatment modalities in lymphedema clarified 23.

In 39 women and 1 man, suffering from either primary or secondary lymphedema,
thermal images of the swollen limbs were taken at a room temperature of 20°C. Two
regions of interest were defined on the affected extremity, and the temperatures of those
areas of the swollen limb were compared with the contralateral side.

28 women had developed a secondary form of lymphedema after receiving treatment for
cancer (22 patients after breast cancer, 6 patients uterine or ovarian carcinoma patients).
Lower temperature values were detected on their swollen limbs than on the healthy side.
The remaining 12 patients (11 woman, 12 man) suffered from primary lymphedema of the
lower extremity. Of these, 7 showed a slightly bilateral form of lymphedema. The median
temperature of the affected (or more involved) side was 0.02°C higher than the healthy
side. In contrast to the findings in secondary lymphedema, marked cooling was not detected in either unilateral or in bilateral disease.

In 19 patients (9 with a swollen leg, 10 with a swollen arm) treated by manual lymphatic drainage, the course of lymphatic swelling was monitored by measurements of circumference of the limbs and by thermography. The mean temperature difference between the affected and healthy side was \(-0.25 \pm 0.59\,^\circ K\) before and \(-0.28 \pm 0.41\,^\circ K\) after therapy. Following therapy, a significant decrease in circumference differences was observed at all measurement sites, but only the maximal temperature and not the mean temperature were significantly reduced.

Different temperature patterns were found to exist in primary and in secondary lymphedema. Consideration must be given to lymphedema when interpreting cold areas in the thermograms of limbs. Removal of edema was followed by a more equal distribution of heat. The value of thermography for monitoring the treatment of lymphedema remains uncertain.

During this study it became obvious, that women who have received radiotherapy for their breast disease presented with elevated temperature values over the irradiated region. Therefore the temperature distribution over the breast and scar after mammary amputation was determined in 30 women, who had thermograms for their secondary lymphedema.

As a result of breast cancer 13 patients received a total and 17 a partial resection of the breast and in 19 women consecutive radiotherapy was performed. While in 3 patients radiotherapy was only completed 1 month before the thermography, all other 15 women had received radiotherapy 12 to 173 months earlier. A significantly greater side-to-side temperature difference was found in irradiated than in non-irradiated patients (2-sided p=0.08). As expected, in amputated, but non-irradiated patients, due to a decreased infrared radiation of the breast compared to the scar over the pectoral muscle, a side-to-side difference of \(0.78 \pm 0.95\,^\circ C\) was obtained, while the difference after radiotherapy was \(1.62\pm 1.29\,^\circ C\). This difference was more pronounced over the axilla (mean temperature of radiated side: \(33.4 \pm 0.9\,^\circ C\), mean temperature of non-radiated side: \(30.6 \pm 1.4\,^\circ C\)) in patients, who had finished radiotherapy just recently. The study demonstrates clearly, that skin changes after radiotherapy can be detected by thermography years after, and do not disappear totally in contrast to single radiation injuries.
2.2.10. Skin Inflammation

Inflammation of the skin can be detected by increased temperature. **Herpes zoster** is a virus-induced disease, which is characterized by inflammation, blister formation and pain in its acute stage. Data on the thermal changes in this disease are scarce. Therefore infrared images from 40 patients suffering from acute or chronic postherpetic pain were recorded and correlated with the intensity of pain and the duration of the disease.

Only 8 subjects presented with a temperature difference between the affected and contralateral side less than 0.2 degrees. The mean temperature difference of all patients was 0.51 ± 0.31 degrees. Higher temperatures were detected in early cases with disease duration 1–9 days (mean temperature difference: 0.70 ± 0.41 degrees) than in patients with pain scores greater than 79 (mean temperature difference: 0.52 ± 0.36). The thermal asymmetry in patients with acute or chronic postherpetic neuralgia seems to correlate better with the duration of the disease than with the intensity of pain.

Patients suffering from herpes zoster of the upper branch of the trigeminal nerve may present with a disturbed thermoregulation of the face. A slight asymmetry of temperature distribution (elevated temperature on the affected side) can also be found in patients with **facial paralysis**.

We compared the thermal images of faces from patients suffering from either disease. The mean temperature of one half of the face (front view, side view) and of half of the nose (front view) was determined. The side-to-side difference of temperature was calculated for each region of interest and these results were analyzed statistically. A higher proportion of patients suffering from herpes ophthalmicus show elevated temperatures on the affected side than patients with facial paralysis.

The conclusion drawn from this study is, that facial paralysis and herpes zoster must be considered together with disorders of the temporomandibular joint, the nasal and frontal sinuses, headache and occlusive disease of the carotid artery in interpretation of thermal images of the face.

2.2.11. Acupuncture Points

**Acupuncture points on the auricle** were identified by contact temperature measurements. To support these findings the correspondence of ear acupuncture points with thermal inhomogeneities on the thermal image of the auricle was investigated.
patients with several disorders of the locomotor system and in 10 healthy subjects 27.

Thermograms of both auricles were performed and the reference temperatures of the region correlated with toes, ankle, knee, hip joint, fingers, hands, elbow and shoulder joint as well as cervical, thoracic and lumbar spine were determined. Temperature values were analyzed statistically with respect to side-to-side differences, underlying diagnosis and compared to healthy controls. The following diagnoses were made in those 50 patients: Raynaud's phenomenon, osteoarthritis of the knee and gonalgia, algodystrophy after trauma (ankle, knee, hand), vertebral blockage of the cervical spine, secondary lymphedema after ablation of mammae, primary lymphedema of the lower extremity, periarthropathy of the shoulder.

Few statistically significant differences of temperature could be observed between patients and healthy controls. Only the mean auricular temperature of patients with shoulder disorders was significantly different from controls.

In single cases the auricle of the symptomatic side showed higher temperatures than the contralateral side. Thermal inhomogeneities did not correspond well with typical reference areas on the auricle.

2.2.12. Knee pain induced disability

A study was performed to investigate the anticipation of physical functioning in patients with knee pain by temperature values of the knee joint 28. Such correlations were not published previously. The Western Ontario and McMaster Universities Osteoarthritis Index (WOMAC) was used for the assessment of impairment and disability in patients suffering from knee problems 64. We have investigated a possible correlation between temperature of the knee joints and the WOMAC index.

40 out-patients with unilateral knee pain and 10 healthy subjects were included in the study. After completing the WOMAC index, thermal images of both knees were recorded with an Agema 870 Thermal Scanner following acclimatization to a room temperature of 20° C for fifteen minutes. Several regions of interest on the image in the anterior view of the knee were defined. One area covered the entire knee, one was placed over the patella, two others above and below the patella. A line scan was recorded at the mid of both patellae. Mean temperatures of all regions of interest were registered and the line scans were classified with respect to typical profiles suggested by EFJ Ring 64 and J-M.Engel 65. The results of the temperature measurements and the WOMAC scores were correlated.

A clinical diagnosis of osteoarthritis (19 femorotibial, 10 femoropatellar) was made in 29 patients. Inflammation of different causes was found in 8 patients and the remaining 3
subjects had knee pain related to injuries of the ligamental apparatus of the knee joint. WOMAC scores and mean knee temperatures of the total patient group differed significantly to the measurements of healthy subjects. However, in the subgroups ligamental injury and femorotibial osteoarthritis the temperature of the entire knee did not show a significant difference from the healthy subjects.

Analysis of discriminance classified 62% of cases correctly with respect to WOMAC-scores. Side to side difference of total knee temperature revealed a correct diagnosis in 42%. Grouping by the line scan was correct in 58% of symptomatic knee joints. In the total sample correlations between side-to side temperature differences and total WOMAC and its subscores were significant, but rather low (correlation coefficient between 0.19 and 0.26).

Some causes of knee pain are not followed by an increased heat emission over the knee joint, although these patients show symptoms such as pain, stiffness or disability. However, in patients with signs of inflammation, hyperthermia and WOMAC scores have a similar power for discrimination.

2.2.13. Sports Medicine

Finally, an overview on thermal imaging in sports medicine summarized the applications of this technique in the study of exercise and injury.

2.3. Summary of diagnostic studies

Thermal imaging has an important impact in assisting the diagnosis of many, predominantly rheumatic diseases. Inflammatory disorders can be better detected than degenerative changes of the musculo-skeletal system.

A relationship between temperature and clinical signs was established in the following disorders:

A correlation of hot spots with pain provocated by firm pressure or resisted movement, and pressure threshold was shown in epicondylitis patients.

In complex regional pain syndrome elevated temperature is paralleled by swelling and pain.

Patients suffering from thoracic outlet syndrome present with paraesthesia in the area of the hypothermic little finger.

A marked temperature elevation of the hand after radius fracture after plaster removal predicts typical X-ray changes of Sudeck’s dystrophy.
The acute stage of Herpes zoster is characterized by an increase of heat radiation from the affected area.

Muscular inactivity either caused by paresis or disuse can be detected by thermal imaging. Only a small correlation was found between temperature values and disability in patients with knee pain.

The diagnostic value of thermal imaging in patients with carpal tunnel syndrome remains questionable. Painful tendon insertions, well recognized in the elbow region, cannot be detected by thermal imaging in the shoulder region. A high number of hot spots can be found in fibromyalgia patients, but half of these hot spots are not located over tender sites. An intermediate group was described in vasospastic disease of the hand. Finally, thermal imaging cannot identify acupuncture points on the auricle.

Temperature signs in epicondylitis, complex regional pain syndrome and thoracic outlet can be successfully used for treatment monitoring. This might be also the case in radiotherapy of malign breast disease. Infrared thermography, performed immediately after physical exercise can help to identify activated muscles. The value of thermal imaging for monitoring patients with lymphedema remains questionable.
3. TREATMENT STUDIES

3.1. Influence of physical treatment modalities on the skin temperature

The author has studied the influence of cryotherapy, heat treatment, hydrotherapy, ointments and two methods of complementary medicine (acupuncture, manipulation) on skin temperature.

3.1.1. Cryotherapy

The use of liquid nitrogen in devices used for cryotherapy has become a common method in Physical Therapy. A wide range of measured temperatures (-50 to -180°C) has been observed in the literature. The temperature of cold gas was therefore measured with increasing distances from the applicator and varying output of the device.

The temperature measurements were carried out using a Technoterm 7200 Thermometer after a period of approximately 5 min, during which the device reached a constant operating temperature.

The results obtained were surprisingly high, with a minimum temperature of -112.9°C recorded in direct vicinity to the outlet of the applicator. At a distance of 20 cm, approximately the distance used in treatment of patients, the temperature recorded was -41.7°C only. Temperatures as low as stated in literature could only be recorded by measuring right at the outlet of the container.

Given that our experiments were conducted under optimized conditions, the conclusion we can draw is that the effective temperature reached in therapy is approximately -20°C.

Treatment with cold packs is frequently used in rheumatic complaints. Based on features of thermo-physics, like heat capacity and the mass of the cold pack, the cooling effect of cold packs can partly be predicted. Data on temperature changes after cold packs are only available for the knee joint and not for any other body region.

Aim of our study was to find out, whether treatment with small packs for long time are similar effective as large packs for a shorter time in lowering the temperature in the lumbar region.

In overall 20 measurements 4 different sizes of Apla retard cold packs (240, 288, 690 and 1050 cm²) were used for a treatment time of 5, 10 and 20 minutes with a surface temperature of -12°C. Temperature was measured with 6 computer-assisted resistant temperature decoders, which were placed under the cold pack on the level of lumbar vertebra 5, one over the left iliac bone and a third on the level of the thoracic vertebra 5.
Another thermometer was placed on the abdomen near the navel, one was placed on top of the cold pack and the last one measured the temperature of the room, which was set stable at 24°Celsius.

Our results indicated, that a treatment time of 5 minutes either with small or with large packs does not achieve a maximum decrease of temperature. A mean temperature decrease of 24°C was found after cooling the skin for 10 minutes. Re-warming of the skin was more likely a function of cooling time and not of package mass.

The conclusion reached in our study is, that for sufficient cooling the mass of cold packs is less important than the duration of cooling. Furthermore, the thermoregulation system can at least for 5 minutes counteract local heat loss.

The occurrence of hyperthermia after a short application of ice was repeatedly claimed. But data, which support this, are hard to find. Also confusion of skin redness (caused by temperature related delay of skin nerve conduction velocity which results in loss of the autonomic control of skin vessels) with hyperthermia may be suspected. Therefore the influence of short cooling for 10 or 30 seconds with covered or melting ice on the temperature of the forearm of healthy subjects was investigated. Using an Agema 870 infrared system, higher than initial temperature levels after recovering from cooling were only detected after application of covered ice. This elevation lasted 7 to 20 minutes. A maximum temperature decrease of 19.7 degrees was observed after melting ice for 30 seconds. Skin temperature after application of melting ice did not recover within 40 minutes. For estimation of temperature changes induced by cryotherapy, localization, duration of its use and the cold agent itself must be considered.

3.1.2. Heat Treatment

Hot packs and infrared radiation are used for a long time for the treatment of musculo-skeletal symptoms. The magnitude of the change of the skin temperature during and after therapy with hot packs or infrared might result in different clinical effects. Therefore the temperature changes of these treatment modalities were also investigated.

15 totally healthy subjects were allocated to three groups. Group 1 was treated with Perazon Parafango Packs (surface temperature of the pack: 47-49°C), group 2 with Moor Ascend Packs (surface temperature of the pack: 46-49°C) and group 3 with an infrared-A-radiator (90% output, distance to the treated body: 50 cm). The subjects were accustomed to the room temperature of 24°C for 15 minutes and were then treated for 20 minutes in the lumbar region. After treatment skin temperature was measured for another 20 minutes.
Measurement was made with 6 computer-assisted thermistors, the time interval was 30 seconds.

Each treatment modality showed a different temperature course.

Skin temperature changes from the use of parafango packs are characterized by a rapid rise of temperature. Peak skin temperature of 44°C was seen after the first 3 minutes. After removing the pack the skin temperature fell rapidly and reached the baseline readings 5 minutes after finishing the treatment. Then a further small increase in temperature was observed, probably due to the marked redness of the skin, possibly derived from substances in the pack, which irritate the skin.

The mudpack, (Moor Ascend), is applied to the body with a surface temperature of 26°C and is heated secondary by a hot mud bag, placed on top of the pack. The course of skin temperature showed a slow rise of temperature with a peak temperature of 42°C reached after 15 minutes. After removing the pack skin temperature decreased slowly and reached baseline values after 10 minutes. As in parafango packs a further small increase in skin temperature can be detected.

Skin temperature during **infrared-A-radiation** is characterized by a slow and steady increase of temperature, which reached its peak value of 40°C on the end of application. In the first 5 minutes after treatment temperature decreased rapidly to a value 2 degrees above the baseline value. A very slow decrease to the baseline value can be detected the next 13 minutes. Different to hot packs the skin temperature did not rise again.

Conclusion of this study is that statistically confirmed different courses of skin temperature are found. The use of hot packs is followed by a marked redness of the skin, which may not only be the result of the heat treatment. A following clinical study comparing these 3 heat treatments in patients with muscle spasms did not find a significantly different effectiveness of the 3 modalities, although there was tendency for increased effectiveness of the fango paraffin packs and infrared A over moor ascend mud packs in influence on pain threshold, pain tolerance and assessment of general improvement.

**Temperature measurements of hands after wax baths** have not been reported in the last 30 years. Data on the influence of unilateral heating of the hand on the temperature of the contra-lateral side are not available.
A study was therefore performed to investigate the rise of temperature after unilateral wax bath on the treated and on the contra-lateral non-treated side and to study the change of grip strength after heating 34.

10 healthy subjects heated the fingers of one hand in a randomized order in a cross-over design. The dip and wrap method or the continuous immersion method was used. Before and after heating thermal images of both hands were recorded and grip strength was measured.

A mean increase of finger temperature of 7.5 degrees C was measured after continuous immersion and 6 degrees C after the dip method. The grip strength did not change significantly after either form of heating. However, a slight decrease was detected after continuous immersion and a slight rise of grip strength was seen after the dip method. 9/10 subjects qualified the dip method as the more comfortable form of heat therapy.

The dip method produced a mean rise of finger temperature, which did not affect the thermoregulation process as much as the continuous immersion.

3.1.3. Hydrotherapy

Hydrotherapy is a complex treatment approach, which uses the physical properties of water, temperature and of chemical compounds either naturally dissolved in the water such as sulphur of CO2 or added to the water such as etheric oils.

Emissivity of the skin is an important feature for temperature measurements by infrared. As infrared emission occurs in the most superficial layers of the skin, and water might be stored in the corneous layer during bathing, it should be possible to detect a change of emissivity of the skin after bathing 35. Examples of changes of skin emissivity after bathing for 15min in thermally indifferent and also in slightly cool water have been presented. The conclusion achieved in this study indicated that bathing has induced only slight changes of emissivity.

Etheric oils are used in hydrotherapy. This is based on the assumption that some etheric oils might enhance the local blood flow of the skin. Therefore an attempt was made, to document such an effect by means of infrared thermography 36. Healthy subjects bathed their forearms and hands in water of 36° for 20 minutes. While the right forearm was immersed in 15 l of plain water, the bathing water of the left forearm contained one of the following etheric oils:

0,2 or 0,6ml/l water rosemary oil (1ml contains 0,05 g of the compound)
0.2 or 0.6 ml/l water turpentine oil (1 ml contains 0.01 g of the compound)
0.2 or 0.6 ml/l water pine-needle oil (1 ml contains 0.075 g of the compound)
0.2 or 0.6 ml/l water juniper oil (1 ml contains 0.0075 g of the compound).

5 probands were investigated for each oil and dose.

The heat radiation of the supinated hands and forearms was recorded with an Agema 870 infrared camera before and after bathing. On each thermogram regions of interest were defined over palms and forearms, and mean, minimum and maximum temperatures of these areas were analyzed statistically.

This analysis showed after bathing with the 3-fold concentration of turpentine oil a trend to different heat radiation compared to bathing in plain water. Temperature changes were better reproduced on forearms than on hands. The results support a possible modification of microcirculation of the skin by etheric oils.

3.2. Ointments

It is well known that creams and ointments affect the infrared emission of the skin. But data on the development of skin temperature after application of topical drugs are not available. Therefore the change in skin temperature after application of antirheumatic ointments, gels or skin irritants is reported. Most gels or ointments produced a transient decrease of skin temperature, which recovered to baseline readings within 30 minutes after application. 1 gel caused hypothermia, which lasted longer than the observation time of 30 minutes. 4 preparations, 1 containing nicotinic acid, 2 etheric oils and 1 capsaicin, caused a slight and transient hyperthermia of the treated skin area.

The time course of skin temperature might be related to the chemical structure of the drugs within the ointment, because two commercial preparations of diclofenac from different manufacturers resulted in identical temperature profiles in the phase of re-warming.

3.3. Complimentary Medicine

The author has studied the influence of two frequently used methods of complementary medicine (acupuncture, manipulation) on skin temperature.

3.3.1. Manipulation

Vertebral blockage is the most important pathology of manual therapy, which results in pain, muscle spasms and disturbed blood flow. This pathology can be removed by
manipulation. If this model of the pathology of certain spinal disorders is correct, some consequences of blocked vertebra may be detected by thermal imaging.

In 29 out-patients with vertebral pain syndromes infrared thermograms were made before the manual examination and immediately after manual therapy\textsuperscript{38}. The back was divided into four regions (cervical spine, shoulder girdle, thoracic and lumbar spine) and the symmetry of all these regions was assessed. Mean, maximal and minimal temperature of both sides of these areas of the back was measured. All patients had at least one vertebral blockage and all showed an asymmetry of the back thermogram. After mobilisation of the blocked vertebra a few had improved symmetry of the temperature pattern. Although some patients had an increased heat flow after therapy, mean temperature of the surface was reduced immediately after treatment. The use of thermography is recommended for monitoring of this special form of back pain. However, identification of the level of the blocked vertebrae is not possible by thermal imaging.

3.3.2. Acupuncture

In classical acupuncture the method of needle insertion (needling technique) varies depending on whether the flow of energy is to be increased or decreased. The aim of this study\textsuperscript{39} was to demonstrate the differences in the effect of a tension increasing and a sedating form of needle insertion by means of acral temperature reactions (ATR).

Ten healthy subjects (5 females and 5 males) participated. The acupuncture point LI 11 was stimulated with the tension increasing technique on the first day and with the sedating method on the following day. A computer-assisted multi-channel Thermometer with 3 thermistors was used to measure the temperature in the region of the groove of the nail bed on the index finger, on the acupuncture point LI 4 and next to the needled point LI 11. Readings were recorded every second for one hour.

After adaptation to the environment (room temperature: 22 ± 1 °C), the acupuncture point was stimulated 4 times at intervals of 5 minutes. Temperature readings were continued for 25 minutes after the final stimulation. The same procedure was used for both forms of needling.

All stimulations, independent of the needling method, resulted in a typical ATR. A definite difference in the overall pattern of the temperature change of the two methods was found in all subjects. The average decrease in temperature was greater for the sedating needling procedure. This result supports the observations that tension increase and sedation needling have different effects on the microcirculation.
The results of this study were confirmed by others using infra red thermal imaging for temperature recording.  

3.4. **Summary of the influence of treatment interventions on skin temperature**  
Thermometry and thermal imaging can quantify the thermoregulation response of the body to therapeutic interventions. This was expected in treatments, which accumulate or remove heat from the body. Nevertheless different to physics the duration of the heat treatment seems to be more important than temperature, heat capacity and mass of the pack. Obviously rather big disturbances in the temperature shell can be neutralized if this heat phenomenon acts for limited time.

On the other hand it became quite clear that the heat regulation system is connected with other regulation systems of the body. Many of these influence the perfusion of vessels, which can result in temperature changes on the surface. Pain and muscle function are the most important links to temperature regulation. Therefore any change or therapeutic modification of these systems might be seen on thermal images.
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