Invited papers

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Computerised thermography for osteo-articular diseases

The assessment of a disease process is dependant on suitable indicators. In diagnosis, treatment or research quantitative assessment methods are needed, for only by this means can the procedure be adequately standardized. Arthritis is often measured by subjective methods, many of which carry large observe-reproducibility errors. Calor and rubor are common indicators of joint inflammation, and these are clearly shown by modern thermographic techniques.

Earlier studies of joint temperature have been limited, since intra articular thermocouples are invasive and unsuitable for routine use. Surface measurements with thermocouples and thermistors are slow and themselves introduce errors through contact and pressure. The two dimensional infra red scan, or thermogram is a rapid and efficient record of temperature, and suitable for temperature monitoring of articular joints.

Studies carried out in this department in Bath over the last 12 years have shown that surface temperature of peripheral joints does relate to the degree of inflammation. For example, examination of synovial fluid aspirated from inflamed joints, shows that changes in biochemistry and cytology occur in direct proportion to the surface temperature of the joint.

Technique

The essential requirement for all quantitative thermographic measurements is rigid standardization of technique [3] The examination procedure is carried out in a room at 20°C with an infra red thermograph mounted on a special stand. Scanning of all joints is made with the camera on a horizontal mount, with vertical adjustment from 20 cms to 150 cms. Patients are cooled prior to their examination in a curtained part of the room for 15 minutes, with the limbs exposed.

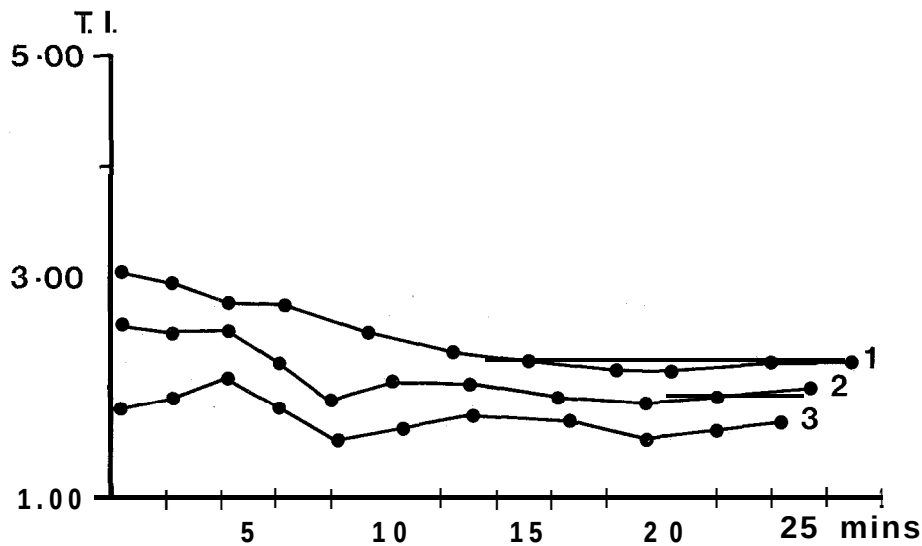

Fig. 1. The fall in the thermographic index of the knees of three subjects cooling in ambient temperature of 20°C.

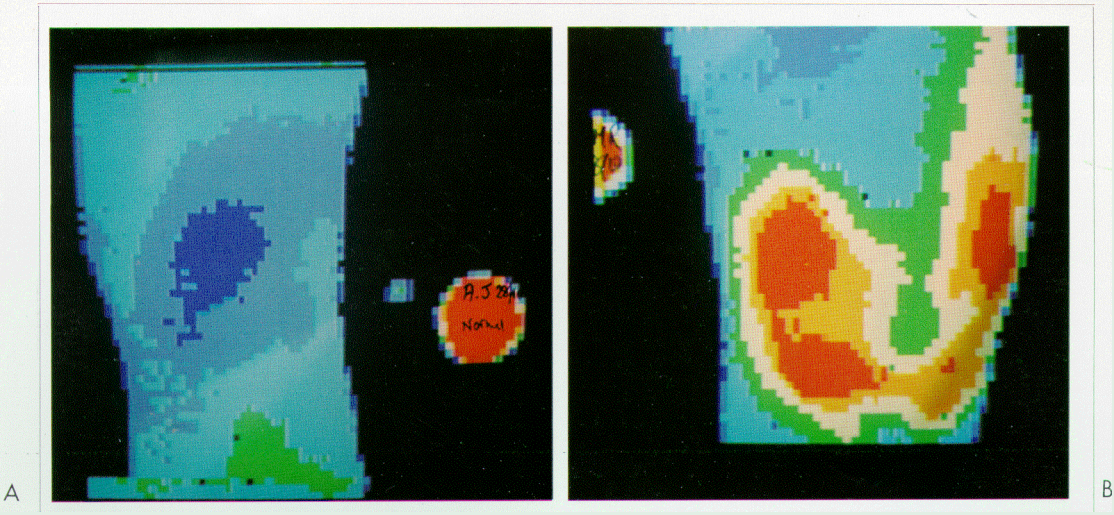

Fig. 2. (A) Thermogram from the computer display of the anterior view of a normal knee showing a cold patella. The reference source (red) is at 32.5°C and the blue isotherms 26-27°C. (B) Thermogram as A from a rheumatoid arthritic knee, with early acute synovitis.

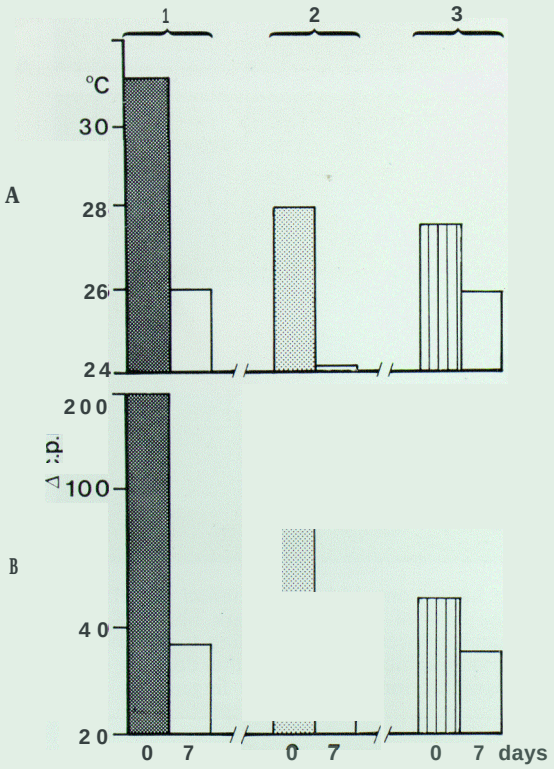

Fig. 3. Comparison of surface temperatures (A) of three rheumatoid arthritic knees (3 patients) with changes in Iodine 131 clearance (B), before and seven days after prednisolone injection.

Standard positions are adopted for each joint and a constant temperature reference usually at 32.5°C included in the picture. Experience has shown that a temperature range of 26-33°C is the most suitable for peripheral joints after cooling at 20°C. However, a second range 28-35°C is used for hands and tibia1 thermograms. The pictures are transferred from the infra red thermograph to a Pd P8 minicomputer, which is compled to a colour television monitor. The thermogram is displayed in a range of colours set at 0.5°C intervals. Each colour always indicates the same temperature and abnormalities are immediately visible. Since the colour image is displayed from digital data, a region of interest may be selected on a 64 x 64 bit x-y axis. The numerical data can be printed at the teleprinter terminal to 0.l°C.

The thermographic index

The method used to quantitate the thermogram was published by Collins [1]. It is based on the proportion of isotherms within a chosen region over a selected temperature range, usually 26-33°C.

The formula $T\ I = \frac{t \times a}{A}$ expresses this calculation

t = baseline temperature 26 or 28

t = difference in degrees between the isotherm measured and that baseline, i.e. at 27.5 (t=26) t=1.5

a = arca in sq cms of each isotherm

A = total area quantitated in sq cms

In practice the area of each isotherm within the selected area is measured and multiplied by its baseline difference. Using half degree intervals, each total is added together and divided by the total area to be quantitated.

Using this formula a scale from 1.00-6.00 is obtained. Normal values are low 2.00 and inflammatory joints are raised up to 6.00. Normal values for this index arc shown in Table I. The rate of cooling of three normal knees using the index is shown in Fig. I. Studies of temperature stabilization, diurnal variation and anti inflammatory drug therapy have been made using this system of quantitation. A total of 8,000 measurements to date have proved the reliability of this thermographic index for peripheral joints.

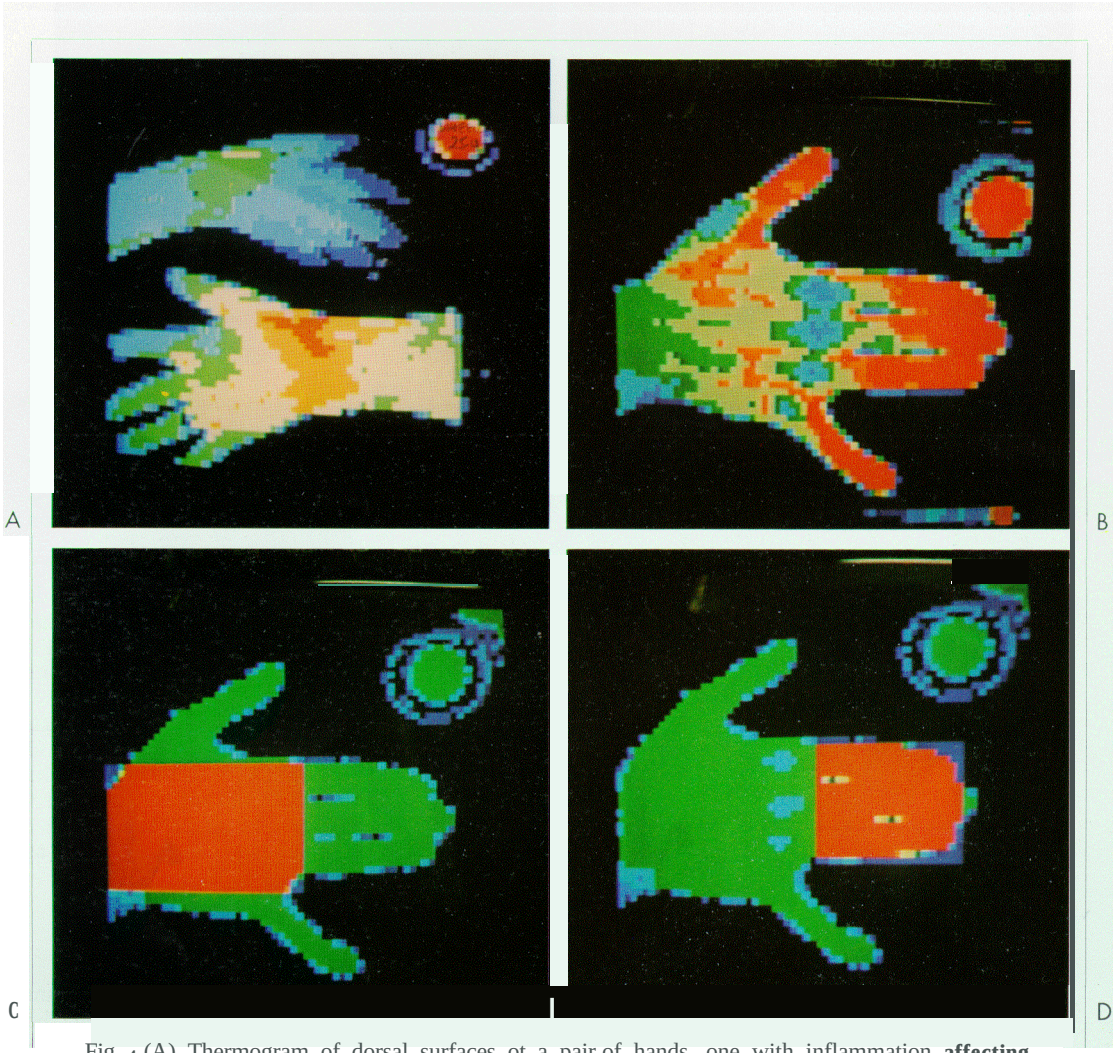

Fig. 4. (A) Thermogram of dorsal surfaces ot a pair of hands, one with inflammation **affecting** the m.c.p. joints and first carpo-metacarpal joint at the base of the thumb. Dark blue-28.0, red = 34.5°C (B) Hyperaemia of dorsum of a normal hand induced by mild cooling for 60 secs in water at 20°C. (C) Area quantitated for the thermographic index from the dorsum of the hand. (D) Area quantitated for the thermographic index from three fingers.

The knee joint

This is the largest and simplest articular joint for thermographic examination. Our patients are routinely scanned in a standing position for anterior views. Single joints scanned this way can be quantitated from a region of interest containing 900 counts, an area approximately 10 cms x 10 cms located over the patella. A normal knee is usually close to 26°C with a characteristic cold patella. Using a reference at 32.5°C (red) the normal joint is seen in shades of blue. In contrast an inflamed arthritic joint marked by synovitis, shows temperature increases, from green-yellow-orange to red (Fig. 2). A chronic rheumatoid arthritic knee may be extremely hot, and show the outline of the joint capsule. Early acute arthritis, however, may show a more localized hyperthermia often in the infra patella area. Lateral views of the knee are also useful and necessary if the patient has a severe flexion deformity or unable to stand. These are conveniently made the patient in a normal sitting position in a chair with the knees flexed at 90". The thermographic index is a little higher in lateral thermograms of the normal knee, and medial views raised even more in some subjects due to the long saphenous vein. These differences, however, are small compared with the increase found in inflammatory joint scans. The injection of infra articular steroids into the knee is an established form of local therapy'. The synovial blood flow is reduced after infra articular steroid injection. This can be demonstrated both by the rate of isotope clearance e.g. Iodine 131 Tc 99 and change in surface temperature (Fig. 3). Thermographic studies of the effects of differing analogues of Prednisolone has shown that even the most insoluble compounds have some systemic effect. By studying the temperature changes in an injected knee and the contralateral untreated joint the local and systemic effects of treatment are shown. The clinical signs of relief from pain and stiffness may last for longer periods, but thermography shows that the inflammation often returns within two weeks of the injection. Increasing the dose of steroid, may improve the initial sharp decrease in thermographic index, but is unlikely to have much influence on the duration of anti inflammatory effect.

Tab. I.

No	Location	Thermographic index: Mean t. index	Thermographic index: Range ±S.D.
10	Lateral elbow	1.93	1.48-2.37
70	Dorsal hands (wrist-m.c.p. joints)	1.73	1.38-2.08
60	Anterior knee	1.65	1.18-1.13
20	Medial malleolus	1.43	0.99-l .87
20	Lateral malleolus	1.34	0.85-l .83
10	1st. m.t.p. (medial)	1.03	0.84-l .23

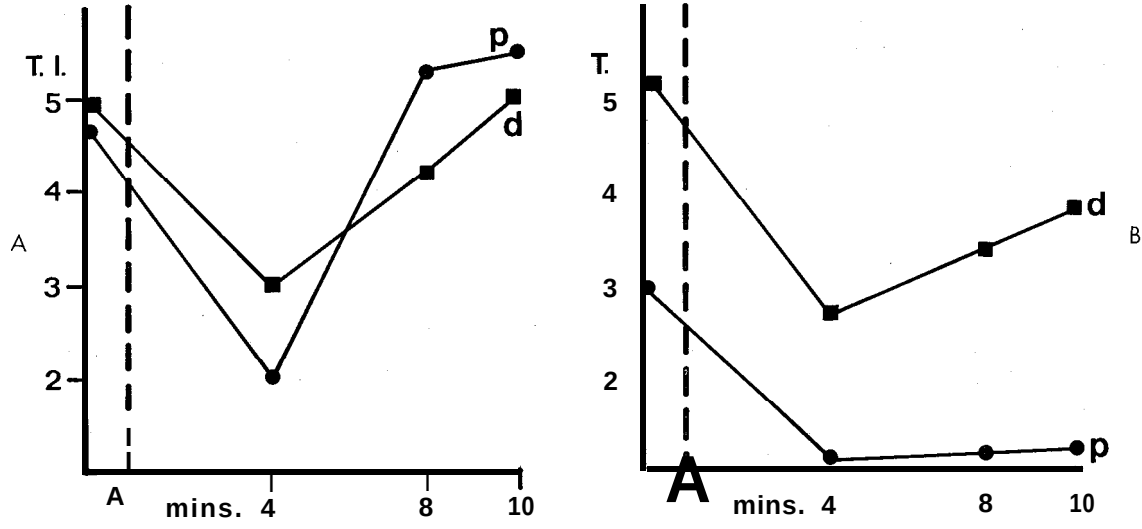

Fig. 5. The change in thermographic indices from the two areas shown in Fig. 4c (■—■) and 4d (O-O) of a normal (A) and rheumatoid Raynaud (B) hand.

The hand

Thermograms of the dorsal surface of the hand are made against a small board held by the patient against the thorax. This serves as a heat screen excluded unwanted radiation from the body, and has a small temperature reference attached. By using a temperature range of 2835°C values for the thermographic index fall within the range of other peripheral joints. The areas selected for quantitation are 1) a rectangle from the wrist to metacarpal joints; 2) a rectangle from the metacarpal to p.i.p. joints of the middle three fingers (Fig. 4).

For the assessment of anti inflammatory drugs the wrist-metacarpal area is measured from both hands, together with both knees. These four sites form a useful composite from which the effect of therapy can be judged. Other specifically inflamed joints can be added to this group as appropriate. In Raynauds disease, the fingers are cold, and fail to produce reactive hyperaemia on

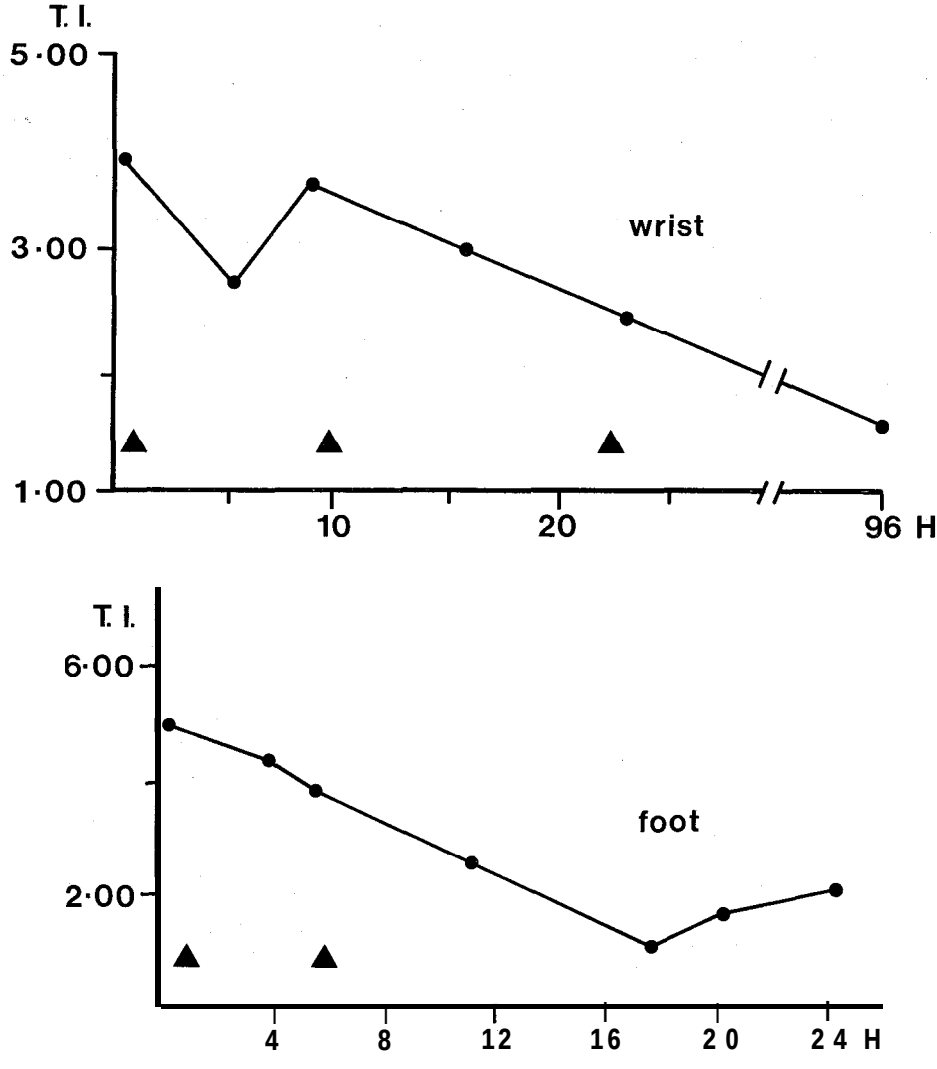

Fig. 6. The short term response to an oral non steroid drug in two cases of acute gout. The triangles indicate the frequency of treatment with indomethacin 50 mg. The graph A shows the transient effect of the first dose, which is re-inforced by the second and third doses. The graph B shows the duration of two 50 mg doses, maximal at 18 hours.

mild cooling. The two areas of hand thermograms are quantitated, and the hand is cooled for 1 minute in a waterbath at 20°C, using a plastic glove to avoid wetting. The normal hand produces a hyperaemia in the fingers within 4 minutes from cooling. The thermographic index from the fingers therefore, becomes greater than the dorsum of the hand. In Raynaud's disease the reverse is seen, i.e. hyperaemia up to the metacarpel joints, and a cold low index in the fingers (Fig. 5). We have used *Inisitol* Nicotinate (Hexopal, Sterling Winthrop) a peripheral vasodilator, on patients with Raynaud's disease. Improved peripheral blood flow has been shown in these patients using the hyperaemia test. The thermographic index is a convenient means of quantitating this reaction.

The elbow joint

Lateral thermograms of this joint in 90° flexion are conveniently made, the heat shield and reference source held against the body, the patient sitting sideways on to the camera. A square region of interest is located over the joint-and the index calculated from the temperature range 26-33°C.

The foot

The planter surface of the foot is difficult to position for thermography, however lateral and medial views present no problem. The malleolus forms a convenient focus for quantitating the ankle, and a square region is measured from this centre. In cases of gout, the 1st metatarsal joint is often inflamed. Thermograms of the medial foot can be quantitated by measuring a narrow rectangle from the toe to the heel. Response to Indomethacin has been clearly shown by this method' (Fig. 6).

The effect of drug therapy

Using the standardized technique described, we have been able to use the thermographic index

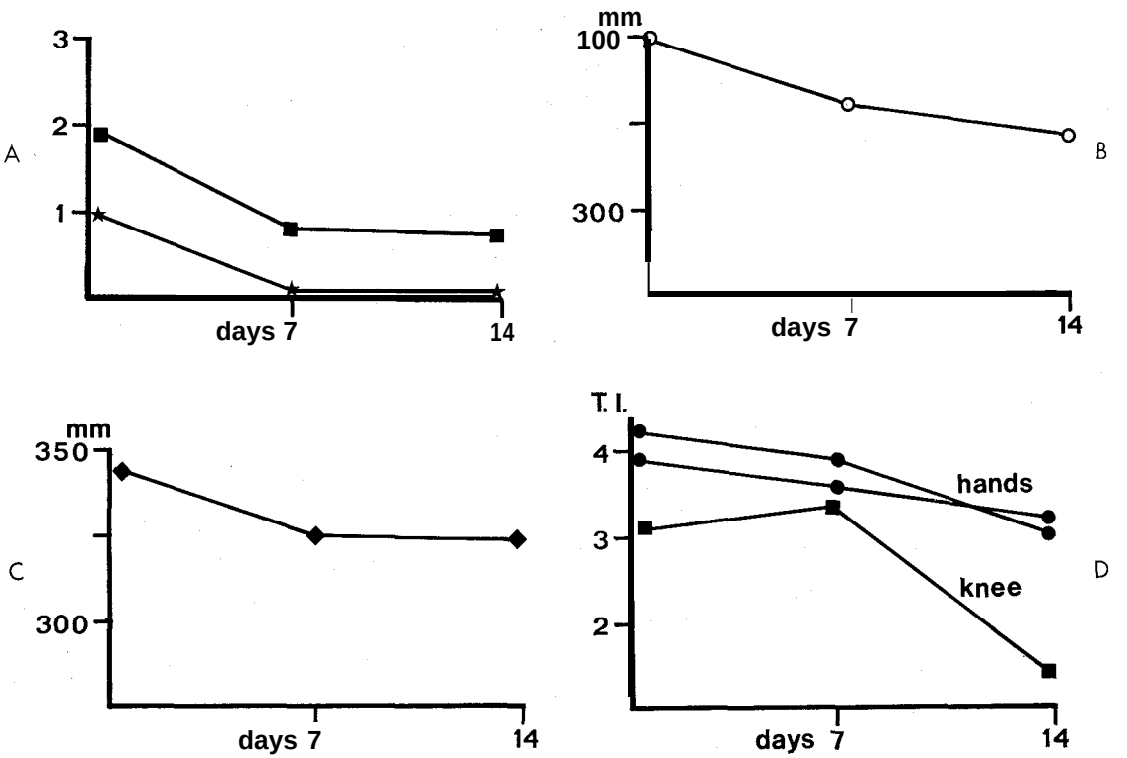

Fig. 7. Four graphs showing the anti-inflammatory effect of a non steroid compound (Benorylate) shown by the thermographic index (A), sphygmomanometer grip test (B), subjective pain scores (C), and finger ring size (D). The thermographic index shows a reduction after 2 weeks therapy in an inflamed knee, not reflected in the pain score, which was improved at 1 week. The slow fall in the hand indices however are comparable.

as an objective measure of anti intlammatory therapy. Analgesic Drugs have consistently failed to lower a raised index, but any treatment which is reducing inflammation, can be shown to lower the index. In a cross over study with Parecetamol and Aspirin, it ha5 been shown that the latter is effective in lowering the index. Other non steroid drugs have been studied, and exhibit greater or lesser reductions in inflammation. In comparison with other clinical measurements, grip strength, morning stiffncss. pain. E.S.R. etc. the index ha5 contributed very useful data (Fig. 7). New anti inflammatory compounds have been studied, and can rapidly be assessed for potency at the prescribed dosage. Other drugs which are not thcmselves considered anti inflammatory i.e. cytotoxic agents, are in USC in some rheumatology clinics. Careful management of the patient is essential, with such treatment. Thermography has provided us with a valuable tool for monitoring such treatment ".

The success of any system used for clinical measurement is dependant on several factors. It must be sensitive to specific changes in pathology, and relate to the disease process. It must also be capable of simple standardization and be acceptablc to clinician and patient. Infra red thermography suitably quantitated does meet these requirements. It is a reliable and objective means of noninvasive studies in the diagnosis and management of osteo-artilular diseases.

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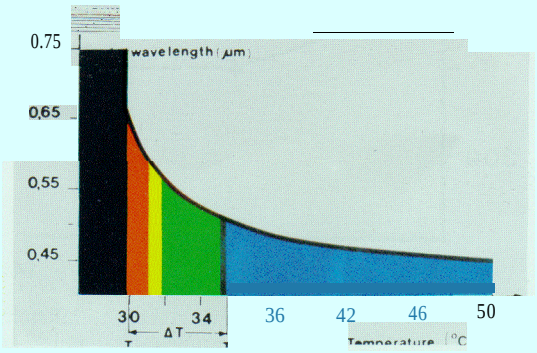
Cholesteric thermography: comparison with infra-red thermography in clinical use

INTRODUCTION

Thcrmology is a science that uses different methods to study temperature differencea. One of these methods is cholesteric thermography. It has been used for quite a long ago, but it was so difficult to perform, that it had fallen into disuse. Actually with some new apparatus. this kind of thermography can find some interesting uses. This kind of thermography gives us information that we will compare with infra-red thermography.

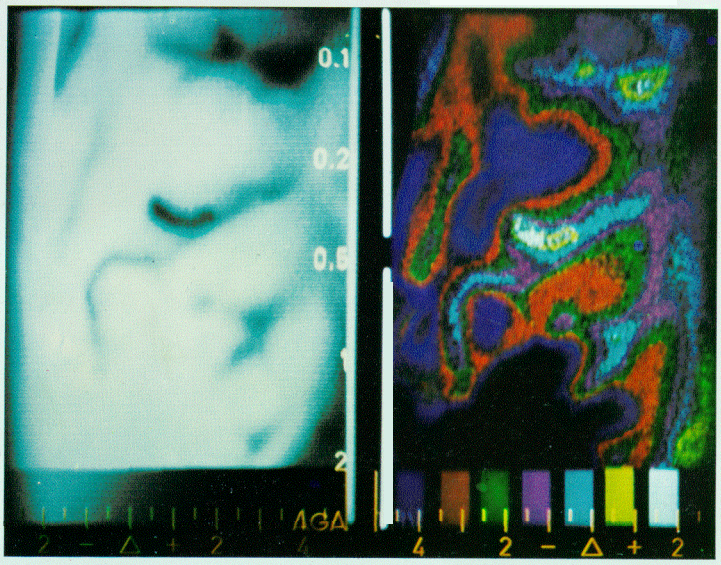
MATERIAL AND METHODS

Cholesteric thermography is done with liquid crystals. Liquid crystals are an intermediary state of matter, between solid cristal and liquid. In this state called mesophase, the molecules of some crystal can slip against each other, a spatial structure remaining between them. It is different from solid crystal structure where there is a definite spatial arrangement, and it is also different from the liquid state where there is no arrangement between the different molecules which are completely independant. There are three different typcs of liquid crystals: nematic; smectic; cholesteric. These three differ in the nature and in the degree of the ordcly arrangement of their molecules. We will compare them with simple geometric ana-



Graph. 1. Relationship between colour and temperature.

logie: nematic has the lowest degree of order of the molecular arrangemcnt: all the molecules arc parallel and have one axis pointing in the same way. Smectic: the molecules in this casc are not only parallel but their position along one axis is fixed So they arc organized side by side in group5 or layers. *Cholesteric: the* arrangement consists of layers, within which each molecule *lies* flat and is parallel to each other; successive *layers* being rotated a fixcd amount from the previous layer. It is this last kind of crystals that we use in thermography. They are formed by esters of cholesterol such *as* Acetate, Bcnzoate, Stearate etc. They have a special optical property, studicd by Ferguson around 1966, of polarizing light and scattering light of certain colors at particular temperaturcs. Since the iridescent color5 exhibited by the liquid crystal materials arc caused by a small part of incident light being scattered back to the eye, the colors are most readily seen if the liquid crystals are observed against a dark or black background. It is possiblc to predctcrmine tem-



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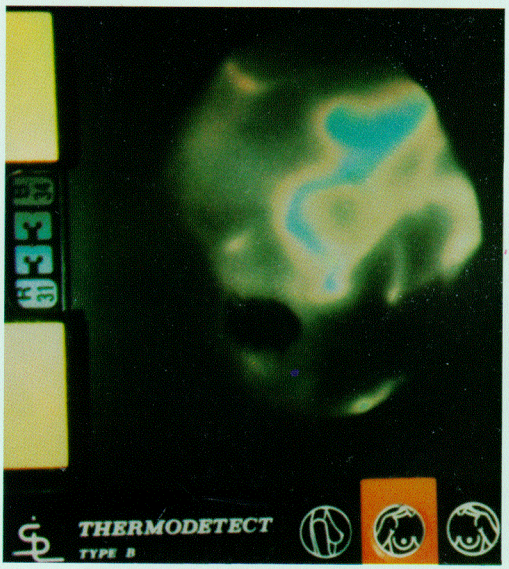

B

C

Fig. 1. A) Vascular pattern near view with AGA camera: grcy scale mode; color5 mode. B) Vascular pattern with cholcsteric sheet. C) Vascular pattern with ACA camera through cholesteric sheet in grcy scale mode.

perature range with the different mixtures of cholesteric esters. Some can extend the temperature scale and Some can move the temperature range on the general temperature scale.

We have a graph between wave length and temperature as shown in Graph 1 for a predctermined mixture: warm is represented in blue and cold in red or black; between we have yellow and green. It It is possible to have different mixtures to cover all the temperature range we want. Those mixtures were first applied to the skin after painting it in black. It was a long, difficult procedure and bothersome to the patient. The skin had to be completely rewashed if a good mixture was not used at first. The procedure was also expensive, crystals being thrown away after use. This was avoided by applying crystals not on the skin but on some predarkened sheets that

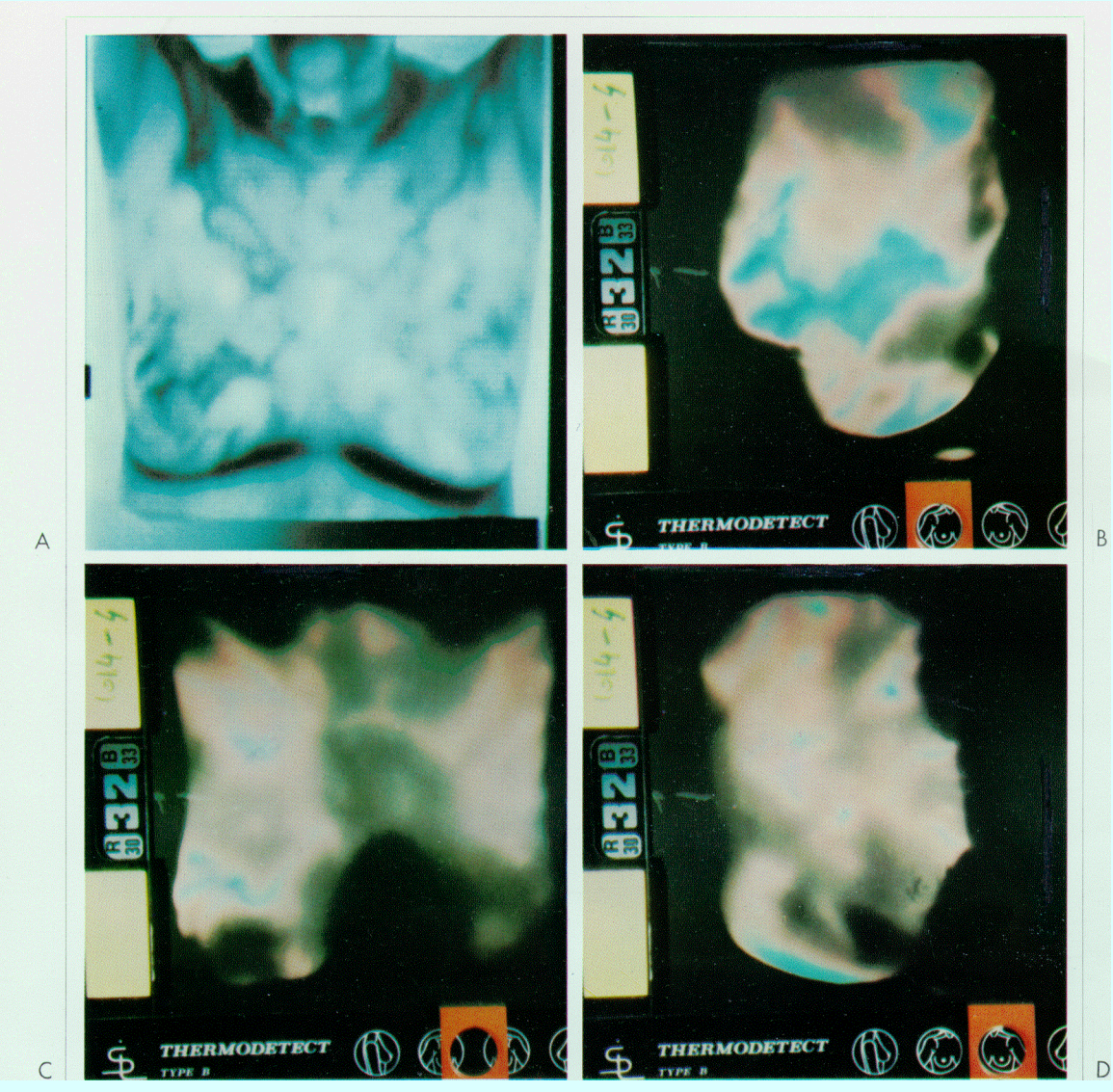

Fig. 2 Right brcast cancer: hypcrthermia of the right breast with hypcrvascularity, (A) AGA camera in grey scale mode: (B, C. D) cholesteric thermography of the same patient. (B): right breast; (C): middle wiew; (D): left breast.

are applied on the skin. The mixture was also fragile and instable, being destroyed in a short time. So the crystals were put in micro-capsules to avoid their coming in contact with air. Thus we had some sheets of different temperature ranges that we can apply against to the skin to measure temperatures by differences of color. We needed to have some references and to protograph these sheets. They were then put in a square frame, and the problem of reflected flash-light was solved by polarized lenses. The square frame was to let the sheet lie gat. By this means we have actually created some special apparatus that can be used easily everywhere.

Sheets can be used by direct examination applied against the skin. And we can photograph the thermal pattern with a camera.

COMPARISON WITH INFRA-RED THERMOGRAPHY

We know that in the body heat comes from metabolism in muscles, brain and liver. The heart is only a pump, the vessels carrying heat everywhere. Cancer is an inserted reheater in the circulation. The skin is only a radiator and one measures heat, coming from underneath by radiation, with an infra-red camera, or coming by conduction, with thermocouples and cholesteric sheets. The infra-red camera shows variations of temperature normaly in black and white, one or the other being warm or cold. The color picture is only an artificial way of calculating easily the differences of temperature by the mean of the isotherms, the color scale being arbitrarily established. For cholesteric thermography the picture is always colored. It is also a kind of isotherm but without a fixed width and with an obligatory succession of colors: from cold to warm black, red, yellow, green, light blue and dark blue (Fig. 1). The exemple shows the difference between these two kinds of thermography in examining the same patient with both methods (Fig. 2).

LIMITS OF METHODS

Cholesteric thermography shows only a little area; it is like a puzzle where one needs to put one piece against the other, keeping the different parts one had examined in mind. Since some pressure must be applied to the sheets for exams of larger areas, the heat distribution is disturbed somewhat. It is more difficult to record exact differences of temperature in degrees between two parts of the body by means of colored references. It can only be used for breast thermography. But it is easy to carry, not really expensive, and it can be used by every clinician to obtain a quick determination of thermal pattern. Infra-red cameras give better views of all the body but need more room; and they are more expensive. They can not be moved easily, but they gives exact differences of temperature. They have a big disadvantage which is the exact reality of measurements, because they don't measure directly temperature but a lot of radiations. This depends on an emissivity coefficient and on the intervening atmosphere; it depends also on the detector used. They are also fragile and need more precautions during use.

But the difficulties of both methods show that they can be used for different purposes.