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The Use of Liquid Cholesteric Crystals for Thermographic Measurement of Skin Temperature in Man†

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The skin over subcutaneous lesions of primary or metastatic carcinomas and sarcomas is frequently warmer than the apparently normal surrounding skin.[1–3] Thus thermotopographic measurement of skin temperature over tumor lesions can be useful for measurement of size, vascular physiology and response to treatment.

Direct measurement of skin temperatures by means of thermocouples or thermistors is exact ($\leqslant \pm 0.1^\circ$ C) but time consuming. Infrared thermography[2–3] represents a substantial improvement. The measurements over a given surface area are sequential and therefore not well suited for observation of rapid vascular reactions. Moreover, presently available equipment is costly.

Cholesteric liquid thermography as introduced by Fergason[4] permits immediate, reproducible visualization of surface temperatures in colors, which respond rapidly to temperature changes. The findings can be recorded photographically. Quantitation can be improved by use of monochromatic light. The cost in time and equipment is minimal.

In the present paper, applicability of temperature measurements of the human skin by means of cholesteric thermography is demonstrated in normal controls. The findings are applied to a select

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group of eight patients with a spectrum of malignant tumors, one patient with a benign fibrolipoma, two patients with acute inflammatory changes and one patient with Wegener's granulomatosis, a chronic, proliferative inflammatory disease.

Materials and Methods

The skin was exposed to room temperature of approximately 25° C for at least 20 min prior to measurement.

The areas of measurement were defatted with a suitable liquid detergent; this was found to be superior to use of alcohol, ether, acetone, xylene or combinations thereof. The defatted skin was covered with two coats of carbon black (carbon black 33 g, polyvinylalcohol 33 ml, detergent, 0.15 mg, aqua dest. ad 100 ml, supplied by Fergason†). After drying, liquid cholesteric crystal solutions were applied, as supplied by Fergason.† The solutions contained oleylcarbonate, nonanoate and benzoate of cholesterol in proper proportions, as 10% solution in chloroform, to show a temperature range of 4° C at temperature levels of 32–36° C or 34–38° C, respectively in colors ranging from red (32.0–32.9° C) followed by a narrow band of yellow (32.9–33.0° C), through green (33.1–34° C) to blue (34.1–36° C). At temperatures above and below the measured range, no color reaction occurred and the background of the carbon black cover became visible. The choice of the above level and range of temperature-sensitivity of cholesteric thermographic material was based on prior observations in thermoelectric measurements of surface temperatures of 128 cancer lesions in man.[5]

Selected lesions were exposed to thermal stress by heating (hair-dryer, 45° C, at 20 cm distance) and cooling (blower, room temperature of about 25° C at 20 cm distance). Temperatures were verified by direct thermocouple measurement (Hartmann and Braun, 6-channel, iron constantan automatic recorder, sensitivity ± 0.1° C). Records of cholesteric thermograms were obtained by direct photography.

† J. L. Fergason, Westinghouse Electric Corporation, Research and Development Laboratories, Pittsburgh, Pennsylvania.

Results

Cholesteric thermograms of normal skin were obtained from the dorsum of the right hand in two individuals of opposite sex. Temperatures over subcutaneous veins were 0.1 to 0.4° C warmer than the surroundings and exceeded the palpable outline of the vein by about 0.4 mm depending on size, site and depth of the vein.

Thermal stress by blowing hot or cool air induced temperature changes which were inversely proportional to the expected circulation of the skin. Thus the initial temperature gradients of 0.1–0.4° C were augmented to 0.9–2.2° C and thermographic distinction of the veins became excellent.

Similar results were obtained when the fingers were immersed into ice water or water of 39° C: the former resulted in cooling of the skin over the veins to temperatures below 32° C. As a result, the draining veins appeared as clearly outlined black streaks in green surroundings measuring 33.5–34° C. Immersion of the fingers into hot water had the reverse effect: the skin over the veins changed to dark blue (35.5° C) against the aforementioned green background. Thermic discrimination was further improved by blowing cool air at the dorsum of the hand while the draining veins were heated by immersion of the fingers into hot water (Fig. 1). Here the initial temperature gradients increased to 1–4° C contrasting the "blue" veins (35.5° C) against light green, then yellow, then red and finally black of the progressively cooled skin between the veins. Similar changes were observed in two nicotine sensitive smokers following inhalation of cigarette smoke (vasoconstrictive effect of nicotine).

Experience with temperature gradients of normal skin and augmentation of temperature gradients by thermal stress were then applied to a selected group of thirteen patients with typical subcutaneous or intracutaneous manifestations of cancer,[8] benign fibrolipoma,[1] acute cellulitis[2] and chronic proliferative inflammation.[1] The eight cancer lesions were 0.9 to 3.3° C warmer than the apparently normal surrounding skin (Table 1).

Cholesteric thermography permitted clear visualization of the

tumor areas. In three patients, the thermographic tumor outline exceeded the palpable tumor mass by 0.5 to 4 cm (representing a considerable difference in actual measurement) implying increased vascularization and tumor spread beyond the visible and palpable tumor mass. This phenomenon is most commonly encountered in patients with malignant melanoma.[5] The remaining five patients showed good agreement between palpable and thermographically

TABLE 1 Tumor Lesions Measured with Cholesteric Thermography

Diagnosis	Site	Temperature °C[a]		Temp. gradient
		Tumor	Surr. skin	tumor-surr. skin °C
Malignant melanoma	Left preauricular	35.9	34.0	−1.9
Chondrosarcoma	Right upper tibia	35.2	33.6	−1.6
Bladder carcinoma	Left thigh	35.0	31.7	−3.3
Renal carcinoma	Right scapula	35.4	34.2	−1.2
Breast carcinoma	Righ foot	38.6	37.2	−1.4
Carcinoma vulva	Left groin	36.2	34.6	−1.6
Bronchogenic carcinoma	Right arm	35.8	34.0	−0.9
Malignant Schwannoma	Left groin	33.8	31.4	−2.4
Benign fibrolipoma	Right forearm	32.0	32.6	+0.6

[a] Each temperature given represents the median of at least five thermocouple measurements.

measured tumor size (Fig. 2). Areas of central tumor necrosis were at least 0.5° C cooler than the surroundings (carcinoma of the bladder, chondrosarcoma). Cooler areas over intact tumor lesions showed subsequent tumor breakdown (carcinoma of the vulva). Veins draining larger, well vascularized tumors (chondrosarcoma, renal carcinoma) were up to 0.9° C warmer than the surrounding skin.

Thermal stress by heating or cooling resulted in marked augmentation of temperature gradients.

Thus the skin temperature over the chondrosarcoma remained constant within ±0.2° C, while the normal surrounding skin

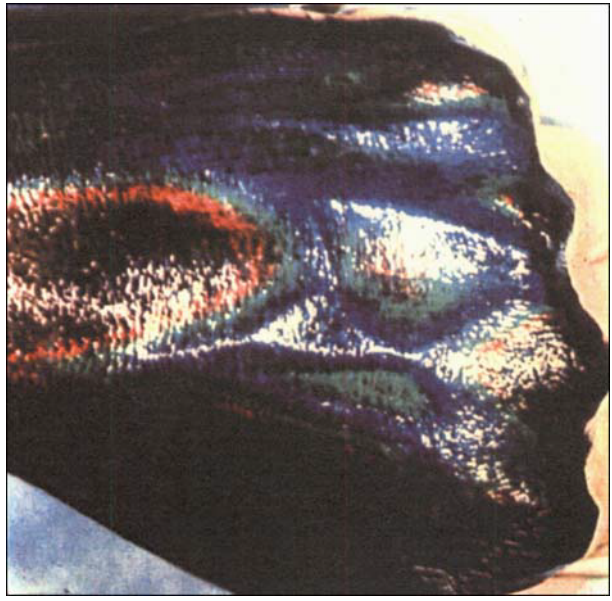

Figure 1. Dorsum of the hand: Outline of draining veins following immersion of fingers into water of 39° C and blowing cool air.

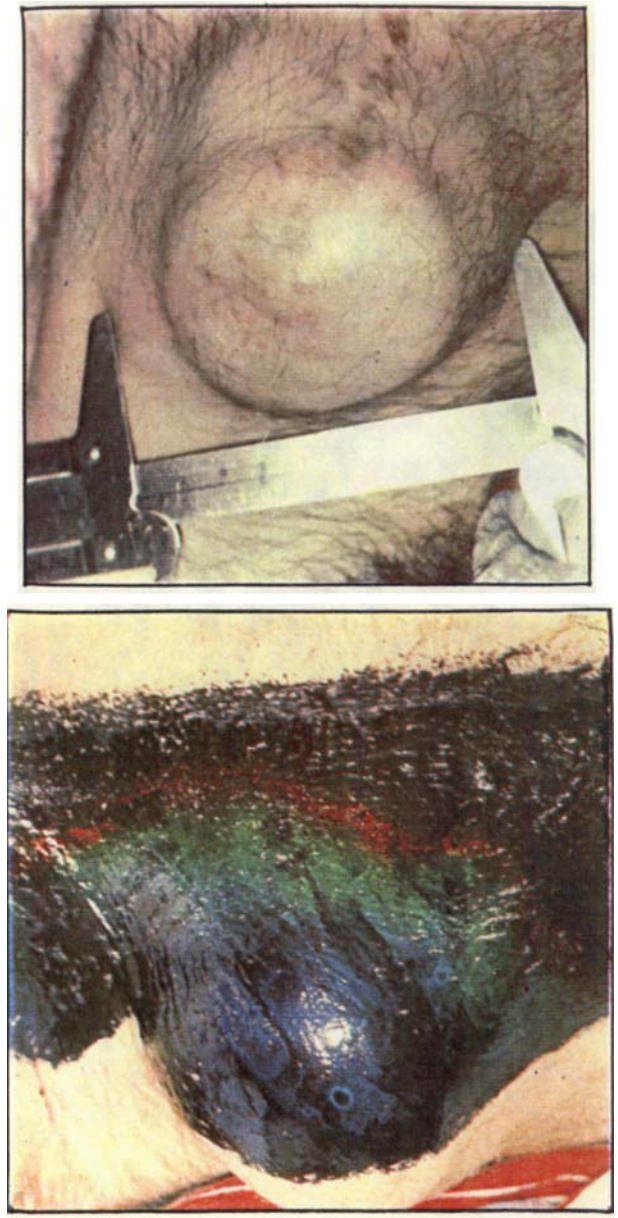

Figure 2. Thermogram of a malignant tumor: Malignant Schwannoma of the groin. (A) prior to thermogram; (B) cholesteric thermogram.

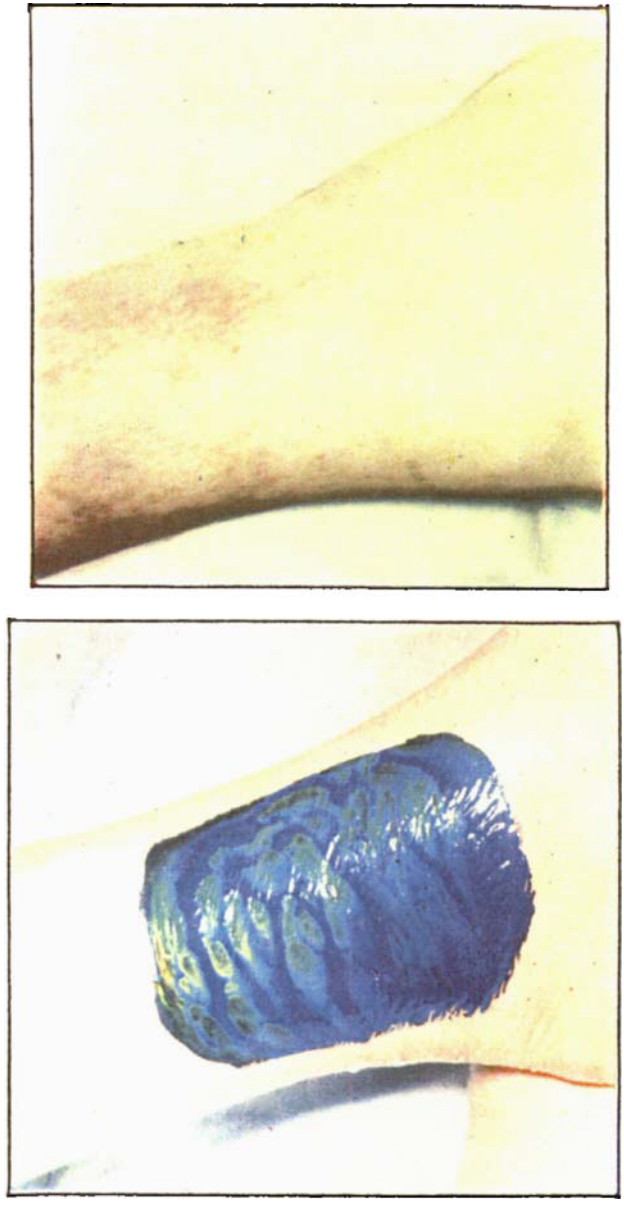

Figure 3. Thermogram of Wegener's granulomatosis of the lower leg. (A) prior to thermogram; (B) cholesteric thermogram.

temperature was increased by 4 + ° C and decreased by 4.1° C respectively, following thermal stress. The original (pre-stress) temperature gradient between tumor and normal surroundings was increased from 1.6° C (Table 1) to 5.7° C by thermal stress.

Benign tumors such as lipomas and fibromas were either isothermic or cooler than the surroundings. This was exemplified by a fibrolipoma (Table 1), which was 0.6° C cooler than the surrounding skin. Thermal stress by blowing with cool air resulted in faster cooling of the tumor than of the surroundings and increased the temperature gradient from 0.6° C to 2.0° C. The thermographic tumor outline corresponded well to the palpable tumor outline.

Acute cellulitis was represented by one patient with erythema of the skin following radiotherapy and one patient with a skin burn. The lesions were 0.6° C and 1.4° C, respectively, warmer than the normal surrounding skin. The thermographic outline exceeded the visible outline of the lesions by less than 10 mm. Cold stress augmented the temperature gradients from 0.6 to 3.0° C in the patient with radiation dermatitis, while the patient with a very superficial burn showed no increased gradient.

The patient with Wegener's granulomatosis had venolar and arteriolar involvement manifested by irregular, patchy areas of cyanosis and pallor in the skin of the right lower leg. The cyanotic areas were 1.7° C cooler than the surroundings, the pale areas showed no reproducible temperature changes. The highly irregular temperature pattern is reflected in Fig. 3.

No allergic or other cutaneous or systemic reaction was noted in any of the patients upon application of these compounds.

Discussion

Liquid cholesteric crystals permit reproducible visualization of temperature gradients of the human skin. The method is ideally suited for observation of rapid temperature changes resulting from vasoconstriction and vasodilation following thermic (or pharmacodynamic) stress. The skin over the majority of sub- or intracutaneous malignant tumors is warmer than the apparently normal

surrounding skin. Hence the method might aid detection of early cancer at such common sites as the female breast,[2,3] despite false negative results[4,5] especially in poorly vascularized carcinomata and false positive results in patients with inflammatory lesions.

Cholesteric thermography proved useful for objective measurement of increased blood flow, frequently associated with cancer. Under exceptional circumstances such increased circulation resulted in visible, palpable and an audible (bruit) pulsation of the lesion as observed in the patient with renal carcinoma (Table 1).

More commonly, increased vascularity and increased blood flow are limited to the marginal tumor areas[6] whereas the center is poorly supplied with blood,[7] leading to central necrosis. It should be pointed out, therefore, that the skin overlying a tumor represents "marginal tumor area" and that cooler areas of the overlying skin herald impending tumor breakdown.

Relation of thermographic tumor outline to actual (microscopic) tumor involvement awaits exploration by surgery. Definition of draining veins is useful to the surgeon.

Augmentation of temperature gradients between tumor and normal surrounding skin by means of thermal stress increases the sensitivity of the method. Constancy of temperature over well vascularized tumor areas despite exposure to lower *and* higher temperatures implies that cutaneous blood flow determines the temperature gradients and that the contribution of local heat-production is negligible.

The sensitivity of the method is further increased by use of cholesteric solutions with a smaller temperature *range*[5] and by use of monochromatic light[8] for sharper outline of isothermic areas.

Summary

Liquid cholesteric thermography was found to be a reproducible inexpensive tool for study of vascular physiology and for outline of eight maligant tumors, one benign tumor, two acute and one chronic inflammatory lesion. The sensitivity of the method was increased by means of thermal stress.

Acknowledgments

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