Thermographic Patterns of Pulmonary Disease*

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Cholesteric liquid crystals, encapsulated onto black mylar sheets, were used to map out the thoracic thermographic patterns of pulmonary disease. In six of seven patients with active infection, and four patients with carcinoma of the lung, overlying skin was excessively warm. In nine of eleven patients with pulmonary thromboembolism, and three patients with regional fibrosis, overlying skin was excessively cool. The data suggest that thermography can be of help in the diagnosis of a pulmonary lesion.

Methods

The Temperature Sensors

Cholesteric crystals¹ encapsulated onto black mylar sheeting² were used to map out the thermographic patterns. Four types of crystals were used to which the manufacturers had assigned the following temperature spectra: 29-32° C, 30-36° C, 33-37° C, and 35-36° C. Six by one inch strips of the material were applied firmly to convex skin surfaces for up to ten seconds at a time and colors appeared within five seconds. Skin temperatures were read according to the color of the crystals when viewed with the light source behind the observer. In each particular crystal spectrum, red was at the cold end, yellow and green were intermediate, and blue was at the upper or hot end. By combining two or more crystal types into the one examination, temperature discrimination to within 0.5° C could be achieved for most of the range of skin temperatures. Where a broad spectrum color such as green appeared, the body cooling process was prolonged until colors were produced (red or yellow) that allowed regional temperature discrimination to within 0.5° C.

In 18 of the patients, the crystal color-temperature reactions were checked by an infra-red detector built as an isovial attachment to a rectilinear isotope scanner. Temperature as read by a needle gauge, differed from the crystal color temperatures, by as much as 1.5° C, even though there was excellent agreement as to the presence or absence of regional temperature differences. Differences on oblique surfaces were disregarded as infra-red detectors are known to be inaccurate unless the skin is at normal incidence.³

While variation in skin to detector distance may have

*Presented in part at the 19th Annual Meeting, American College of Cardiology, New Orleans, March 1, 1970. Supported in part by NIH grant TI AM 5053, and MIRU grant PH 43-67-1441.
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¹Edmund Scientific Company, Barrington, New Jersey.
played some part, the major cause for the discrepancies appeared to stem from incorrect crystal color-temperature specifications that were provided by the manufacturer. The 30-36°C tape, for instance, turned blue while the 33-37°C tape remained yellow-green, and therefore, the former tape may have had a smaller spectrum than suggested by the manufacturer. Moreover the 33-37°C tape provided good agreement in absolute temperature readings, with the infrared detector. Because of such difficulties, we elected to calibrate the crystals by an independent method.

Calibration has proved to be difficult. The standard gray scale was intended for infra-red detectors, and objections were raised to its use with a contact technique. For want of a better method, the crystal tapes have been calibrated by immersion in a commercial water bath where the water temperature was known, and could be increased at will. Several thermometers were in close proximity to the tapes, and a water agitator assured a uniform temperature within the bath.

The tapes were dipped into the water bath for short periods of time, and colors noted with all light source behind the observer. During each temperature calibration, the tapes were carefully inspected for damage. In general, no damage occurred until the tapes had been in contact with water for at least ten minutes. Injury was first seen as premature spotty bluish discoloration, at temperatures that caused the remainder of the tape to remain a yellow, red, or green color. Where the tapes appeared to be uninjured at the conclusion of the calibration, they had subsequent (dry) responses that were indistinguishable from other tapes of the same type and shipment.

Different shipments of the crystal tapes have had different color temperature responses, perhaps due to some variation of the cholesterol crystal complex in each batch. The 33-37°C and 39-32°C tapes have not varied in color temperature reaction over the last three batches, and colors have appeared at the temperatures close to those specified by the manufacturers. The recent 35-36°C crystal tape has had a spectrum 1°C lower than suggested; i.e., 34-35°C. The major error, however, has been in the 30-36°C tape. The manufacturer suggests that green extends from 35 to 36°C, but in our experiments, blue has appeared at 34.5°C.

The Procedure

Each patient was unclothed to the waist and exposed to room air for 10 to 15 minutes, or until the skin temperature evoked a red or yellow reaction in at least one of the crystal tapes. For the period of cooling, care was taken to ensure a symmetrical posture with arms semi-abducted; and as many skin folds as possible were eliminated. All sources of room ventilation were diverted away from the patient. All the patients with pulmonary disease were examined in the hospital wards where temperature and humidity could not be controlled. Many were seen again in the nuclear medicine laboratory (for lung scanning) where room temperature was 24-26°C. Most of the normal controls were examined in a special procedure room where temperature and humidity were rigidly controlled at 22°C and 20 percent respectively.

When the thoracic skin had cooled sufficiently, the first of several thermograms was taken. For each thermogram, each area on one side of the chest was immediately compared to the corresponding area on the other side of the chest; the whole chest was rapidly scanned in this manner. Symmetry of the arms, face, and abdomen were also noted. It was assumed that if the rest of the body was thermographically symmetrical, then no preferential cooling of the chest had occurred.

Every patient found to have an abnormal thermogram had the abnormality confirmed on at least one other occasion hours or days later, and frequently under different environmental conditions. In 18 of the patients, another liquid crystal thermogram was conducted in the nuclear medicine department, at the time of lung scanning with simultaneous infrared thermography.

RESULTS

Normal Patterns

Normal controls were taken from two sources. Fifty-eight patients were studied shortly before an exercise test associated with another project; and 23 patients with non-thoracic disease were examined in the hospital wards or nuclear medicine laboratory.

In the special procedure room (where temperature and humidity were rigidly controlled), the thermograms in the initial part of the study were prone to much artifact from preferential cooling of one side of the chest. In every case of unequal cooling, the face and arms were also involved. Asymmetry cleared with re-routing of air currents, and shorter exposure to 22°C room air.

In the hospital wards, unequal cooling was seen when the bed was adjacent to the wall heater or cooler, and usually the patient had been exposed to such heat or cold for at least several hours. Therefore, it was found more satisfactory to divert the air currents, re-clothe the patient, and return at least one hour later to continue the examination.

Having ensured symmetrical cooling, the thermogram was symmetrical with several exceptions. Small asymmetrical areas, those below a diameter of 5 cm, were usually disregarded. Some patients have had a “tiger” like pattern of the whole chest, where small asymmetries of up to 3 cm diameter are the rule. Average temperature on one side, however, was not unlike the other. Secondly, “artifactual” asymmetry frequently occurred near skin folds (axillae, breasts, neck, and fat folds); where there was visible asymmetry of skin texture (scars, nevi), or where hair distribution was asymmetrical.

Two organs appeared to affect the symmetry of the normal thoracic thermogram. Mediastinal heat sometimes extended more to the left than to the right, at the level of the pulmonary conus and just below. This was inconsistent in area and extent, even in the one subject. Leftward extension of mediastinal heat was not greater than 1 cm for 0.5°C temperature asymmetry, in our normal patients. Liver heat, on the other hand, was consistent and could be demonstrated as asymmetry over the anterolateral costal margins. In fact, right costal margin heat was demonstrable in every normal subject where the body cooling period was long.
<table>
<thead>
<tr>
<th>Case No.</th>
<th>Age, Sex (yrs)</th>
<th>Diagnosis</th>
<th>Thermographic Response Over Lesion</th>
<th>Lung Scan Activity Over Lesion</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>cold ($\Delta T = -1.5^\circ C$)</td>
<td>(angiographic confirmation only)</td>
</tr>
<tr>
<td>1</td>
<td>44, F</td>
<td>Embolus right mid/lower zone</td>
<td>cold ($\Delta T = -2^\circ C$)</td>
<td>reduced</td>
</tr>
<tr>
<td>2</td>
<td>59, M</td>
<td>Bilateral emboli: RLL basal</td>
<td>cold ($\Delta T = -1.5^\circ C$)</td>
<td>reduced</td>
</tr>
<tr>
<td>3</td>
<td>25, M</td>
<td>Bilateral emboli: RLL lat/basal</td>
<td>cold ($\Delta T = -2^\circ C$)</td>
<td>reduced</td>
</tr>
<tr>
<td>4</td>
<td>62, M</td>
<td>Bilateral basal emboli: LLL post-basal</td>
<td>Symmetrical thermogram ($\Delta T = 0$)</td>
<td>reduced</td>
</tr>
<tr>
<td>5</td>
<td>68, F</td>
<td>Bilateral basal emboli: LLL</td>
<td>Symmetrical thermogram ($\Delta T = 0$)</td>
<td>reduced</td>
</tr>
<tr>
<td>6</td>
<td>61, M</td>
<td>Embolus right lower zone</td>
<td>cold ($\Delta T = -2^\circ C$)</td>
<td>reduced</td>
</tr>
<tr>
<td>7</td>
<td>73, M</td>
<td>Embolus RLL</td>
<td>cold ($\Delta T = -2.5^\circ C$)</td>
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</tr>
<tr>
<td>8</td>
<td>58, F</td>
<td>Embolus right mid-zone</td>
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<td>reduced</td>
</tr>
<tr>
<td>9</td>
<td>64, M</td>
<td>Embolus LLL post-operative</td>
<td>cold ($\Delta T = -1^\circ C$)</td>
<td>reduced</td>
</tr>
<tr>
<td>10</td>
<td>54, M</td>
<td>Embolus LLL</td>
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<td>reduced</td>
</tr>
<tr>
<td>11</td>
<td>60, F</td>
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<td>cold ($\Delta T = -1^\circ C$)</td>
<td>reduced</td>
</tr>
<tr>
<td>12</td>
<td>63, F</td>
<td>Absence of left pulmonary artery</td>
<td>Symmetrical thermogram ($\Delta T = 0$)</td>
<td>absent</td>
</tr>
<tr>
<td>13</td>
<td>14, M</td>
<td>Fallots Tetralogy RUL artery small</td>
<td>Symmetrical thermogram ($\Delta T = 0$)</td>
<td>reduced</td>
</tr>
<tr>
<td>14</td>
<td>15, P</td>
<td>Fallots Tetralogy left pulmonary artery small</td>
<td>Symmetrical thermogram ($\Delta T = 0$)</td>
<td>reduced</td>
</tr>
<tr>
<td>15</td>
<td>54, M</td>
<td>RML old tuberculosis</td>
<td>cold ($\Delta T = -1^\circ C$)</td>
<td>reduced</td>
</tr>
<tr>
<td>16</td>
<td>50, M</td>
<td>RML recurrent infection</td>
<td>cold ($\Delta T = -1.5^\circ C$)</td>
<td>reduced</td>
</tr>
<tr>
<td>17</td>
<td>50, M</td>
<td>RLL post-pneumonic fibrosis</td>
<td>cold ($\Delta T = -1.5^\circ C$)</td>
<td>reduced</td>
</tr>
<tr>
<td>18</td>
<td>27, M</td>
<td>RLL pneumonia</td>
<td>hot ($\Delta T = +2^\circ C$)</td>
<td>reduced</td>
</tr>
<tr>
<td>19</td>
<td>86, M</td>
<td>RLL pneumonia</td>
<td>hot ($\Delta T = +0.5^\circ C$)</td>
<td>reduced</td>
</tr>
<tr>
<td>20</td>
<td>47, M</td>
<td>RUL abscess apex (cavity) mid-zone</td>
<td>cold ($\Delta T = -1^\circ C$)</td>
<td>reduced</td>
</tr>
<tr>
<td>21</td>
<td>21, M</td>
<td>Right empyema</td>
<td>hot ($\Delta T = +2^\circ C$)</td>
<td>absent</td>
</tr>
<tr>
<td>22</td>
<td>30, M</td>
<td>LLL pneumonia</td>
<td>hot ($\Delta T = +1.5^\circ C$)</td>
<td>reduced</td>
</tr>
<tr>
<td>23</td>
<td>56, M</td>
<td>Right apical tuberculosis</td>
<td>hot ($\Delta T = +0.5^\circ C$)</td>
<td>reduced</td>
</tr>
<tr>
<td>24</td>
<td>58, M</td>
<td>LLL tuberculosis</td>
<td>5 months therapy</td>
<td>Symmetrical thermogram ($\Delta T = 0$)</td>
</tr>
</tbody>
</table>

**Congenital Anomalies**

**Regional Fibrosis**

**Regional Infection**

**Carcinoma**

**ABBREVIATIONS:** RUL and L'UL = right and left upper lobes. RLL and LLL = right and left lower lobes. RML = middle lobe. $\Delta T$ = temperature difference in °C between skin over the lesion, and skin of the corresponding area on the other side.

**CHEST, VOL. 58, NO. 5, NOVEMBER 1970**

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enough to allow red-yellow colors to appear at the costal margin area.

With these exceptions in mind, the criterion of abnormality for this study was thermographic asymmetry. Results were recorded as \( \Delta T \), where \( \Delta T \) represented the temperature difference in degrees centigrade, between two anatomically symmetrical points of the chest.

**Abnormal Patterns (Table 1)**

*Thromboembolism:* Eleven patients (cases 1 to 11) were referred where the diagnosis of pulmonary thromboembolism seemed definite, and where the lung scan and/or pulmonary angiogram supported the diagnosis. Of the predisposing conditions, cardiac disease was present in seven, and in two others painless edema of one leg developed days before the pulmonary episode.

Seven of the 11 patients had unilateral disease; or alternatively, major involvement of one side, and very minor evidence of disease on the other side. All seven had areas of cool skin over the regions shown to be affected by the lung scan and/or pulmonary angiogram (Fig 1). Thermographic asymmetry was as great as 2.5°C, and could have been detected by palpation in at least two of the subjects.

Four of the subjects had bilateral involvement by the thromboembolic process. In two, the thermogram was asymmetrical (patients 2 and 3). The side of greater involvement at each thoracic level was cooler, but the side of lesser involvement was missed. The other two patients (cases 4 and 5) had symmetrical and therefore normal thermograms. In both, lung scans and pulmonary angiograms suggested extensive, but symmetrical involvement of the basal pulmonary vasculature.

Patient number 2 was followed daily from the onset of his thromboembolism (Fig 2). When first seen, he was in shock, and had central skin coolness; much as can be seen in acute myocardial infarction. By day 2, the central coolness had resolved and was replaced by left anterior chest coolness, where a pleural friction rub was easily audible. Over the next week the left coolness shrank to the left lateral pectoral region, while a large area of coolness appeared at the right base to become the dominant thermographic feature. The pattern remained stable until the twelfth day, when the patient was considered well enough to undergo radioisotope scanning. Corresponding to the coolness at the right base (\( \Delta T = -2^\circ \text{C} \)), there was an absence of isotope activity. Although isotope activity was generally less on the left side, there was no specific defect under the small area of skin coolness at the left pectoral region. The day-to-day changes that this patient experienced in thermographic patterns is similar to the changes seen with daily lung scans.

*Congenital pulmonary artery lesions.* Two patients (cases 13 and 14) both with Fallot's tetralogy, had inequality of pulmonary arterial supply to the lung fields, as shown by pulmonary angiography. No thermographic abnormalities could be found. Patient number 12 had congenital absence of the left pulmonary artery and the lung scan showed complete absence of activity there. Once again thermography was normal; the lung fields were symmetrical. Subsequent aortography demonstrated numerous bronchial collateral circulation to the left

![Figure 1. Thromboembolism (case 6). Posteroanterior chest x-ray film and anterior radioisotope lung scan, with the anterior thermographic findings superimposed on the latter. Over the right base anteriorly and laterally, skin was cooler by up to 2°C (\( \Delta T = -2^\circ \text{C} \)). The results of left lateral scan suggested that the reduced activity at the left base was due to cardiomegaly.](http://journal.publications.chestnet.org/pdfaccess.ashx?url=/data/journals/chest/21503/ on 06/21/2017)
lung and helped explain the apparent anomaly. As well, the right (normally perfused) lung was the seat of chronic disease, the patient having had recurrent respiratory infections there over most of her 63 years of life.

Regional Fibrosis: Three patients (cases 15 to 17) were seen where the diagnosis of regional pulmonary fibrosis was considered unequivocal, and where the lesion was easily visible on chest x-ray examination. Two had recurrent infection at apparently the one site, while the third had an old tuberculous lesion. All three had areas of cool skin ($\Delta T$ to $-1.5^\circ C$) over affected segments, and the thermographic response was indistinguishable from that of thromboembolism.

Regional Infection: Five patients (numbers 18 to 22) with unilateral and localized acute bacterial infection could not be examined with the liquid crystals until skin temperatures fell to within discriminatory levels ($\approx$ below $35^\circ C$). When studied, all five had hot areas of skin over affected regions (Fig 3). Two of the patients were seen again several weeks after the infection had settled. Surprisingly enough, the patterns had reversed with skin coolness ($\Delta T$ to $-1^\circ C$) over previously hot ($\Delta T$ to $+2^\circ C$) areas.

Two patients (cases 23 and 24) had recent tuberculosis. In one, the current infection was probably the first ever, and overlying skin was warmer ($\Delta T +0.5^\circ C$). The other patient had been treated for five months and residual radiologic signs were minimal. Findings on thermogram were normal.

Carcinoma. All four patients of this group (cases 25 to 28) had gross radiologic manifestations of the disease, and three had evidence of significant associated pulmonary infection. In these aspects, the group was a selected one. All four had areas of increased skin warmth ($\Delta T$ to $+2^\circ C$), that were not as extensive in size as the abnormalities on lung scanning.

**DISCUSSION**

When compared to infra-red thermographic machines, liquid crystals provide relatively coarse temperature discrimination (at the best, to $0.5^\circ C$). Most temperature differences less than $0.5^\circ C$ remain undetected, except in the $34-35^\circ C$ range. Unfortunately, interpretation is subjective as it depends on the perception of changing colors, and the colors can appear to change if the direction of the light source changes. Nevertheless, with the procedural precautions mentioned in this study, regional patterns established by the liquid crystal tapes have correlated well with those of the infra-red detector; and thermographic abnormalities have correlated well in acquired pulmonary disease with those of the lung scan.
The results of this study have confirmed the work of Squire:¹ pneumonia and active pulmonary tuberculosis are associated with warm overlying skin. In addition, we have found that pulmonary thromboembolism and regional fibrosis cause the overlying skin to be cooler, while carcinoma results in warmer overlying skin, much as it has been shown to do elsewhere.

The inference must not be made that thermography will detect or help differentiate all pulmonary lesions. To begin with, congenital lesions have been thermographically neutral. Small and/or deep acquired lesions cannot be expected to affect cutaneous patterns. At least some patients who have recovered from an acute inflammatory episode have reversed their patterns with cool skin over previously hot areas. In the presence of bilateral disease, the thermogram may be symmetrical and therefore normal.

Moreover, the presence of obesity or large breasts makes any interpretation difficult, and the thermogram may be meaningless unless precautions are taken to ensure even body cooling, and unless some knowledge exists about the normal variants and causes for “artifactual” asymmetry.

Despite all these provisos and limitations, thermography has been fruitful in the majority of patients seen with significant localized pulmonary disease. An introduction to the principles of thermography has enabled some of the referring physicians to recognize by palpation alone, regional differences of 1.5 °C and over. The second application of the present study has been in the radioisotope laboratory, where abnormalities on the lung scan have been divided into “hot,” “neutral,” and “cold,” to enhance the correct interpretation of the lung scan.

A radioisotope lung scan is said to be an indicator of regional pulmonary blood flow; and as seen in this study, isotope activity can be reduced in a variety of conditions, some of which increase overlying skin temperature. Therefore, regional pulmonary blood flow can only be one of several determinants of overlying skin temperature. The excess regional heat of infection and carcinoma may have been due to an increase in bronchial circulation, inflammation of the pleura, cutaneous or subcutaneous vasodilation: or just simply excess local heat production from tissue catabolism. It is impossible to assess the relative importance of these variables.

ACKNOWLEDGMENT: I would like to express appreciation to the staff of the Nuclear Medicine Department, Birmingham Veterans Hospital; and in particular, to Dr J. Pittman for his advice and help, and to Mrs. F. Kontzen for technical assistance.

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CHEST, VOL. 58, NO. 5, NOVEMBER 1970