

Circulation

JOURNAL OF THE AMERICAN HEART ASSOCIATION



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Circulation 1970;42:199-204

Circulation is published by the American Heart Association, 7272 Greenville Avenue, Dallas, TX 72514

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Thermographic Patterns of Angina Pectoris

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SUMMARY

Liquid crystals, encapsulated onto black Mylar tapes, were used as cutaneous temperature sensors in 50 male patients, who had thermographic examinations while they were being exercised on the treadmill, in an attempt to induce angina pectoris. Twenty-eight of the group remained free of pain and the exercise thoracic thermogram was essentially unchanged from the control or resting state. Twenty-two patients developed angina pectoris during exercise, of whom 21 had associated ST depression in the electrocardiogram, and 17 thermographic abnormalities. When the pain was unilateral (nine patients), skin coolness was invariable and was within the distribution of the pain. When the pain was central (13 patients), skin coolness was present in some of the patients (eight of 13) and was not always within the area of pain. When present, the skin coolness was transient and settled within minutes of relief of pain.

Additional Indexing Words:

Skin temperature Exercise

THE TERM "angina pectoris" was introduced by Heberden two centuries ago.¹ Since that time, there has been only occasional interest in the transient vasomotor events that can accompany the syndrome. Trousseau² noted unilateral arm pallor and more recently, Mainzer³ noted decreased pressure in the brachial artery on the side of anginal pain. Both signs appeared during the pain, and both regressed after relief of pain.

Such observations suggest that regional vasoconstriction does occur during the pain of angina pectoris. It would be expected that any vasoconstriction would be detectable by a change in overlying skin temperature, and therefore, we decided to chart the thermographic patterns in a group of patients with angina pectoris.

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Supported in part by Myocardial Infarction Research Unit Grant PH 43-67-1441.

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Received April 9, 1970; accepted for publication April 21, 1970.

Methods

The Patients

Fifty hospital patients were studied. No females were included in the series and five male patients were not included because of excessive hair on the arms and chest. The presence of abundant hair precluded close contact with the skin of the temperature sensors. Two more patients were excluded during the exercise test because of excess sweating at which time they were free from pain.

All 50 patients had a history of chest pain, which was considered clinically to be angina pectoris, and 12 had had myocardial infarction 3 months to 7 years previously. They were all in the hospital for evaluation or treatment of their chest pain, and a treadmill exercise was part of this evaluation.

The Temperature Sensors

Cholesteric liquid crystals,⁴ encapsulated onto black Mylar tapes were used to map out the thermographic patterns of the chest and arms. Four types of liquid crystals were available,* with the following temperature spectra: 29 to 32 C, 30 to 34 C, 34 to 35 C, and 33 to 36 C (fig. 1). Temperatures were read according to the color of the crystals when viewed with the light source

*Edmund Scientific, Barrington, New Jersey.

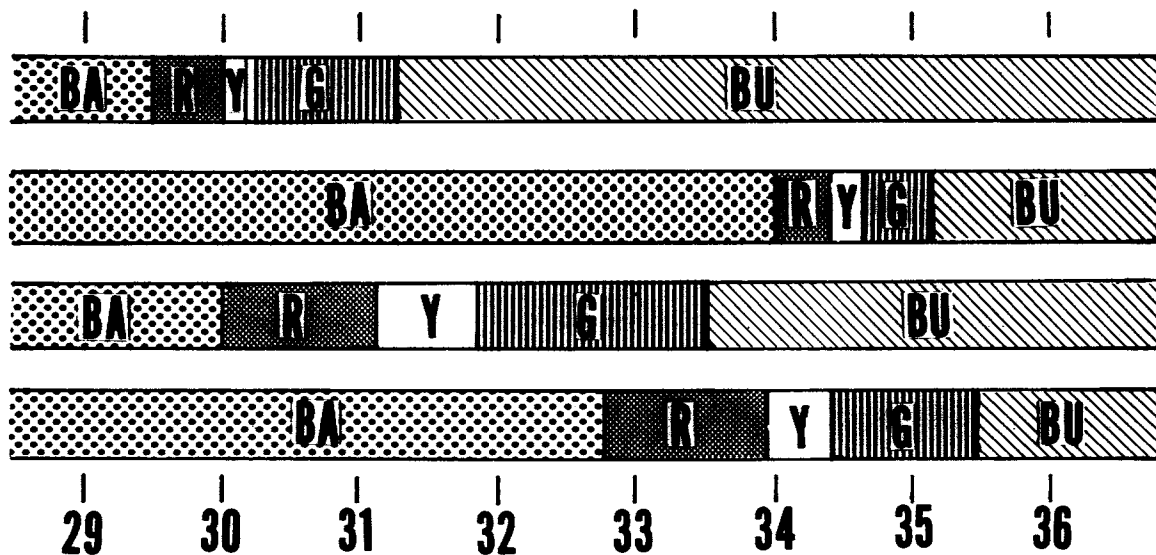


Figure 1

Color temperature correlations of a recent batch of liquid crystals, calibrated by immersion of the crystal tapes into water baths of known temperatures for short periods. The colors are represented by different shades and the following abbreviations: BA = black; R = red; Y = yellow; G = green; BU = blue. The numbers at the bottom refer to the temperature in degrees centigrade.

behind the observer. In each crystal type, red was at the lower end of the discriminatory spectrum, yellow and green were intermediate, and blue was at the hot end. Specific color to temperature correlations were reached by noting the colors when the tapes were immersed for short periods of time into water baths of known temperature.⁵

Strips of the crystal Mylar complex were placed on convex skin surfaces of the chest for up to 10 sec at a time, and crystal colors appeared within 5 sec. Longer contact times were undesirable because of skin heating and accumulation of sweat. Temperature discrimination to 0.5 C could be achieved by combining several crystal types into the one examination and having red and yellow colors produced by at least one of the crystal types. These two colors always had narrow temperature bands, whereas green and blue were produced over larger temperature ranges.

Protocol

The treadmill test was performed in a room kept at 22 C and humidity of 20%. The patient was unclothed to the waist and exposed to room air for approximately 15 min before the control thermogram was recorded. During this period the control or resting electrocardiograms were taken. A minimal area of thoracic skin was involved with electrode placement.

Keeping the treadmill room at a set temperature and humidity involved efficient air condition-

ing which, in the initial part of the study, resulted in a distressing number of air currents that cooled one side of the body preferentially. Such artifactual thermographic asymmetry was minimized subsequently by diverting direct air currents away from the body and restricting the cooling period when possible to less than 20 min.

After 15 min exposure to room air, the thoracic skin temperature was frequently between 33 and 34.5 C, so allowing use of either the 33-36 C or the 34-35 C tape. The chest and arms were scanned rapidly with the crystal tapes, comparing the temperature of symmetrical parts of the body all the time. Absolute temperatures were not recorded; only regional patterns and temperature differences were. The control thermogram was used as a base line for each patient.

Each patient was exercised on the treadmill by a graded exercise test (GXT)⁶ with an initial speed of 1.7 mph and incline of 10%. Every 3 min both speed and incline were increased (to 2.5 mph and 12% grade, then 3.4 mph and 14% grade). No patient in this series exercised beyond 9 min.

The treadmill test was conducted by an independent physician who terminated the exercise when severe fatigue, dyspnea, pain, or ST depression occurred, or when heart rate reached 90% of predicted maximum.⁶ During the exercise, the observer took repeated thermographic scans of

the arms and the anterior and lateral aspects of the chest, always comparing one side with the other. At the conclusion of the test the patient was rested in either the sitting or supine position, while follow-up electrocardiograms and thermograms were taken.

Results

Pre-Exercise Patterns

Thermographic asymmetry has been reported to occur following myocardial infarction, and between attacks of angina pectoris.⁷ Therefore, great care was taken to examine our patients before exercise.

In all the patients, skin over the central anterior aspect (over the mediastinum) was warmer than the skin over the lung fields. Forty-one of the 50 patients had lateral thermographic symmetry (over the lung fields), within the sensitivity of the crystal tapes, but with the following exceptions: Asymmetry frequently occurred near skin folds (axillae, breasts, fat folds, and neck), where skin texture was different on the two sides of the chest (scars, nevi), or with asymmetry of hair distribution. Such asymmetry was classified artifactual and disregarded.

Nine patients had thermographic asymmetry of the chest and arms, in spite of attempts to achieve balanced cooling. In all except two patients, the asymmetry extended to the face and the abdomen and became minimal or disappeared when the patient was moved from the bed to the treadmill and exercised. The thermogram at the end of the second minute of exercise was used as the control pattern. The two exceptions retained thoracic asymmetry in spite of exercise, with cooler skin over the left chest and arm regions. Both had healed myocardial infarction, and one appeared to have a ventricular aneurysm, while the other had residual aching on the left side suggestive of a shoulder-hand syndrome.⁸ Only these two patients appeared to correspond to the post-infarctional thermographic asymmetry described previously.⁷

Apart from these factors, the great majority of patients had greater skin heat over the right costal margin (over the liver) than on the left

side and 20 to 25% had leftward extension of mediastinal heat at or near the pulmonary conus. The latter was probably due to heart beat, but was inconsistent even in the same subject, being present on one examination, and absent on the next occasion hours or days later. Leftward extension of the mediastinal heat did not exceed 1 cm for more than 0.5 C asymmetry.

With all these variations of normal in mind, the criterion of abnormality during exercise was a change in the thermographic pattern from the resting or control state. In most cases this involved developing asymmetry. In the results, thermographic asymmetry will be represented by ΔT , where ΔT will be the temperature difference in degrees centigrade, between two anatomically symmetrical points on the chest or arms. In some of the patients, the abnormality was central skin coolness, where mediastinal skin became cooler than skin over adjacent lung fields. In these patients, ΔT will be the temperature gradient in degrees centigrade between affected regions and adjacent central skin.

Exercise Patterns

In 28 of the 50 subjects exercised, angina pectoris was not induced, and the treadmill test was terminated because of fatigue, dyspnea, ST depression, or tachycardia. The ST segments of the electrocardiogram were depressed in nine of this group, five being in association with digitalis therapy or abnormal resting ST-T segments, or both. None of this group had any change in the thermogram from the resting pattern. In some patients, the mediastinum-to-lung field temperature gradient did diminish, but mediastinal skin always remained warmer than skin over the lung fields.

The remaining 22 patients developed chest pain between the second and seventh minute of exercise on the treadmill and, with one exception, had significant ST depression in the electrocardiogram appearing in temporal relationship to the pain (before or after). As exercise was terminated at the onset of definite pain, the pain was never severe, and was relieved within 8 min by rest. Seventeen

of these 22 patients had thermographic abnormalities, with skin coolness in or near the distribution of the pain. The skin coolness was seen to precede the pain by as much as 90 sec in at least five of the patients with lateralizing pain. In the other patients, the onset of both pain and thermographic changes was too subtle to be sure of the temporal relationship.

Thermographic results will be presented according to whether the pain was lateral or central.

Lateral Pain (Fig. 2)

In nine patients, the anginal pain may have started in a central position, but at its most intense moment it was felt to be totally to one side (left in seven, and right in two). Thermographic abnormalities were easily detectable in all nine subjects as asymmetric skin coolness totally within the distribution of the pain. Three cases of temperature response will be described. In the examples ΔT will represent the temperature difference in degrees centigrade between two anatomically symmetrical points on the chest.

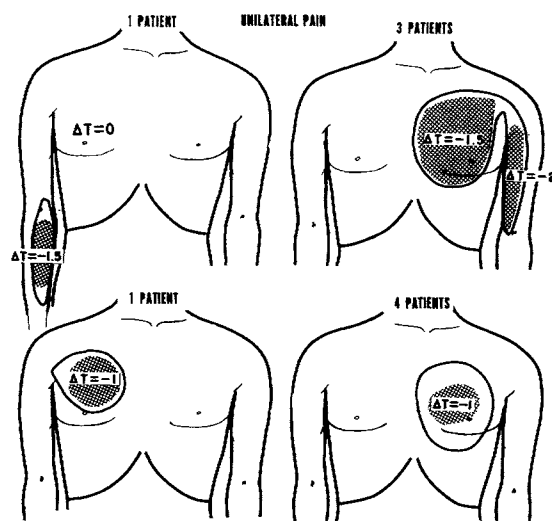


Figure 2

Four types of thermographic patterns seen during unilateral or asymmetric angina pectoris. The area of pain is indicated by the bold line; the region of skin coolness is shown by the crosshatching. ΔT = extent of temperature asymmetry in degrees centigrade.

Lateral Pain, First Example

The patient, a 46-year-old male, had had a myocardial infarct 6 years previously, and exertional angina since. After 4 min of exercise, pain of moderate severity developed in the left anterior chest and left arm. Thermographic signs preceded the pain by 25 sec and were more marked in the arm ($\Delta T = -2.0$ C) than in the chest ($\Delta T = -1.5$ C). With rest, the pain disappeared at about 6 min after exercise, but skin coolness persisted for another 7½ min.

Lateral Pain, Second Example

A 54-year-old male gave a 3-month history of angina pectoris radiating to the right chest and arm. After 4 to 5 min of exercise, he complained of pain in the right lower forearm. The exercise test was continued in view of the unusual location of the pain, until the sixth minute, at which time the ST segments became depressed and the pain began to radiate proximally to a distribution that was more consistent with angina pectoris. Thermographic signs at first were limited to the right wrist ($\Delta T = -1$ C), and had extended to the medial side of the right elbow before exercise was stopped. As the wrist was not included in the thermographic scanning at the beginning of exercise, temporal relationships remained unknown. Thermographic symmetry of the arms was

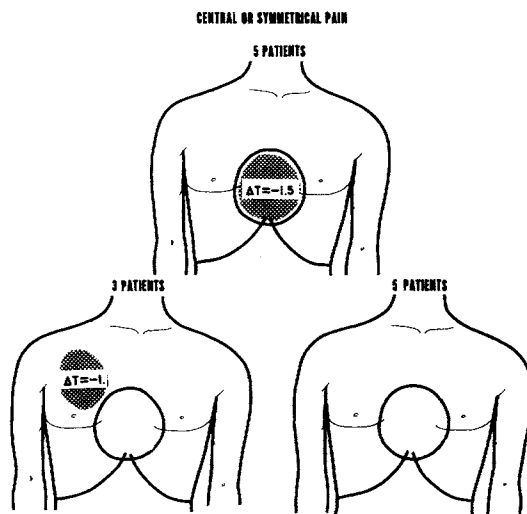


Figure 3

Thermographic patterns seen during the central or symmetrical pain of angina pectoris. The areas of pain and skin coolness are indicated by the bold line and crosshatching, respectively. ΔT = temperature change in degrees centigrade. The five patients represented in the right lower figure had no thermographic abnormalities during the pain.

restored 5 min after exercise was stopped and after the pain had subsided.

Lateral Pain, Third Example

A 48-year-old male with a 2-year history of exertional angina pectoris had already had several exercise studies in our laboratory. Therefore, the time of onset of his pain, as well as the distribution of the pain, was anticipated. Thermographic signs in the left pectoral area appeared in the sixth minute of exercise and preceded the pain by 90 sec. The exercise test was stopped at the first indication of pain, which lasted 2 min. Skin coolness over the left pectoral region was limited to -1 C and disappeared 6 min after the pain had subsided.

Central Pain (Fig. 3)

Thirteen patients developed pain localized to the middle or lower sternal regions. Alternatively, the pain radiated symmetrically over the anterior chest. Eight of the 13 patients had thermographic changes, five having central patches of cool skin, and three having the cool area to one side. Two instances of this pattern will be described.

Central Pain, First Example

The patient, a 52-year-old male, had had centrally located exertional angina pectoris for 10 months. In the treadmill study it came on after approximately 5 min of exercise. At this time skin over the middle and lower sternal areas, and extending out approximately 6 cm to each side was cooler than over the lung fields, and at least 1.5 C cooler than the manubrial region, though only 0.5 C cooler than the immediately adjacent epigastrium. Both pain and coolness disappeared quickly after cessation of exercise.

Central Pain, Second Example

The patient, a 55-year-old male, had angina pectoris in association with aortic stenosis. At just over 5 min of exercise he developed central chest pain poorly localized. The area of skin coolness was over the medial aspect of the right pectoral region ($\Delta T = -0.5$ C). In spite of repeated questioning, the patient denied any lateralizing features of the pain. Both pain and thermographic asymmetry disappeared within 3 min of resting.

Five of the 14 patients with central pain had no thermographic signs. In each of the five patients, pain was mild and subsided within 2 or 3 min after cessation of exercise.

Discussion

This study has demonstrated that the

majority of patients with exertional angina develop transient areas of skin coolness within or adjacent to the area of pain. In our patients with lateral pain, skin coolness was invariable, while with central pain, about two thirds of the patients had regional cutaneous hypothermia. Previous authors⁹⁻¹¹ have described similar areas of skin coolness in myocardial infarction. In initial studies of our own, the thermographic asymmetry with myocardial infarction has been more extensive and longer lasting than in exertional angina pectoris. The two conditions appear to represent differing intensity of the same process.

In all but two of our 50 patients, the control thermogram before or at the beginning of exercise was symmetrical. Such results are in disagreement with those of Doret and Ferrero,⁷ who found thoracic thermographic asymmetry in 15 of 21 patients in between attacks of angina pectoris. The most likely explanation for such discrepancies is a difference in patient selection. In this series, any male with a past history of angina or myocardial infarction who was referred for routine exercise testing was accepted for study (except for the four subjects with too much hair on the chest). Doret and Ferrero⁷ gave little explanation of their patient selection. It is possible that they had patients with frequent resting pain. Alternatively, our liquid crystals were not as sensitive as their contact thermocouples; or the long contact time with their thermocouples changed cutaneous temperatures in a differential fashion; or they tested areas that were inaccessible or were avoided in this study (for example, near skin folds).

Two mechanisms exist by which the areas of referred pain in angina pectoris could have become cool. Firstly, there is some evidence that regional vasoconstriction does occur on the side of pain³ and may even be responsible for the perception of heart pain in a remote area.⁷ Secondly, there have been reports on the presence of localized sweating in the region of the chest pain.¹² We have observed the latter only in myocardial infarction with central pain. The low humidity (20%) of our

exercise room may explain the apparent absence of regional hyperhydrosis in the patients of this series. The relative contribution from each of the two factors, however, cannot be assessed at this time.

Whatever the underlying physiologic cause of the skin coolness, thermography appears to have some potential as an objective method of assessing the presence or absence of angina pectoris. Indeed, with refinements in technic, it may become possible to anticipate the onset of angina.

The areas of skin coolness, are not entirely specific, however. We have seen transient central skin coolness in the acute stages of pulmonary catastrophes (such as thromboembolism and massive atelectasis). Lateral chest coolness of longer duration can be seen with unilateral pulmonary disease where regional pulmonary blood flow is reduced (thromboembolism, fibrosis, cysts).⁵ On the other hand, in seven patients with clearcut chest wall pain not related to the shoulder-hand syndrome; that is, wound pain, cervical arthritis, shoulder arthritis, aching and tender ribs, we have not been able to demonstrate skin coolness, but the number of patients is as yet too small for unequivocal conclusions.

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